

Seismic Stratigraphic and Quantitative Interpretation of Leonardian Reefal Carbonates, Eastern Shelf of the Midland Basin: Insight Into Sea Level Effects, Geomorphology and Associated Reservoir Quality*

Abidin B. Caf¹ and John D. Pigott¹

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Abstract

When coupled to petrophysical analysis and quantitative interpretation, a 3D seismic stratigraphic analysis of Leonardian shelf margin reefal buildups on the eastern shelf of the Midland Basin reveals carbonate buildups which respond to changes in sea level and are accompanied by systematic changes in lithology and reservoir quality. Identification of six seismic operational sequences (parasequence sets) and three major seismic sequences bounded by regional unconformities with the utilization of Vail seismic methodology and corresponding Galloway petrophysical motifs demonstrate allocyclic rather than autocyclic controls, as the cycles approximately correspond to the Leonardian global sea level curve in the Midland Basin. Within these sequences, parasequence set buildups are identified with distinctly differing geometries and seaward dipping slope angles, interpreted as reefs. They are HST, RST, and LST buildups with changes in the buildup geometry controlled by the relative changes in the sea level. Highstand buildups are the largest and with the steepest angles, while smaller Regressive and Lowstand buildups have more planar slope geometry. Information from the petrophysical analysis and the quantitative seismic interpretation revealed that fluctuations in sea level also control the mechanisms behind the dolomitization and the increasing trend in porosity from shelf edge to the distal buildup features. This systematic integrated petrophysical-seismic sequence analysis provides better understanding of the relationship among the lithology, interpreted reservoir quality, organic content, and regional geometries. Such a systematic knowledge of the Leonardian strata may assist in both new nonconventional and conventional exploration strategies.

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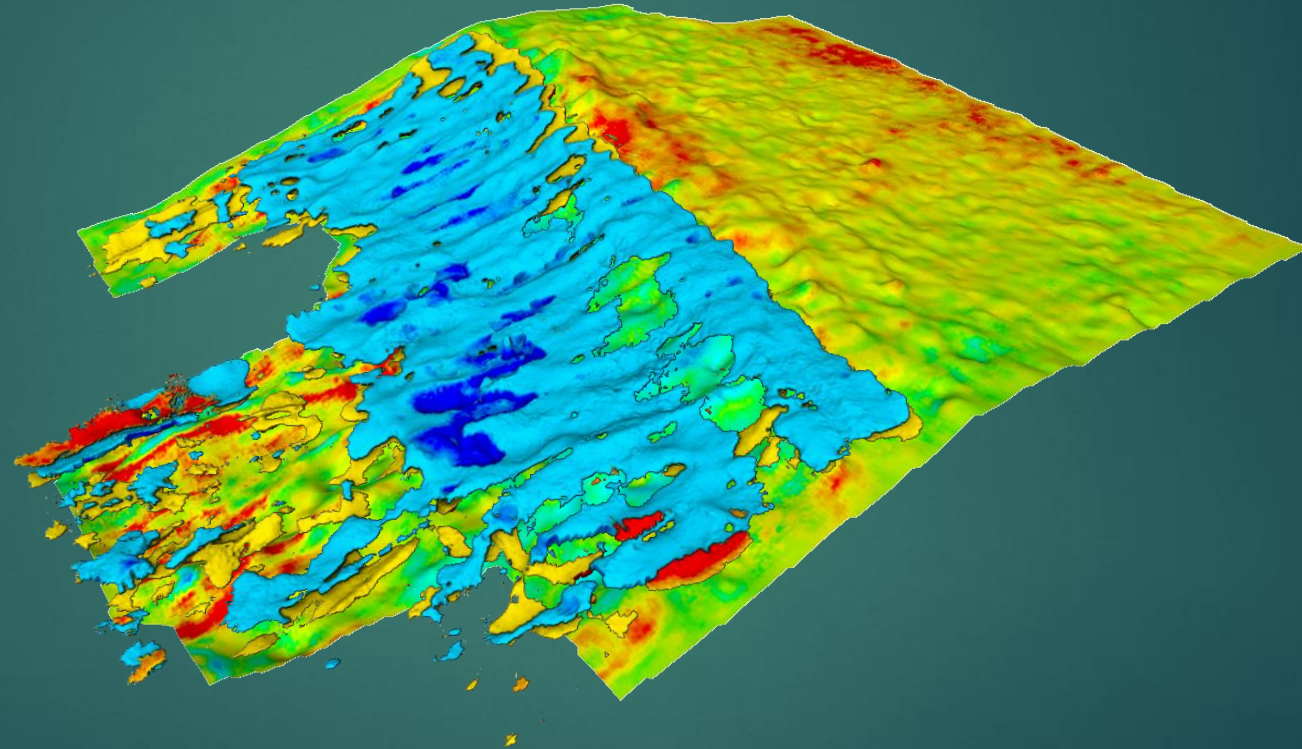
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SEISMIC STRATIGRAPHIC AND QUANTITATIVE INTERPRETATION OF LEONARIDAN REEFAL CARBONATES, EASTERN SHELF OF THE MIDLAND BASIN: INSIGHT INTO SEA LEVEL EFFECTS, GEOMORPHOLOGY AND ASSOCIATED RESERVOIR QUALITY



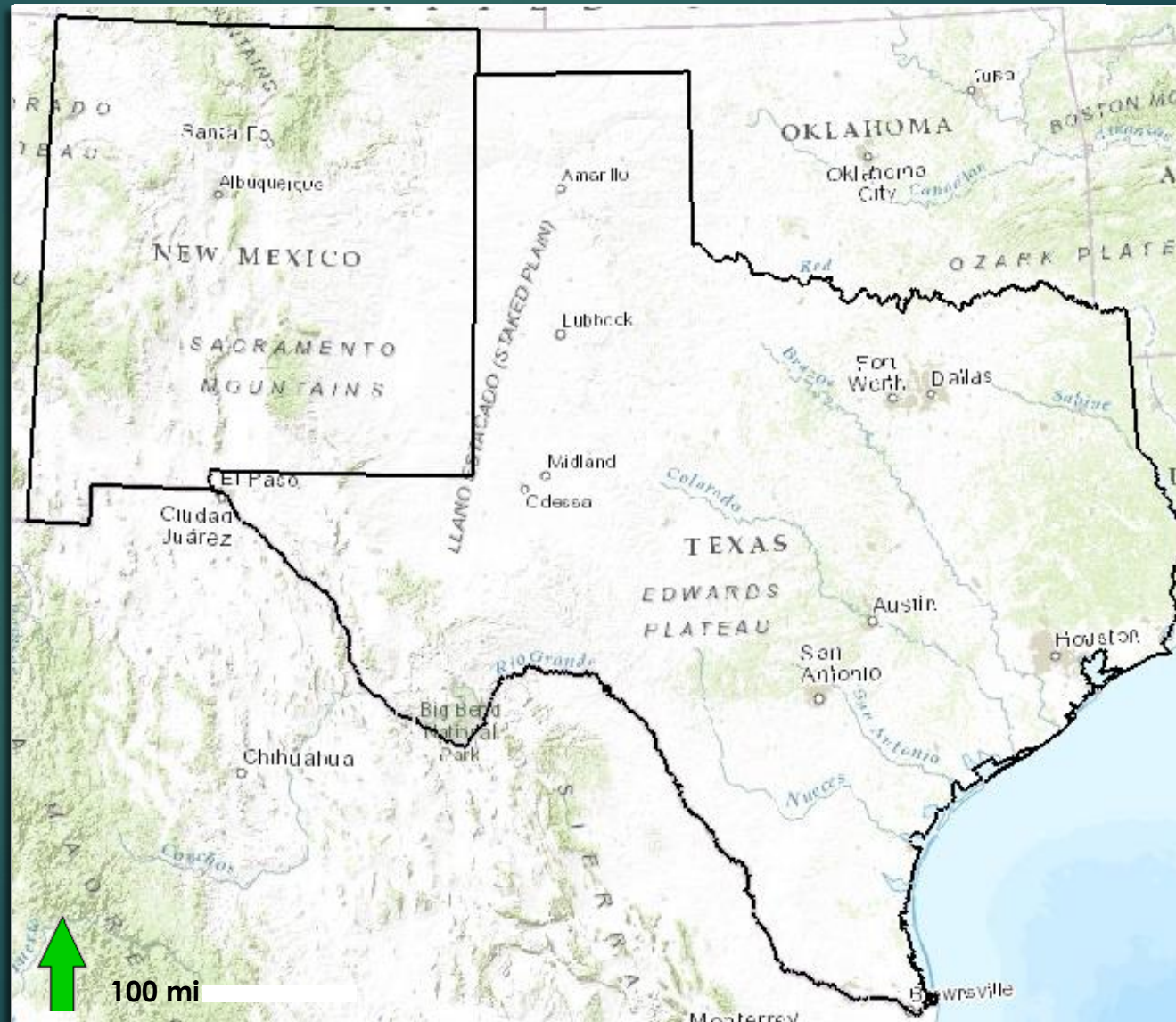
Abidin B. Caf and John D. Pigott*
University of Oklahoma



Strategy

- **Introduction**
 - Problem Definition
 - Study Location
- **Data & Methods**
 - Available Data & Data Quality
 - Methods
- **Geologic Setting**
- **Seismic Stratigraphic Interpretation**
- **Quantitative Seismic Interpretation**
 - Post-Stack Acoustic Impedance Inversion
 - 3D Porosity Estimation via Probabilistic Neural Network (PNN)
- **Petrophysical Techniques**
- **Integrated Interpretation & Discussion**
- **Conclusions**

Location



After BEG UT, 2008

Problem Definition

- Area's main exploration target is the Pennsylvanian (Canyon and Cisco) Horseshoe Atoll reefal buildup (Ball, 1995).
- Little attention paid to the overlying Lower Permian (Leonardian) Strata.
- Few petrophysically constrained seismic studies have been conducted on these Leonardian buildups.
- Consequently, the objective of this study is to conduct a quantitative seismic stratigraphic interpretation of the Leonardian shelf edge in order to infer depositional environments and the associated reservoir quality in response to eustatic changes.

WORK FLOW: CRAFTING AN ACCURATE GEOCONSTRAINED INTERPRETIVE TABLE FOR QUANTITATIVE SEISMIC STRATIGRAPHY

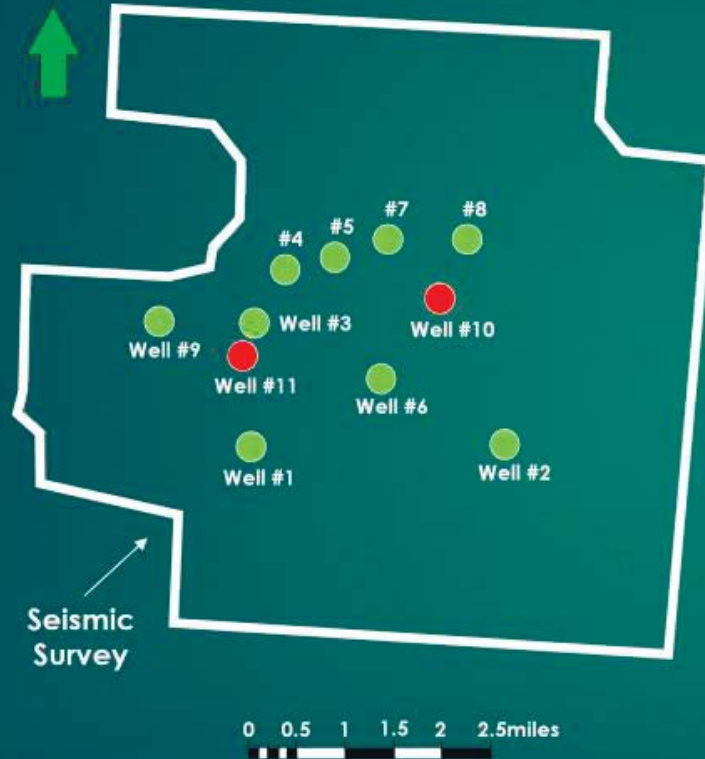


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Data and Methods

Wells and Seismic



- ~25 Mi² 3D seismic data
 - Bin size is 25 by 25 m
 - The record length is 3 s
 - Sample interval is 2 ms
 - Total number of samples 750 per trace.
 - Post-stack time migrated, and ACG gain is applied (Davagustto, 2013).

● 2 Wells with GR, Caliper & Neutron logs

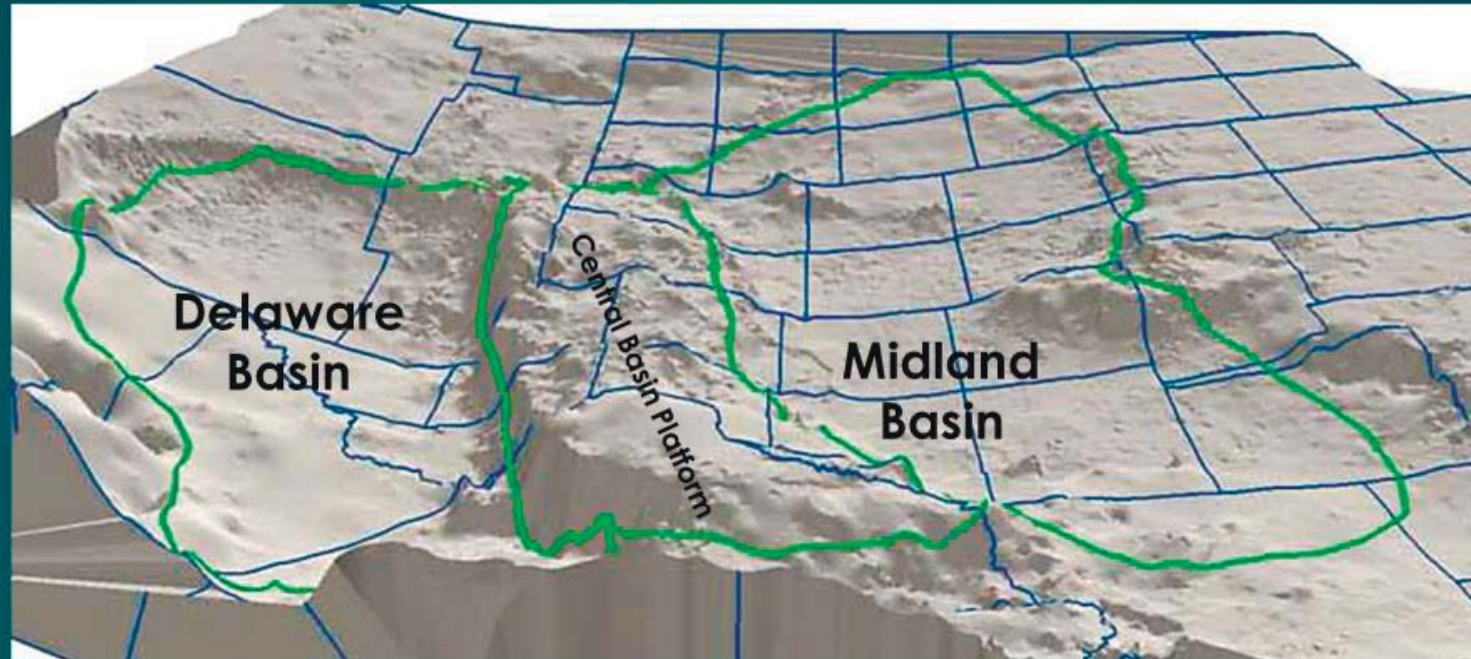
● 9 Wells with GR, Caliper, Sonic, Bulk Density, Neutron, Resistivity (deep & shallow), Pe

Presenter's notes: The following data were provided for this study: A 3-D seismic volume composed of 360 in-line planes and 410 crossline planes, over approximately 25 mi²; eleven wells, nine of which are complete sonic density, neutron, gr, resistivity; two wells with only GR caliper and neutron; formation tops acquired from Railroad Commission of Texas

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Geologic Setting



(Modified from Concho Resources September Investor Presentation)

STRUCTURE AT BASE OF WOLFCAMP

Presenter's notes: Above is a figure built from formation tops of wells drilled in the Permian Basin. What we are viewing is the structure at the base of the Permian Wolfcamp that clearly illustrates the geologic provinces of the Permian Basin. The westward dipping Midland Basin is to the East, the prominent Central Basin Platform separates the two basins and the asymmetric Delaware Basin to the West.

Geologic Setting

Paleogeography

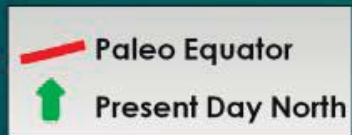
Carboniferous (300 Ma)



Middle Permian (280 Ma)



Early Triassic (245 Ma)



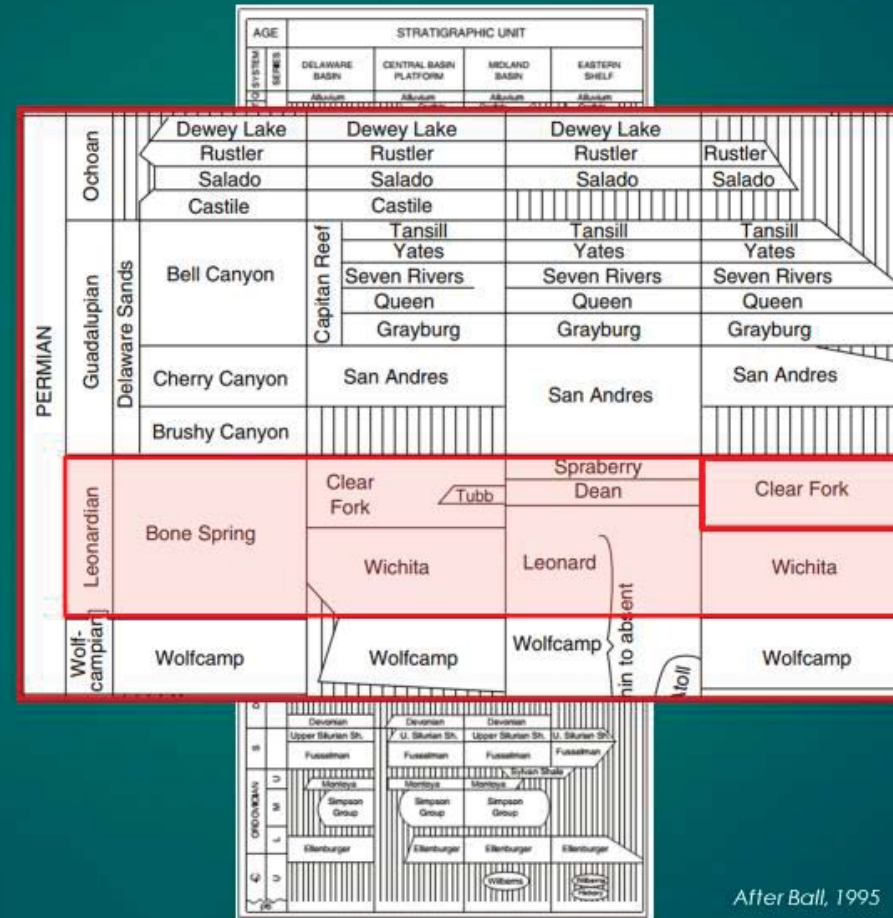
0 1000 mi

After Blakey, 2013

Presenter's notes: The structural history of Permian basin can be subdivided into three distinct stages: Development of the Tobosa Basin (Ancestor of the Permian Basin) during Cambrian to Mississippian time, Division of the Tobosa Basin into several smaller basins separated by uplifts during the early Pennsylvanian through Early Permian, and structural/tectonic stability and infilling of the basins from the Middle Permian to the Early Triassic. At late Permian times, basin became restricted from the sea by closure of Hovie Channel and evaporates deposited

Geologic Setting

Stratigraphy



Presenter's notes: The regional stratigraphy of the study area comprises of units from Ordovician to the Permian age. The primary target unit of petroleum exploration of the study area is the Late Pennsylvanian to Early Permian aged Horseshoe Atoll reefal buildup. Our interval of study is Leonardian aged Clearfork strata, which can be defined as carbonate-and clastic mixed lithology, but mainly carbonate.

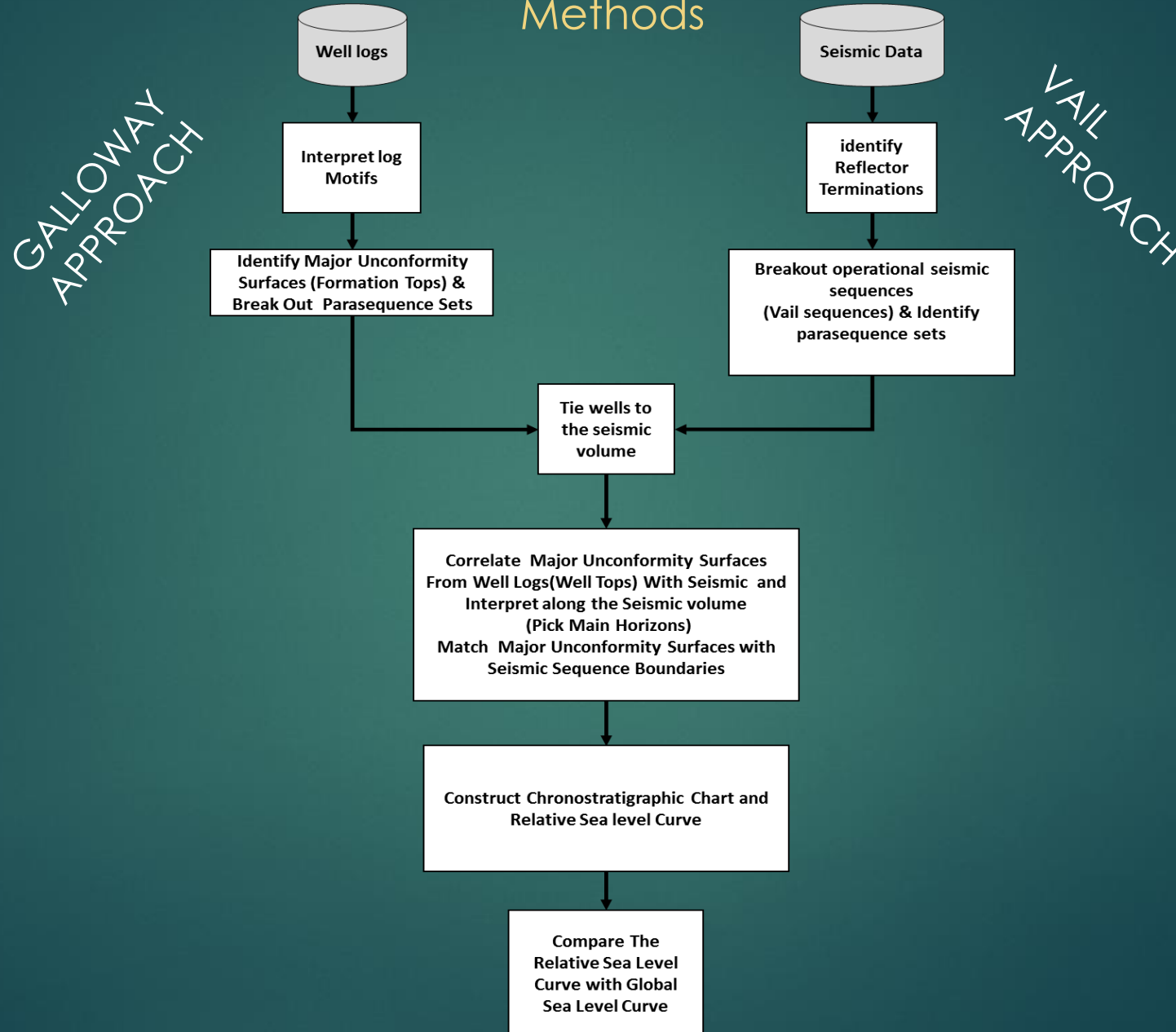
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Presenter's notes: Interpretation can be divided into two types: Galloway approach – start from well and constrain with seismic; or Vail approach – start from seismic and constrain with well. Procedure here is integrative.

Seismic Stratigraphic Interpretation

Methods

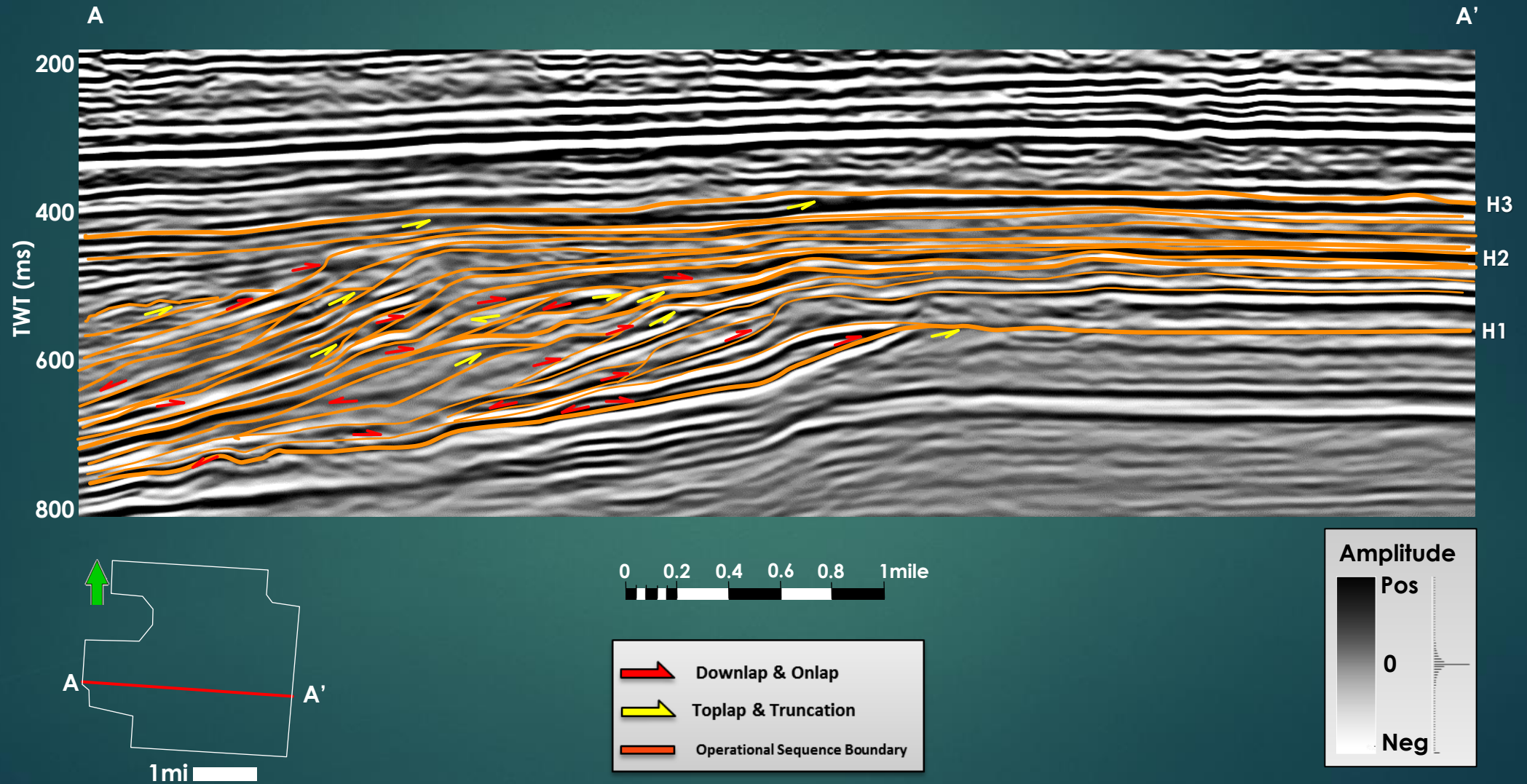


Seismic Stratigraphic Interpretation

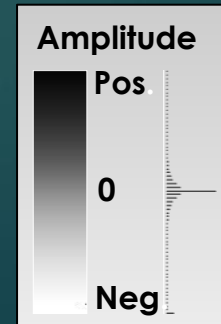
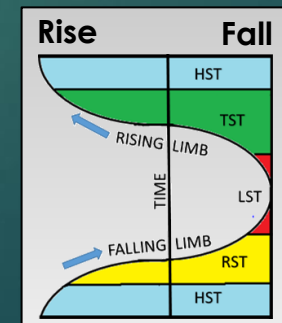
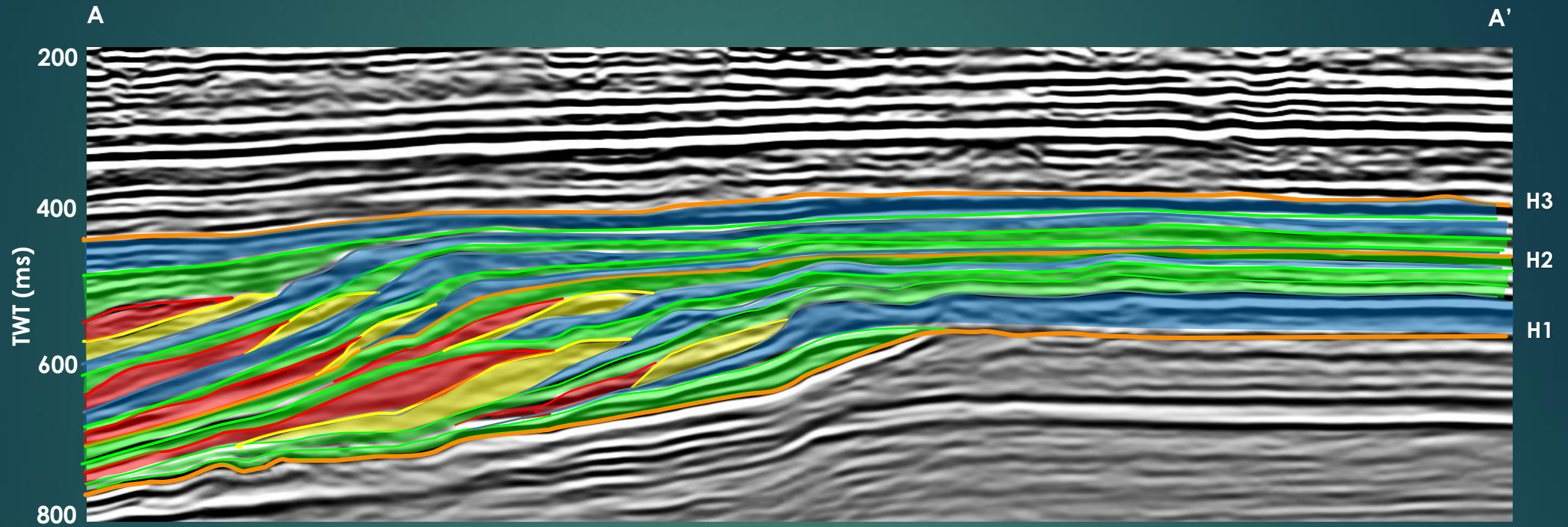
Classic Vail Approach

- Select representative cross section with borehole constraint
- Interpret faults
- Interpret reflector terminations (toplap, truncation, offlap, downlap, and onlap)
- Define operational seismic sequences (parasequence sets) based on termination analysis
- Interpret seismic parasequence sets

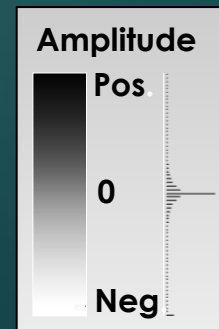
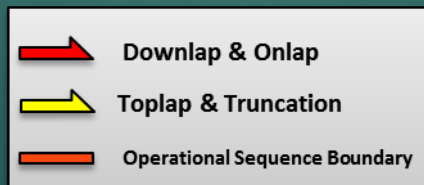
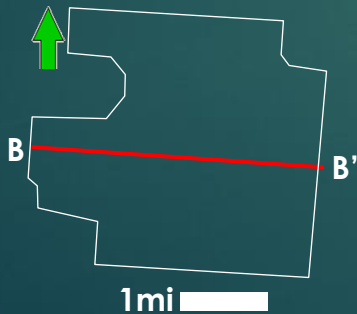
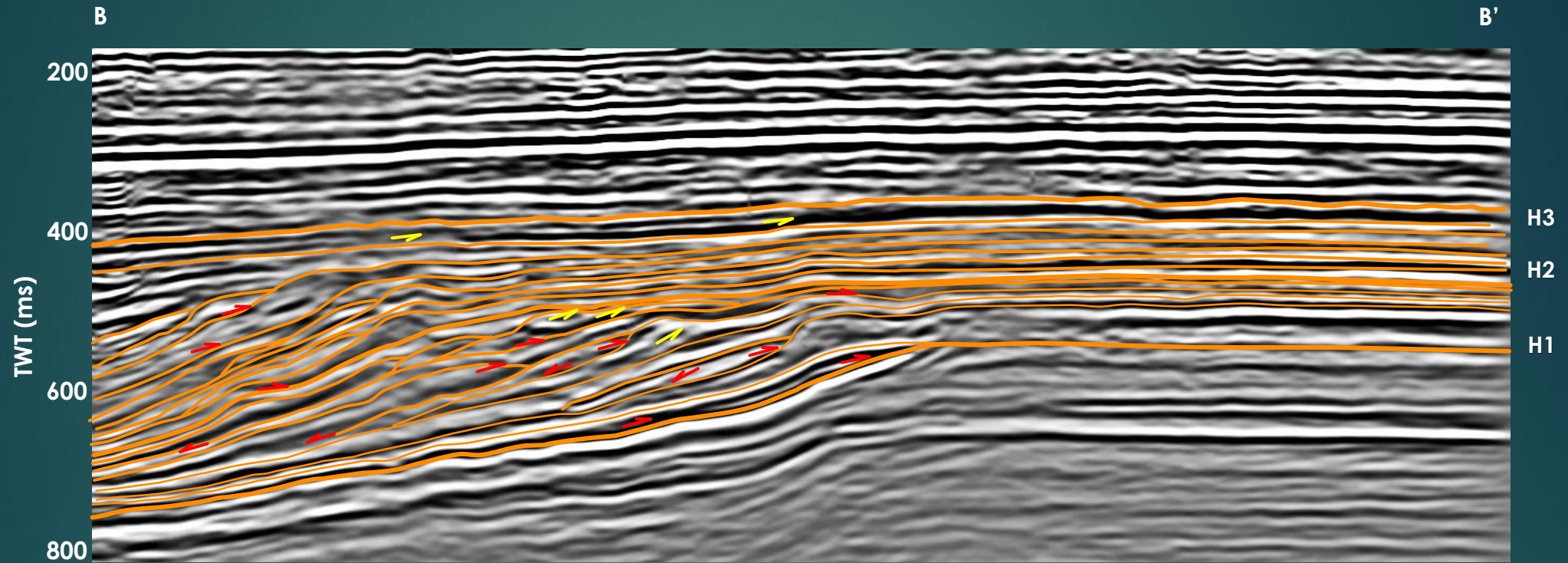
Seismic Stratigraphic Interpretation



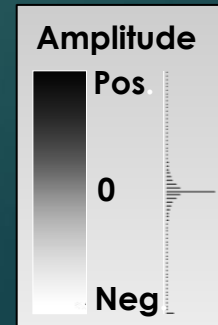
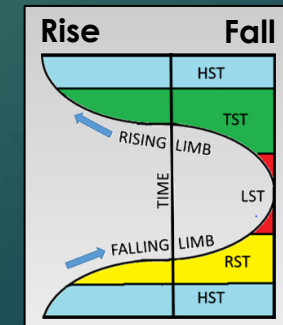
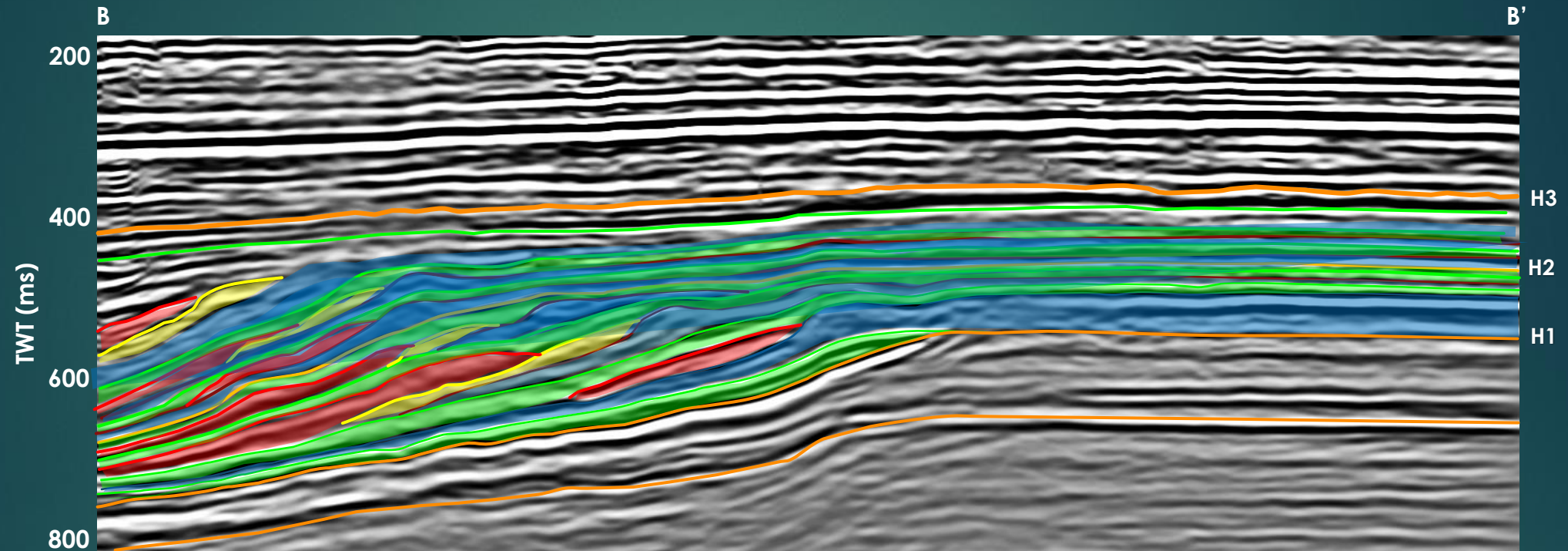
Seismic Stratigraphic Interpretation



Seismic Stratigraphic Interpretation

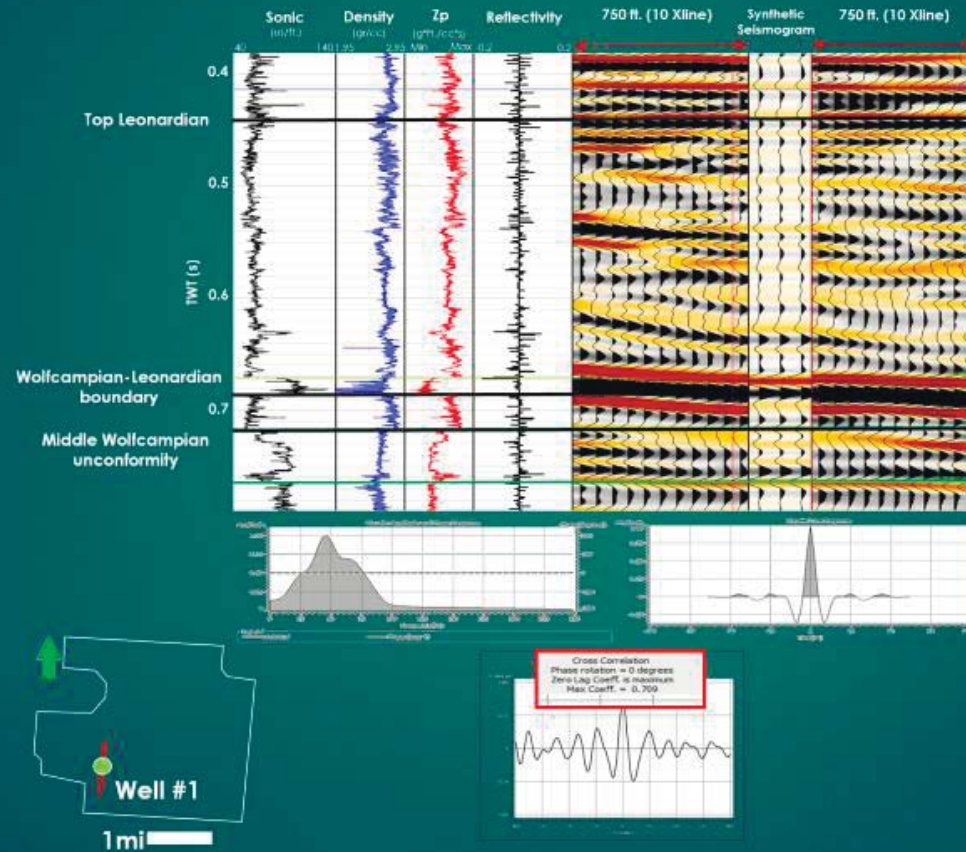


Seismic Stratigraphic Interpretation



Seismic Stratigraphic Interpretation

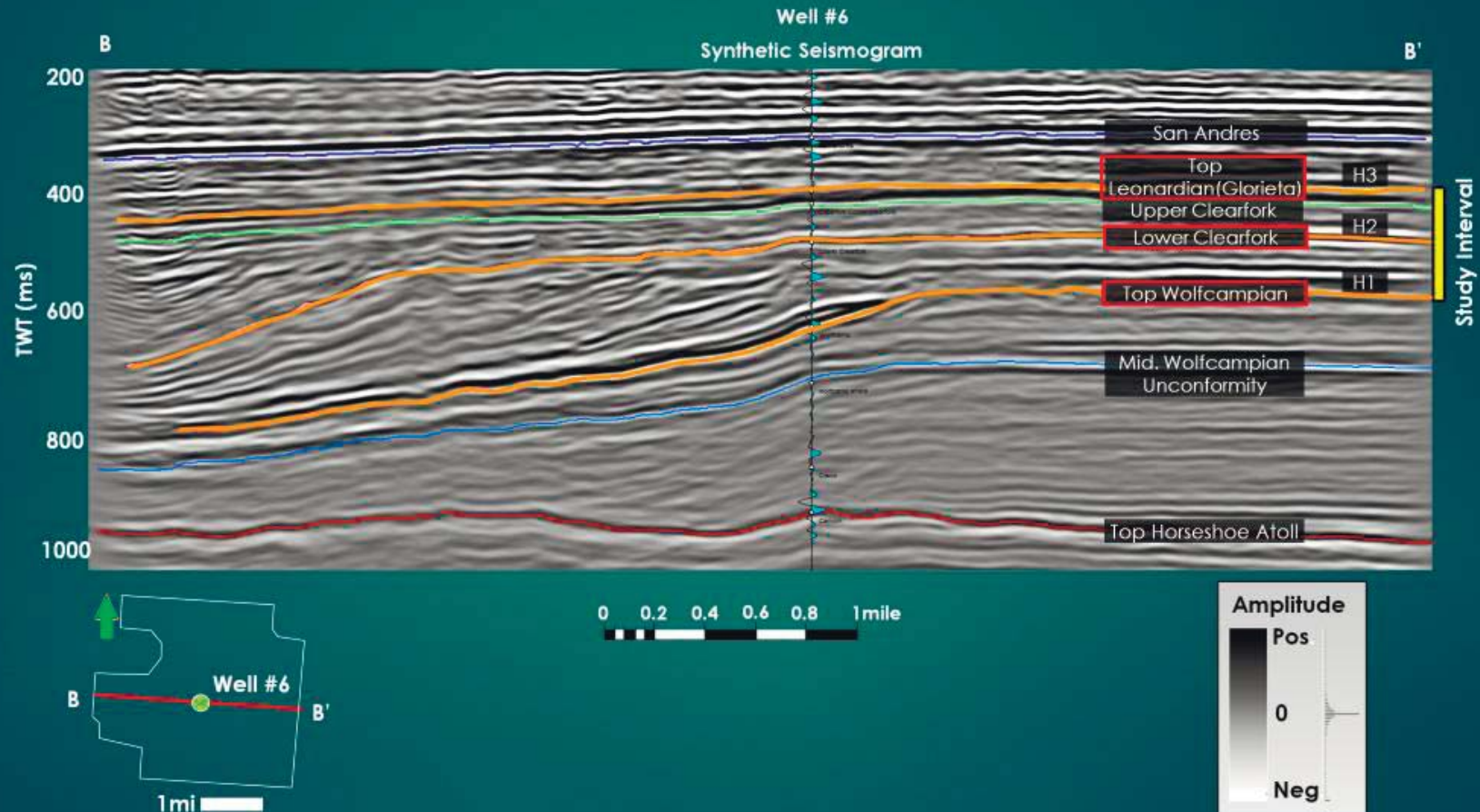
Well-to-Seismic Tie



Presenter's notes: To constrain the seismic stratigraphic interpretation to the wellbore data, well to seismic tie is performed. We can see the synthetic on the middle (matches very well with the seismic) correlation is 70%.

Seismic Stratigraphic Interpretation

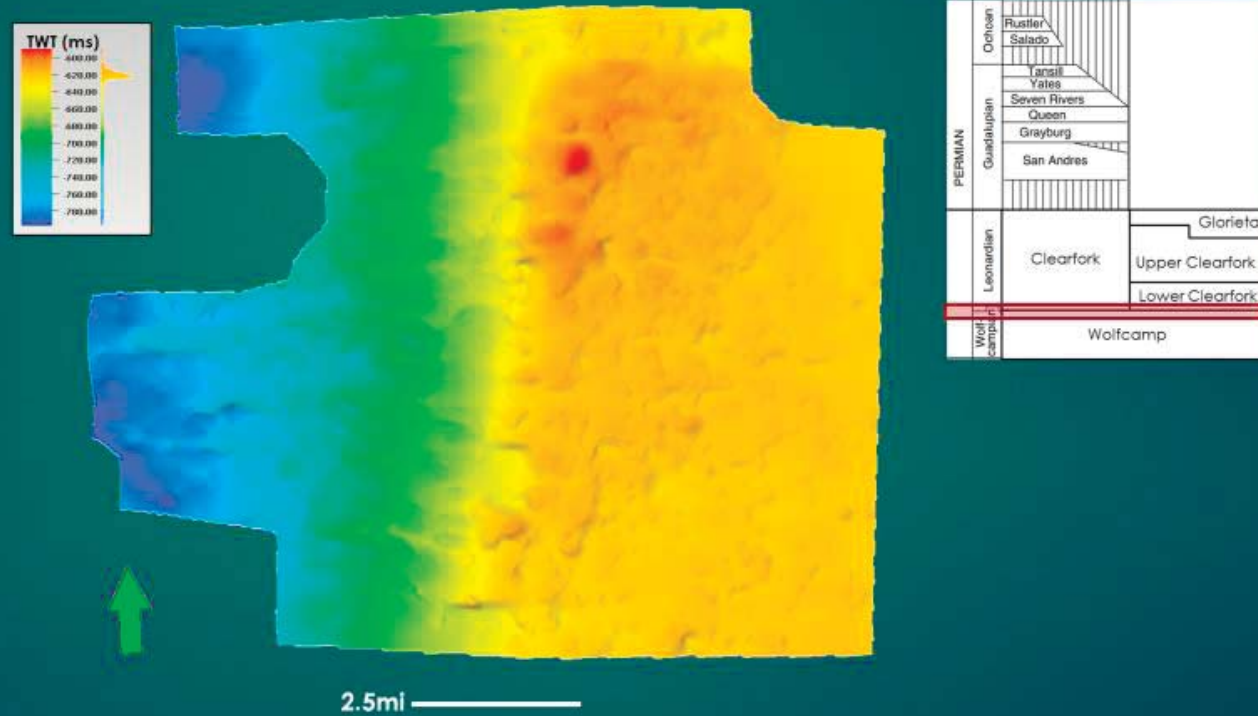
Well-to-Seismic tie



Presenter's notes: After well tie, we can see that our operational sequence boundaries correlate to the main horizons of interest. With the well top information available from five wells and correlated well tops from remaining four wells, four major horizons were interpreted. They were Top of Wolfcampian, Lower Leonardian (Lower Clearfork), Upper Leonardian (Upper Clearfork) and Top Leonardian (Glorieta) formations. H1 and H3 correspond to the tops of major lithologic formations in the wells, and, except for H2 they are regionally extensive unconformity surfaces, they represent major boundaries of third order cycles or Vail sequences. H2 is also an operational sequence boundary, but corresponds instead to a Galloway sequence boundary.

Seismic Stratigraphic Interpretation

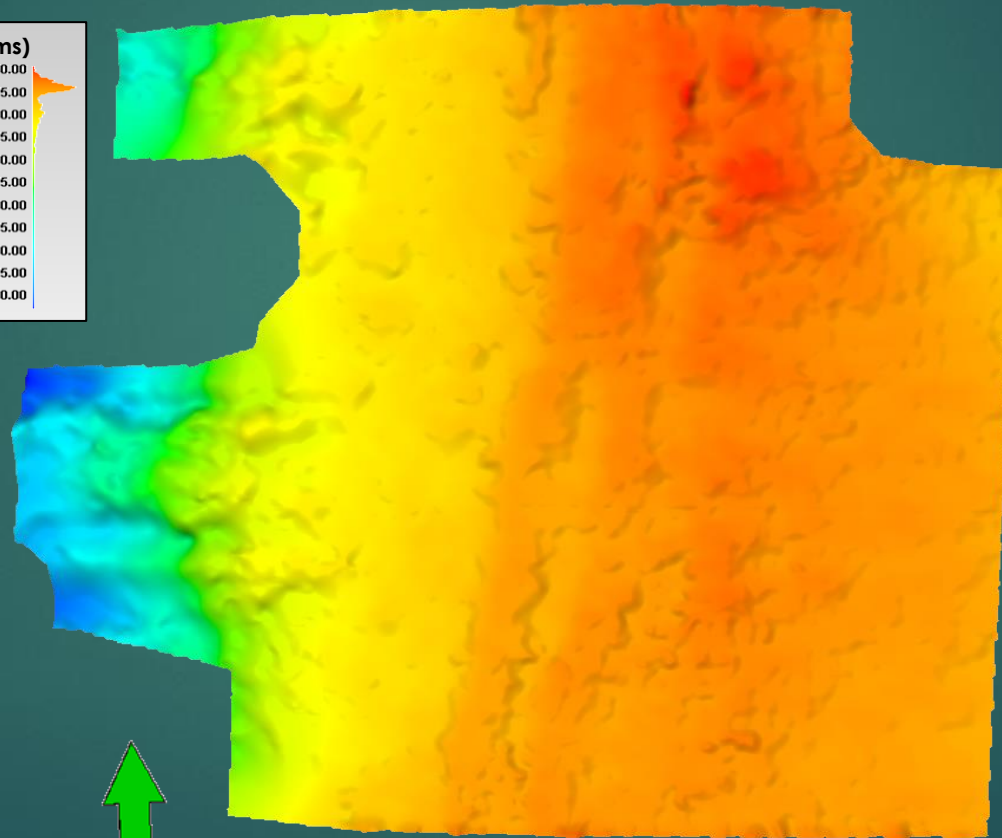
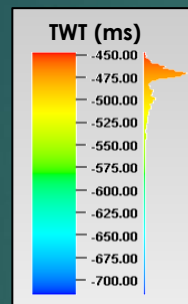
H1 (Wolfcamp-Leonardian UC1 Boundary)



Presenter's notes: Three principal seismic horizons are chosen.

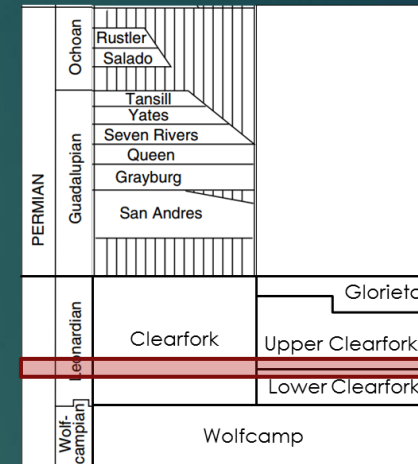
Seismic Stratigraphic Interpretation

H2 (Middle Leonardian-Lower Clearfork)



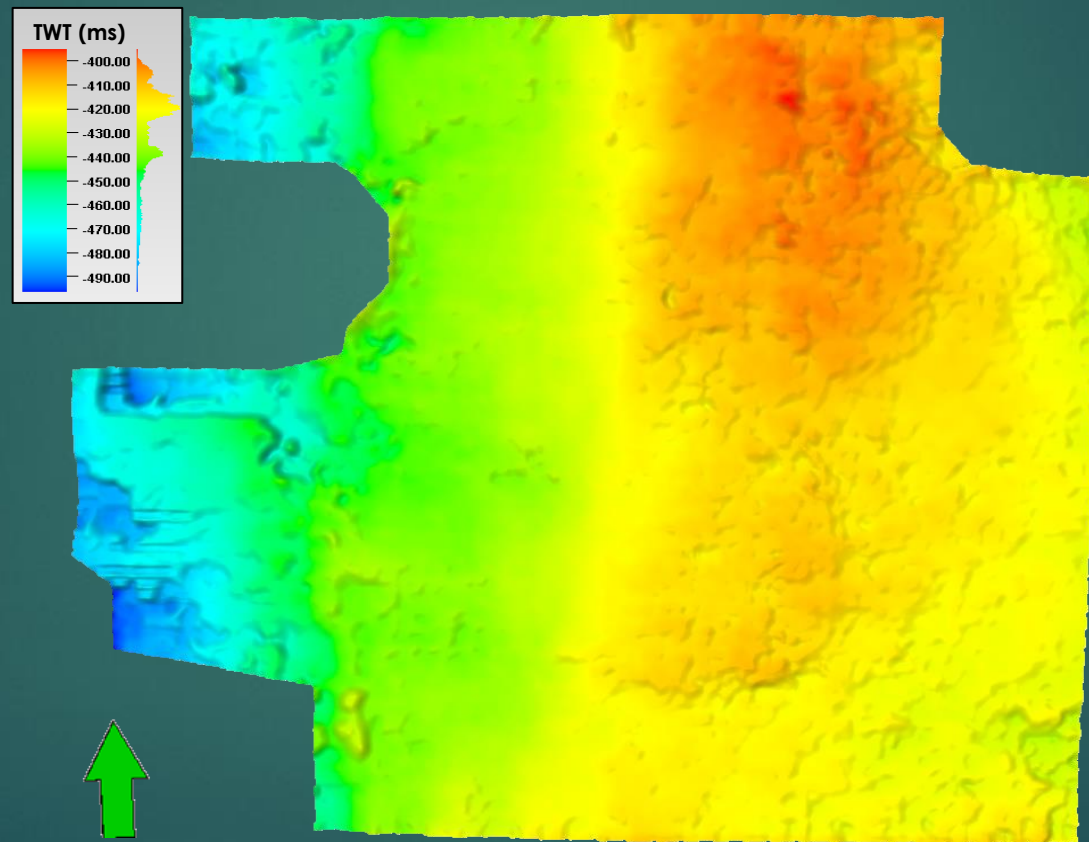
2.5mi

A horizontal white scale bar representing a distance of 2.5 miles.

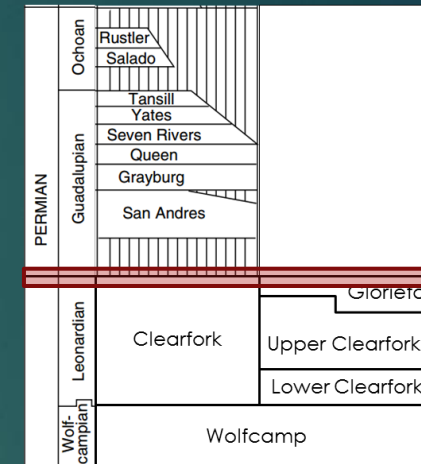


Seismic Stratigraphic Interpretation

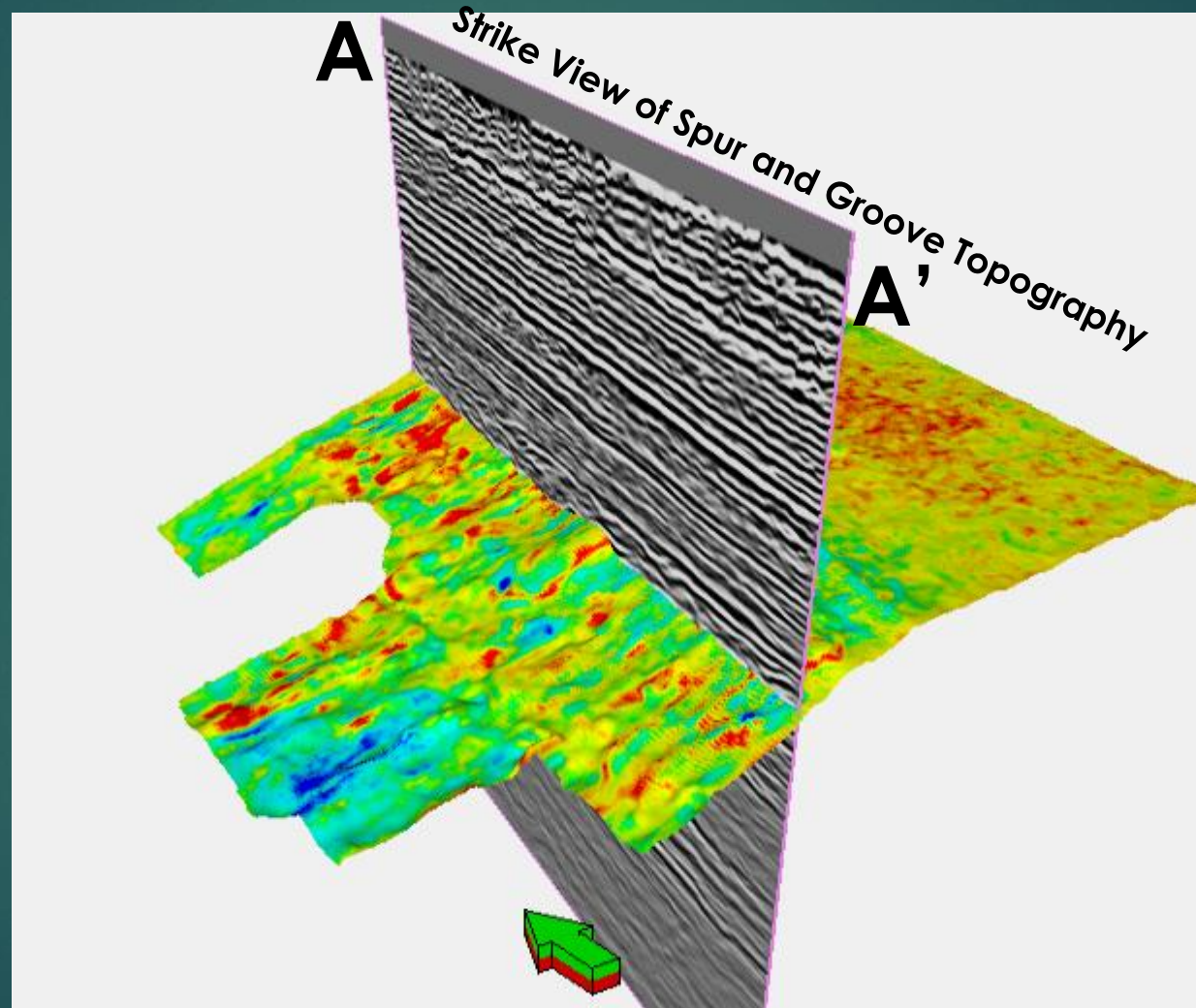
H3 (Top Leonardian UC1 Boundary)

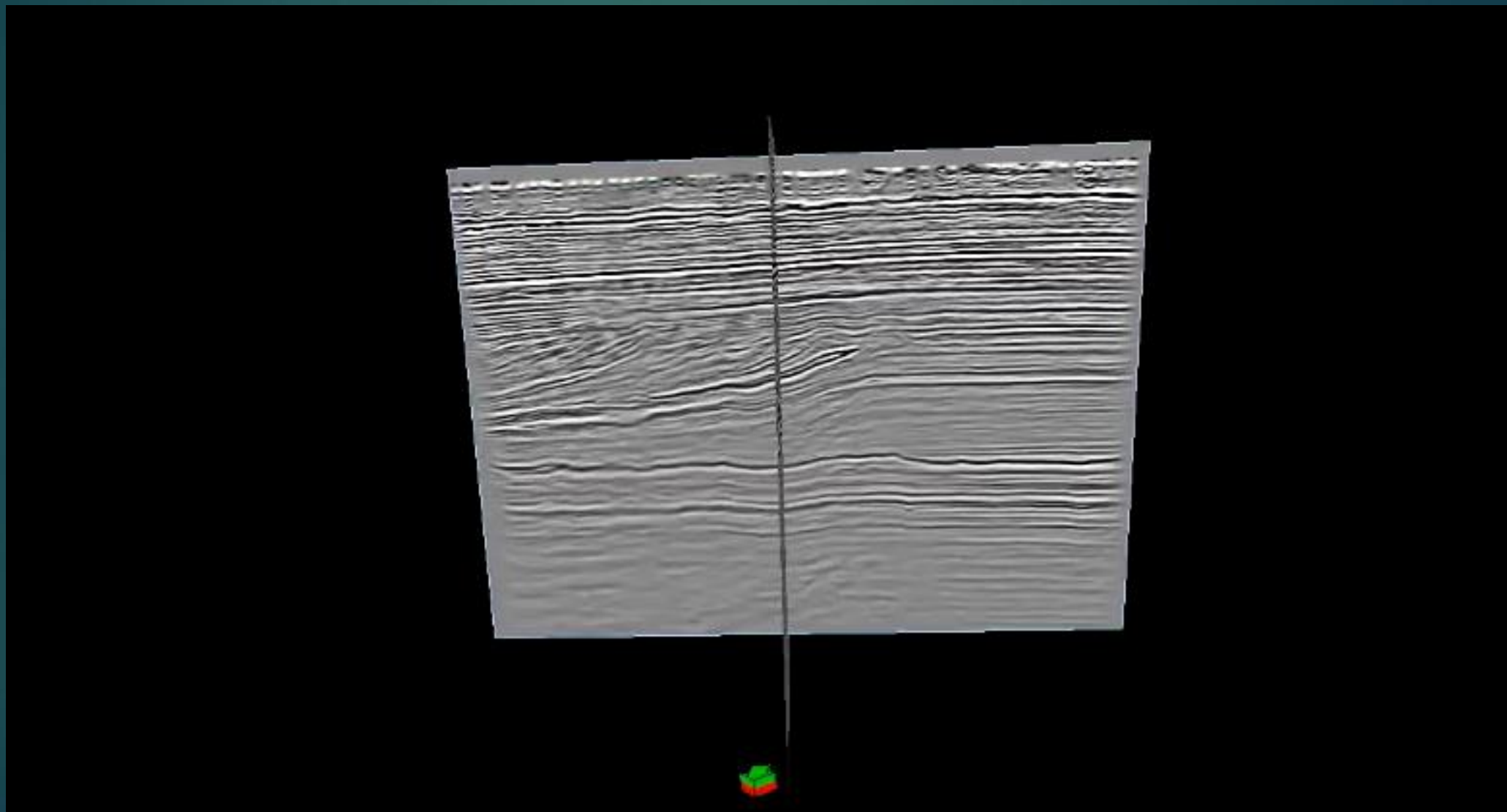


2.5mi



Seismic Stratigraphic Interpretation

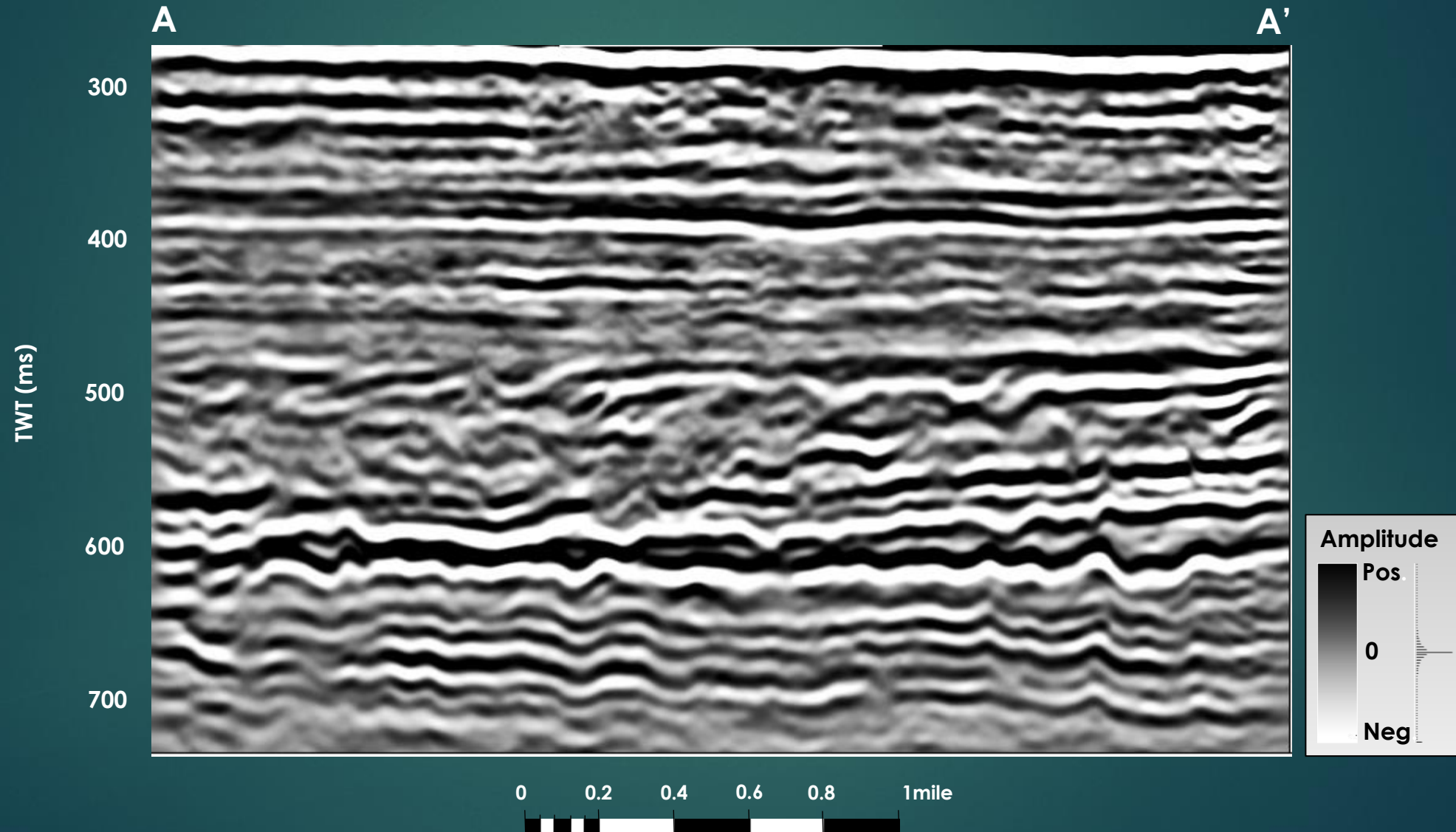




Seismic Stratigraphic Interpretation

Strike View of Spur and Grooves

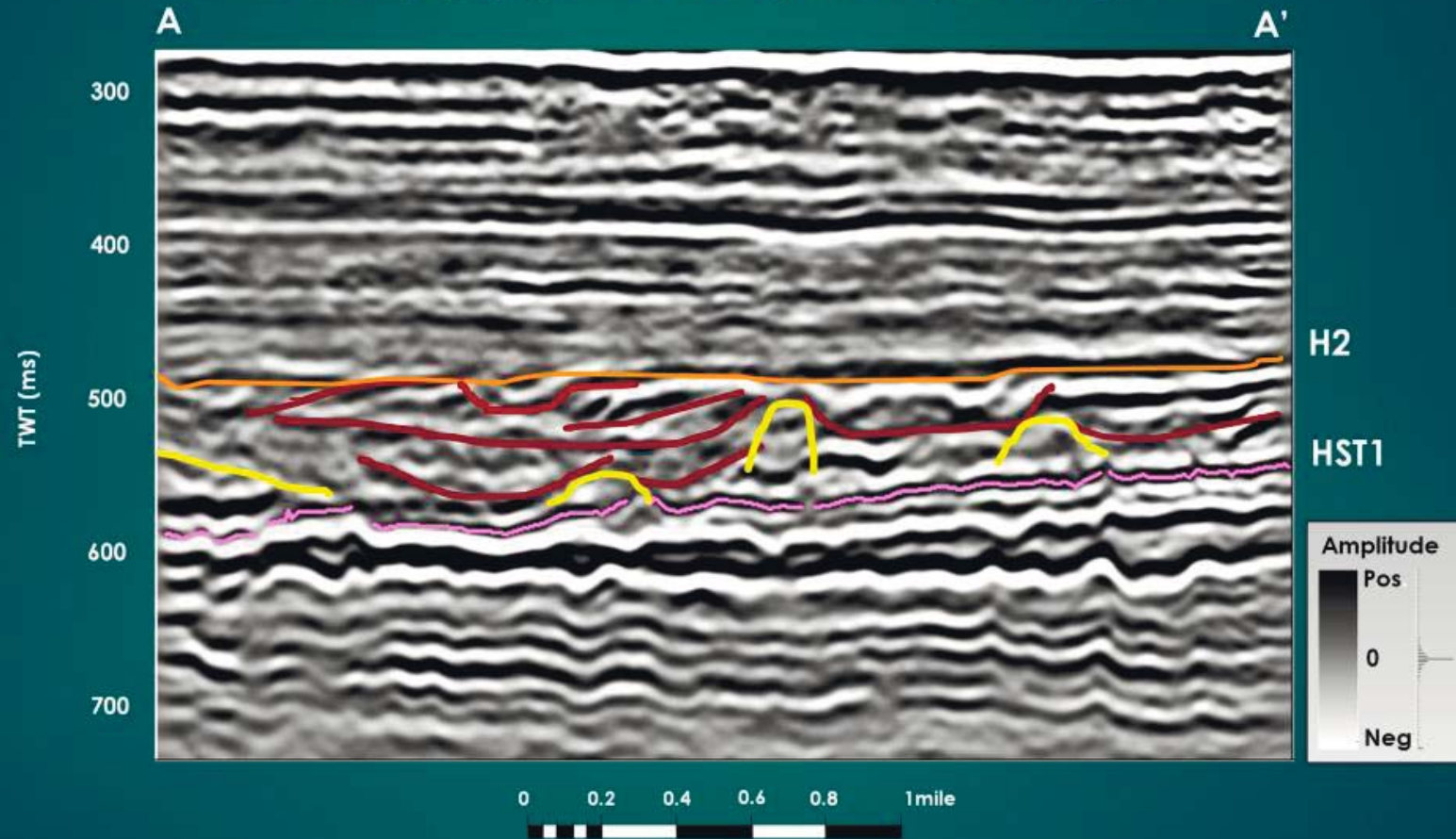
Antecedent topography: Multi-storied groove fill, persistent spurs



Seismic Stratigraphic Interpretation

Strike View of Spur and Grooves

Antecedent topography: Multi-storied groove fill, persistent spurs

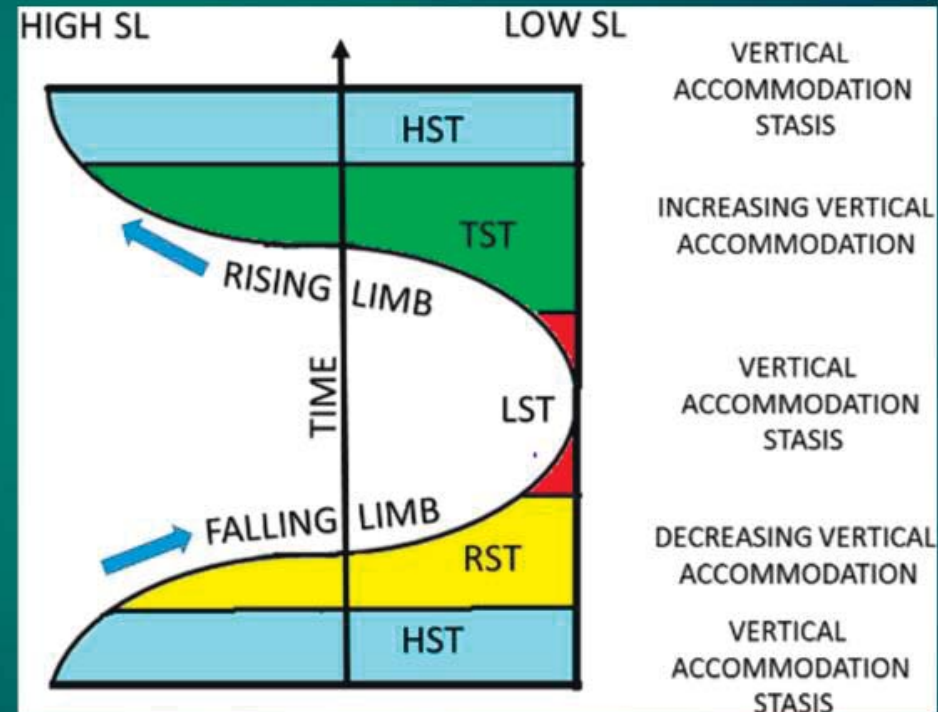


Presenter's notes: Spur and grooves in strike reveal antecedent topography with multi-storied cut and fill and sigmoidal accretion units as well as semi-persistent spurs.

Seismic Stratigraphic Interpretation

Galloway Motif Approach

- Utilize gamma ray log stacking patterns to identify vertical trends in grain size and vertical trends in inferred process energies.
- Sequence boundaries separate the parasequence sets with maximum flooding surfaces between TST's and HST's.

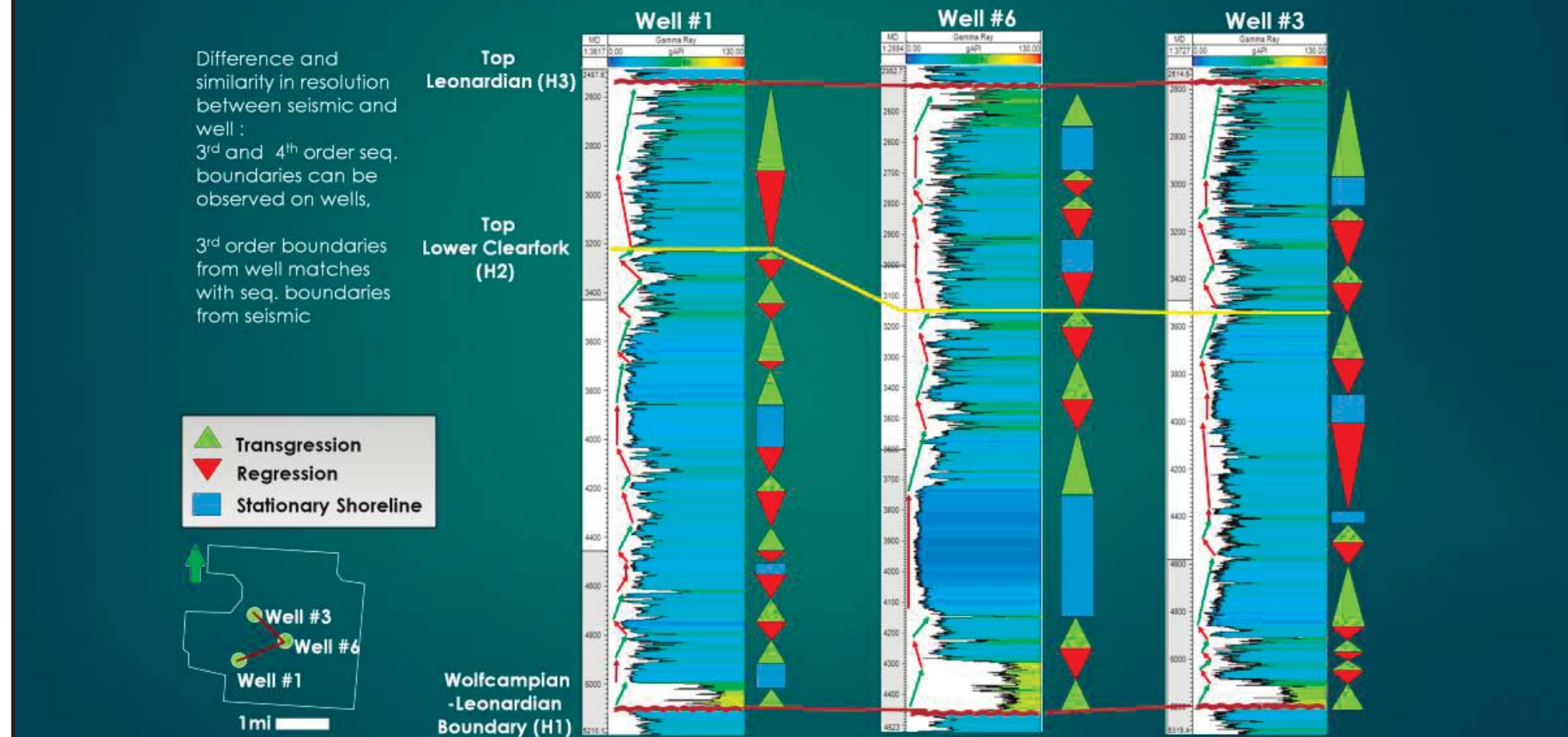


From Pigott and Bradley, 2014

Presenter's notes: Along with the seismic sequence interpretation, a "Galloway motif Approach" is utilized by interpreting the Gamma ray log motifs at wells #1, #3, and #6, in order to delineate seismically resolvable (third order) and seismically unresolvable (fourth order) coarsening upward, fining upward and stationary shoreline cycles, based upon the assumption that the changes in Gamma ray log signature delineates changes in vertical accommodation fill.

Seismic Stratigraphic Interpretation

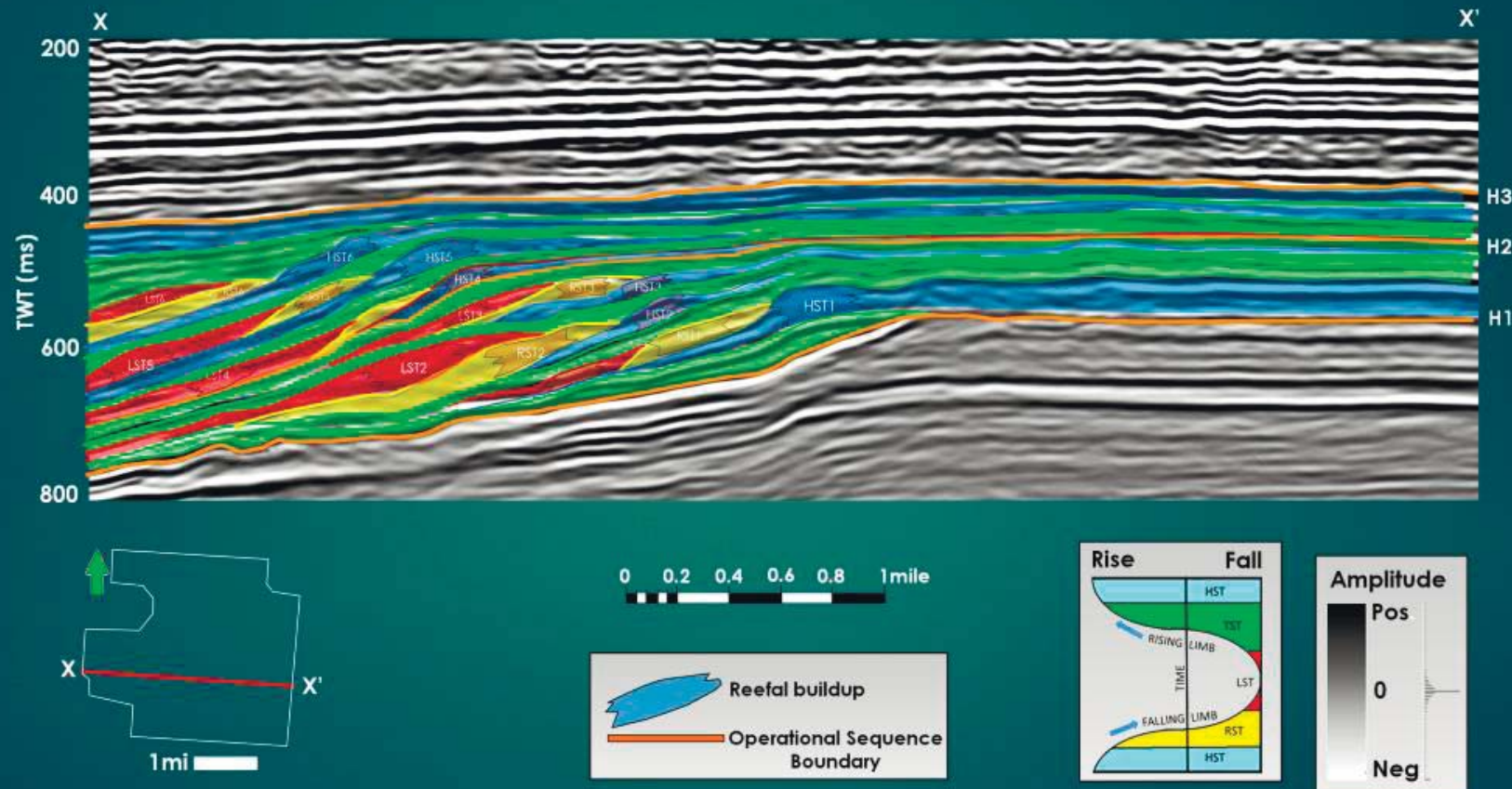
Galloway Motif Application



Presenter's notes: Comparison of the Vail Parasequence sets interpreted from the seismic reflections and Galloway parasequences interpreted from well logs reveal the difference in the resolution as well as the similarities. That is, each of the seismic horizons indicate a Type 1 unconformity, which corresponds to the Vail operational seismic sequences, (except H2), which are third order parasequence set boundaries, in contrast to fourth order parasequence sets revealed by the interpretation of Galloway motifs. Moreover, regionally widespread unconformity surfaces of H1 and H3 and Galloway sequence boundary H2 can be observed both in seismic and the wells.

Seismic Stratigraphic Interpretation

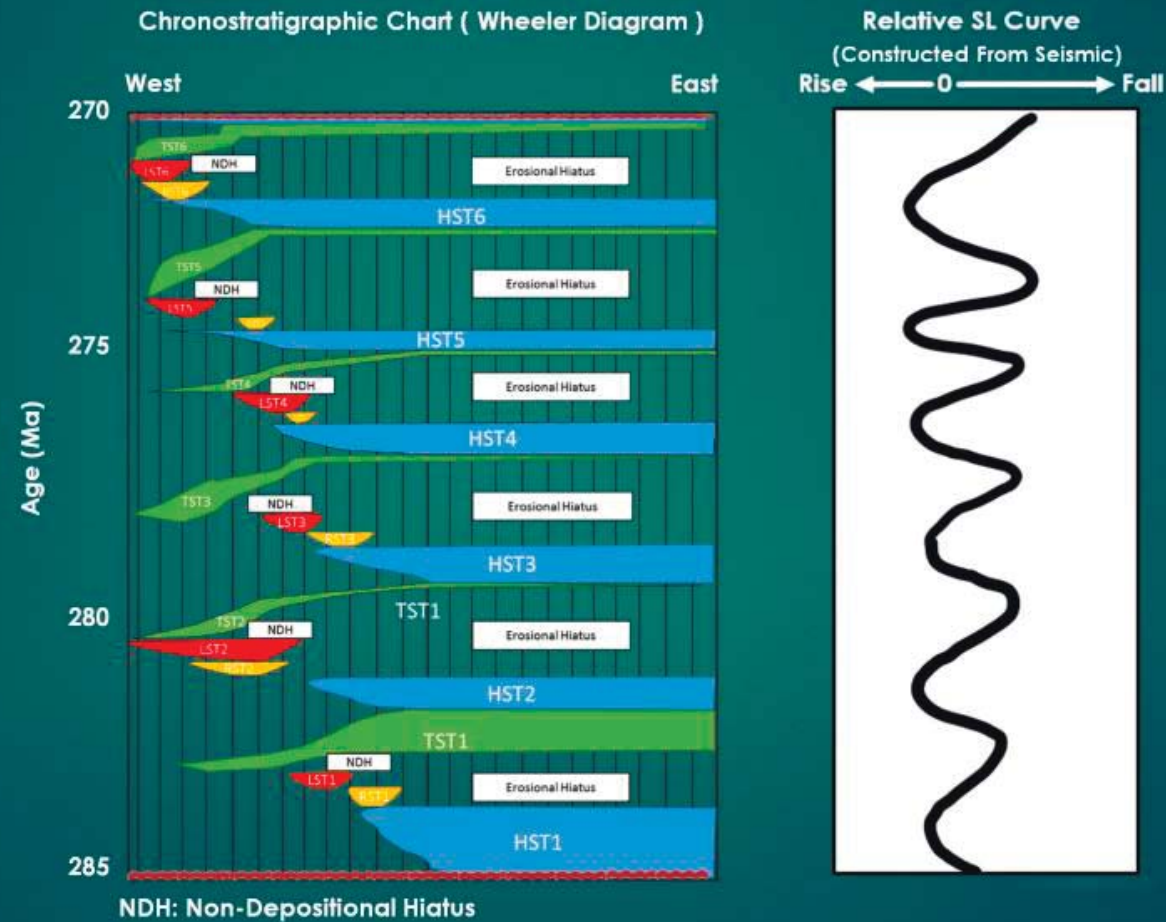
Interpreted Buildup Features



Presenter's notes: Numerous buildup features can be identified along the seismic survey. "Carbonate buildup" can be defined as carbonate deposits, including any sedimentary carbonate deposits which form positive bathymetric features. Taking the classification of buildup features into account, these are consequently interpreted as shelf margin buildups deposited at Leonardian shelf margin in the Eastern Shelf of The Midland Basin. Commonly, reef buildups prograde into deep water and bank buildups prograde into shallow water (Pigott, unpublished lecture notes). Though the core data are lacking, from the response of the buildups to sea level changes, and from their generally prograding nature, it is assumed that these buildups represent primarily the bryozoan-sponge-algal reefs so common to the Permian Basin

Seismic Stratigraphic Interpretation

Constructed Wheeler Diagram and Relative Sea Level Curve

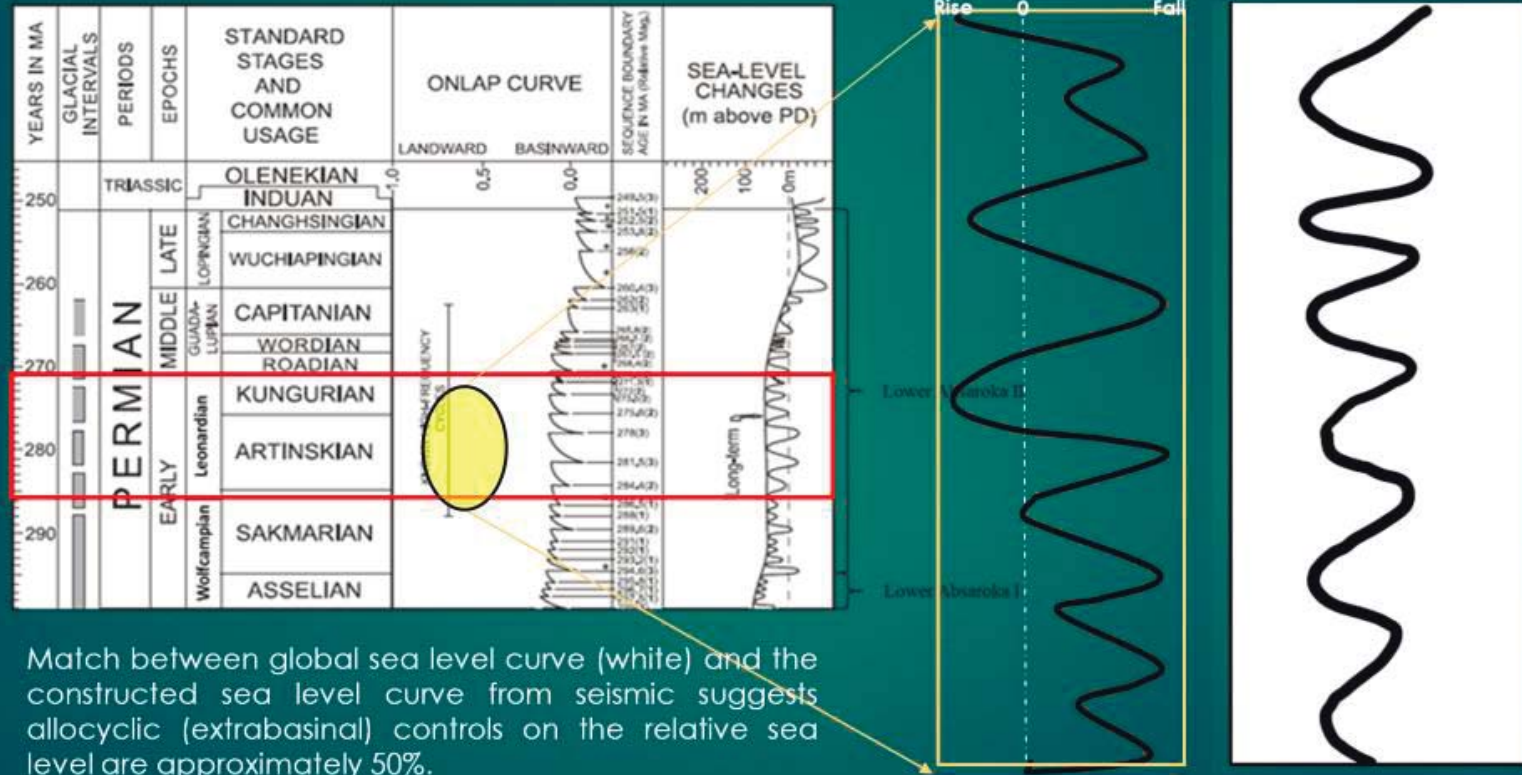


Presenter's notes: Because of seismic sequence analysis, chronostratigraphic charts and relative sea level curve constructed. It is important because chronostratigraphic chart and sea level curves can reveal the temporal and the spatial distribution of rocks as well as the depositional environment corresponding to the changes in accommodation space.

Seismic Stratigraphic Interpretation

Global Sea Level Curve Comparison

Global Sea Level Curve (After Haq et al., 2008)



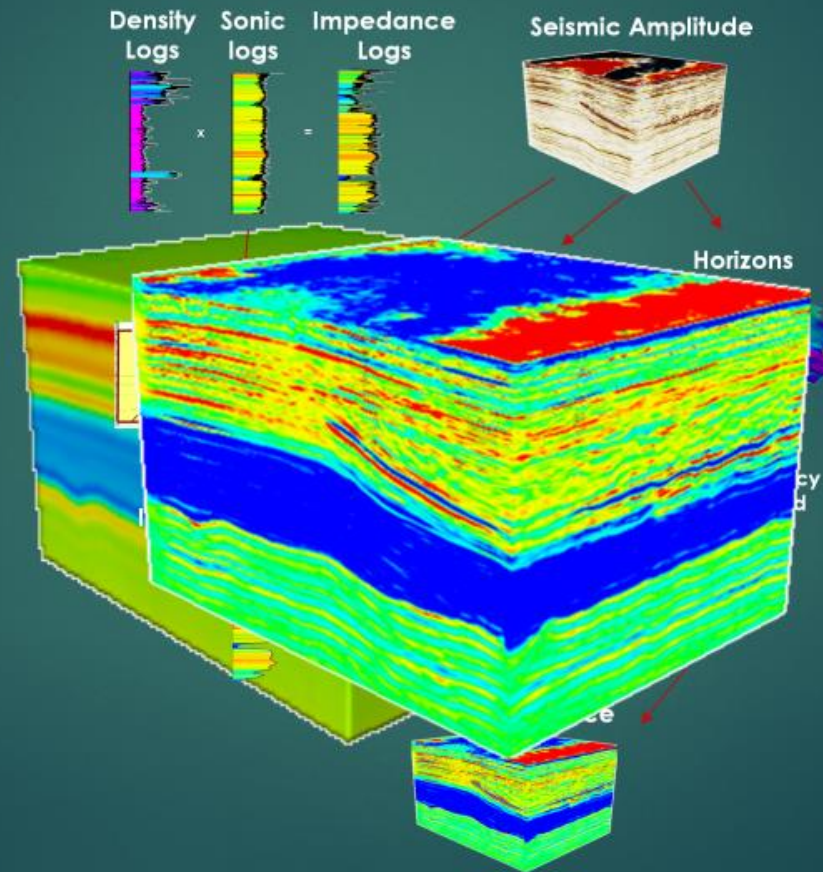
Presenter's notes: Comparison of global sea level curve with the relative sea level curve created from seismic stratigraphic analysis is important. It can reveal the mechanism behind the base level change and sediment cyclicity throughout the basin. When such comparison made in this case, it was discovered that relative sea level curve from seismic POORLY matches with the Global sea level curve, indicating allocyclic processes exert an almost equal effect upon the changes in the vertical accommodation, rather than intrabasinal (autocyclic) processes, such as global glacial fluctuations dominating.

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Quantitative Seismic Interpretation

Post-Stack Acoustic Impedance Inversion

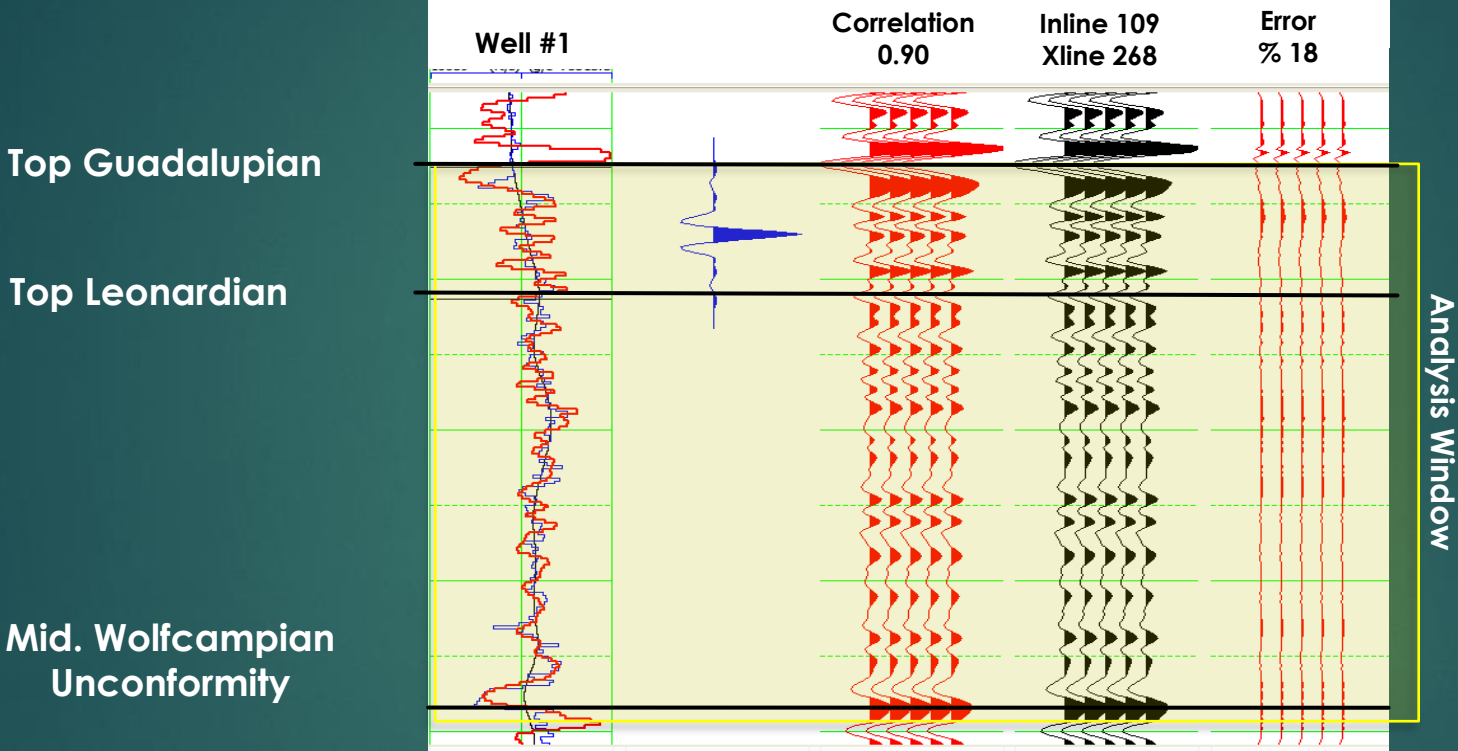


Presenter's notes: First, a band-limited inversion is computed from the migrated seismic data using a recursive (trace-integration) or similar algorithm. Next, the edited sonic and density logs are combined to form impedance logs. These impedance logs are then low-pass filtered and interpolated to form a background impedance model. Finally, the relative (band-limited) impedance inversion and low-frequency impedance model are added to form an "absolute" (broadband) impedance inversion volume. Recursive gives middle freq. (it's the inverse of classical 1d convolution ($\text{reflectivity}(i) = \text{wavelet}(i) * \text{noise}(i)$); $\text{Reflectivity} = \text{AI}(\text{lower layer}) / \text{AI}(\text{upper layer})$; Background model gives low freq. (filtered well logs + horizons).

Quantitative Seismic Interpretation

Post-Stack Acoustic Impedance Inversion

Inversion Analysis for Well #1



- Original Log
- Inverted Log
- Initial Background Model

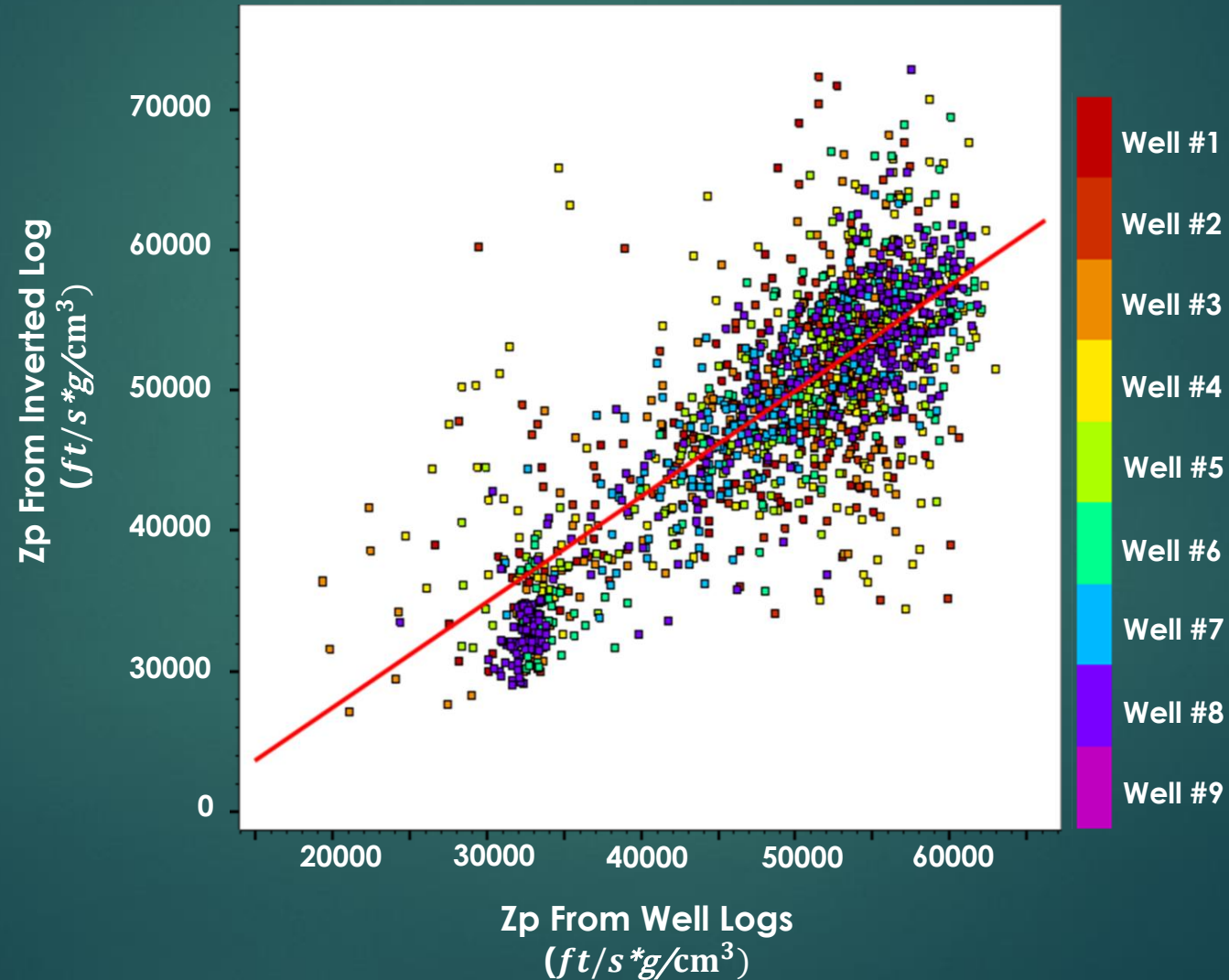


Quantitative Seismic Interpretation

Post-Stack Acoustic Impedance Inversion

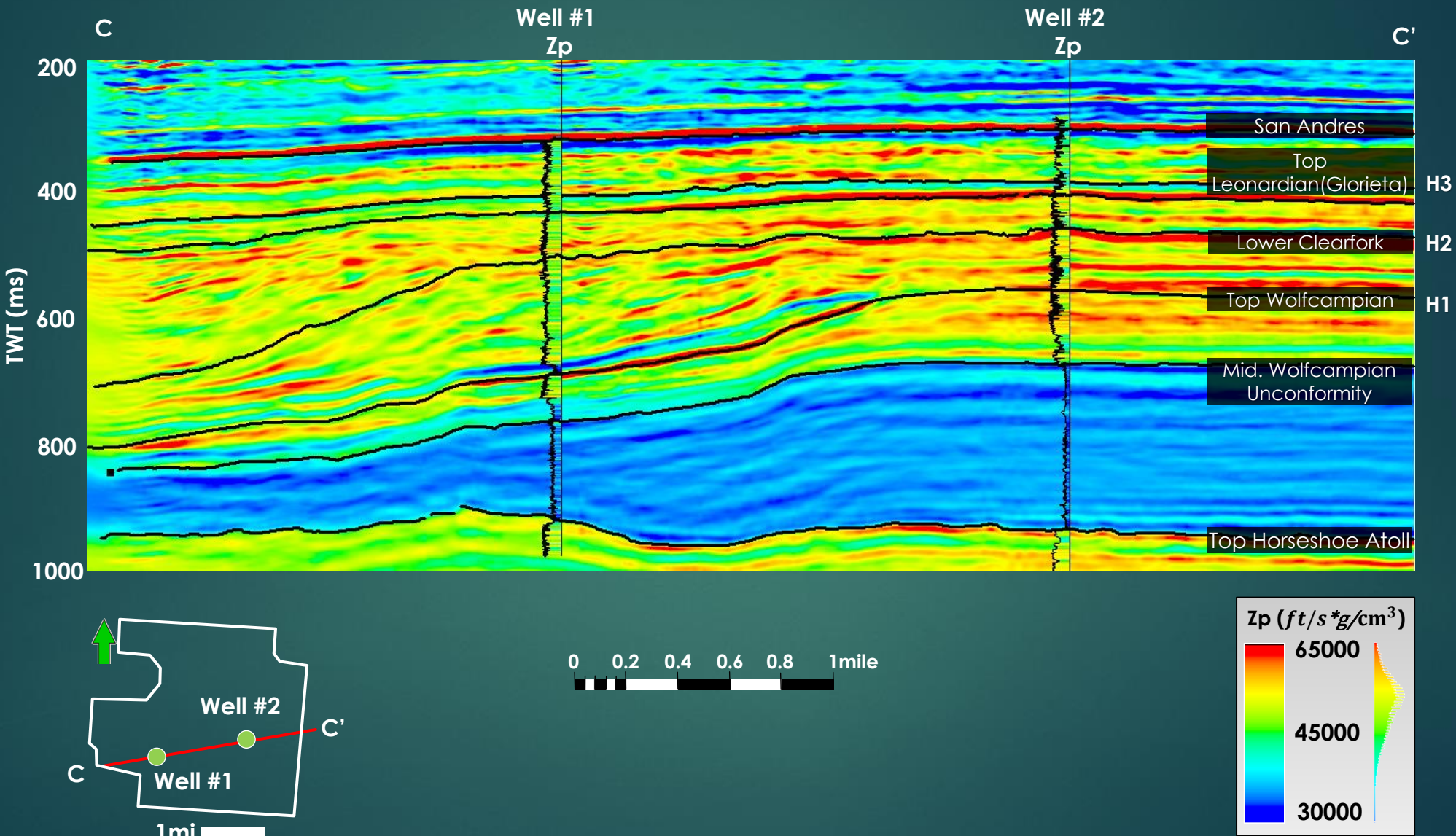
Correlation Coeff. 0.82

P-Impedance (Inverted Log) vs P- Impedance (Original Log)



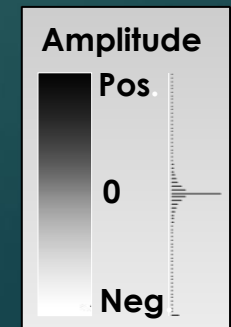
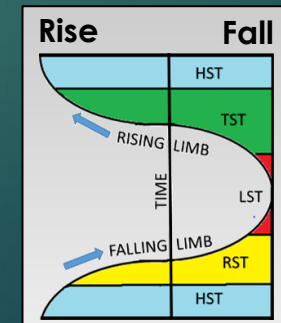
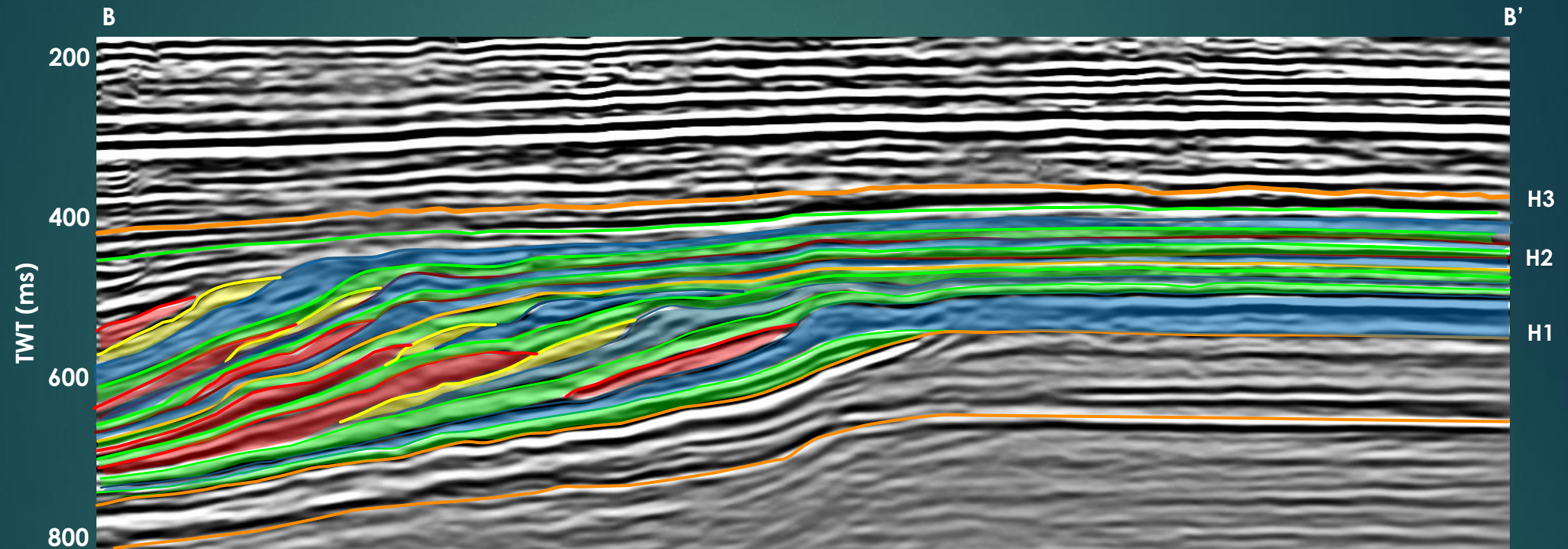
Quantitative Seismic Interpretation

Post-Stack Acoustic Impedance Inversion



Seismic Stratigraphic Interpretation

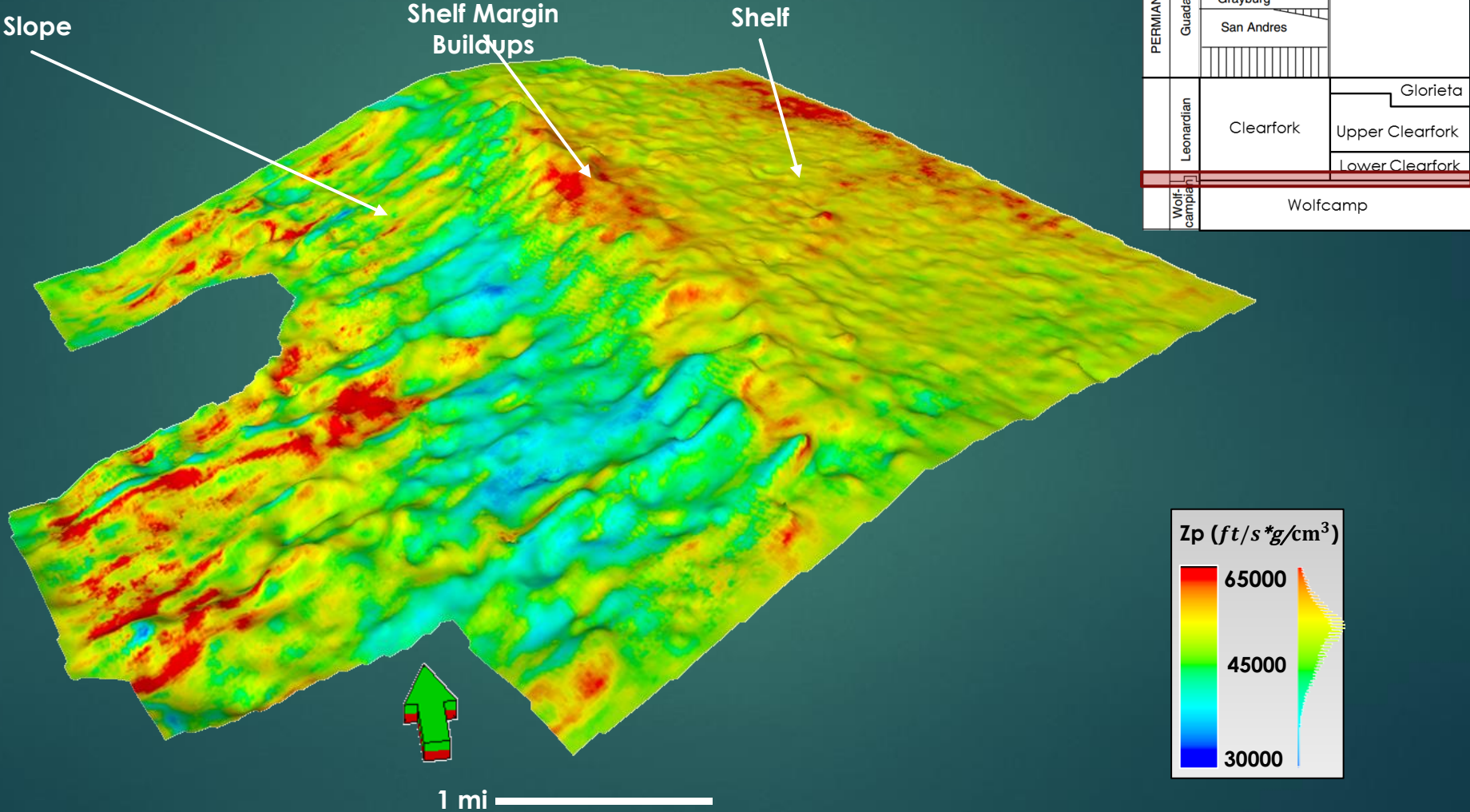
H1 (Wolfcamp-Leonardian UC1 boundary)



Quantitative Seismic Interpretation

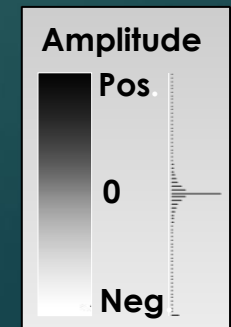
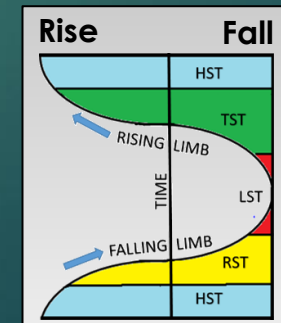
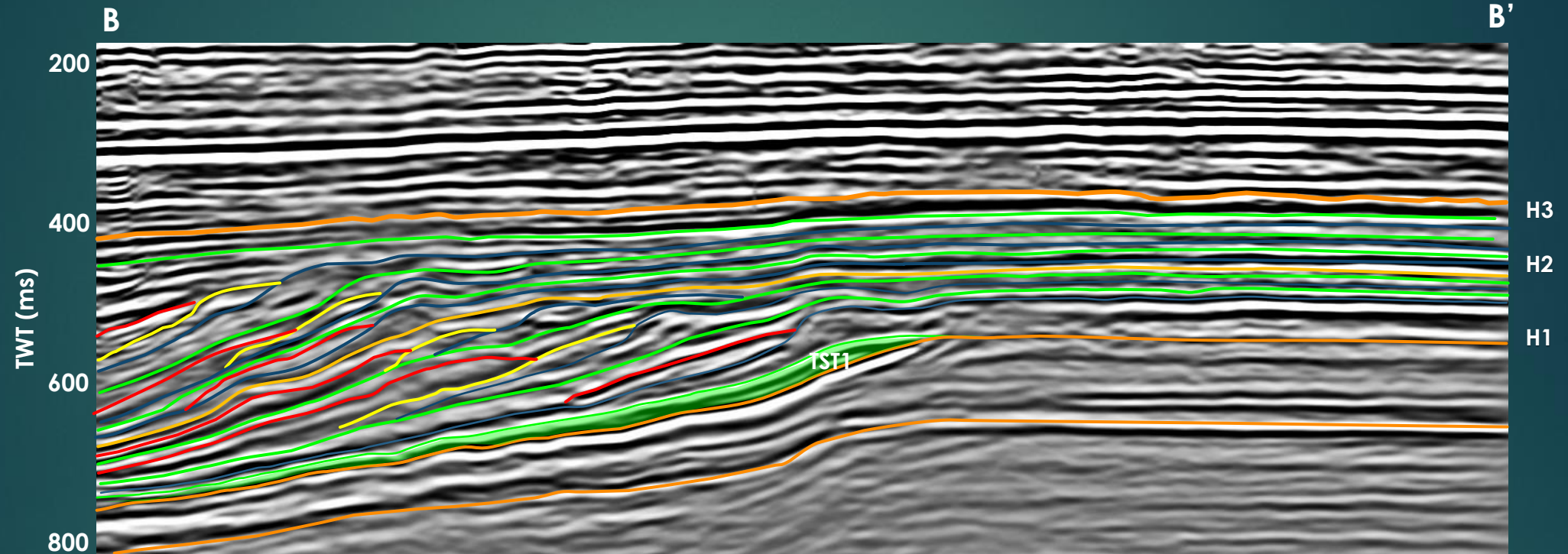
Post-Stack Acoustic Impedance Inversion

Extracted Acoustic Impedance on H1 (Wolfcamp-Leonardian UC1 boundary)



Seismic Stratigraphic Interpretation

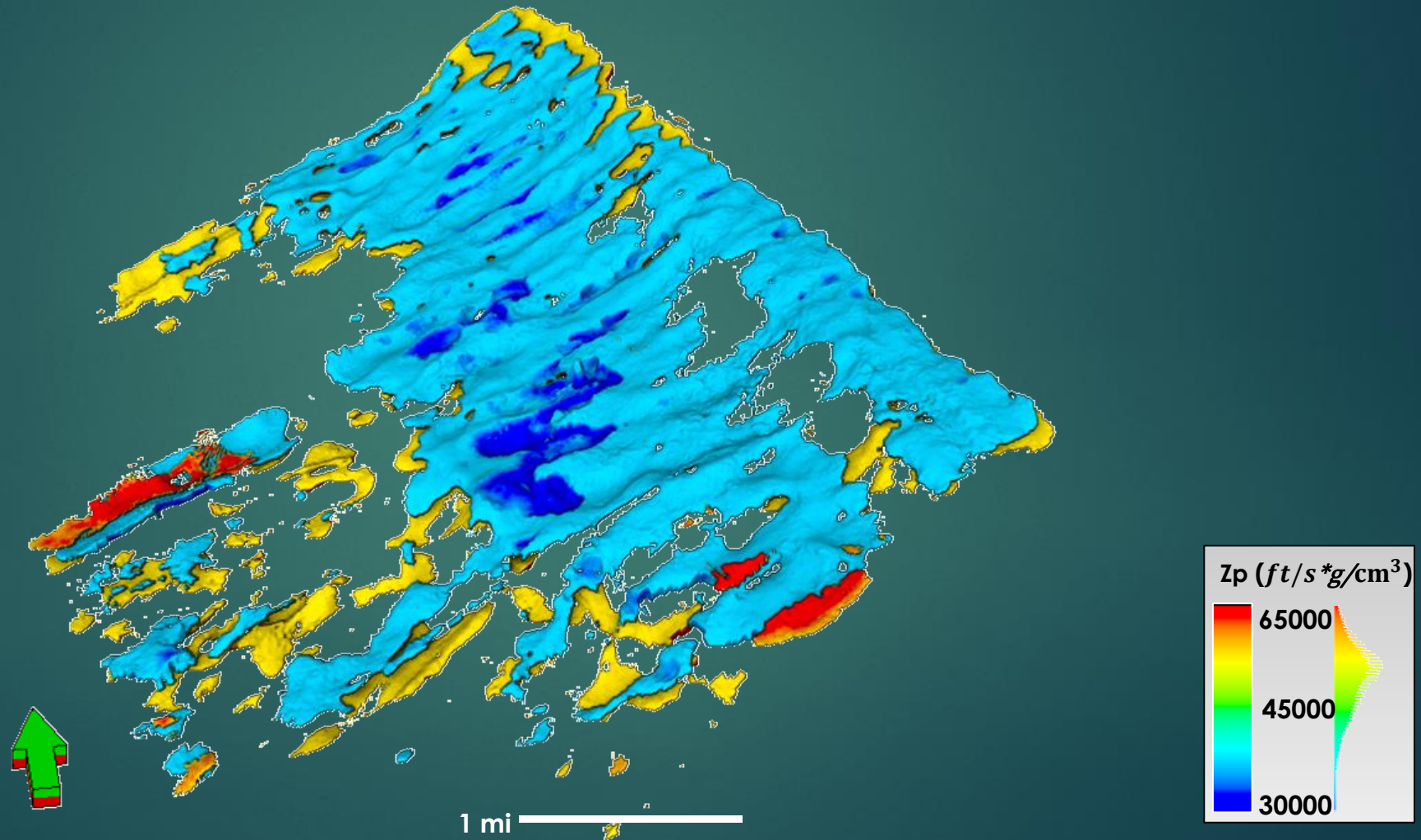
TST1



Quantitative Seismic Interpretation

Post-Stack Acoustic Impedance Inversion

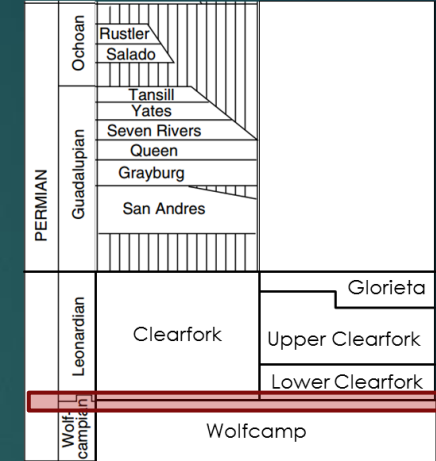
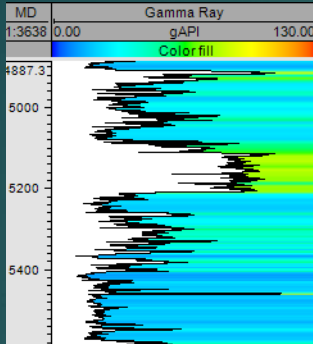
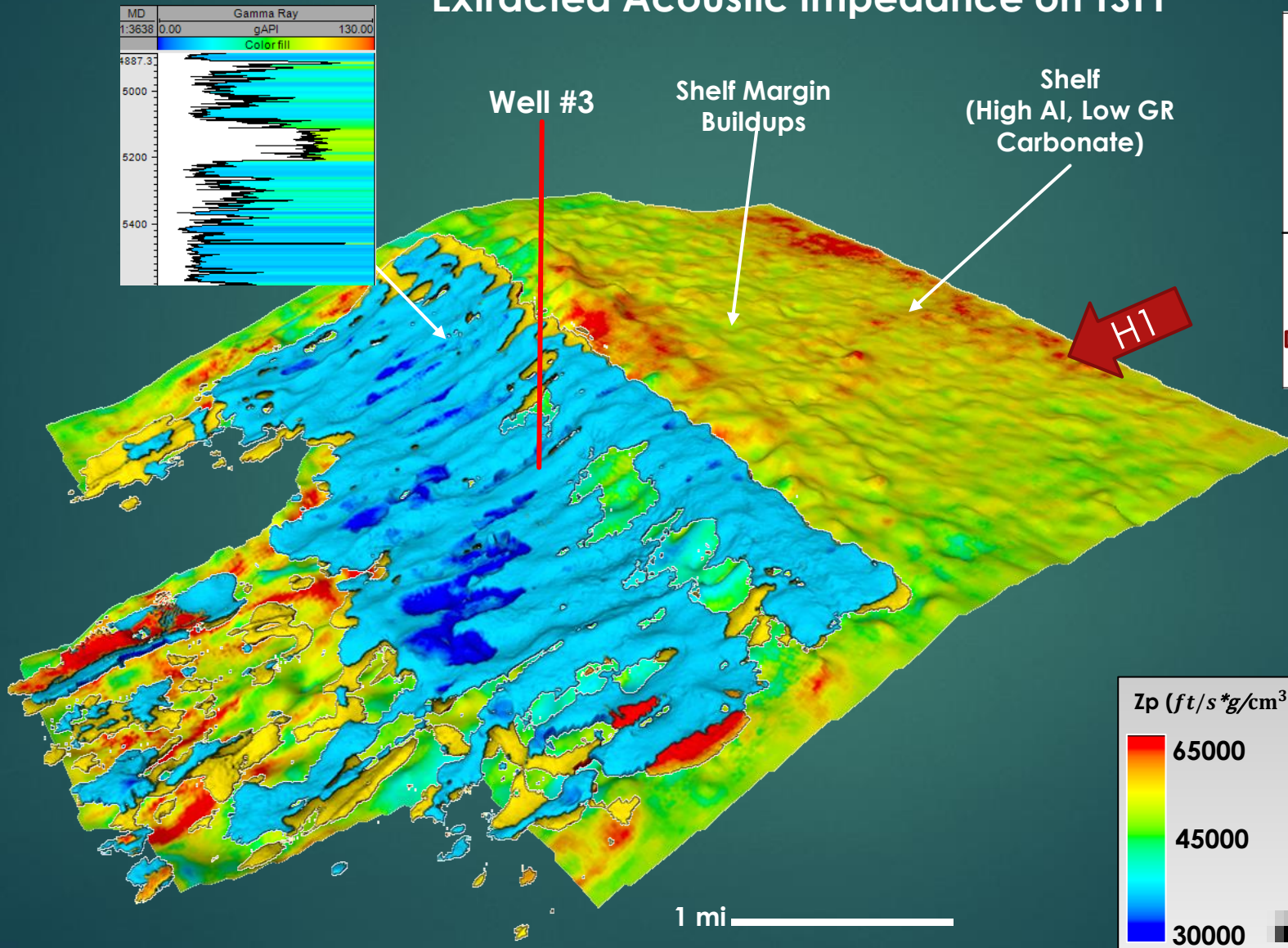
Extracted Acoustic Impedance on TST1



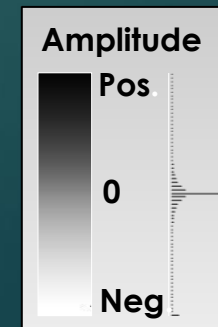
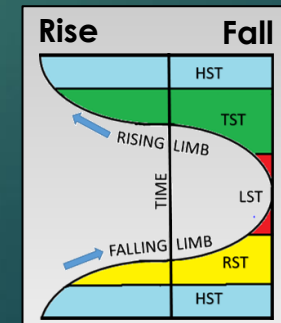
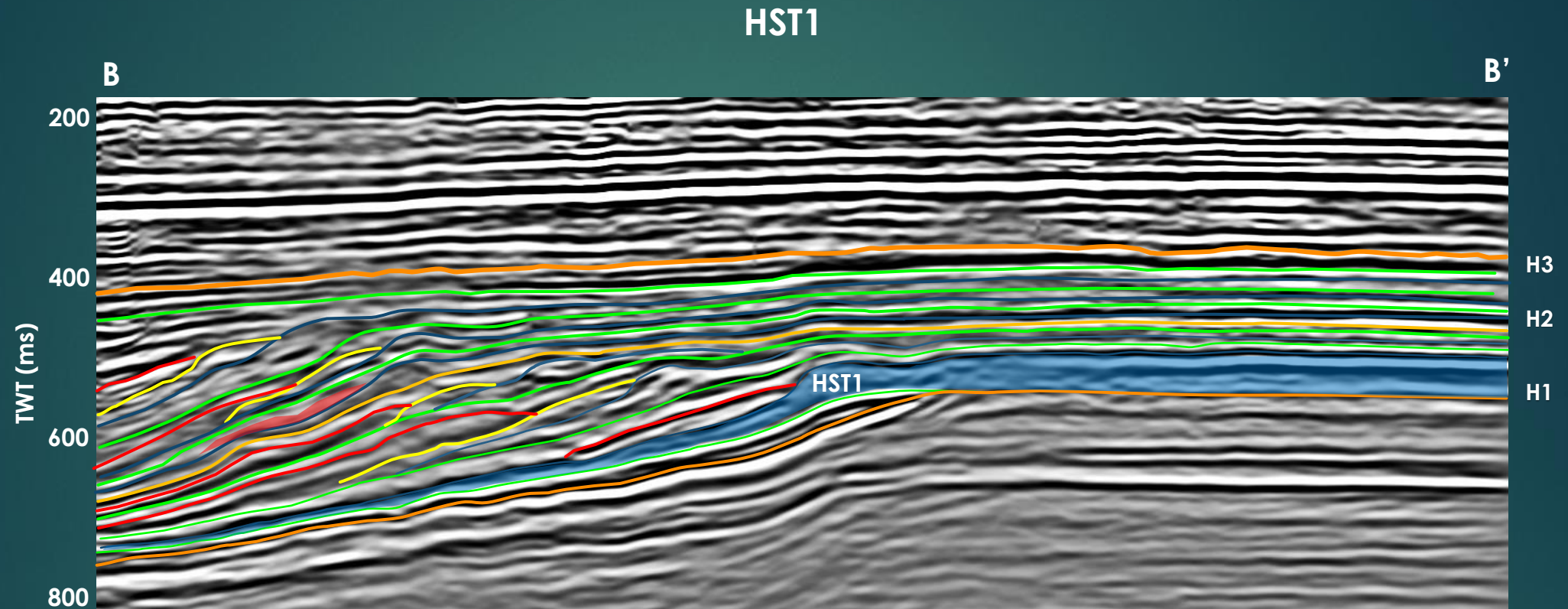
Quantitative Seismic Interpretation

Post-Stack Acoustic Impedance Inversion

Extracted Acoustic Impedance on TST1

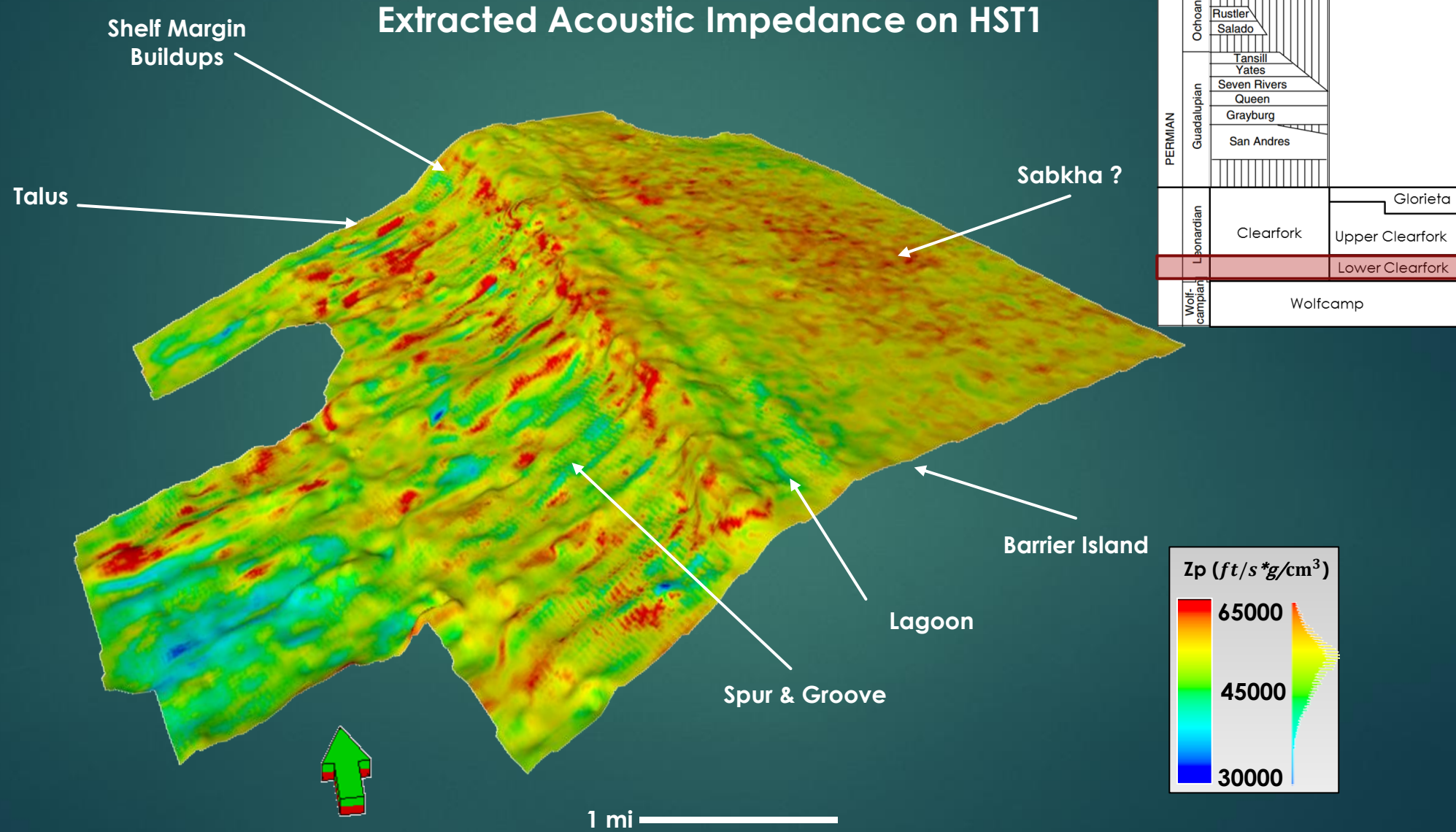


Seismic Stratigraphic Interpretation



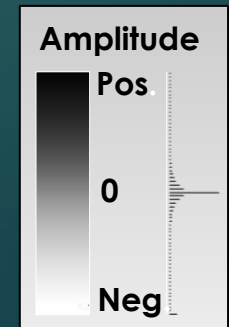
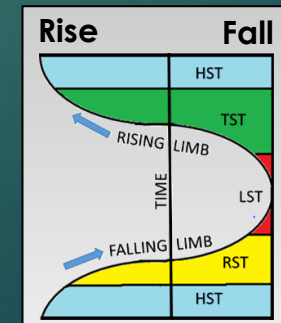
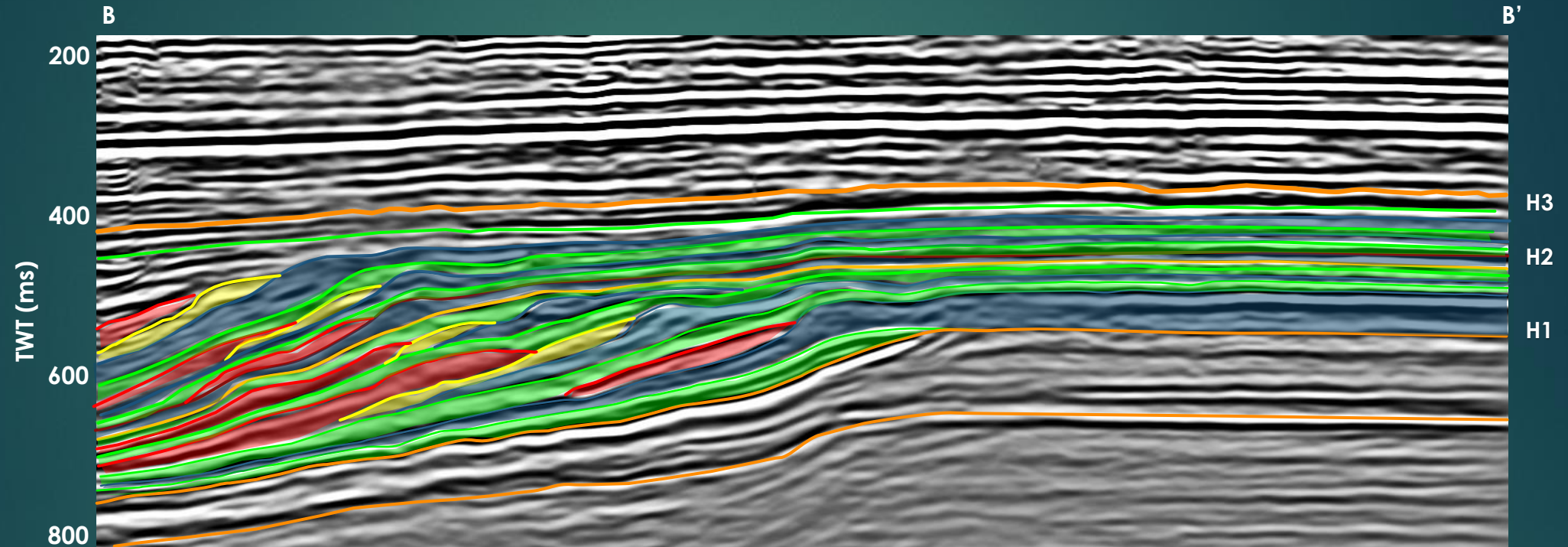
Quantitative Seismic Interpretation

Post-Stack Acoustic Impedance Inversion



Seismic Stratigraphic Interpretation

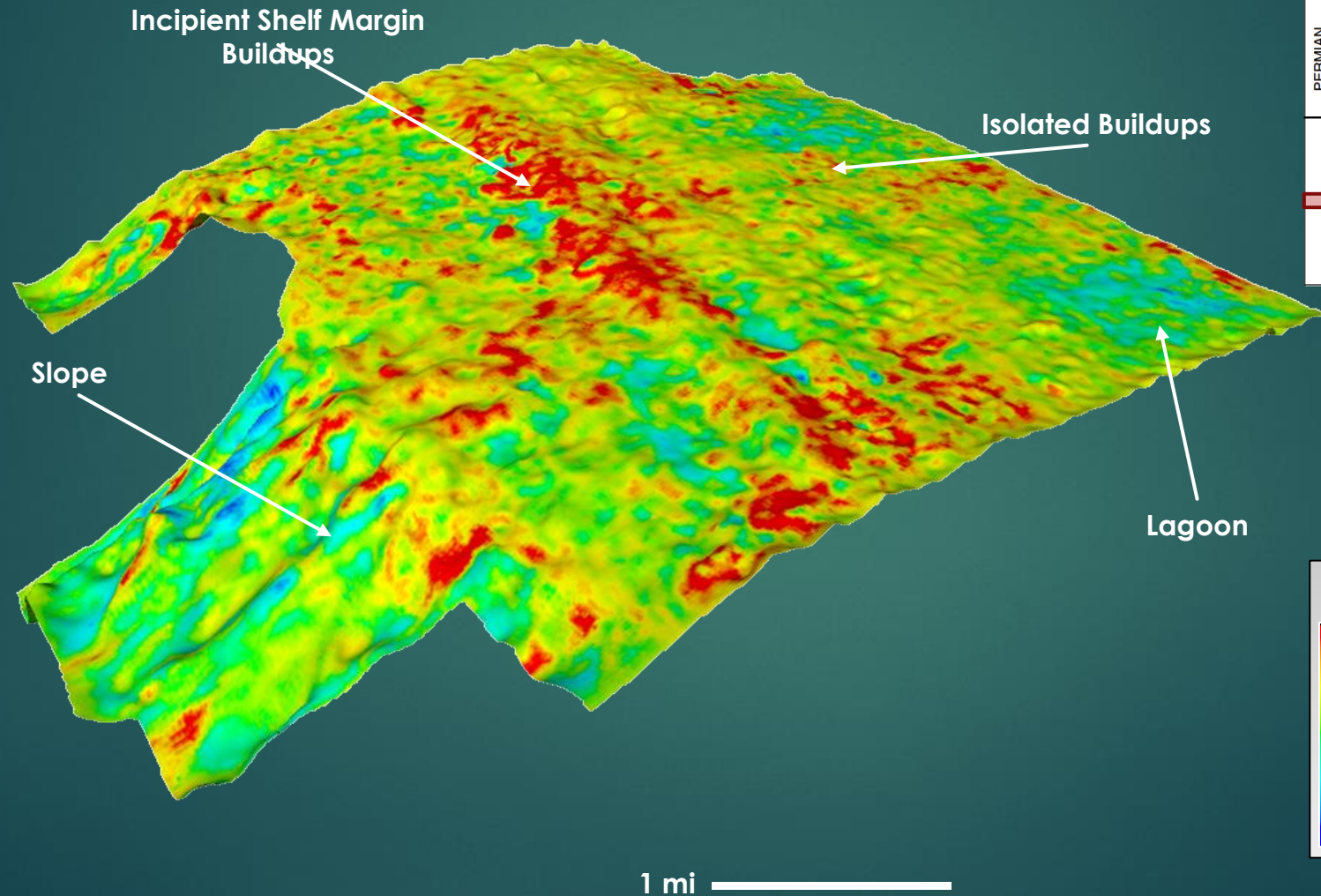
H2



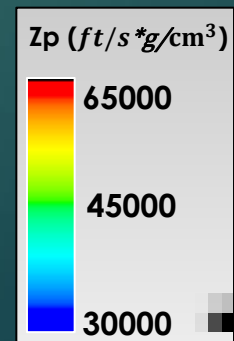
Quantitative Seismic Interpretation

Post-Stack Acoustic Impedance Inversion

Extracted Acoustic Impedance on H2

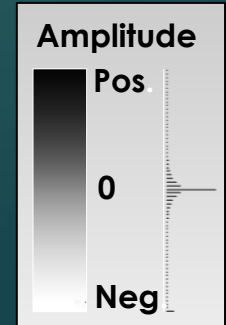
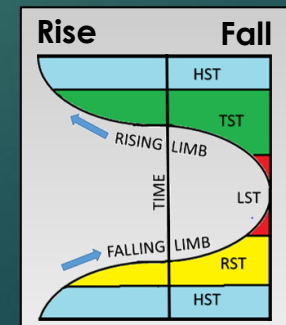
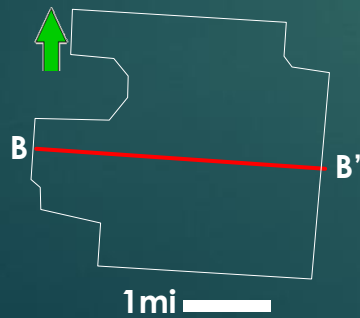
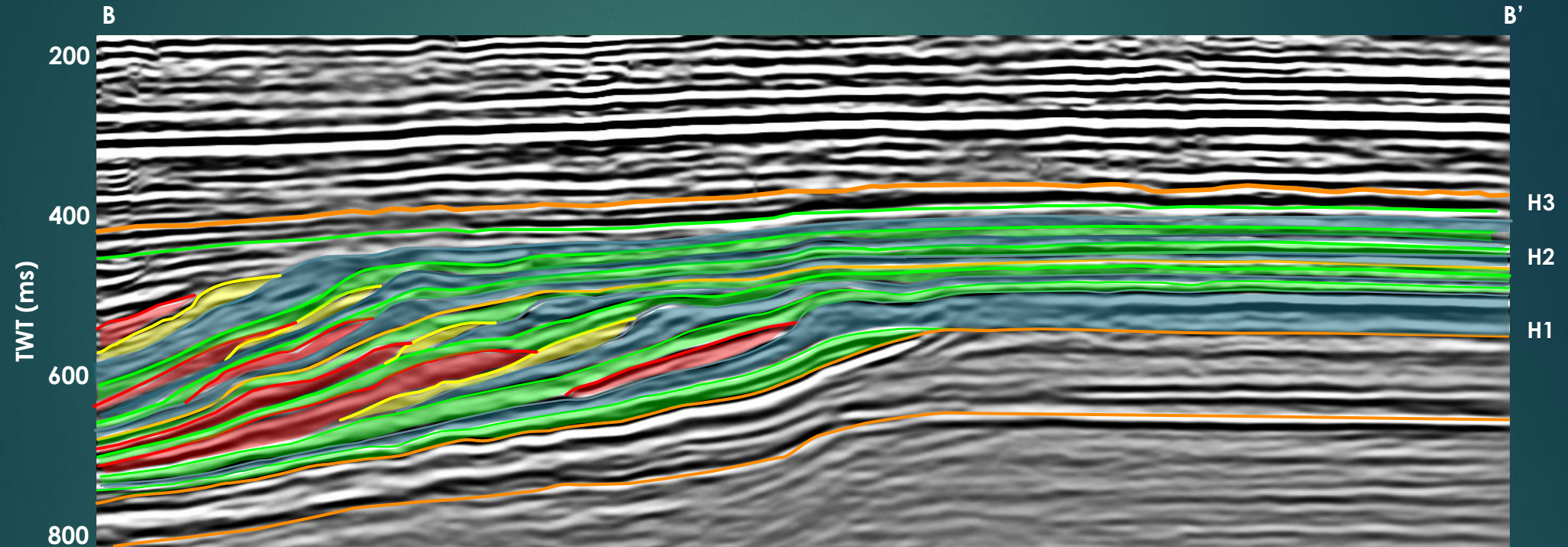


PERMIAN	Ochoan	Rustler	
		Salado	
	Guadalupian	Tansill	
		Yates	
		Seven Rivers	
		Queen	
		Grayburg	
		San Andres	
	Leonardian		Glorieta
		Clearfork	Upper Clearfork
			Lower Clearfork
Wolfcampian			Wolfcamp



Seismic Stratigraphic Interpretation

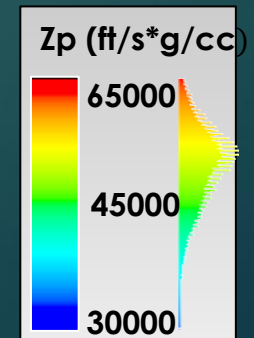
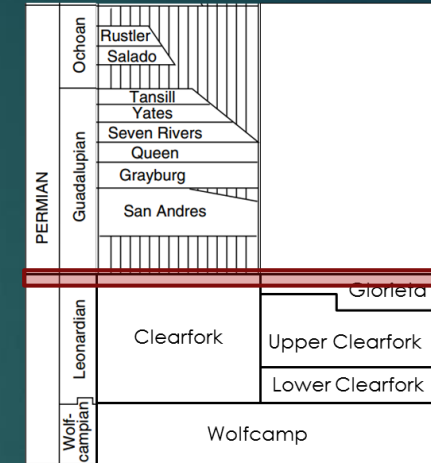
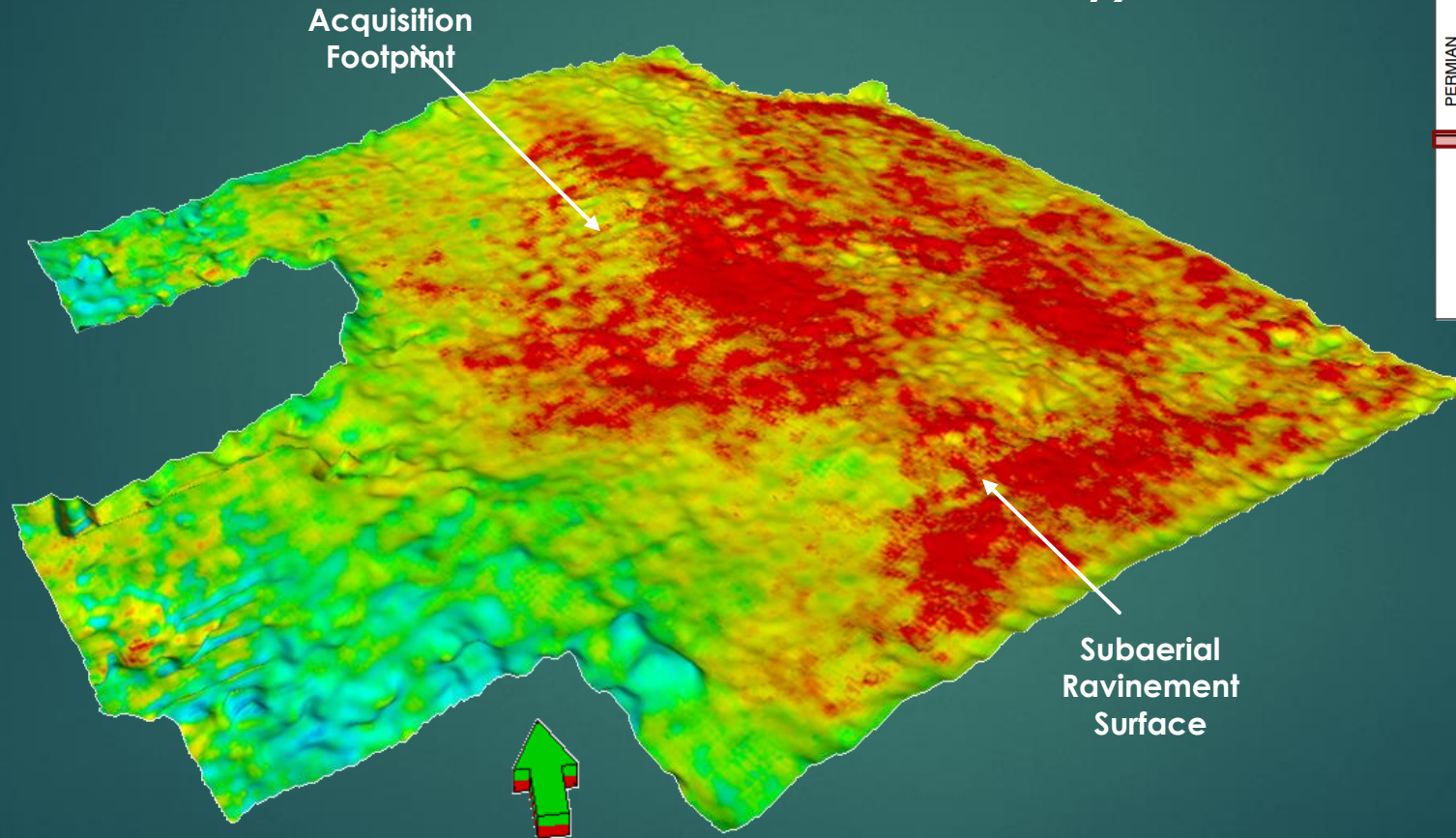
H3 (Top Leonardian UC1 Boundary)



Quantitative Seismic Interpretation

Post-Stack Acoustic Impedance Inversion

Extracted Acoustic Impedance on H3 (Top Leonardian UC1 Boundary)

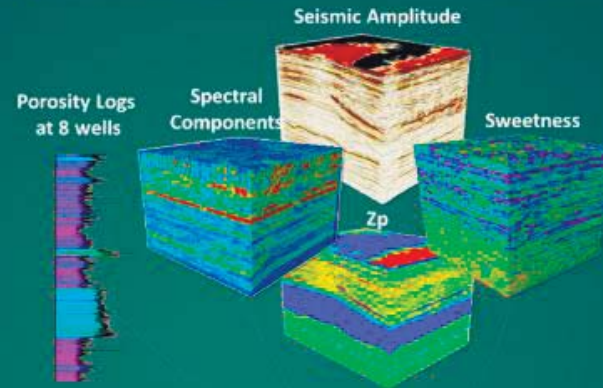


Strategy

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- **Integrated Interpretation & Discussion**
- **Conclusions**

Quantitative Seismic Interpretation

3D Porosity Estimation via Probabilistic Neural Network (PNN)



Multi Attribute Stepwise Linear Regression

Decide Convolution Operator Length & number of Attributes

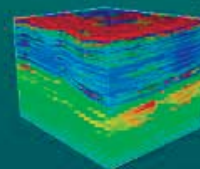
Train Neural Network (PNN)

Apply Trained Neural Network Volume

Validation

Compare The Prediction at Wells Not Used In Training

Predicted Porosity



After Verma, 2015

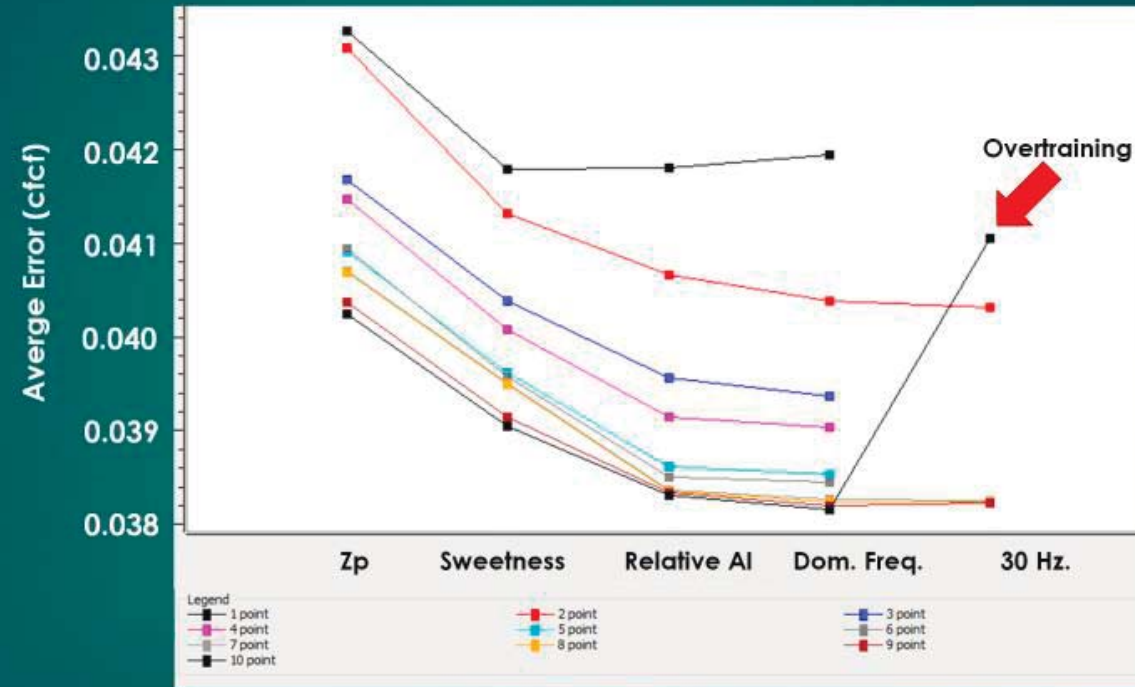
Presenter's notes: Neural networks can help to enable seismic data to be related to porosity without explicitly defining parameters such as water content, lithology, or pore, pressure that affect the acoustic impedance. Additionally, neural networks can incorporate an interval of seismic data rather than a single sample value to predict porosity values. The procedure of neural network porosity prediction performed in this study can be divided into three steps:

1. Calculate a set of sample-based attributes from the seismic volume and definition of vertical zone of interest termed as "operator length". The objective of the first step is to derive a linear multi-attribute transform, between a subset of the attributes and the target log values (in this case porosity), defined by the operator length, in which the well logs are correlated to the seismic attributes.
2. Train the Probabilistic Neural Network (PNN) with the given the set of attributes and the operator length. This process tries to come up with non-linear regression between set of attributes and the target log.
3. Apply trained neural network to generate the 3D volume of porosity and validation of this result with one well that is not used in the training.

Quantitative Seismic Interpretation

3D Porosity Estimation via Probabilistic Neural Network (PNN)

Validation Error vs Operator Length



Best set of attributes and operator length yield the minimum validation error. Using more attributes than needed yields “overtraining” Example: the 30 Hz Spectral Component is discarded.

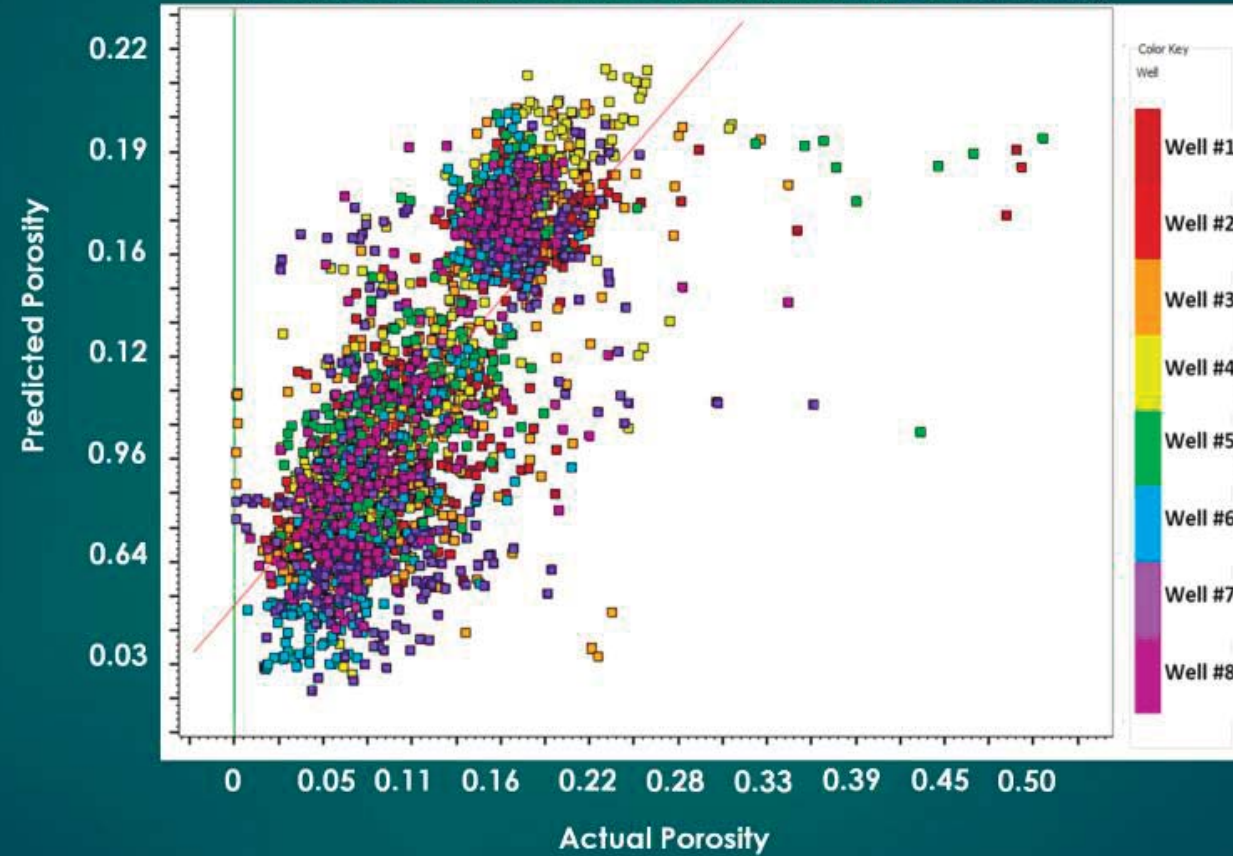
Presenter’s notes: Objective of the first step is to derive a linear multi-attribute transform, between a subset of the attributes and the target log values (in this case porosity), defined by the operator length, in which the well logs are correlated to the seismic attributes. Decision of valid operator length is important since the difference in frequency between the target logs and the seismic data. The best attributes and operator length results with the minimum validation error. Extending the operator length is equivalent to adding attributes at adjacent stratal slices to the stepwise linear regression workflow, increasing the chances for Kalkomey’s (1997) false positive correlation or often called “overtraining”.

Quantitative Seismic Interpretation

3D Porosity Estimation via Probabilistic Neural Network (PNN)

Correlation Coeff. 0.74

Predicted Porosity vs Actual Porosity (Multi-Linear Regression)



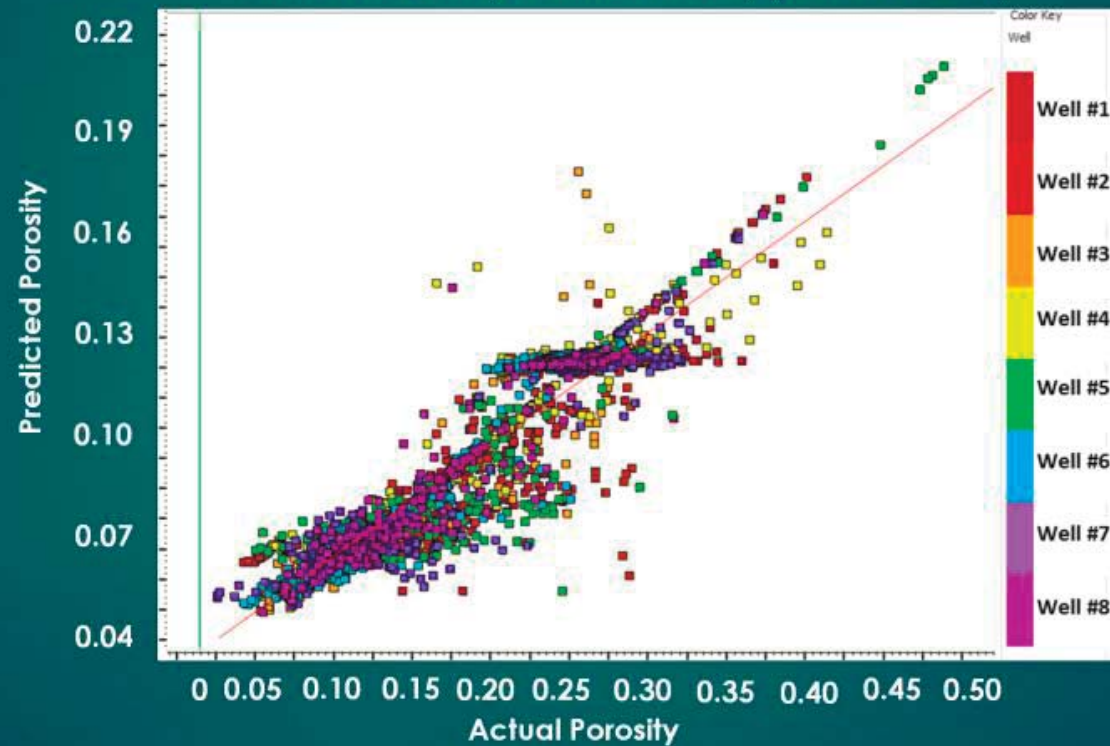
Presenter's notes: Crossplot of calculated porosity versus predicted porosity using multi-attribute linear regression with the previously mentioned four attributes. Therefore, four attributes (Acoustic Impedance (Z_p), Sweetness, Seismic Amplitude and Dominant Frequency) with 10 point operator length are chosen for neural network training for this study.

Quantitative Seismic Interpretation

3D Porosity Estimation via Probabilistic Neural Network (PNN)

Training the Probabilistic Neural Network (PNN) with the given set of attributes and operator length increases correlation to 0.92.

Predicted Porosity vs Actual Porosity (Neural Network)



Presenter's notes: The second step in the process is to train the Probabilistic Neural Network (PNN) with the given the set of attributes and the operator length. This process tries to come up with non-linear regression between set of attributes and the target log. Figure 35 shows the crossplot between predicted porosity from the neural networks and the actual porosity from well logs. Cross correlation is increased to 0.92.

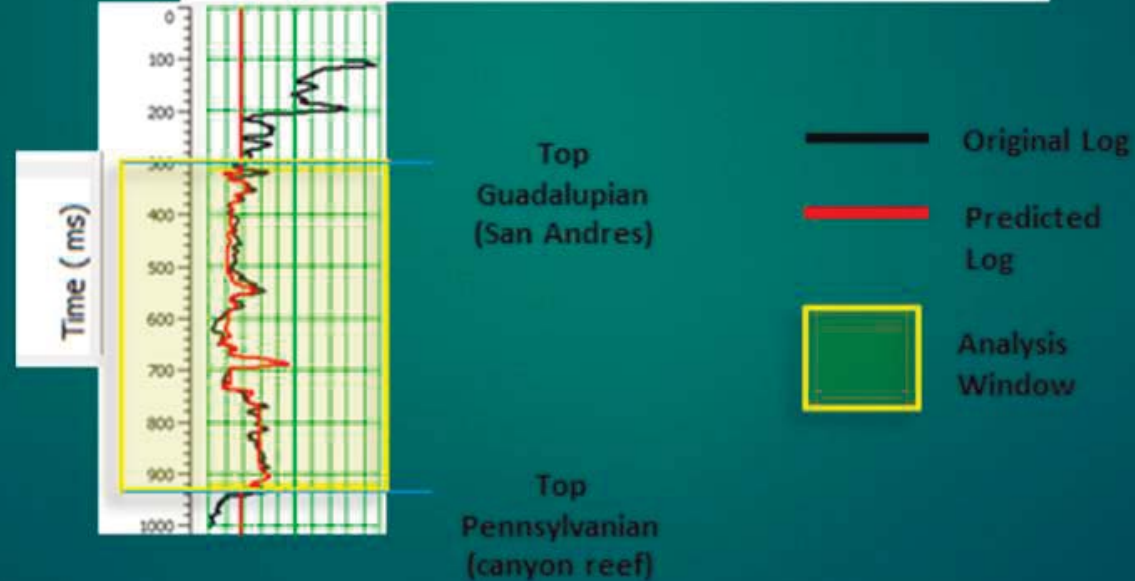
Quantitative Seismic Interpretation

3D Porosity Estimation via Probabilistic Neural Network (PNN)

Validation of Results Using The Blind Well

Validation Correlation is 0.89

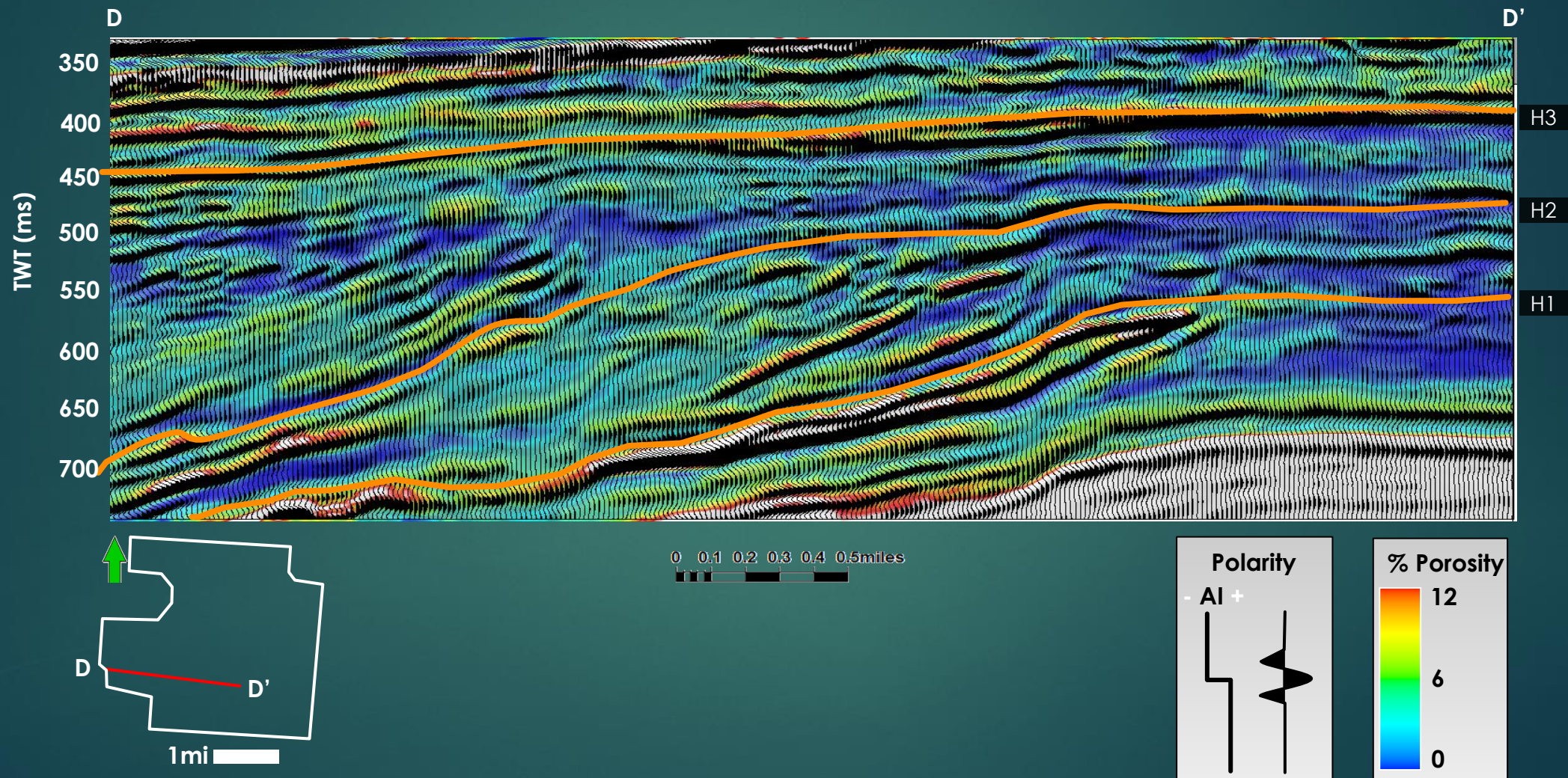
Validation of caf_Neural_Network Probabilistic Neural Network
Using 4 attributes
Correlation = 0.891487, Average Error = 0.0319616 [cfcf]



Presenter's notes: The third step is the application of the trained neural network to generate the 3D volume of porosity and validation of this result with one well that is not used in the training (Blind Well).

Quantitative Seismic Interpretation

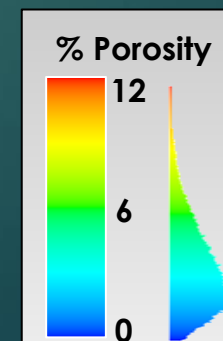
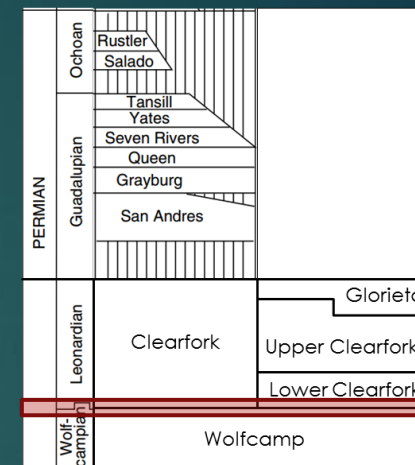
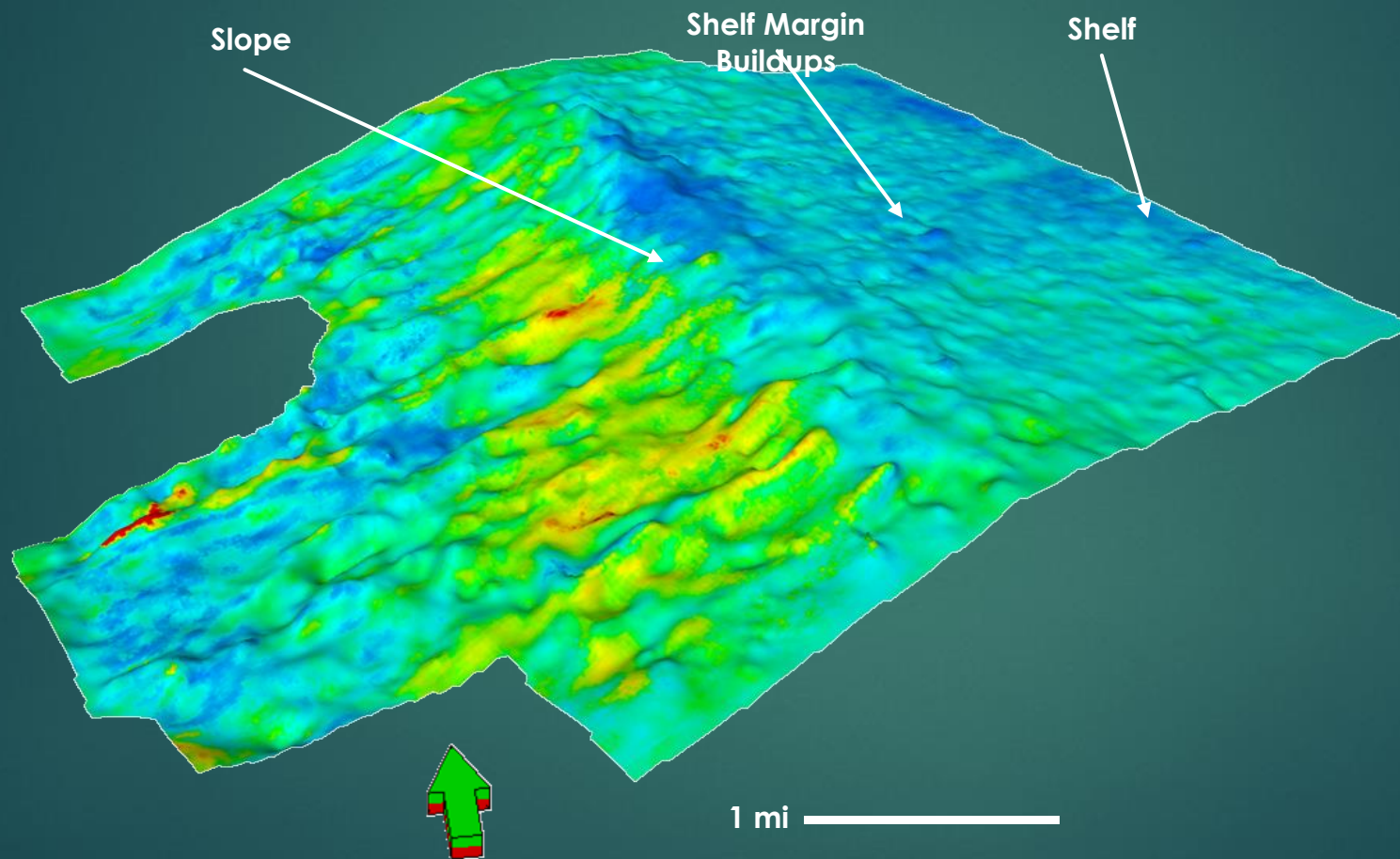
3D Porosity Estimation via Probabilistic Neural Network (PNN)



Quantitative Seismic Interpretation

3D Porosity Estimation via Probabilistic Neural Network (PNN)

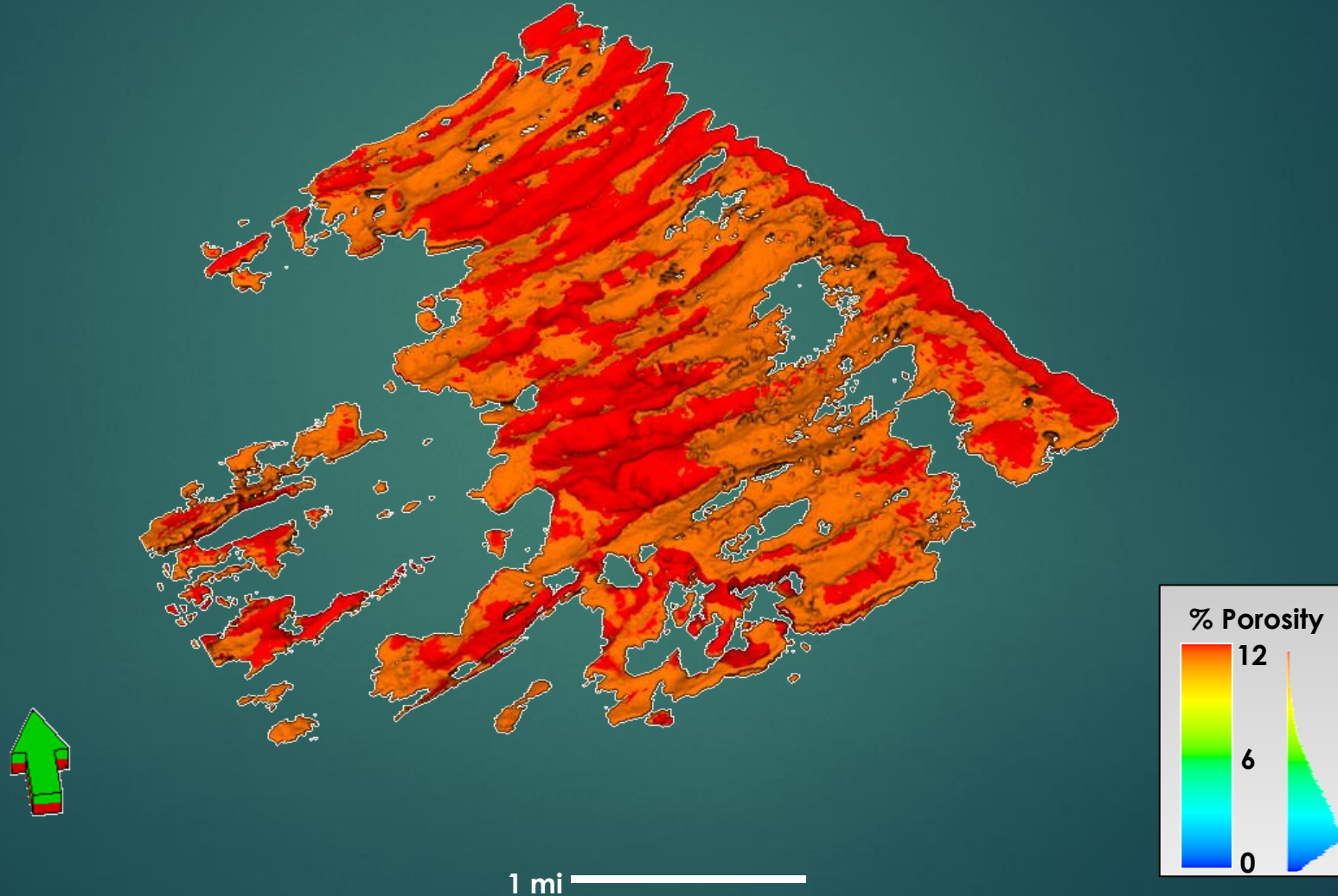
Extracted Porosity on H1 (Wolfcamp-Leonardian UC1 boundary)



Quantitative Seismic Interpretation

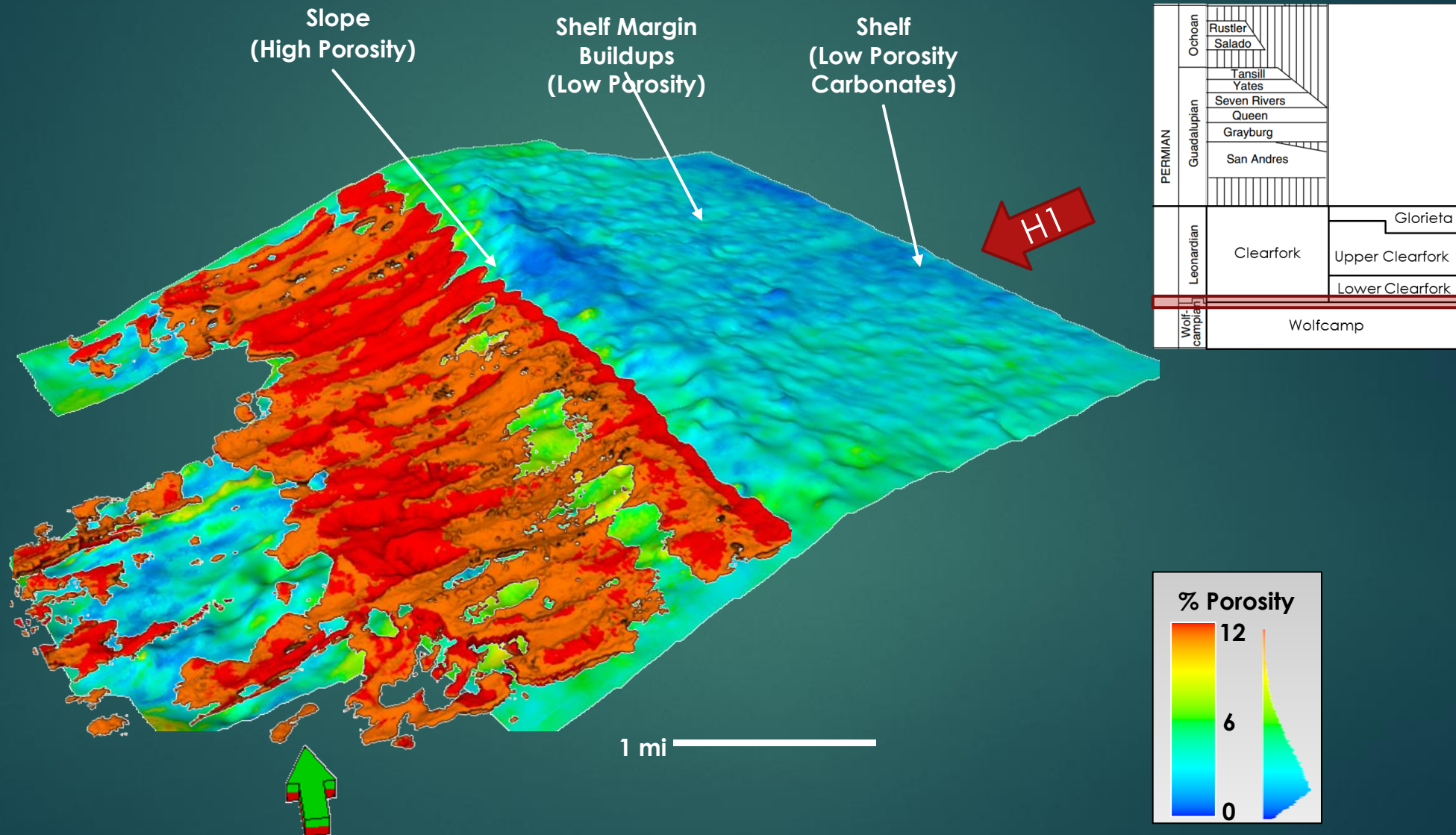
3D Porosity Estimation via Probabilistic Neural Network (PNN)

Extracted Porosity on TST1



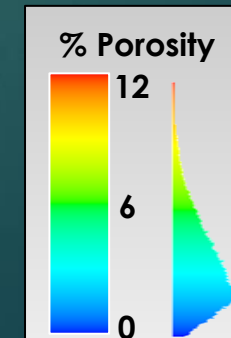
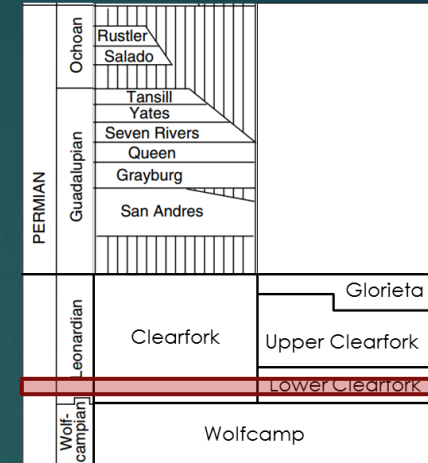
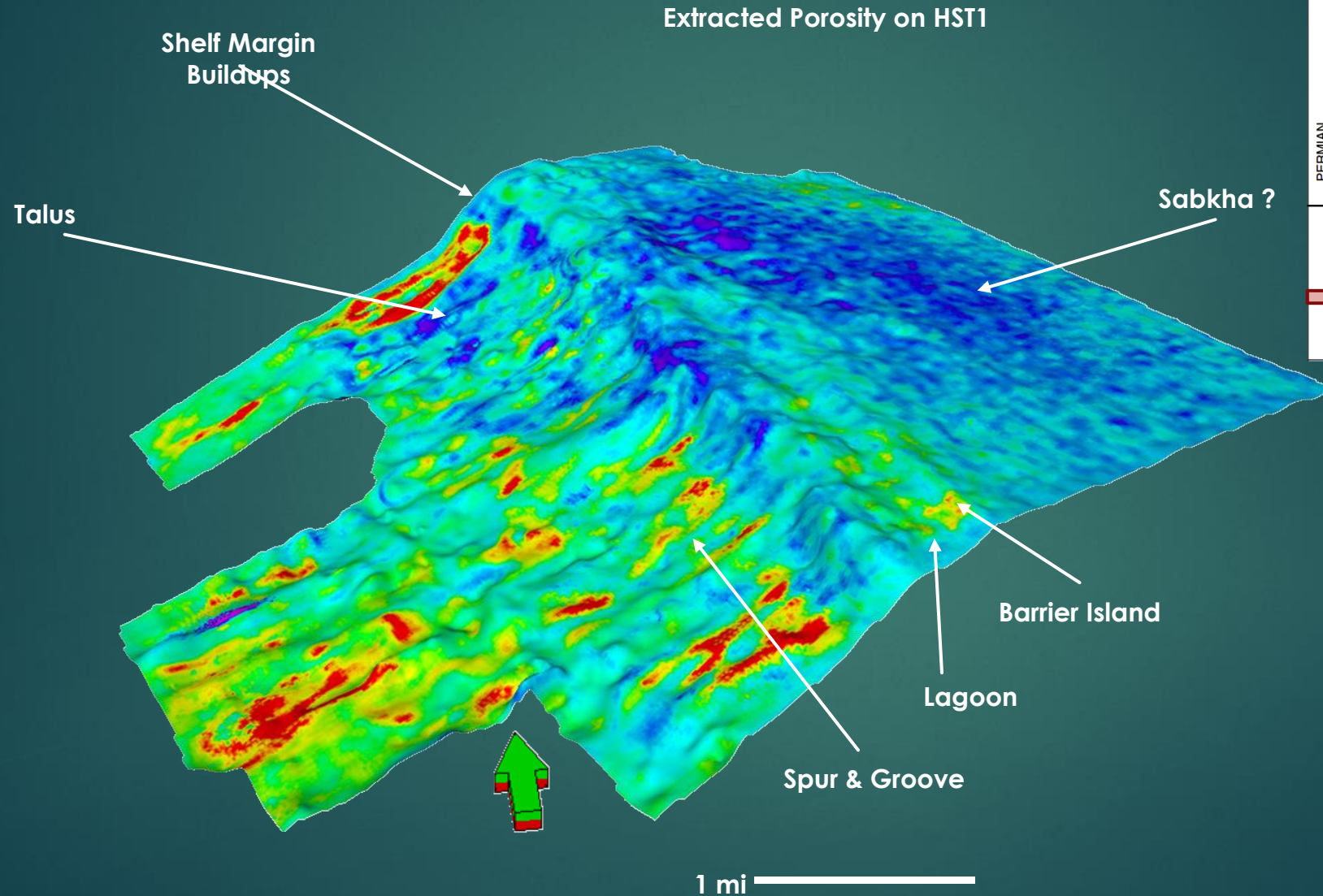
Quantitative Seismic Interpretation

3D Porosity Estimation via Probabilistic Neural Network (PNN)



Quantitative Seismic Interpretation

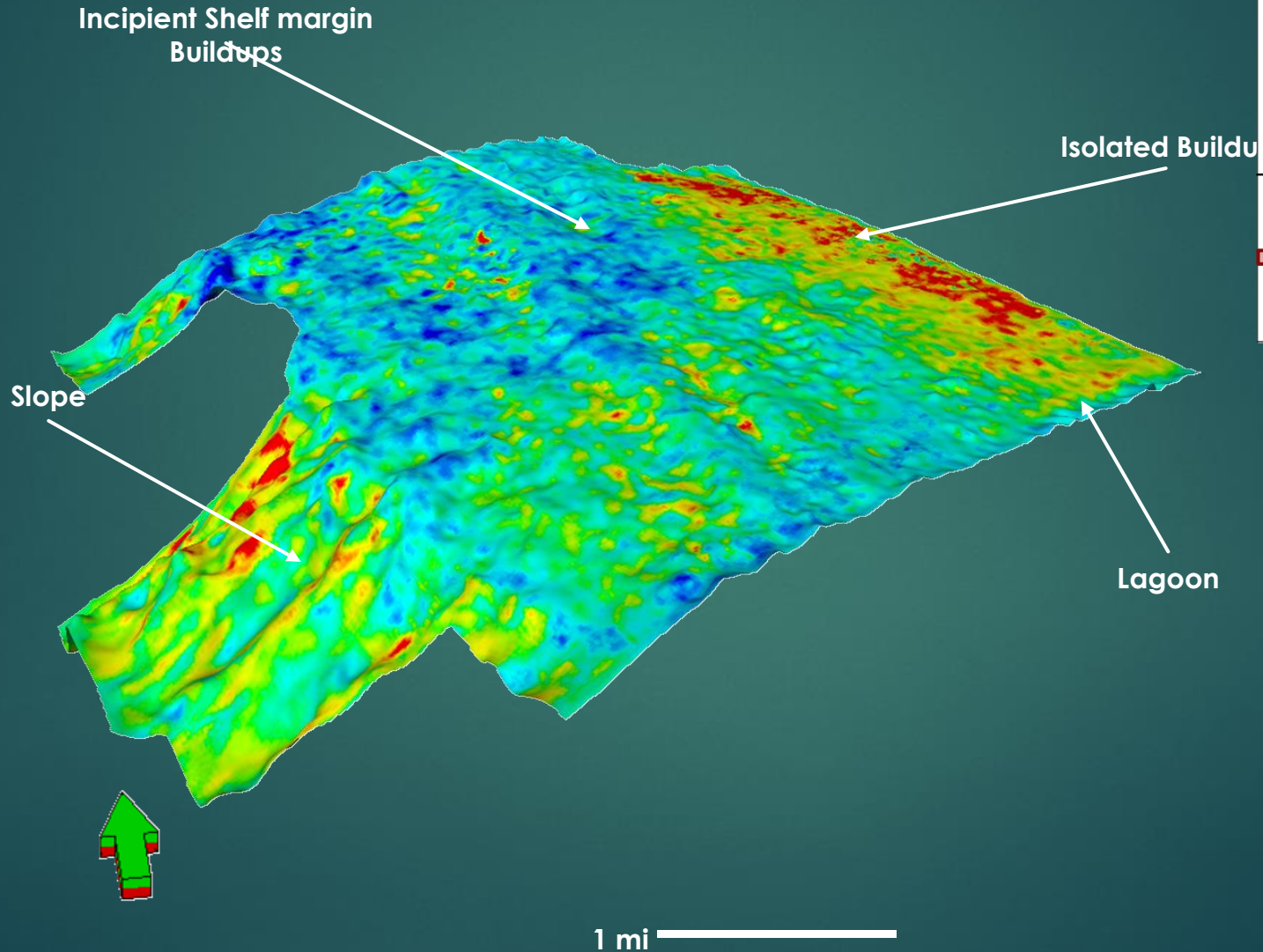
3D Porosity Estimation via Probabilistic Neural Network (PNN)



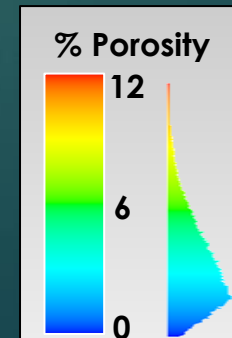
Quantitative Seismic Interpretation

3D Porosity Estimation via Probabilistic Neural Network (PNN)

Extracted Porosity on H2



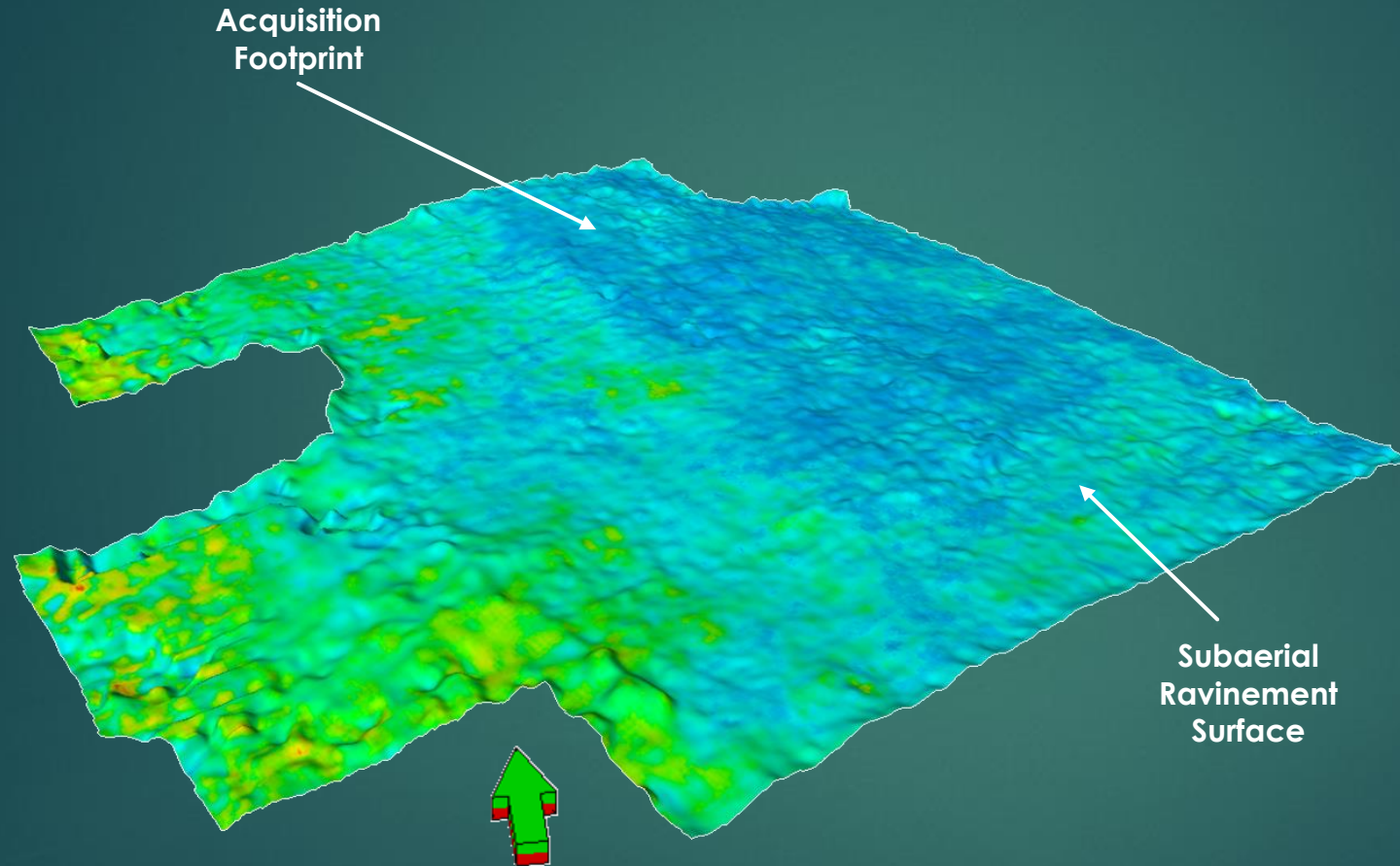
PERMIAN	Ochoan	Rustler	
		Salado	
	Guadalupian	Tansill	
		Yates	
		Seven Rivers	
		Queen	
		Grayburg	
		San Andres	
	Leonardian		Glorieta
		Clearfork	Upper Clearfork
			Lower Clearfork
Wolfcampian			Wolfcamp



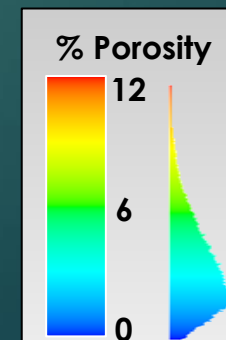
Quantitative Seismic Interpretation

3D Porosity Estimation via Probabilistic Neural Network (PNN)

Extracted porosity on H3 (Top Leonardian UC1 boundary)



PERMIAN	Ochoan	Rustler	
		Salado	
	Guadalupian	Tansill	
		Yates	
		Seven Rivers	
		Queen	
		Grayburg	
		San Andres	
	Leonardian		Glorieta
		Clearfork	Upper Clearfork
			Lower Clearfork
	Wolfcampian		Wolfcamp

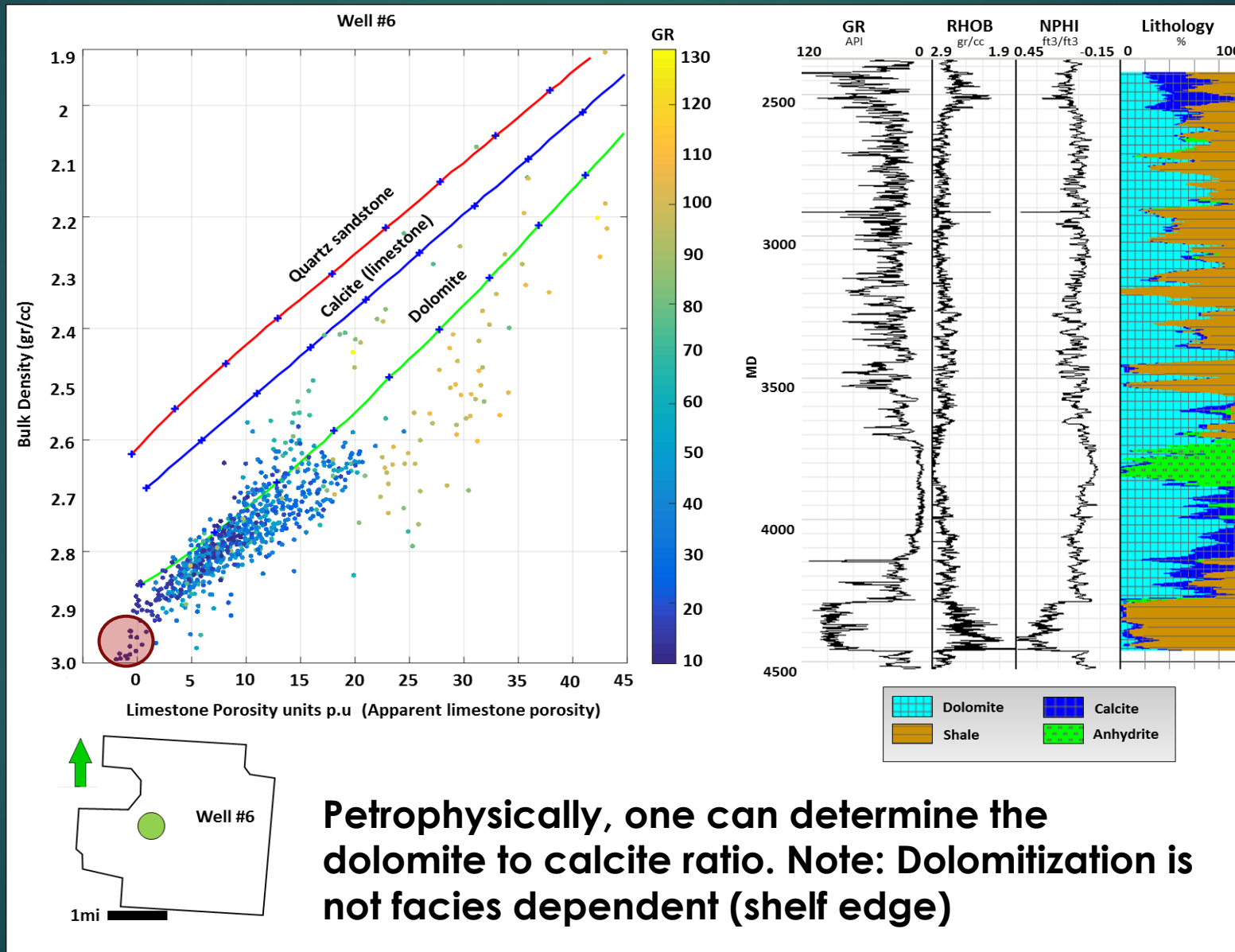


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- Petrophysical Techniques
- Integrated Interpretation & Discussion
- Conclusions

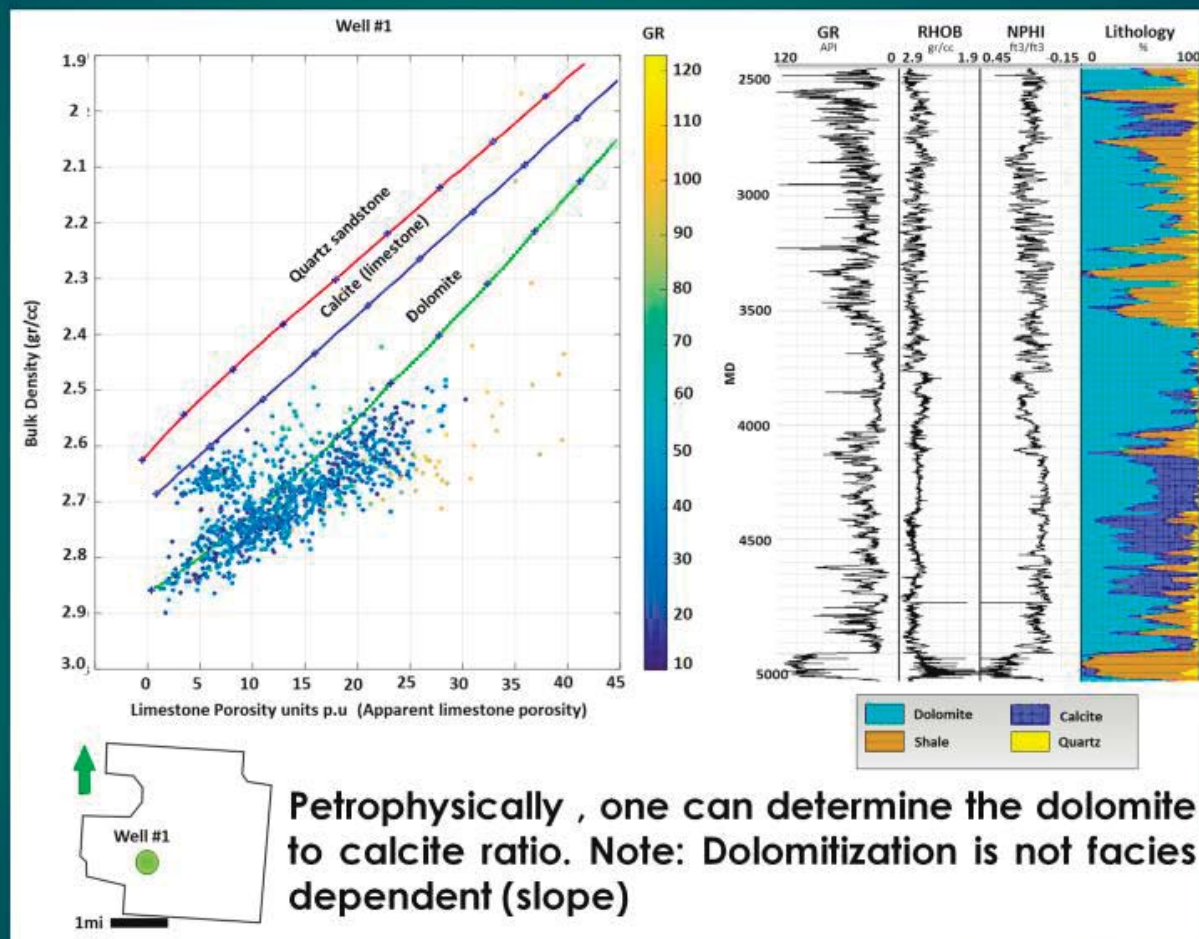
Petrophysical Techniques

Lithology Estimation



Petrophysical Techniques

Lithology Estimation

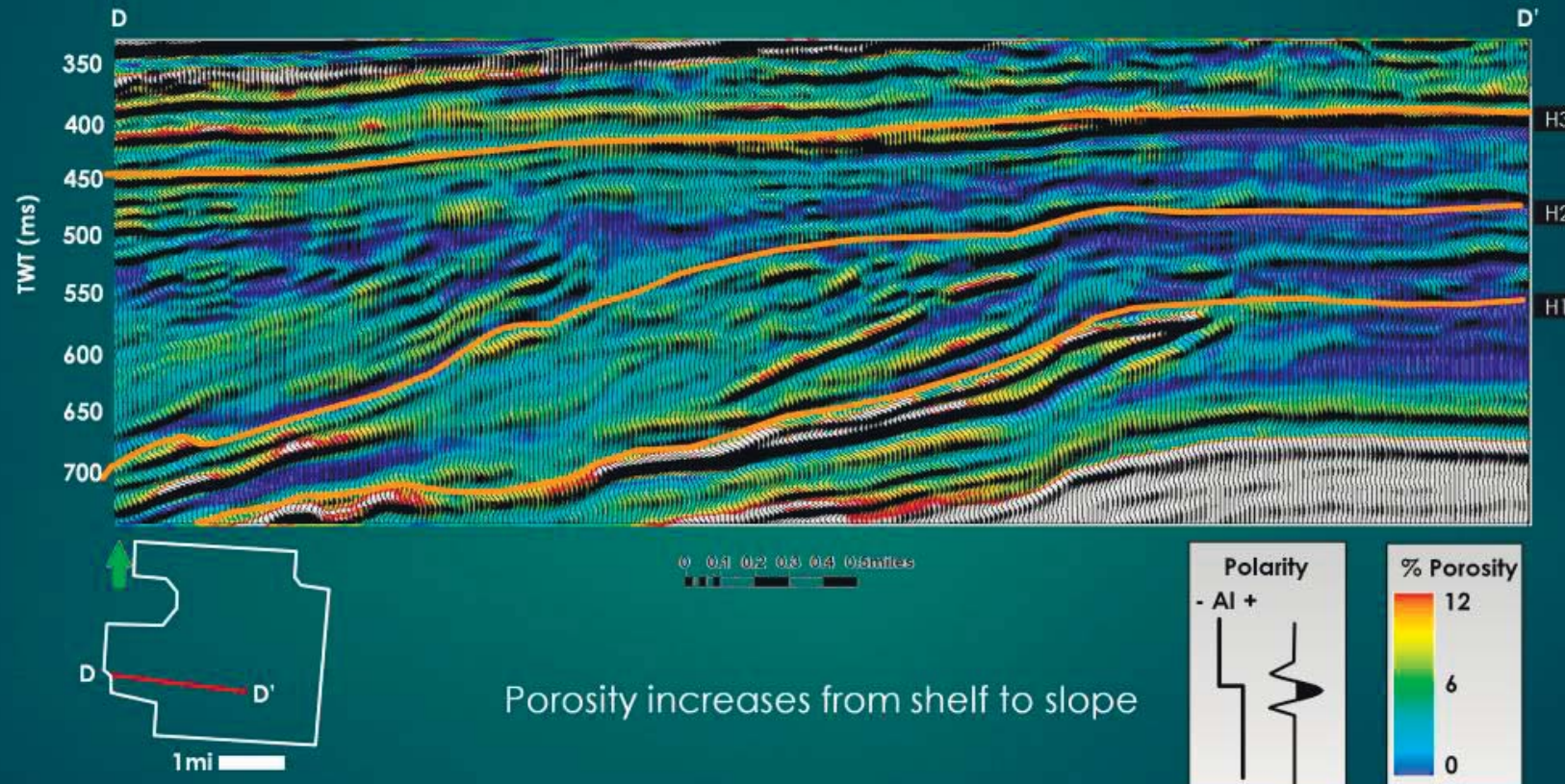


Presenter's notes: To use the neutron-density charts one can enter the neutron porosity values to the abscissa, density values to the ordinate. Adding gamma ray values to the third dimension, shales can be differentiated from dolomites and evaporate. Since no core data, petrophysical methods were the only way to constrain quantitative interpretation to a real rock data. Dolomite is dominant with some shale breaks in between.

Strategy

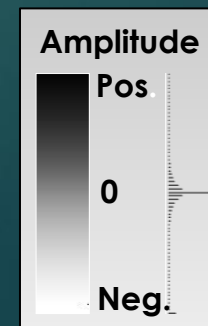
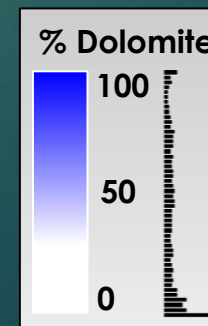
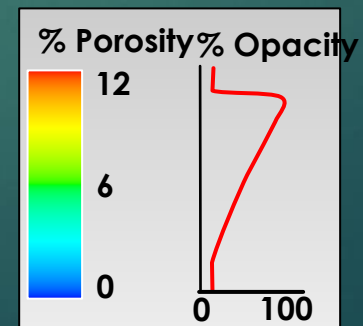
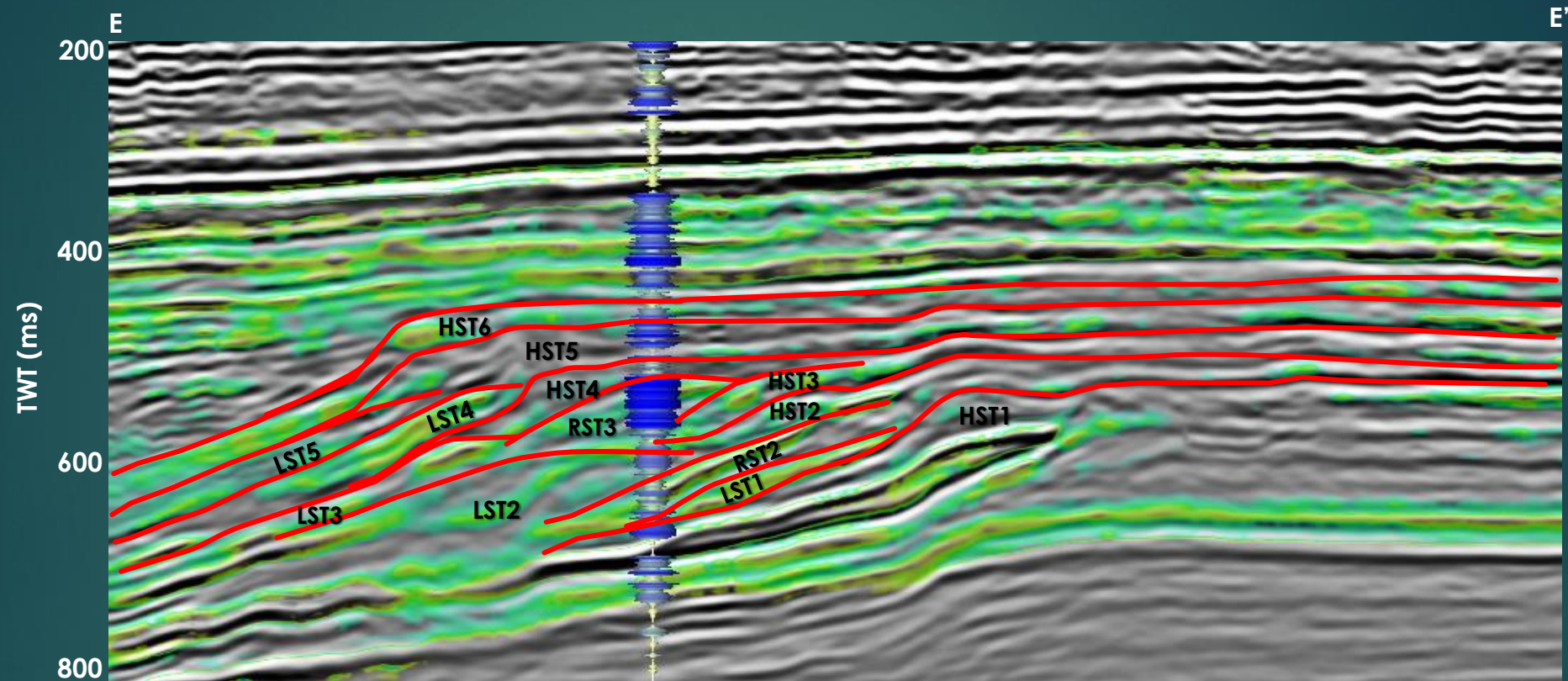
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Integrated Interpretation and Discussion

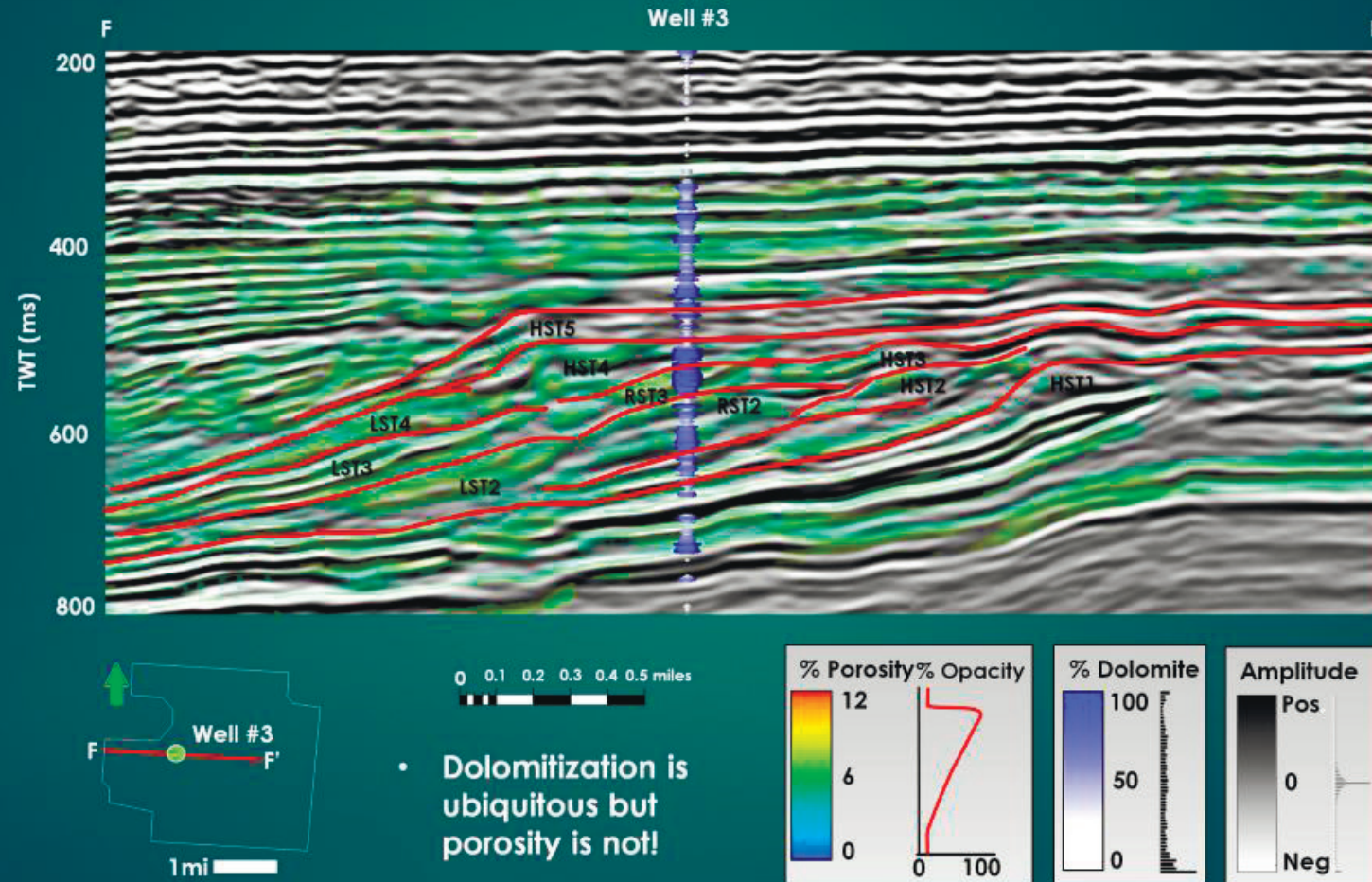


Presenter's notes: Petrophysical interpretations show that dolomite is the dominant lithology. Furthermore, Interpretation of estimated porosity (from PNN) together with the petrophysical interpretation, show that porosity has increasing trend from shelf margin to the distal.

Integrated Interpretation and Discussion

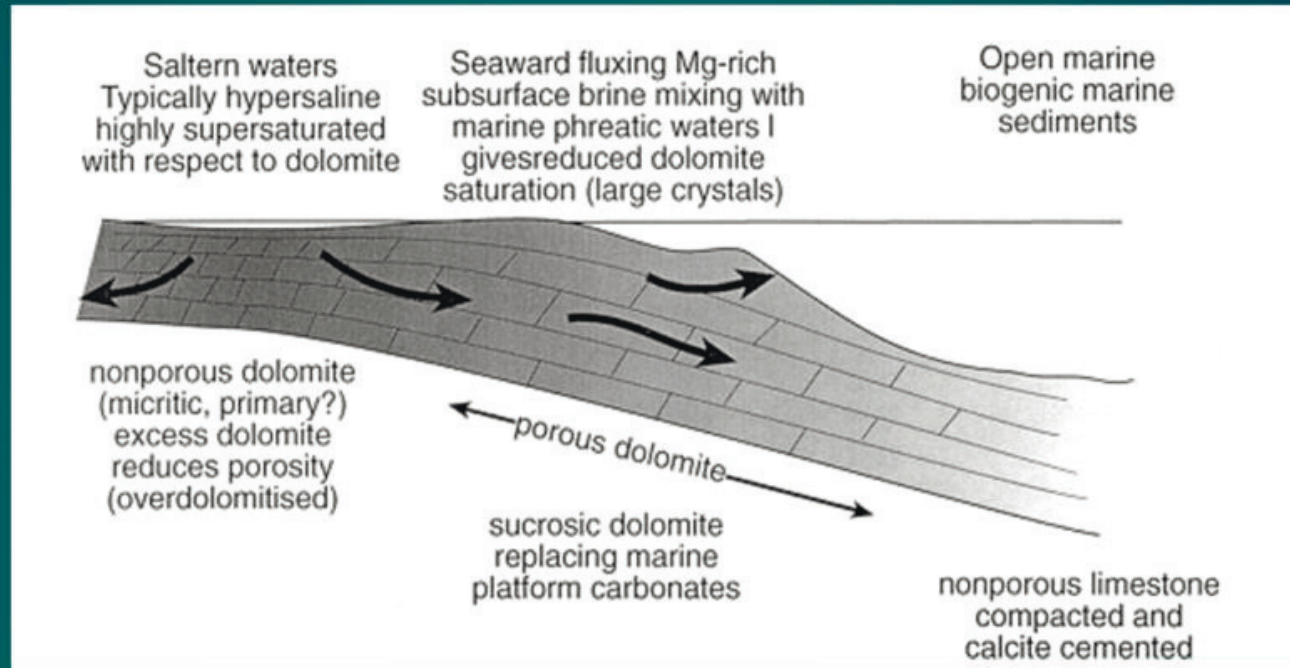


Integrated Interpretation and Discussion



Presenter's notes: Not every dolomite is porous, but LST's are more porous. Possible mechanism behind this might be the third order cycles. That is: at lowstands, sea level will be below the lagoon, inhibiting the reflux dolomitization mechanism, therefore preserving the lowstand deposits from "overdolomitization".

Integrated Interpretation and Discussion

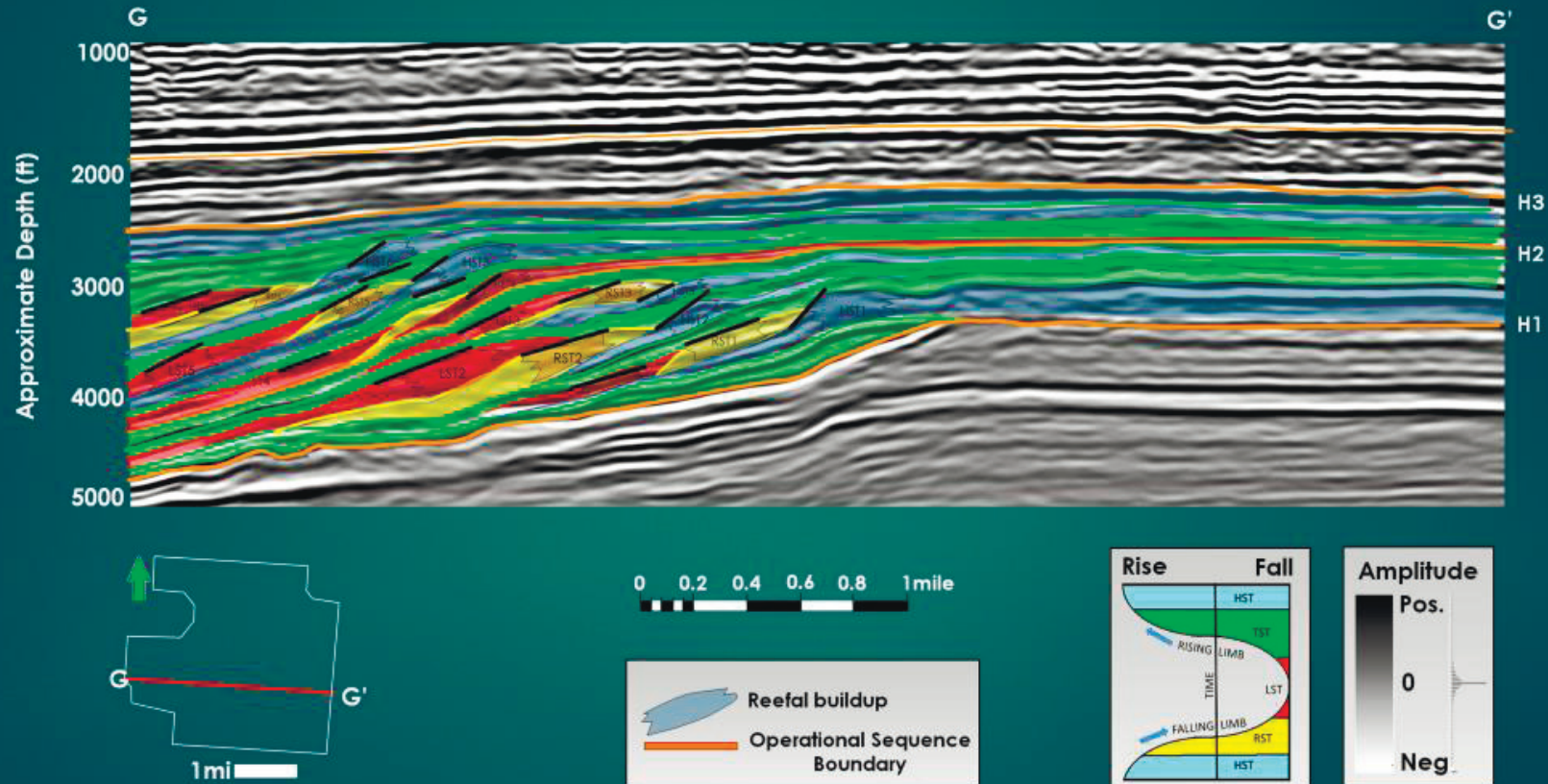


Leonardian-Guadalupian Reflux Dolomitization Model for Leonardian shelf margin buildups where reflux occurs during HST times (From Warren, 2000, after Saller, 1998)

Presenter's notes: Reflux dolomitization = in platform, lagoons are supersaturated respect to dolomite. It fluxes down to basin from the shelf edge. While doing that it loses its dolomite concentration. Therefore, basinal portion is less dolomitic, while most of the dolomitization occurs in shelf edge.

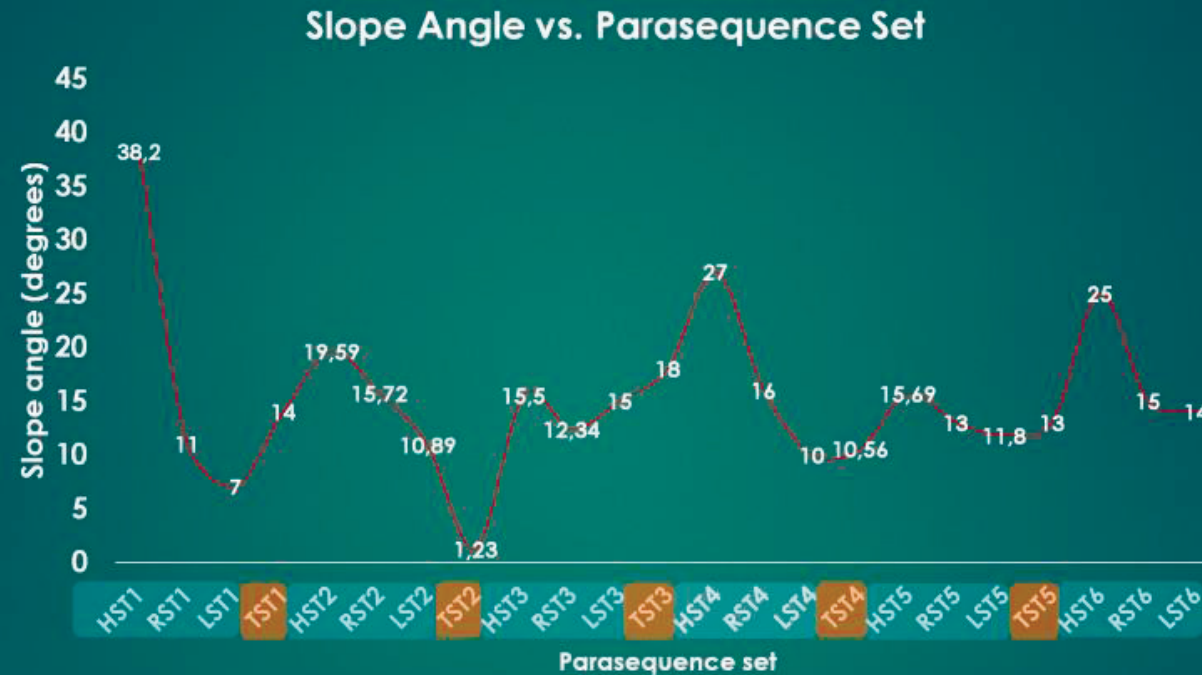
Integrated Interpretation and Discussion

SHELF SLOPE ANGLES ALSO VARY WITH RELATIVE SEA LEVEL CHANGE



Presenter's notes: Additional effect of relative sea level change was also observed on the geomorphology. Specifically, slope angles of buildups and their geometry is discovered to be controlled by the sea level fluctuations. When reef slope angles are measured from depth converted seismic, slopes are steeper on HST buildups, while RST and LST buildups have less steep slopes.

Integrated Interpretation and Discussion

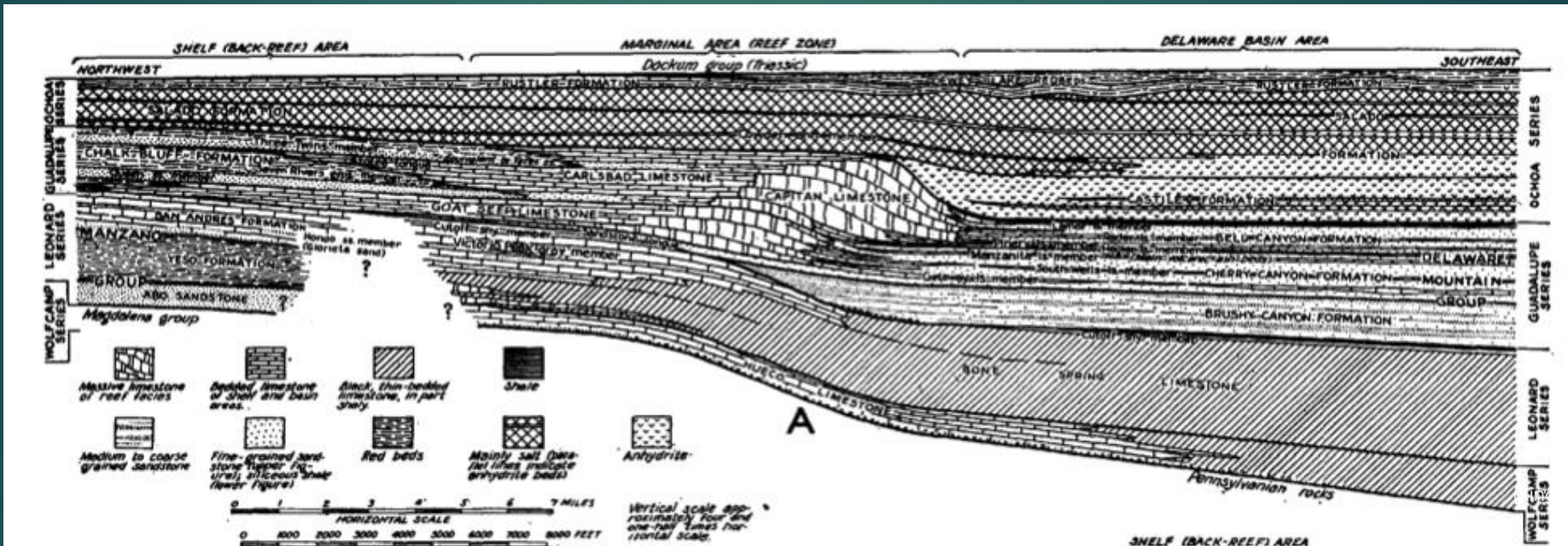


Blue shaded rectangles indicate times of carbonate buildups, while brown shaded boxes represents clastics. HST buildups have the steepest slope angles. **WHY?**

Presenter's notes: Blue shaded rectangles indicate times of carbonate buildups, while brown shaded boxes represents clastics.

Integrated Interpretation and Discussion

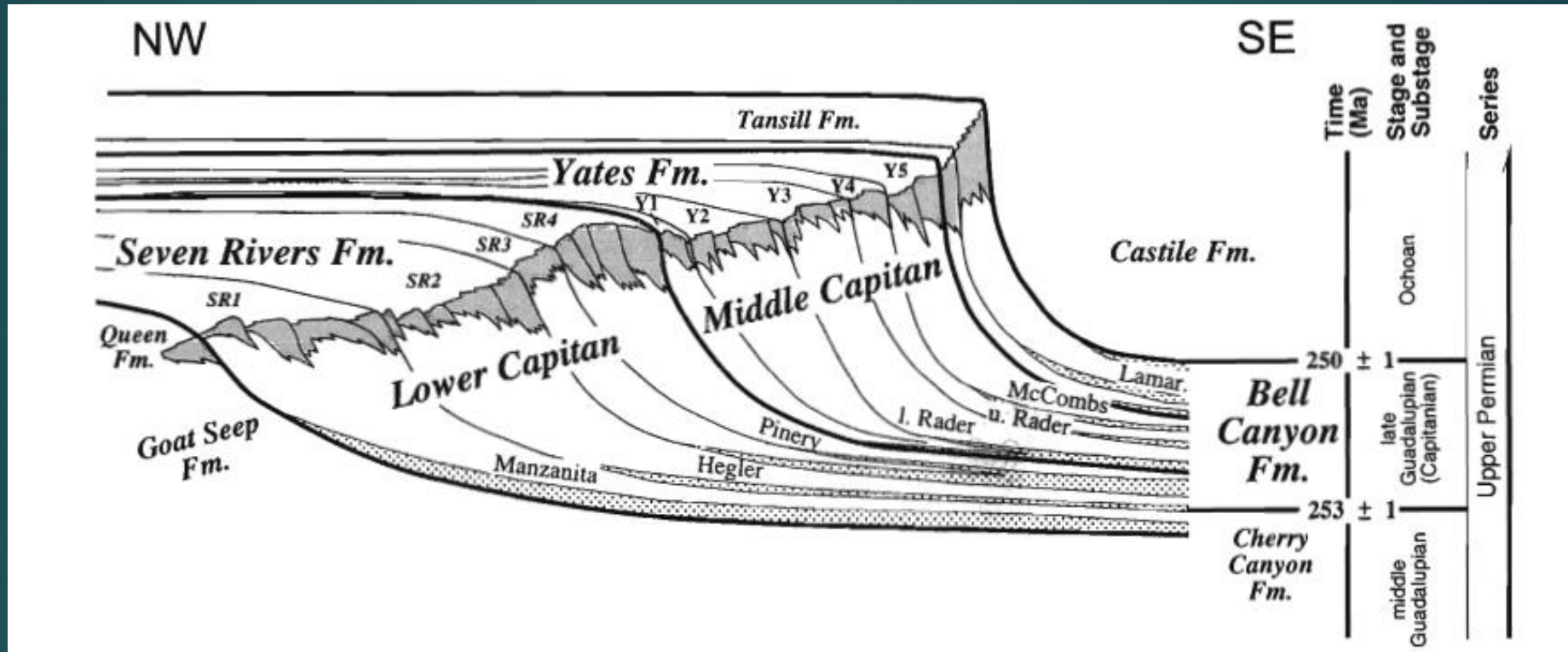
However, these observed seismic changes in buildup progression geometry differ from present paradigms of Permian reef evolution



- P. B. King was first to workout the stratigraphy of the Delaware Basin.
- His classic outcrop observations lead to early paradigms of depositional continuity and increase in slope dip of Guadalupian reefs.

Integrated Interpretation and Discussion

...50 years later, the paradigm has evolved into the gentle ramp to steep rim concept



(Osleger and Tinker 1999, Dates from Ross and Ross 1987)

- E.g. Osleger (1998), Tinker (1998), Kerans and Tinker (1999), Osleger and Tinker (1999)

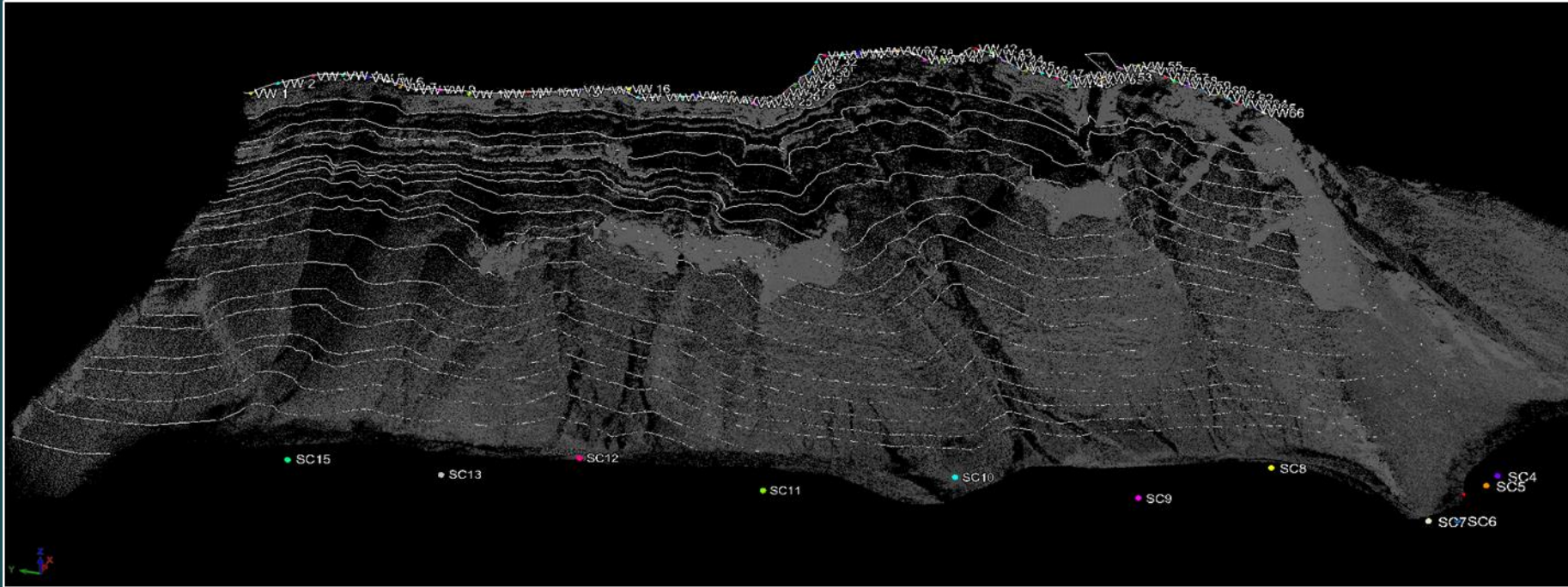
Integrated Interpretation and Discussion



■ Eastern Wall of Slaughter Canyon

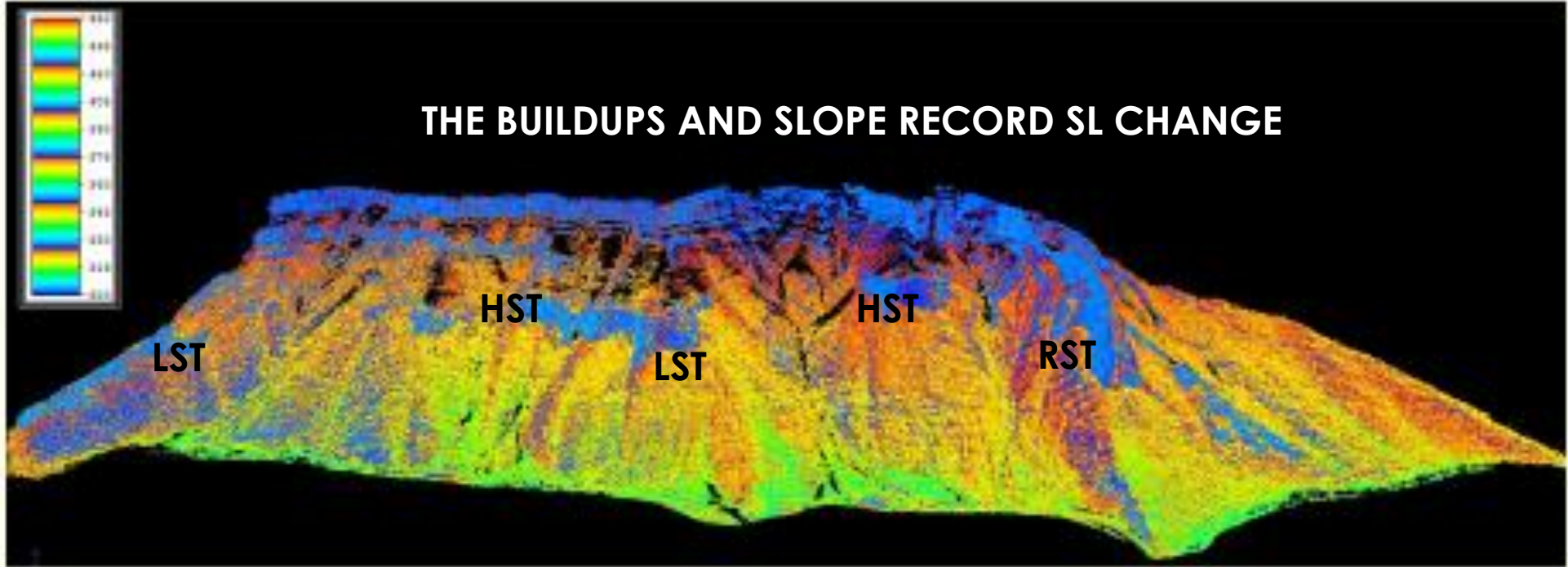
But in outcrop, upon closer inspection, the reefs appear discontinuous and slopes are not static, alternating through time.

Integrated Interpretation and Discussion



Slaughter Canyon Lidar of reef and talus slopes (filtered point cloud data displayed in reflectance dB min: 300, max: 450, Grey scale) and incorporating Osleger and Tinker 1999's interpretation of the back reef stratigraphy continuing through the buildups reveal changes in dip. (Garrett et al., 2015)

Integrated Interpretation and Discussion

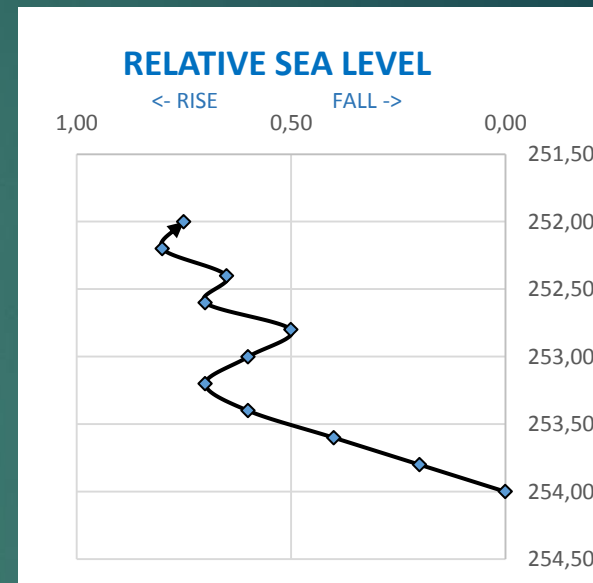
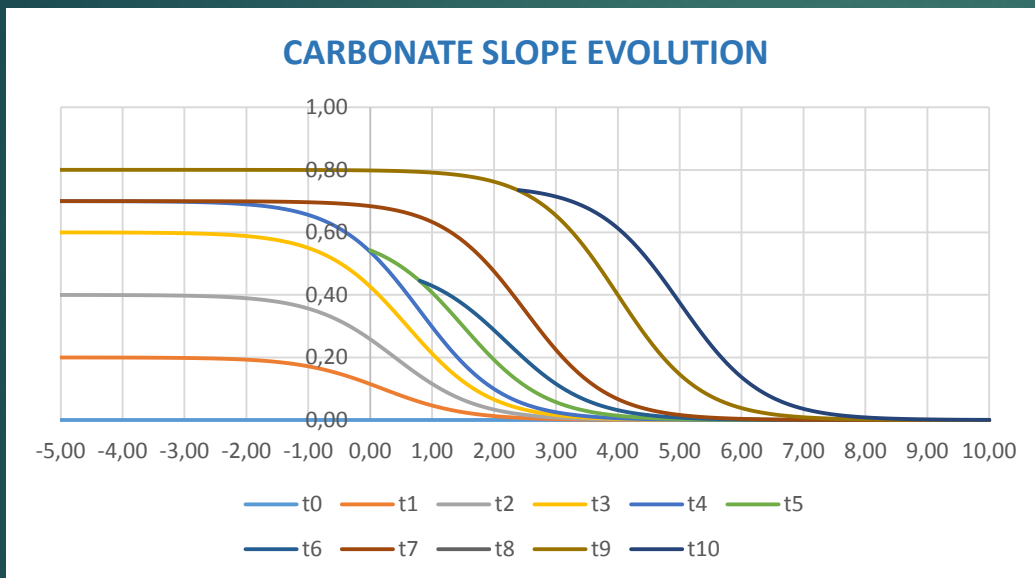


■ Filtered point cloud data displayed in reflectance

These late Guadalupian reef buildups are discontinuous and slope angles change with each differing parasequence set (Garrett et al., 2015)

Integrated Interpretation and Discussion

HYPOTHESIS: HST's are the steepest as no remaining vertical accommodation and can only prograde.



Age (ma)	254.00	253.80	253.60	253.40	253.20	253.00	252.80	252.60	252.40	252.20	252.00
Vertical accom rate km/ma		1.00	1.00	1.00	0.50	-0.50	-0.50	1.00	-0.25	0.75	-0.25
Horizon accom rate km/ma		1.00	1.00	1.00	1.00	3.50	3.50	1.50	5.00	2.50	5.00

ANALYTICAL MODEL* OF PERMIAN CARBONATE RIMMED PLATFORM SLOPE EVOLUTION AS FUNCTION OF ACCOMMODATION CREATION AND FILL WITH CHANGES IN RELATIVE SL RISE

***CARBSLOPE**

THEREFORE...

- ▶ CARBONATE SLOPE DEVELOPMENT AND CONSEQUENT FACIES TRACTS ARE VALID RECORDERS OF VERTICAL AND HORIZONTAL ACCOMMODATION CHANGE OWING TO CHANGES IN RELATIVE SEA LEVEL.
- ▶ IT IS UPON THIS DYNAMIC GEOMORPHIC BASE THAT SUBSEQUENT DIAGENESIS AFFECTS RESERVOIR QUALITY.

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- **Conclusions**

Conclusions

- **For the Leonardian Midland Basin Eastern Shelf Edge, three major sequence boundaries are identified and interpreted through seismic sequence analysis:**
 - Wolfcamp-Leonardian boundary (H1),
 - Lower Clearfork (H2) and,
 - Top Leonardian (Glorieta) (H3).
- **Three distinct shelf edge carbonate buildups associated with the parasequence sets are identified as a result of relative sea level induced changes in accommodation:**
 - HST buildups are the larger and thickest buildups with the steepest seaward dipping angles (15-38 degrees),
 - RST buildups step down and are smaller and have sea ward dipping angles of (10-15 degrees),
 - LST buildups are more planar in morphology and have the lowest seaward dipping angles(7-10 degrees),
 - There are no observable TST buildups.
- **3D porosity prediction from the Probabilistic Neural Network (PNN) and lithology estimation from petrophysical methods reveal extensive LST porosity associated Dolomitization.**

Coda

Quantitative seismic stratigraphic interpretation of the Eastern shelf margin of the Midland Basin provides new insight into Leonardian carbonate reef development, dolomitization and porosity distribution which coincide with fluctuations in Permian basin sea level. These findings point to new, untested conventional play concepts in the Permian Basin.

Thank You

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