



2023 SPE EUROPE ENERGY GEOHACKATHON

#. Seismic Data interpretation

Luca Fava

11 October 2023

#DatafyingEnergy

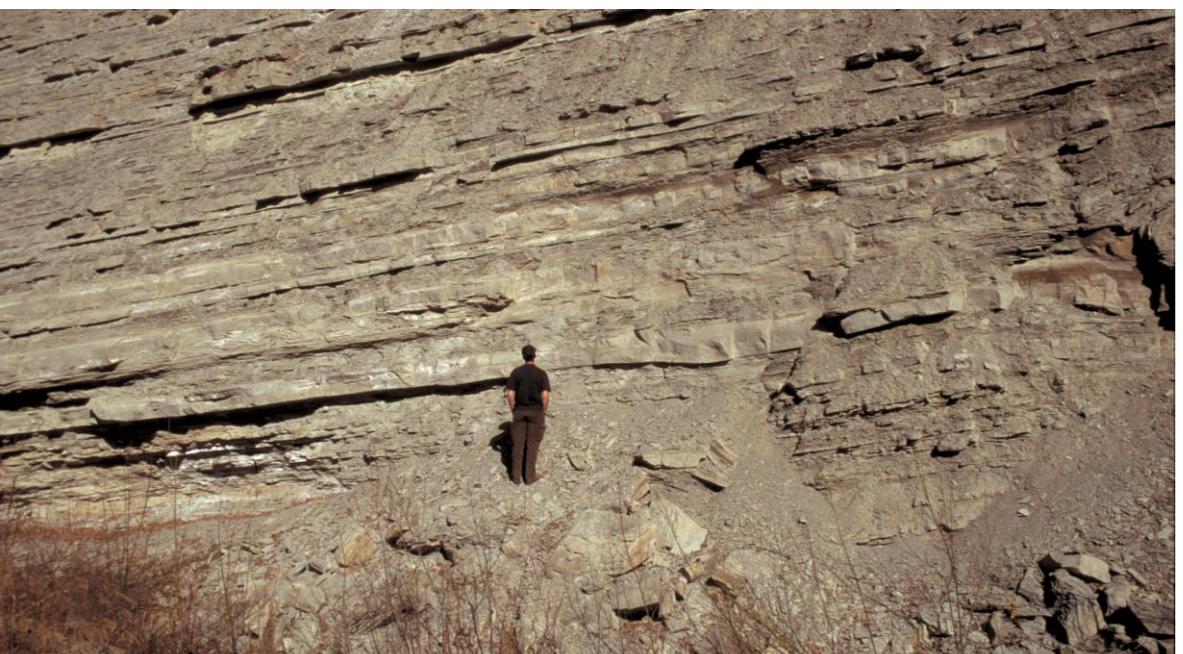
Seismic Data Interpretation

Luca Fava

1988 – Programming in Basic and Pascal



1998 – MS in Geology at Parma University



2002 – Started my career as a Geophysicist in Eni (Milan)

- Seismic Interpretation
- Depth Migration
- Seismic Inversion
- Depth conversion, structural uncertainty
- AVO analysis

2009 – Moved to Copenhagen with Maersk Oil in Exploration

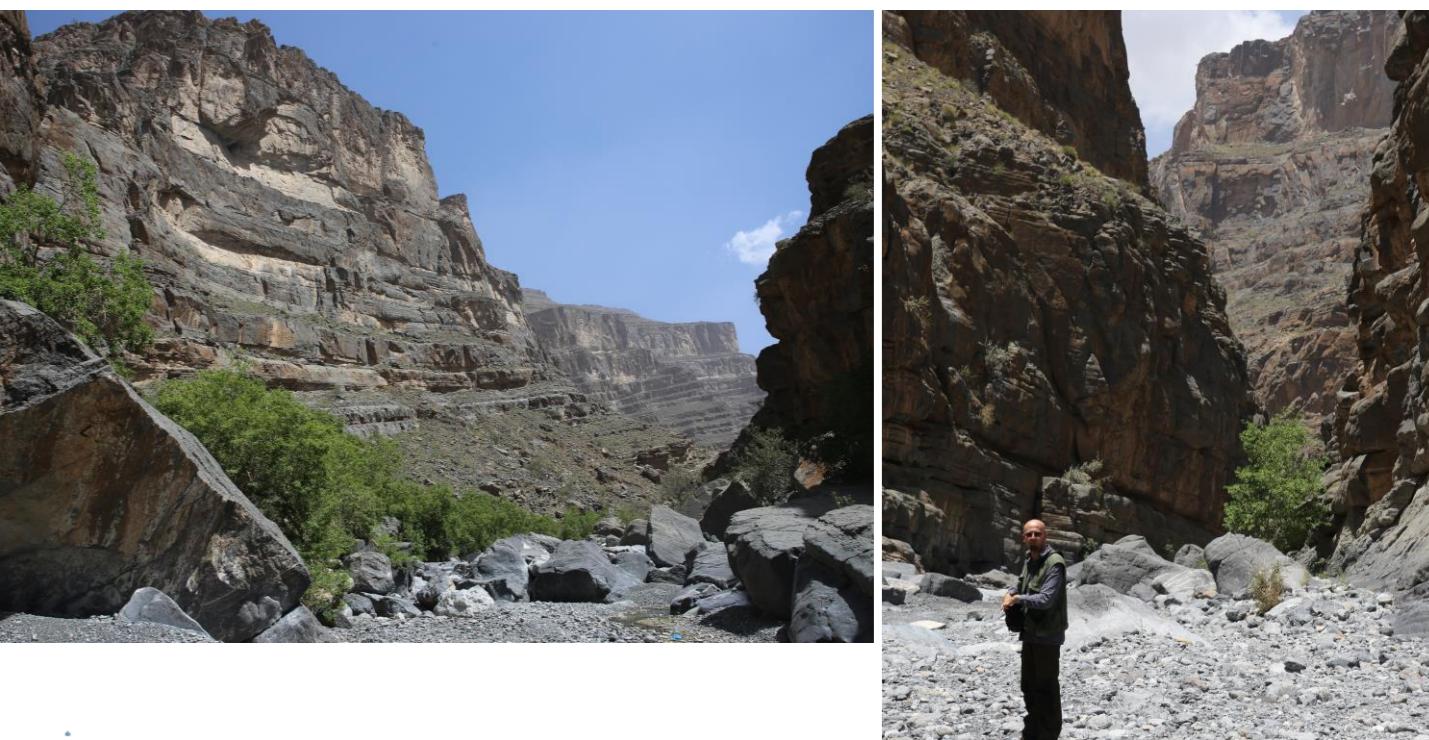
- Play Analysis
- Seismic Interpretation
- Prospect generation
- Depth conversion



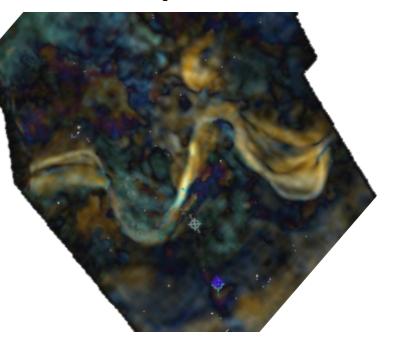
2012 – Field work in Kurdistan with Maersk Oil

2013 – Joined OMV in Abu-Dhabi

- Exploration campaign, seismic acquisition, seismic interpretation, drilling one well



2018 – OMV New Zealand, Exploration



2022 – Joined Petrom in Romania, DM Geoscience Team in Exploration

Seismic Data Interpretation

Agenda

1. Seismic Interpretation general concepts
 - a. Seismic Reflection
 - b. Well-to-Seismic Tie
 - c. Depth conversion
2. Interpretation
 - a. Geological understanding
 - i. Structural Settings
 - ii. Stratigraphy
 - iii. Geo-morphological features
 - b. Interpretation workflow
 - c. Interpretation Pitfalls
 - a. We see only what we know
 - b. Biases
3. Seismic Attributes
4. Seismic Interpretation for Geothermal
5. ML in Seismic Interpretation
 - a. Seismic Facies Clustering
 - b. Supervised interpretation

Seismic Data Interpretation

1. General concepts

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3. Seismic Attributes

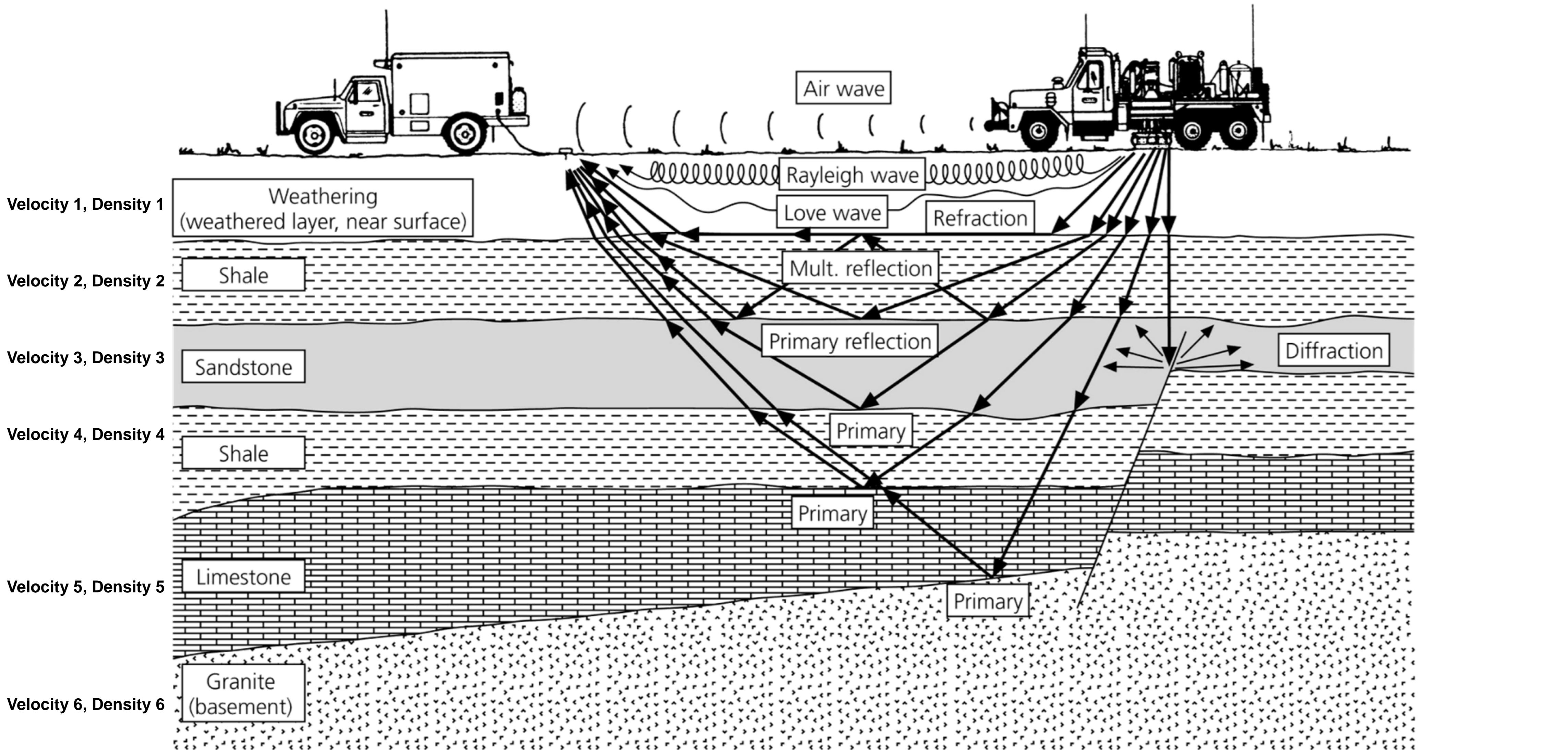
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5. ML in Seismic Interpretation

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General concepts

Seismic Reflection



General concepts

Seismic Reflection: what are we looking at when we see a Seismic line?

Layer 1

Velocity 1, Density 1 (v_1, ρ_1)

Incident
wave

Reflected
wave

Acoustic Impedance 1 = $v_1 \times \rho_1$

Interface

R = Reflection Coefficient

Velocity 2, Density 2 (v_2, ρ_2)

Transmitted
wave

Acoustic Impedance 2 = $v_2 \times \rho_2$

Layer 2

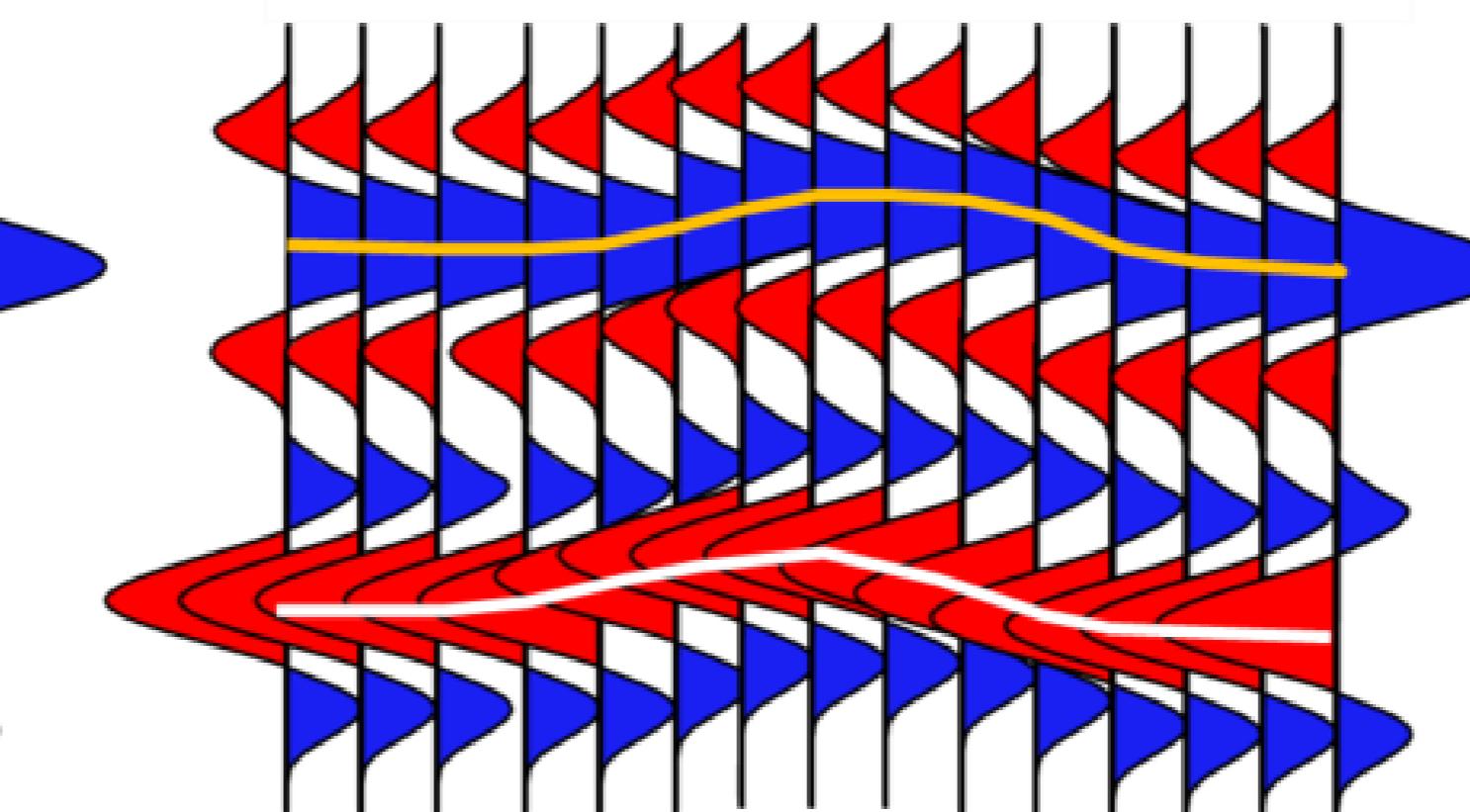
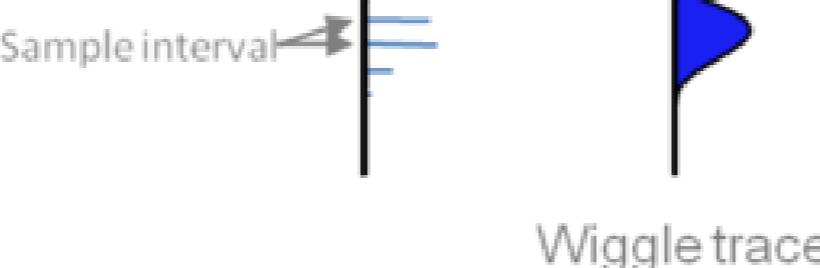
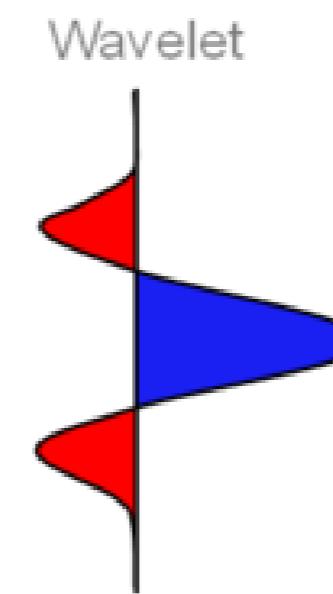
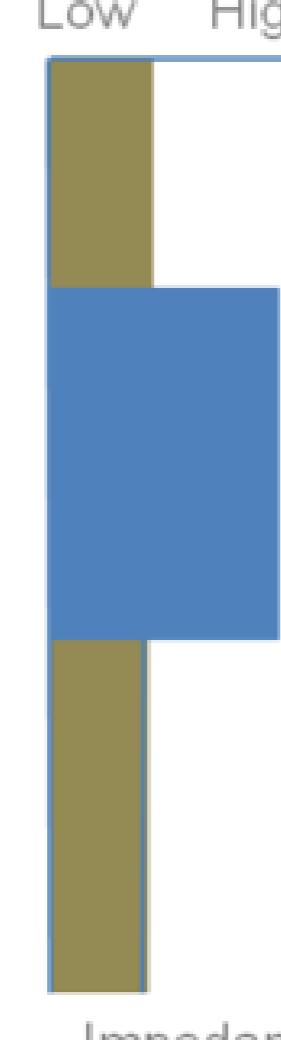
Low High

- Refl. Coeff. +

Seismic trace

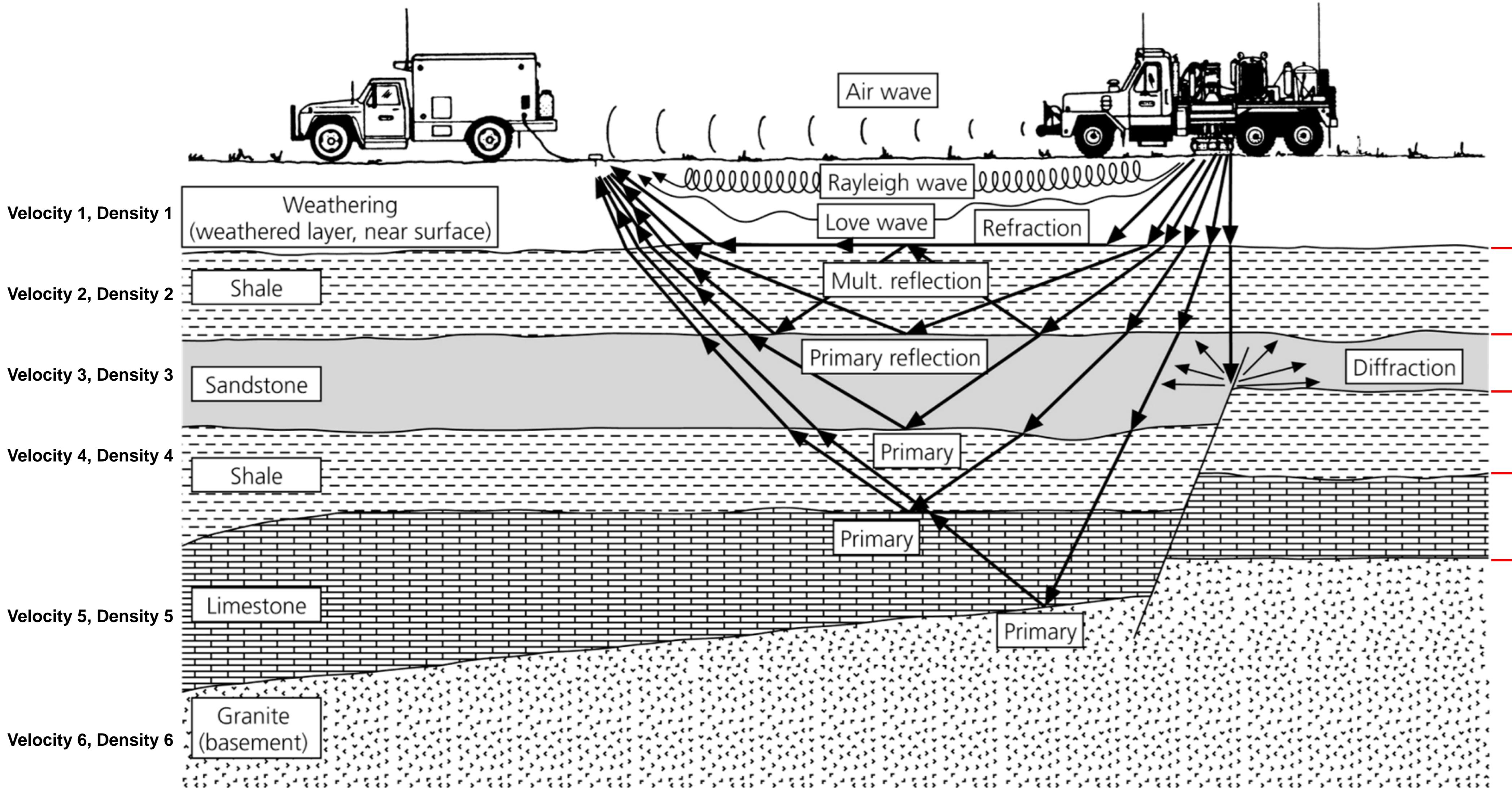
Many wiggle traces (seismic section)

$$R = \frac{(v_2 \times \rho_2) - (v_1 \times \rho_1)}{(v_2 \times \rho_2) + (v_1 \times \rho_1)}$$



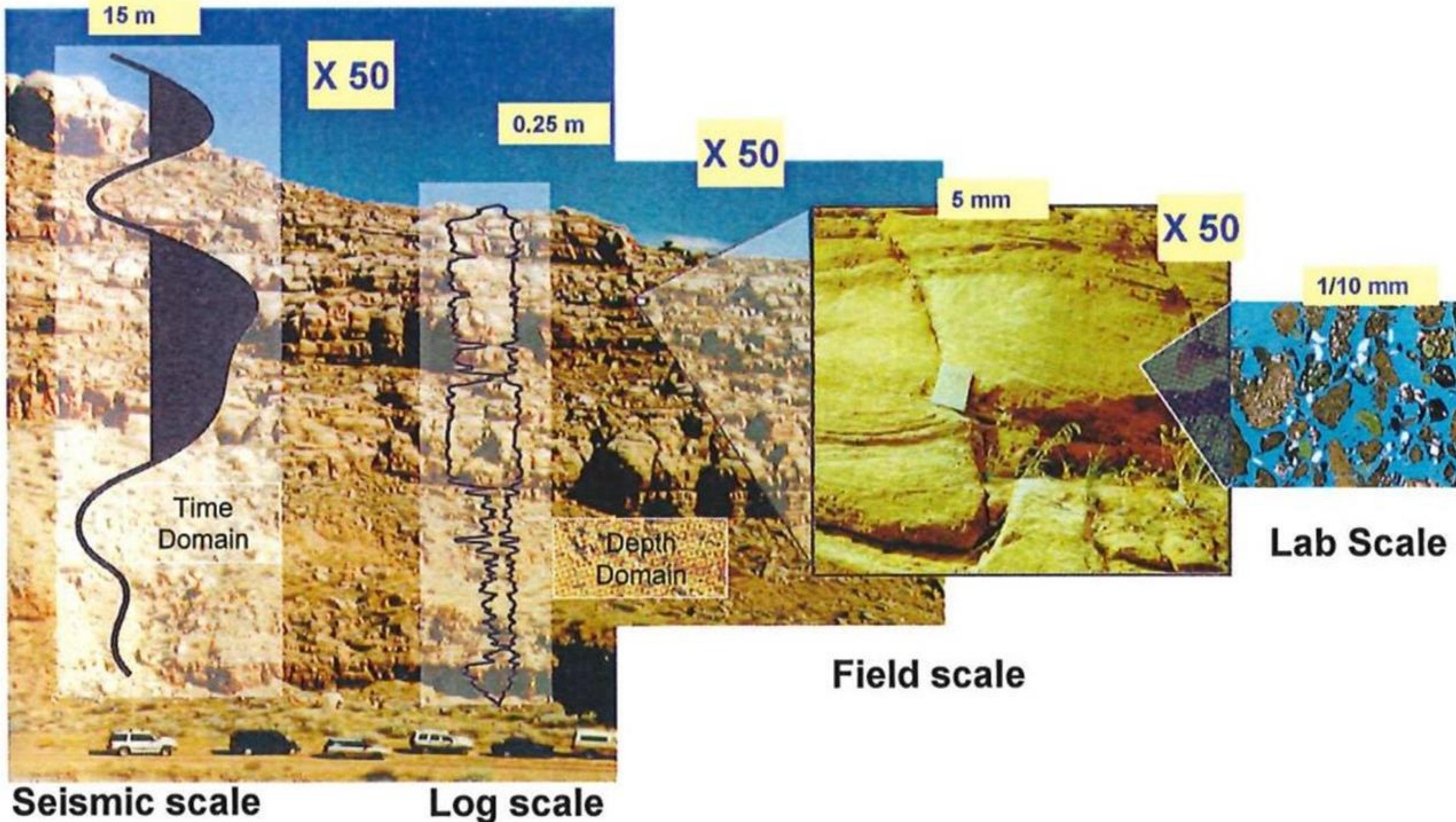
General concepts

Seismic Reflection



General concepts

The scale problem

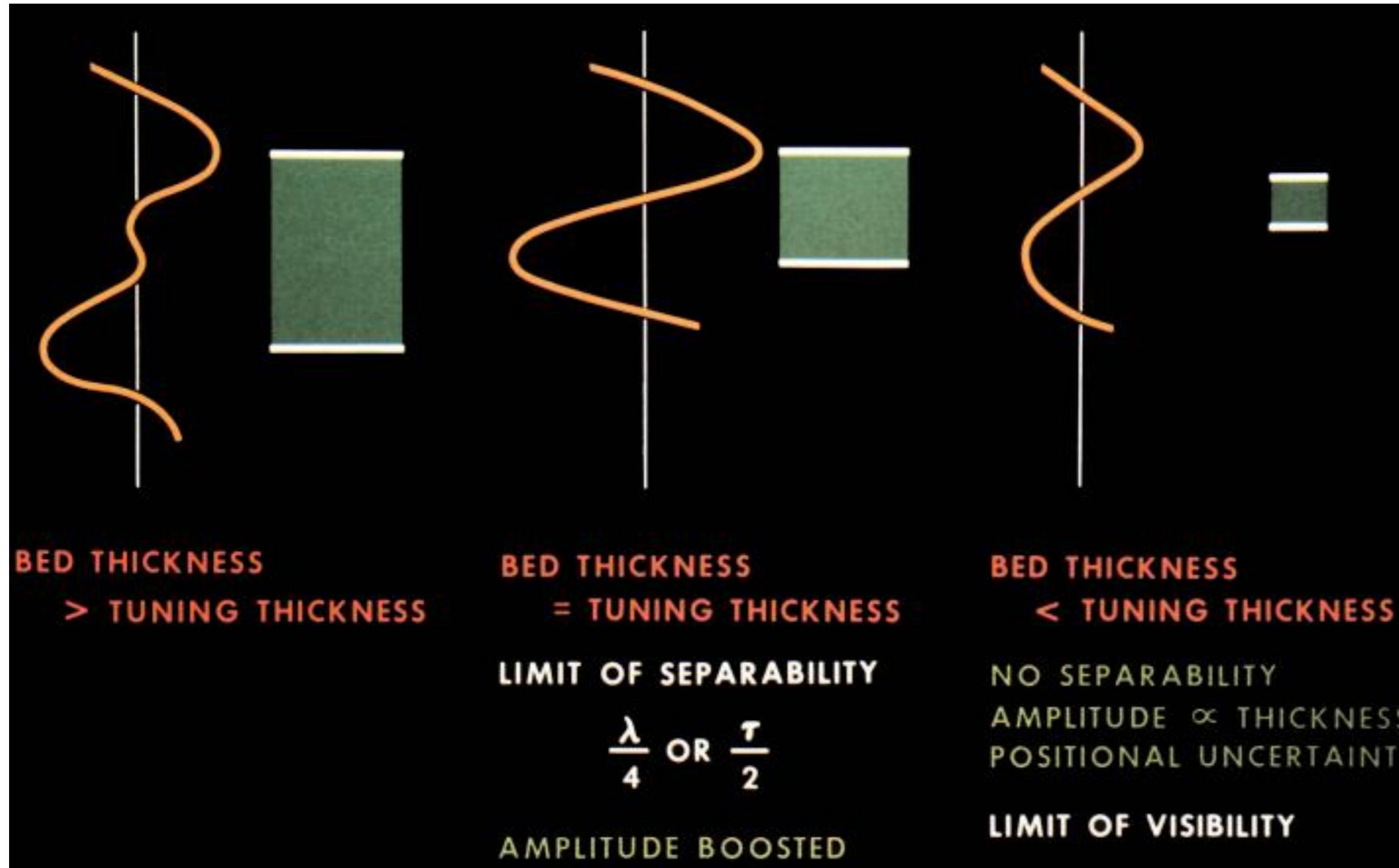


General concepts

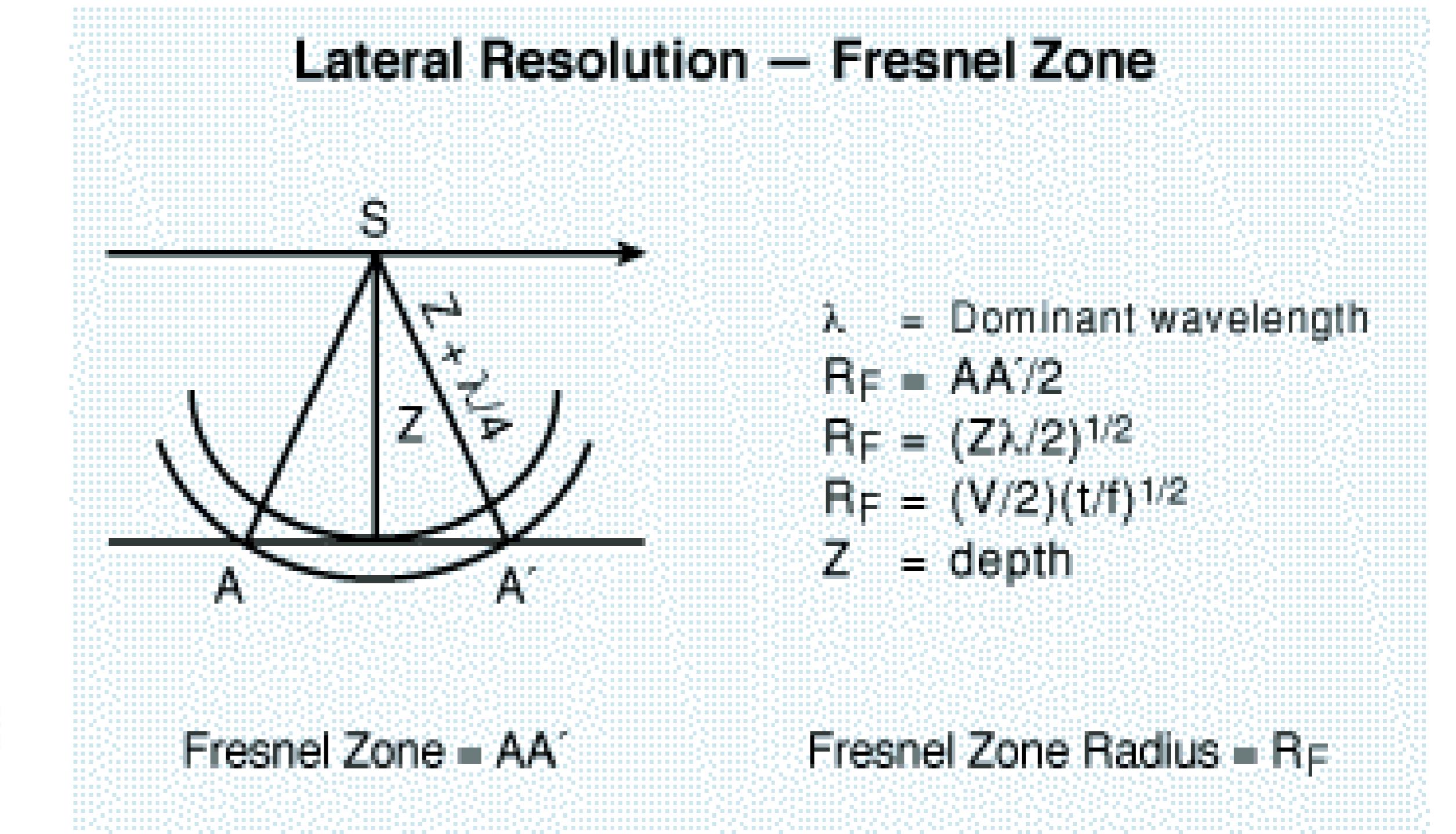
Seismic resolution

Seismic resolution is the ability to distinguish between two features from one another.

- 1. Vertical Resolution:** determines the thickness of the beds, such as two close seismic responds corresponding to different depth levels. It represents the distance between two interfaces as separate reflectors.
- 2. Horizontal Resolution:** determines the termination of beds by using seismic reflection. It recognizes two lateral displaced features on the single interface.

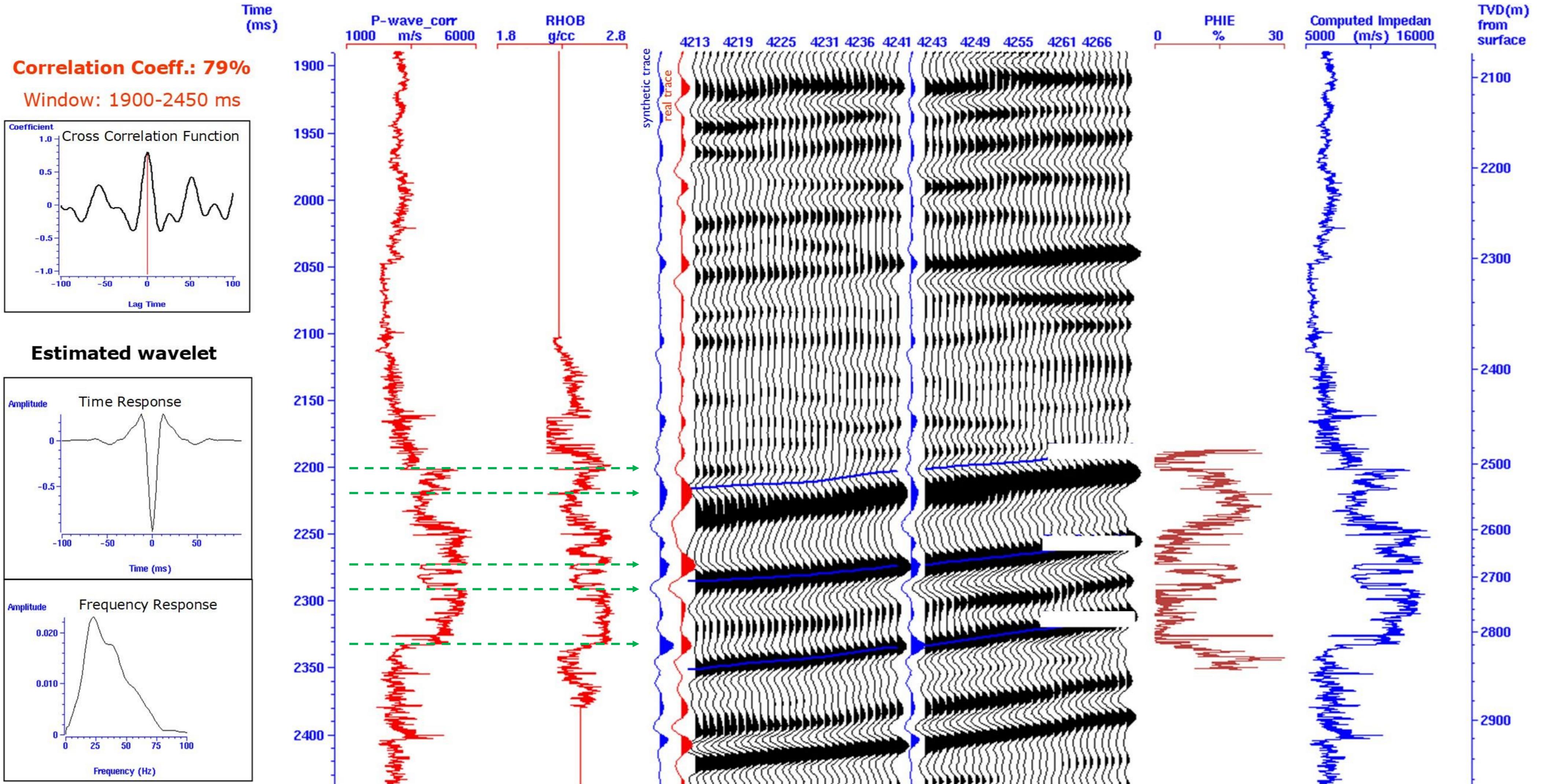


From: Brown (2011)



General concepts

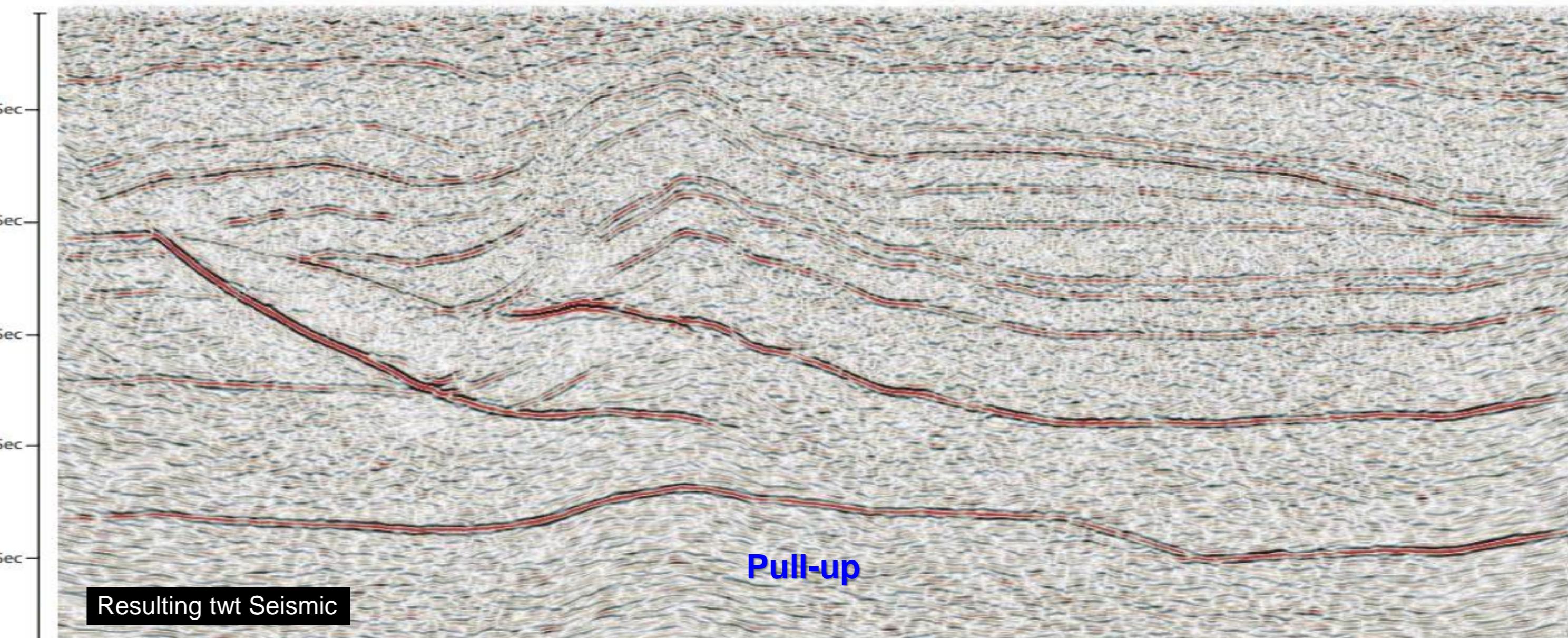
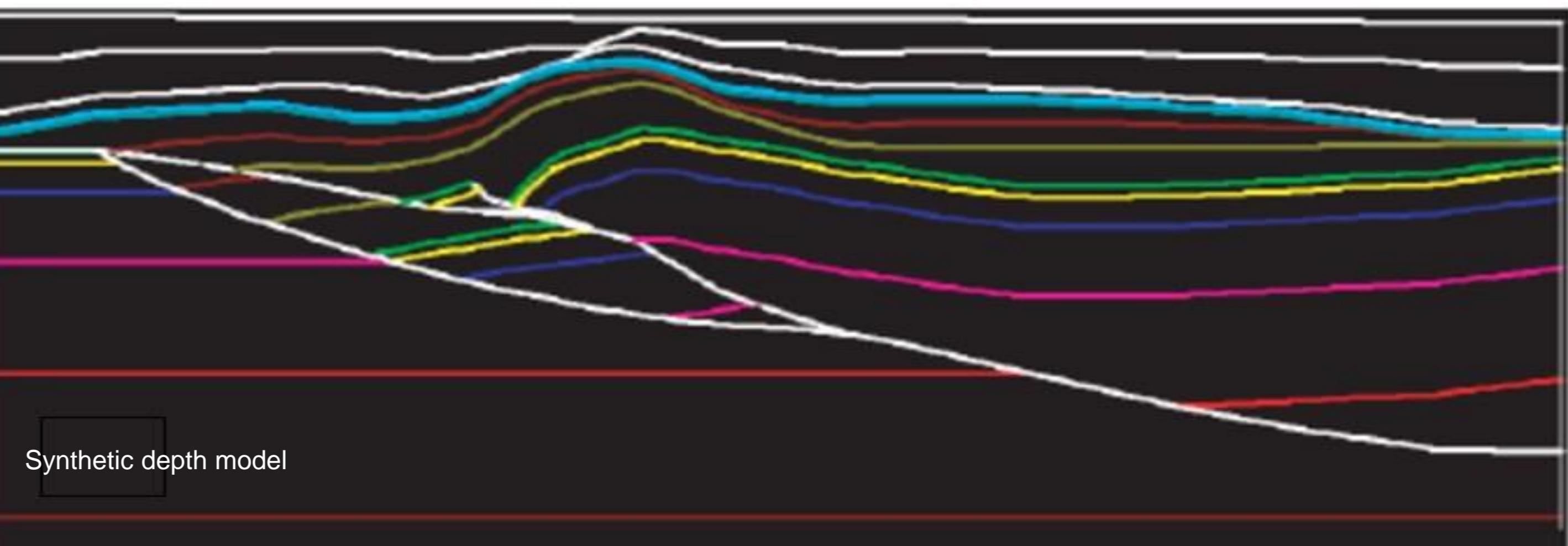
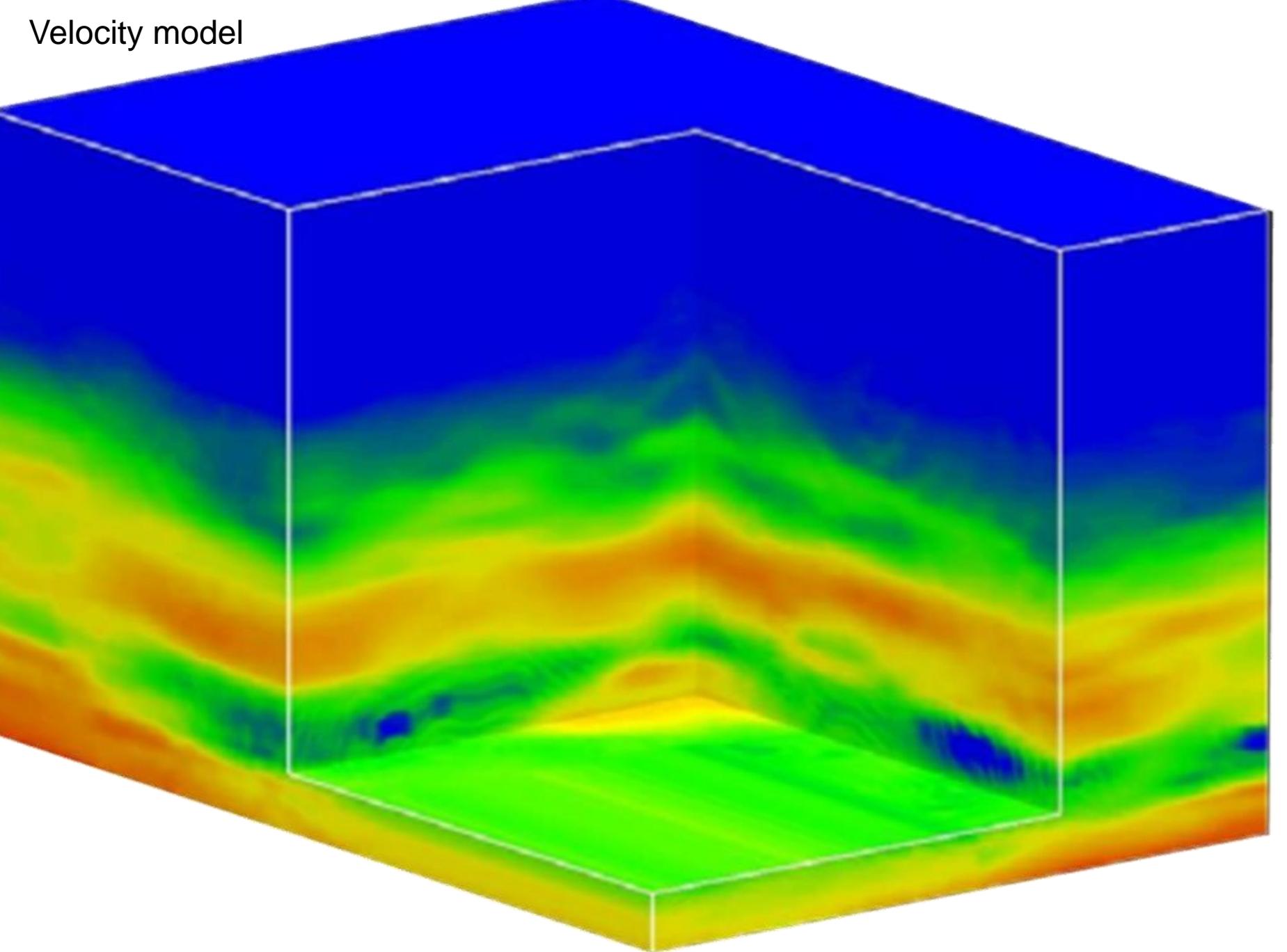
Well-to-Seismic tie



General concepts

Depth Conversion

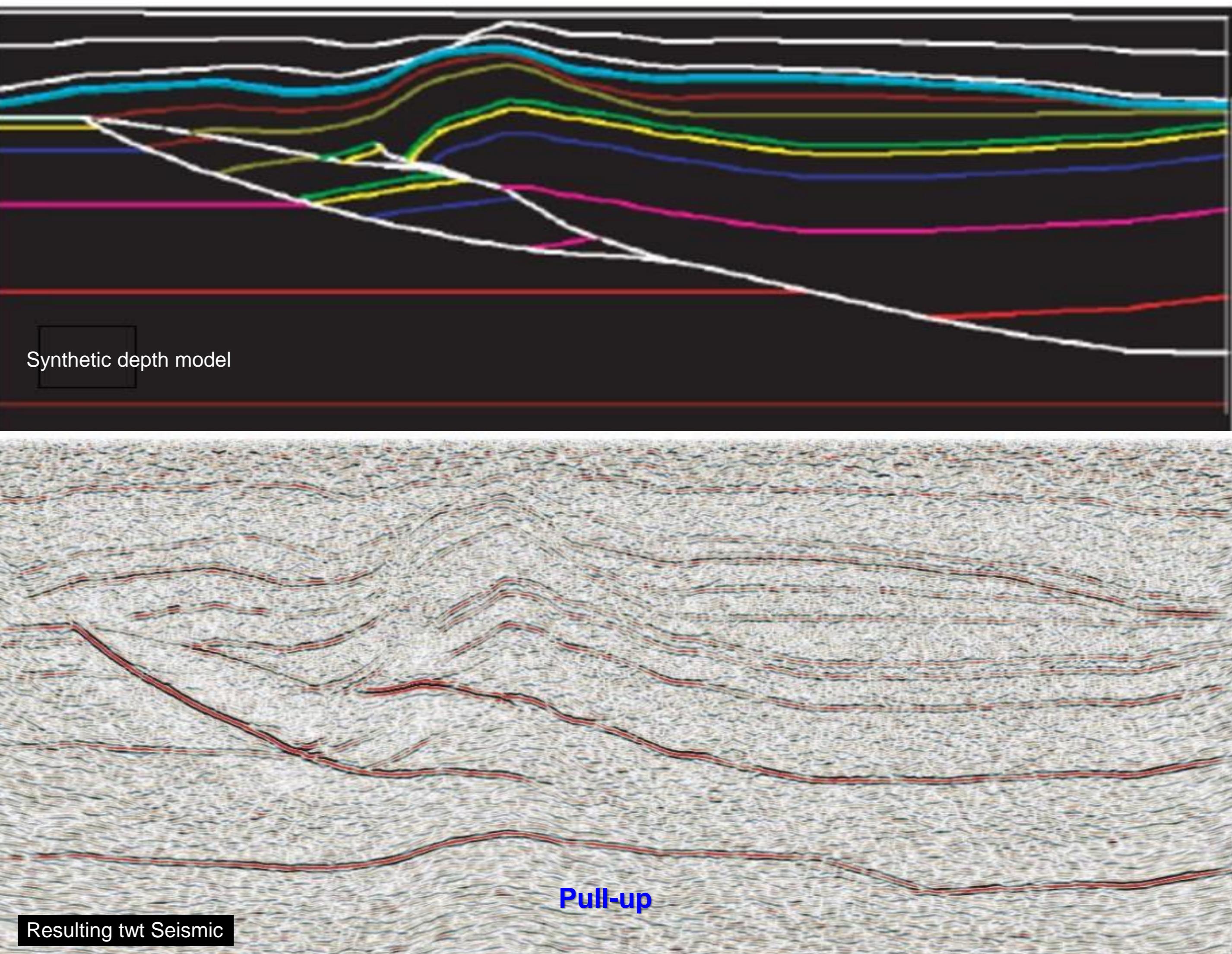
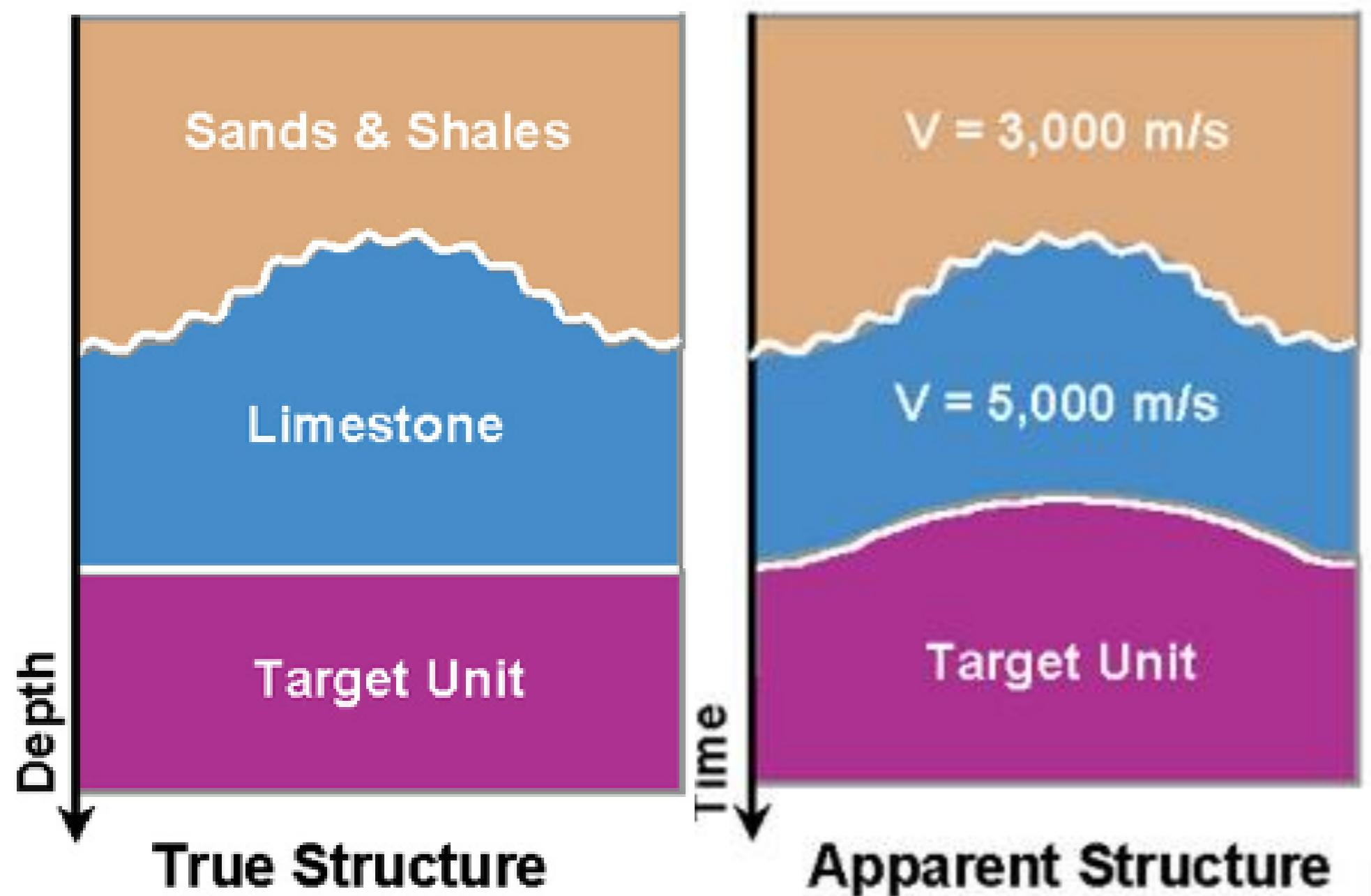
- Geology is in depth, but “raw” seismic data are recorded in Time (TWT)
- Thus, a velocity model is needed to convert the seismic data into the depth domain
 - To put the seismic events in the right depth position to tie with wells information
 - To have the right structural image as velocity anomalies can create structural artifacts (pull-ups or push-down)



General concepts

Depth Conversion

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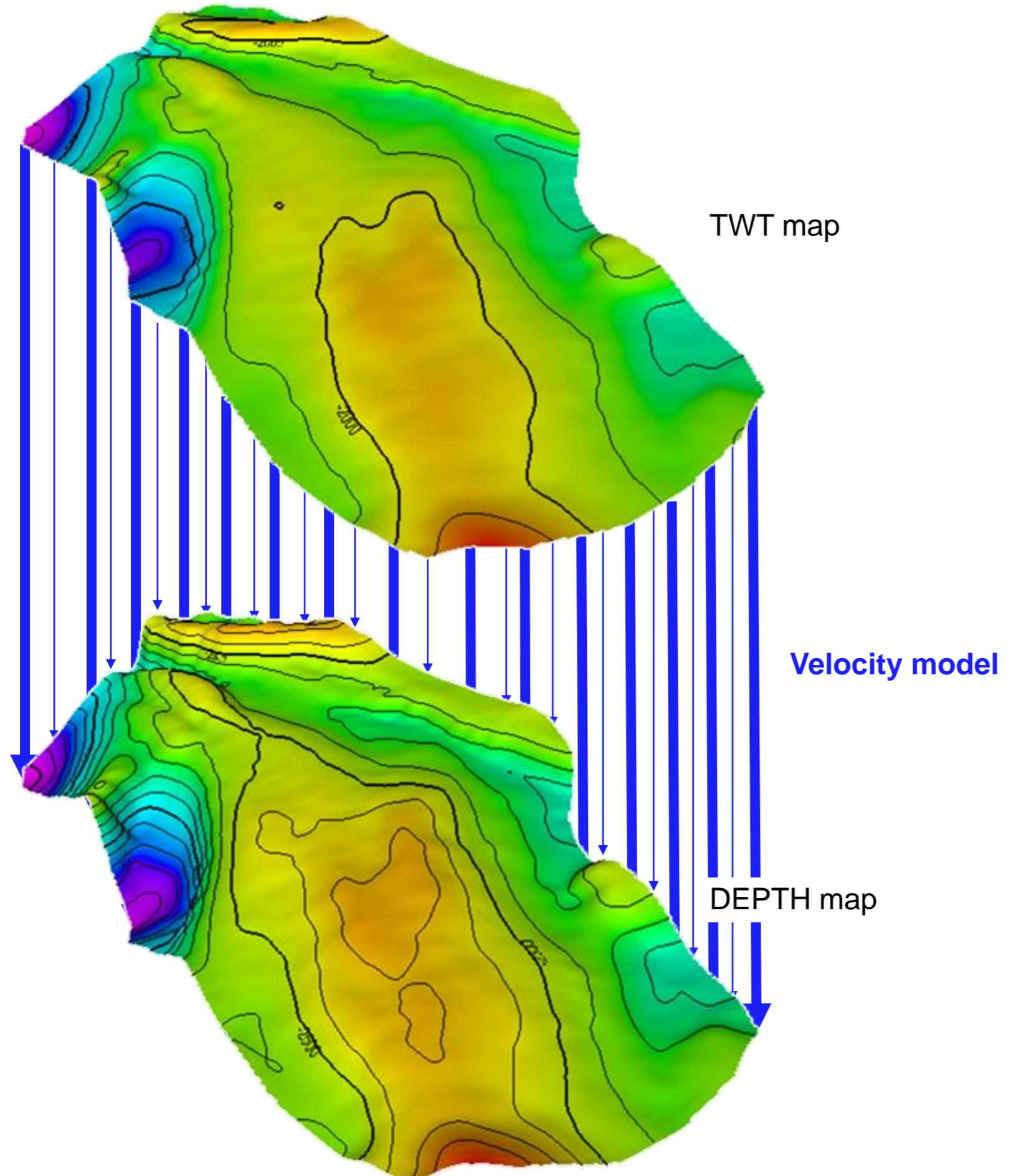
General concepts

Depth Conversion vs Depth Migration

Depth Conversion:

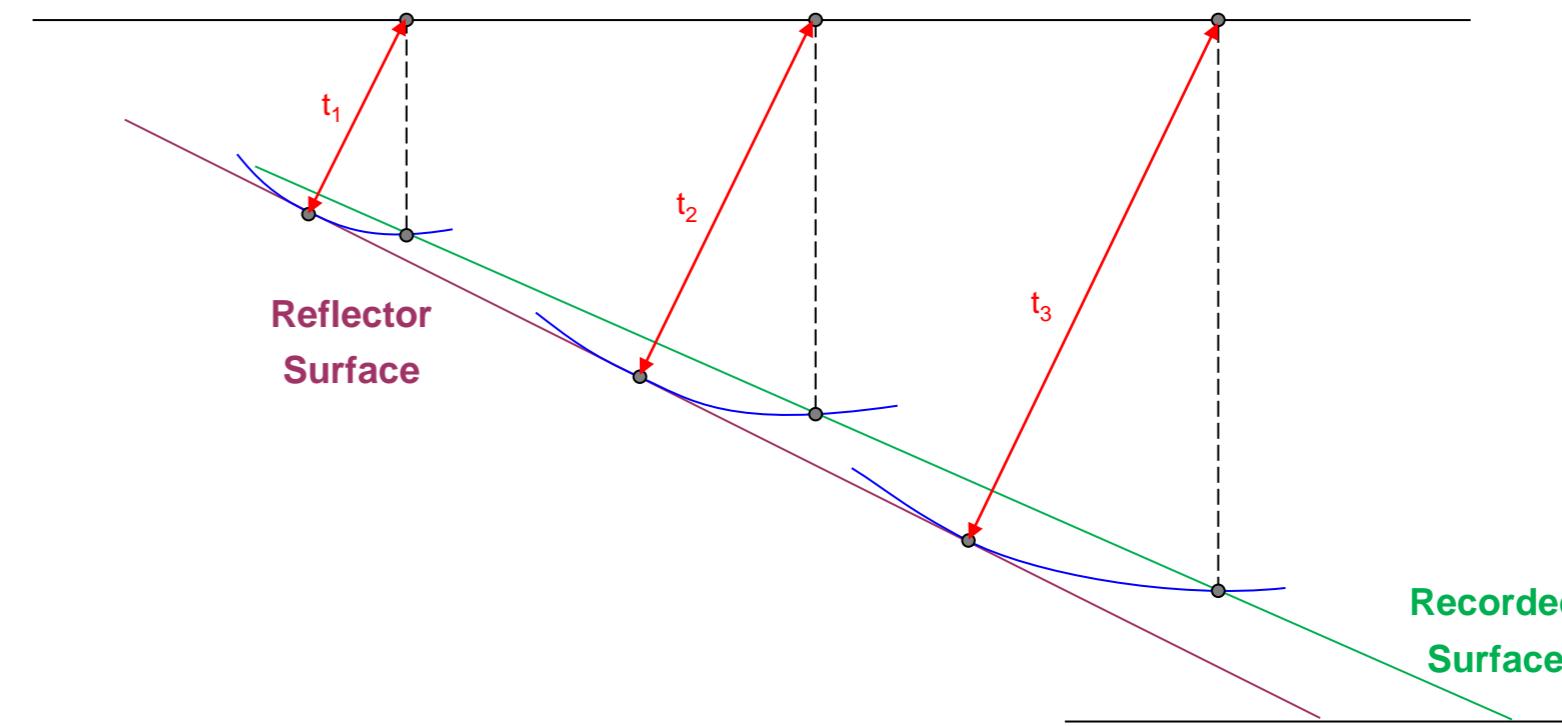
It is a vertical process only.

It is a vertical stretching of the Seismic data in time to Depth (TWT x Vel).

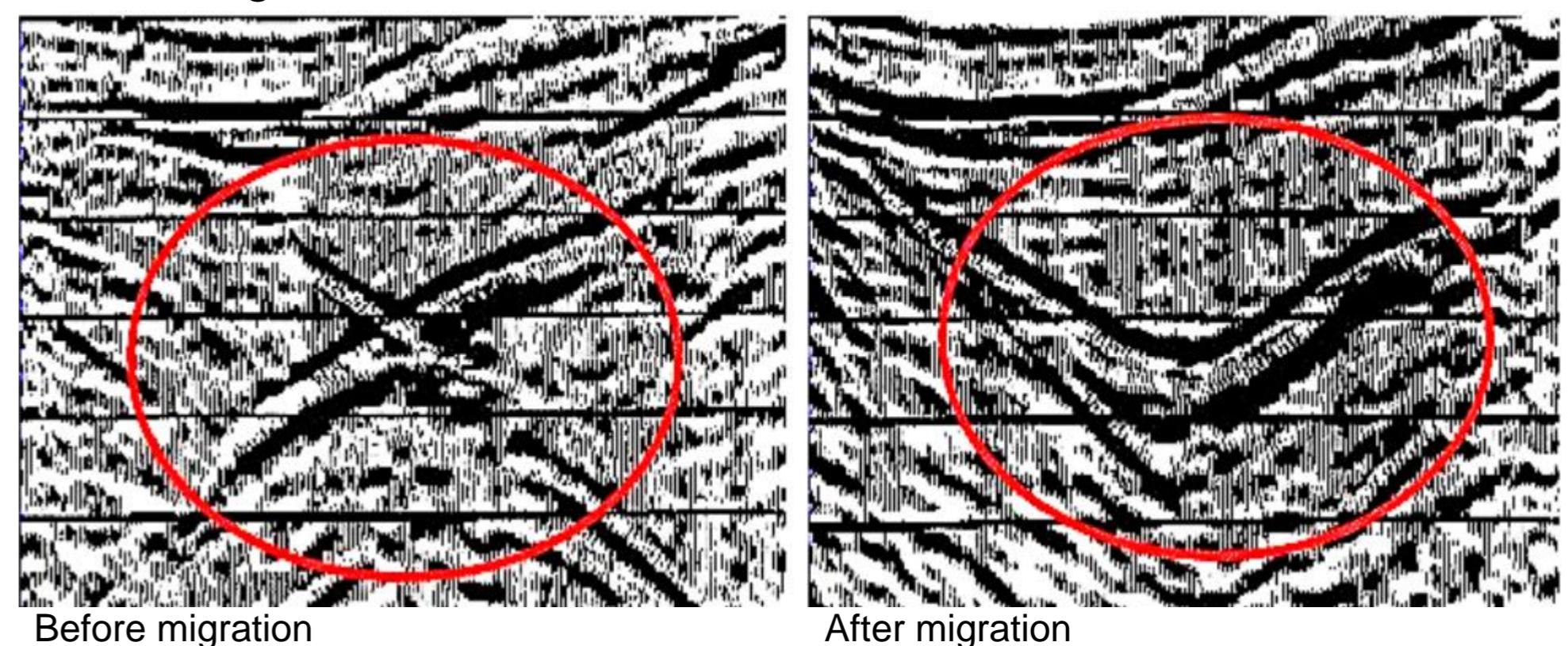


Depth Migration:

Migration is needed in case of dipping events. The time recorded for a point along the inclined surface is $2t_n$, but when we plot the section we think of the reflections arriving from directly beneath the shot. The result is that the reflector will appear in the wrong position in space. The right velocity model is required to collapse the seismic data back to correct position in space (better focusing the image).



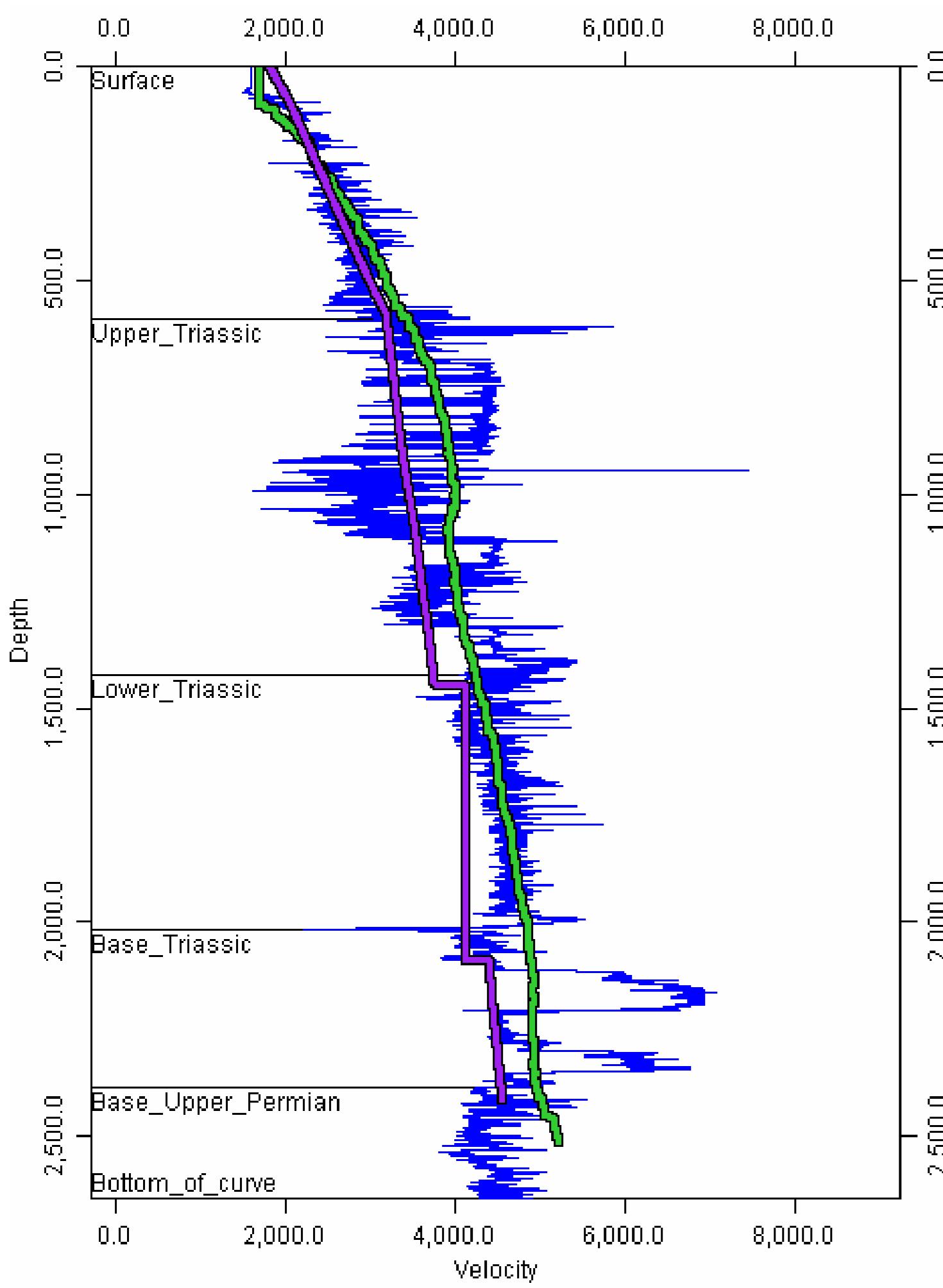
For example, a sharp synclinal feature will result in a "bow-tie" shape of the reflection event in the non-migrated seismic section.



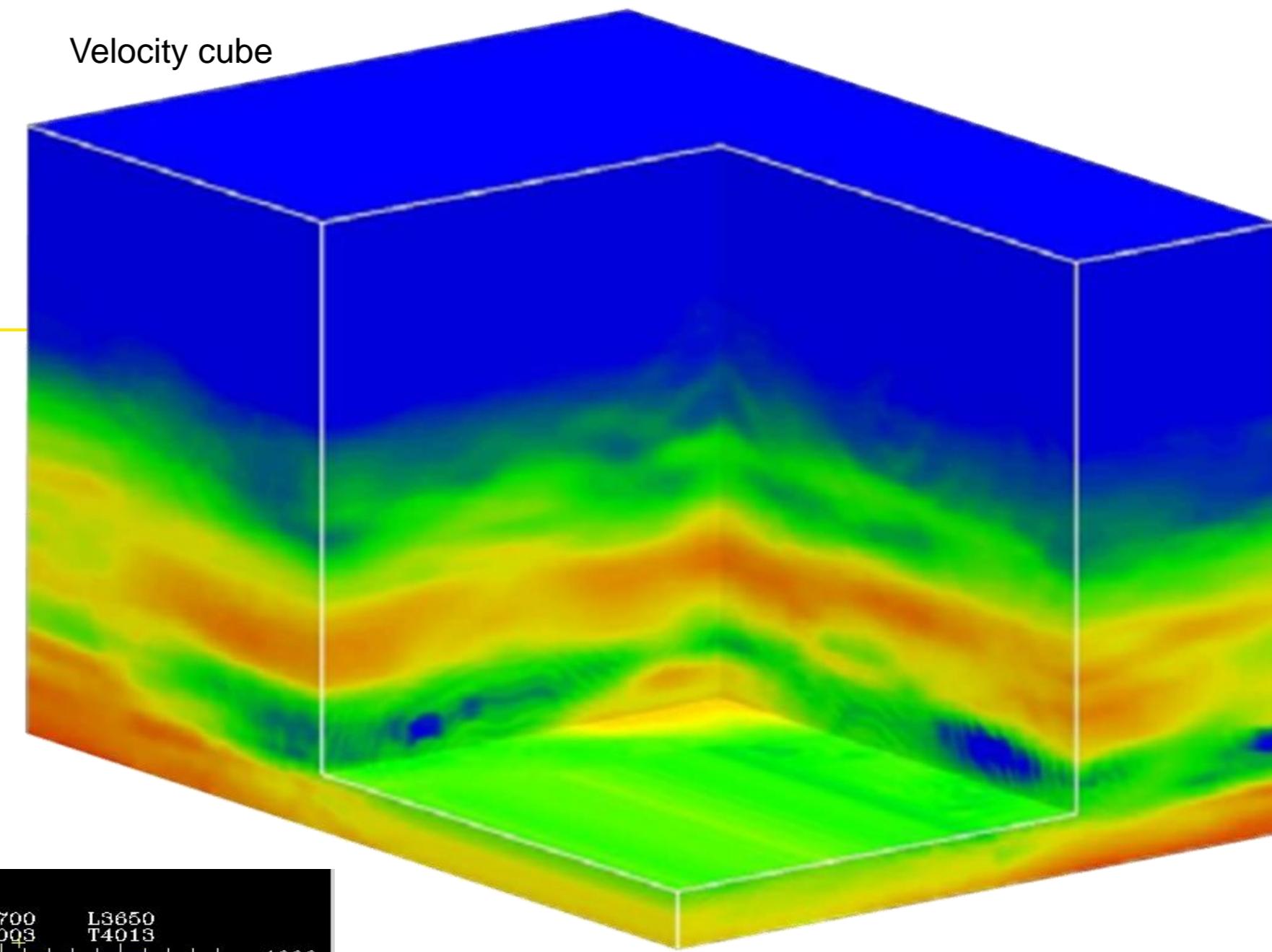
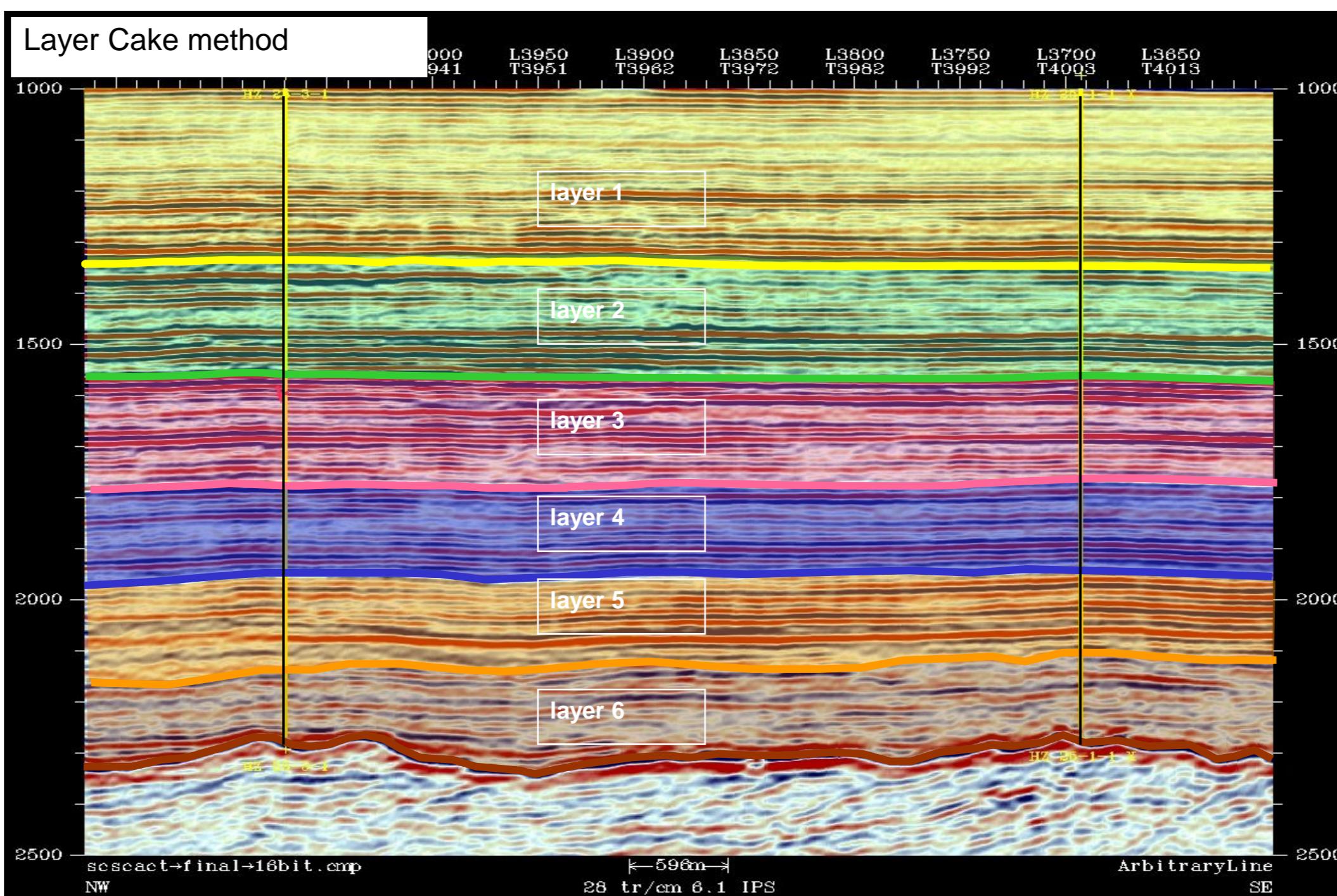
General concepts

Depth Conversion

Well Function



Different methodologies based on data availability and goal of the Depth Conversion



Seismic Data Interpretation

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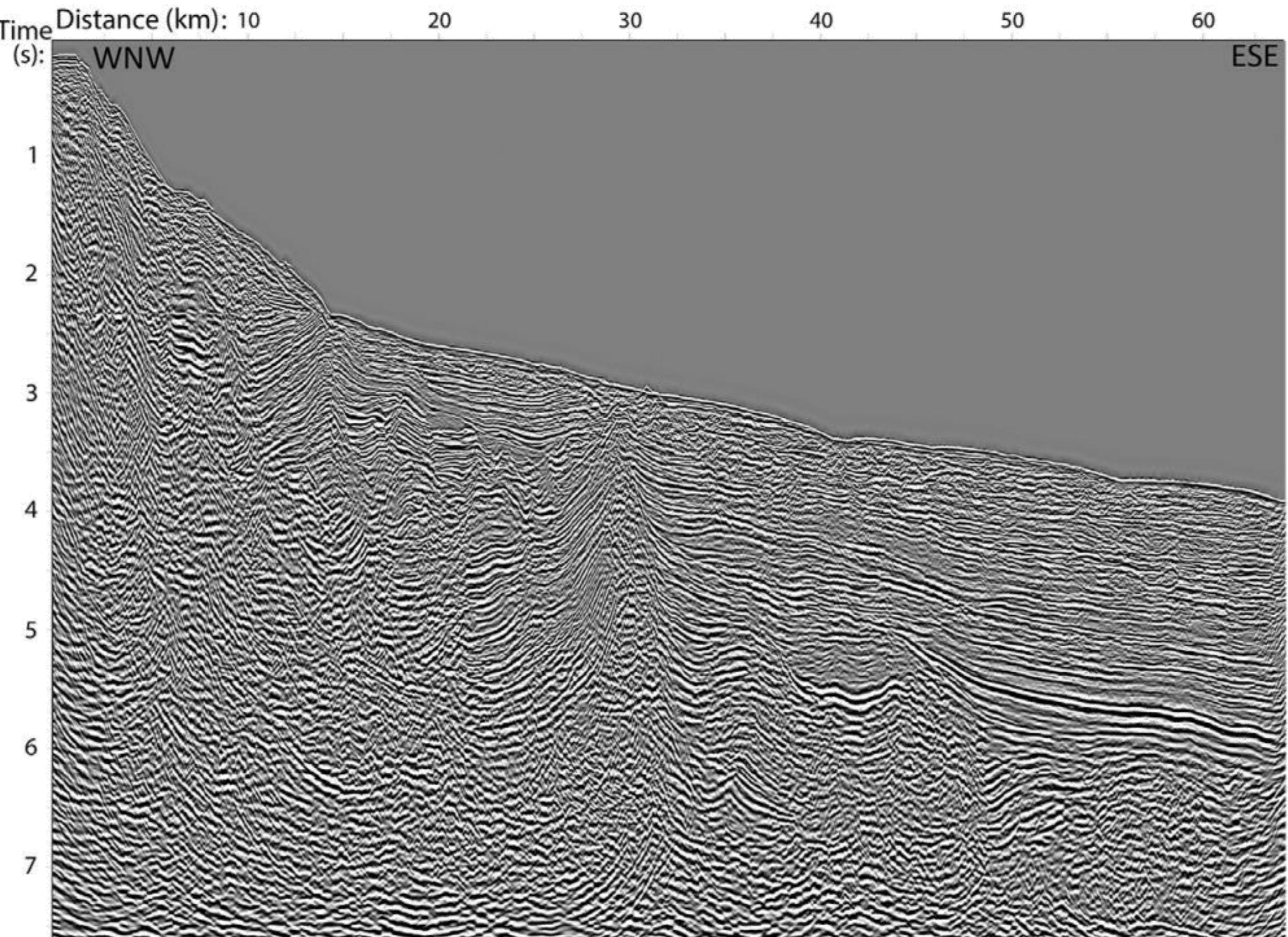
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Interpretation

Example of a seismic line

Image very difficult to interpret, unless the interpreter has some geological knowledge and model in mind.

From: Holz et al., 2017

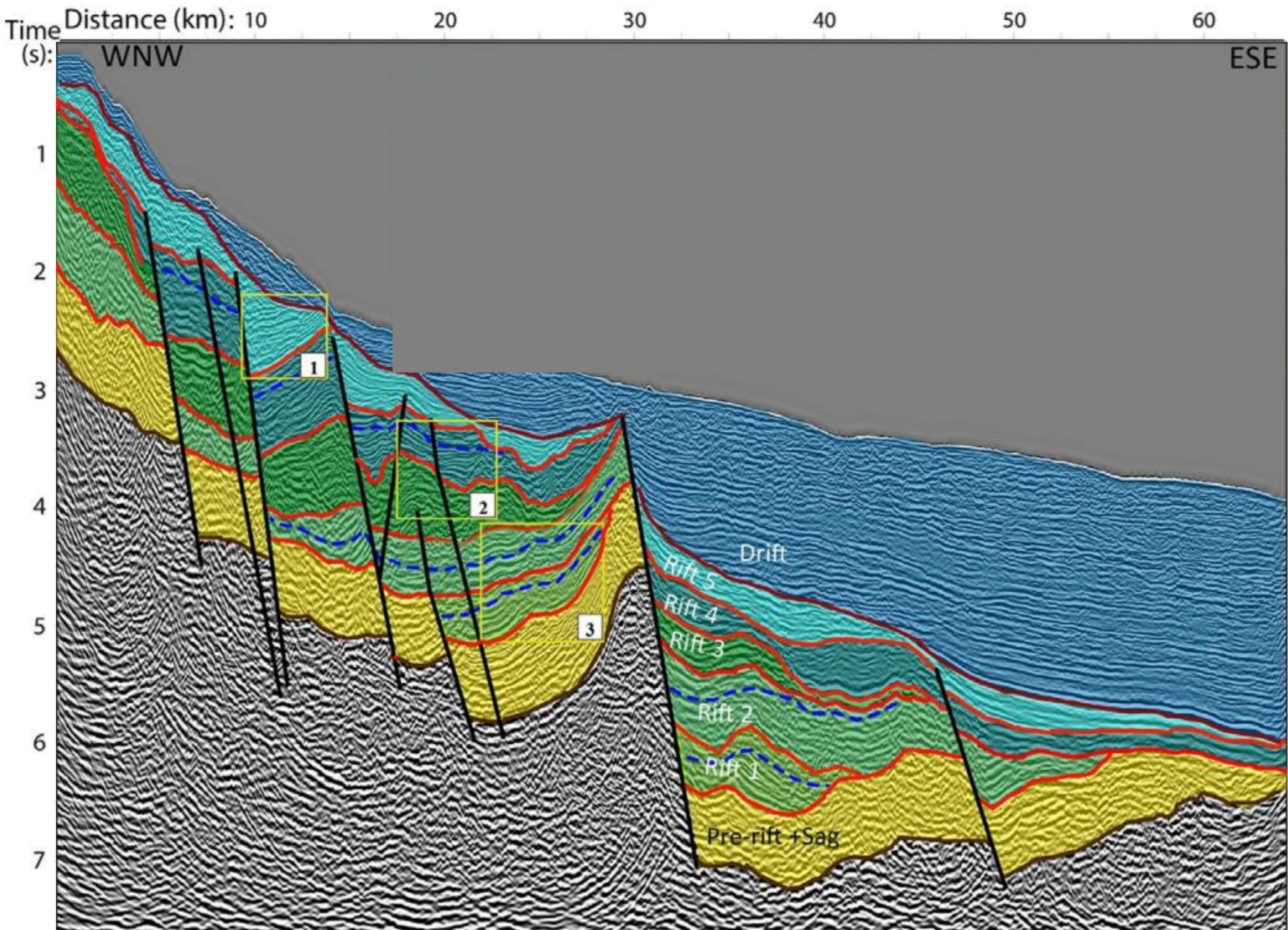


Interpretation

Example of a seismic line

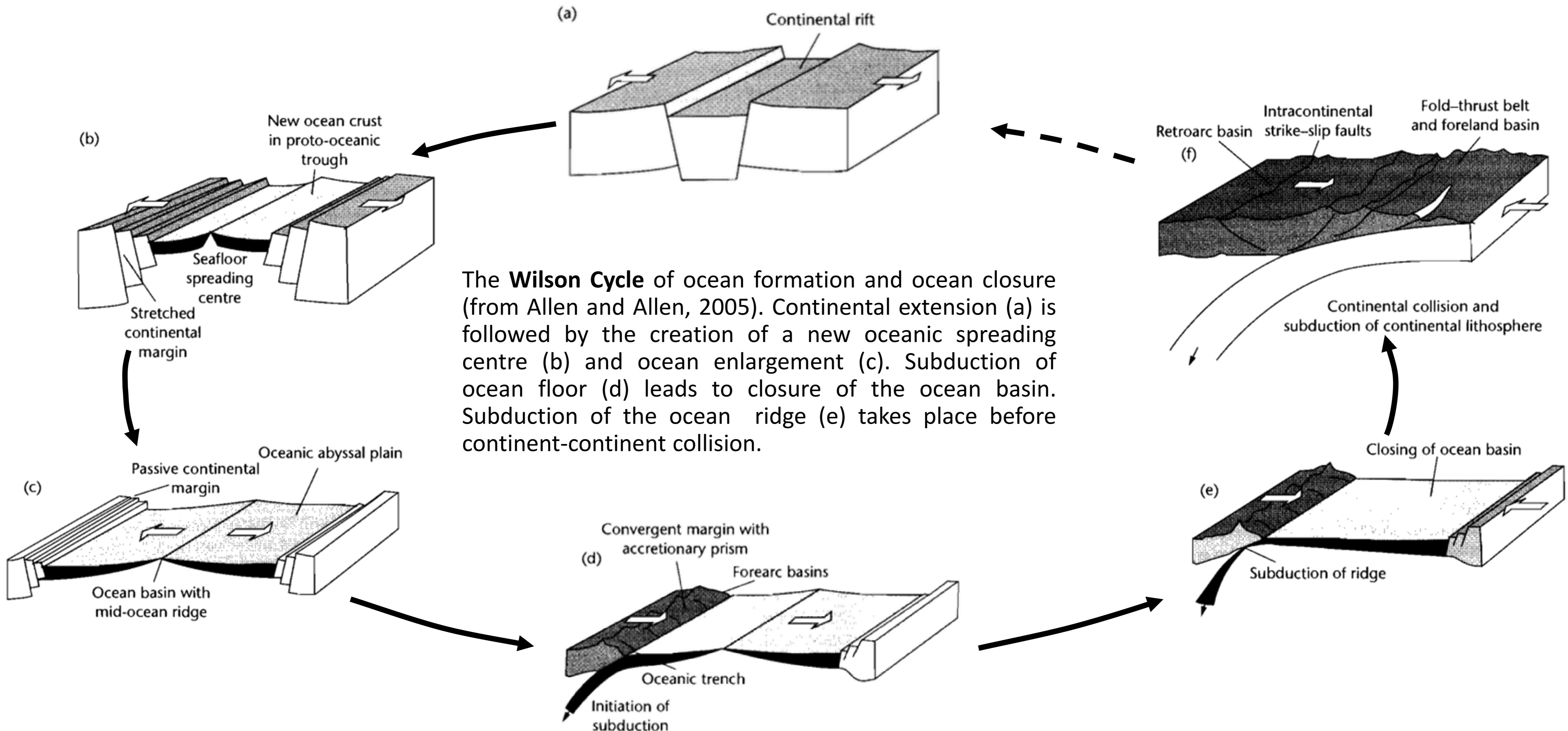
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Interpretation

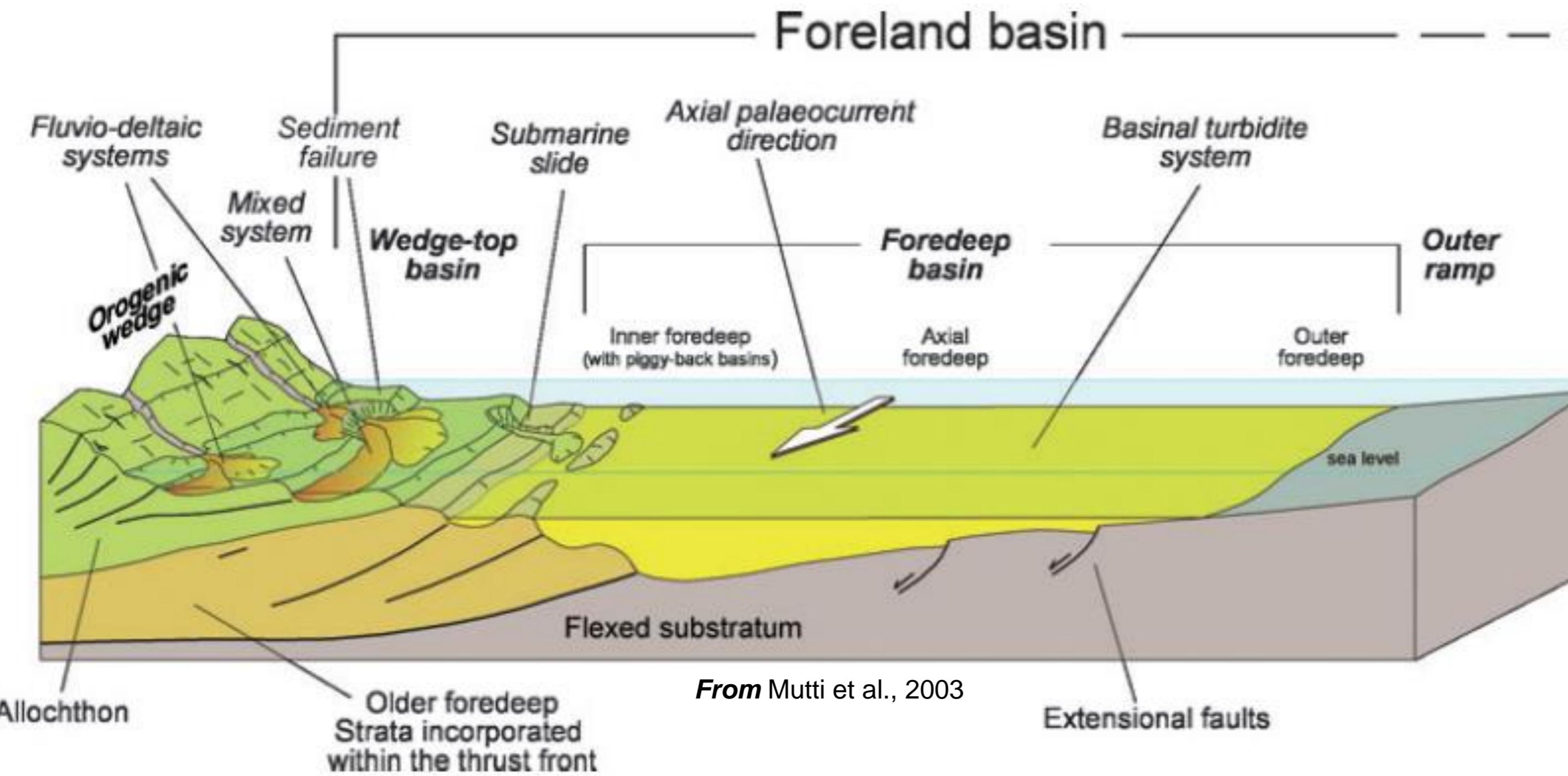
Sedimentary Basins in their Plate Tectonic Environment



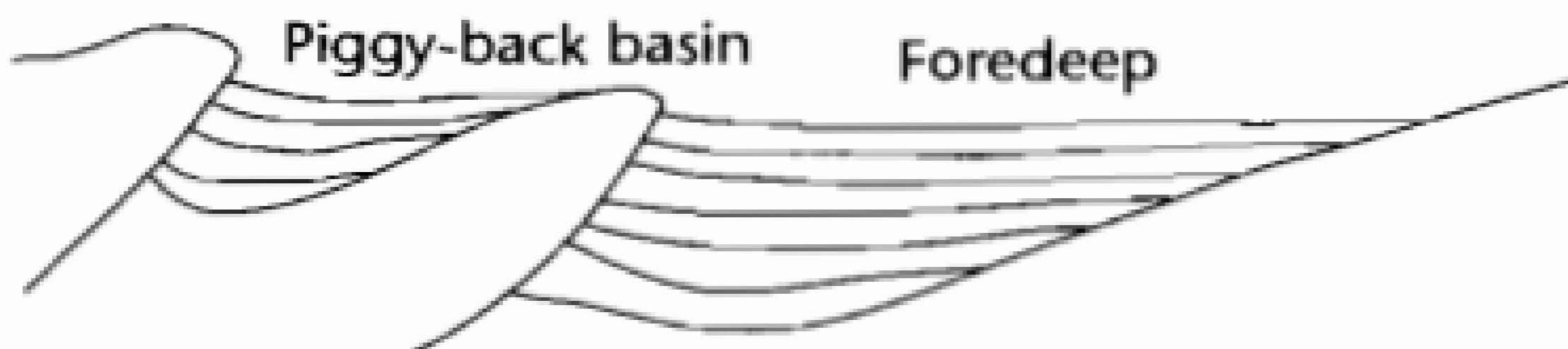
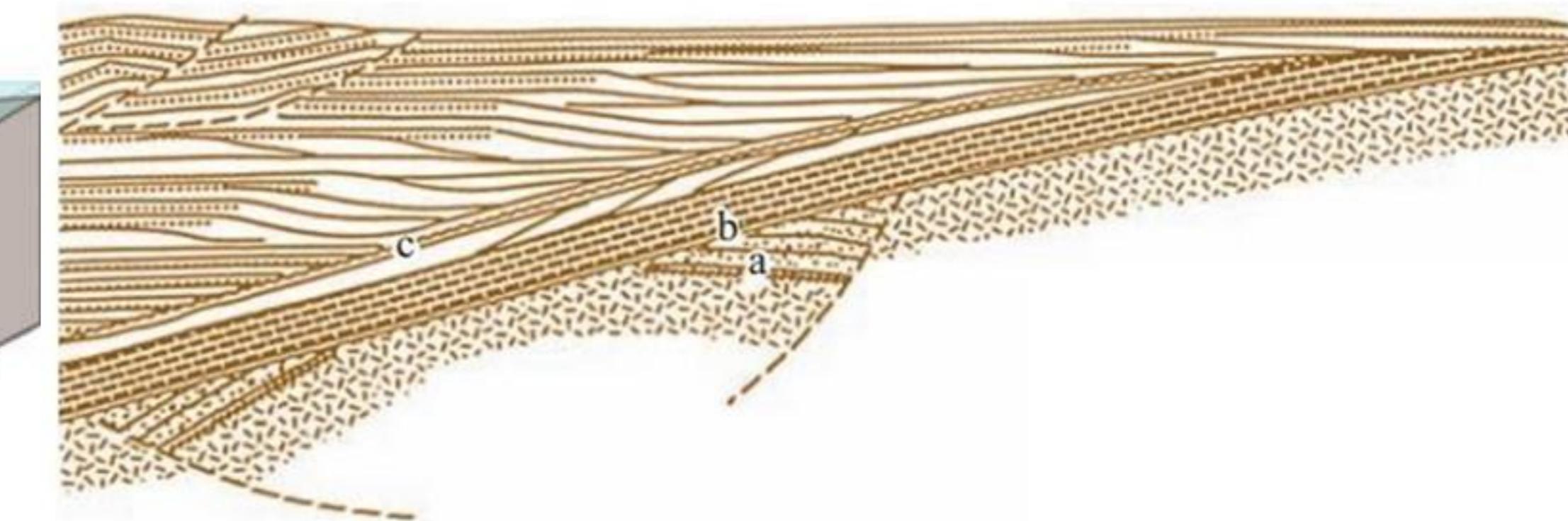
The **Wilson Cycle** of ocean formation and ocean closure (from Allen and Allen, 2005). Continental extension (a) is followed by the creation of a new oceanic spreading centre (b) and ocean enlargement (c). Subduction of ocean floor (d) leads to closure of the ocean basin. Subduction of the ocean ridge (e) takes place before continent-continent collision.

Interpretation

Structural Settings: continental collision

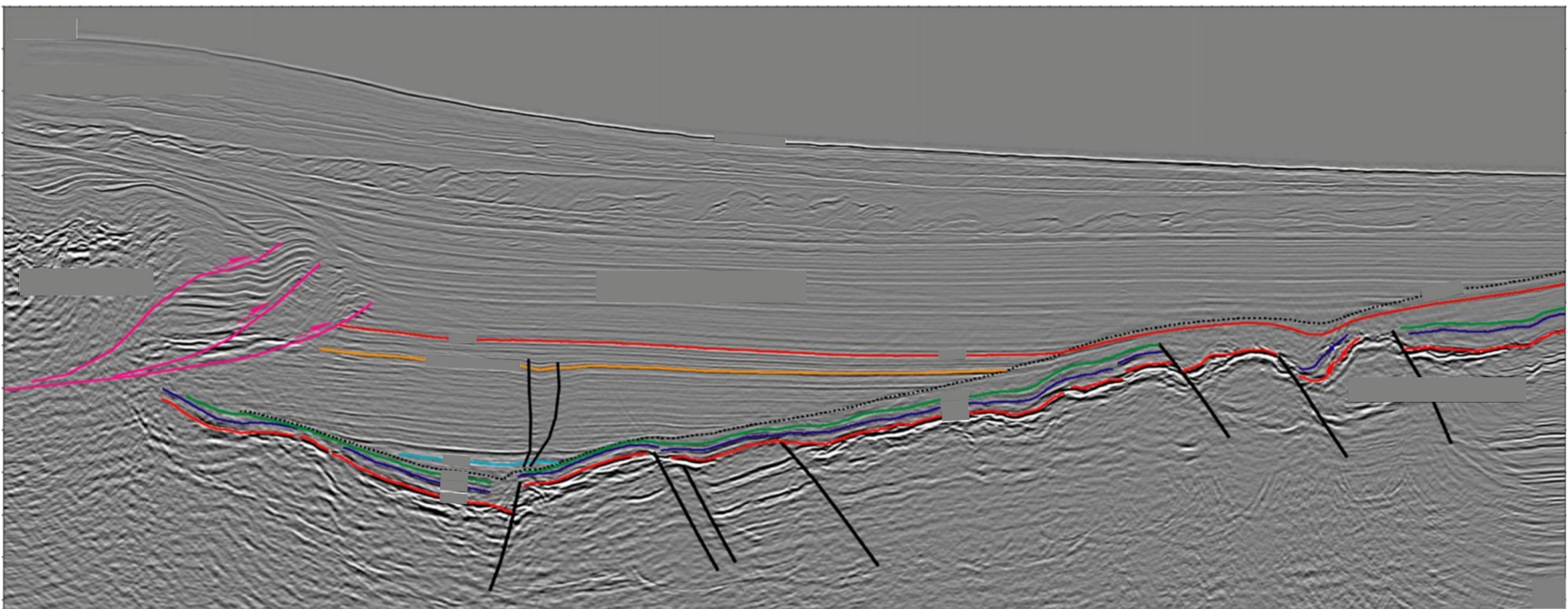


Schematic Model of a Foreland basin



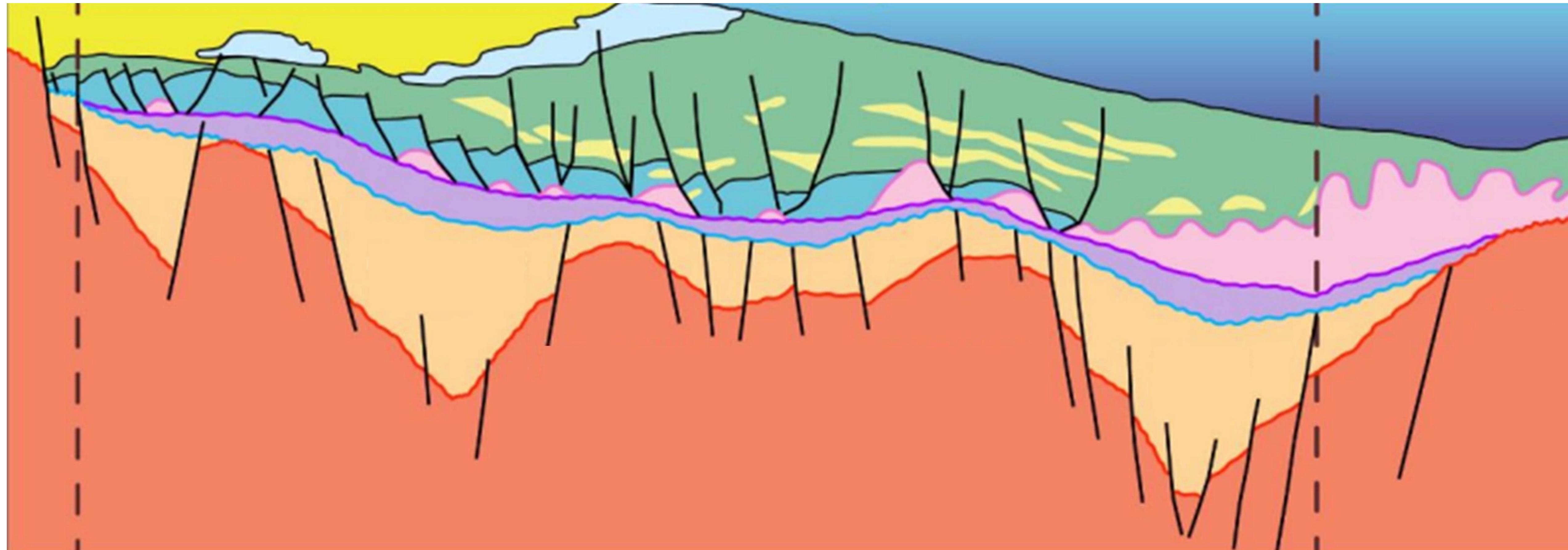
Interpretation

Continental collision: seismic example



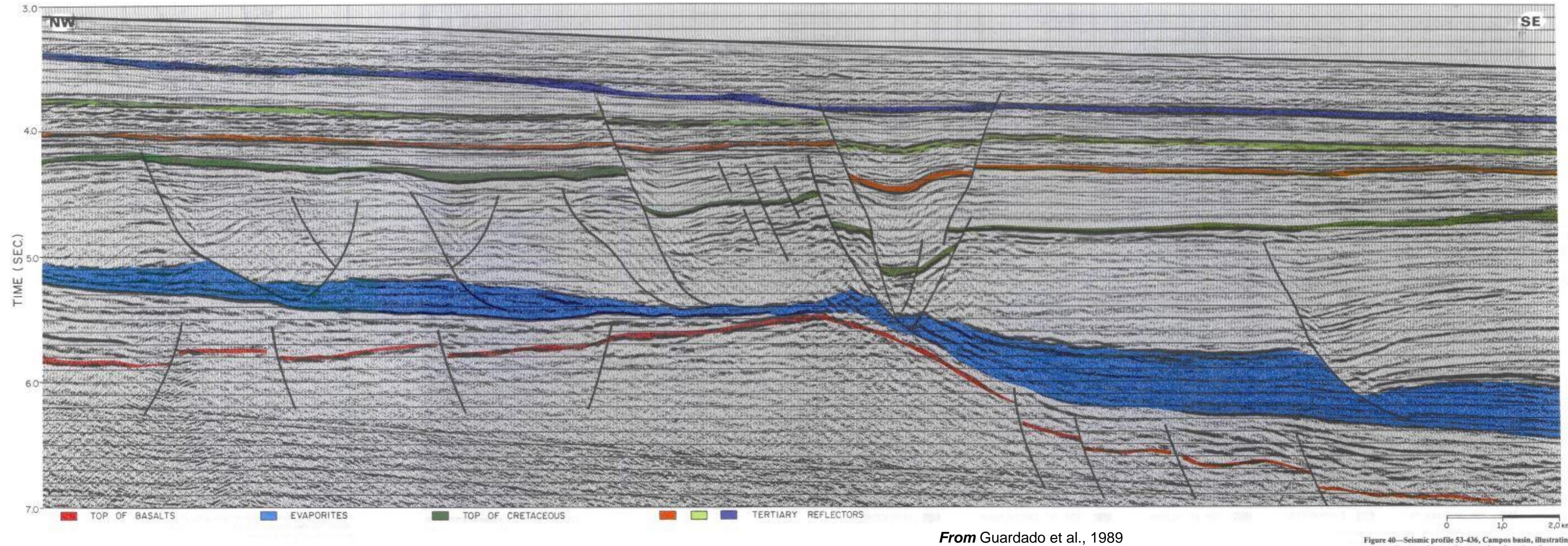
Interpretation

Structural Settings: passive margin



Interpretation

Passive margin: seismic example

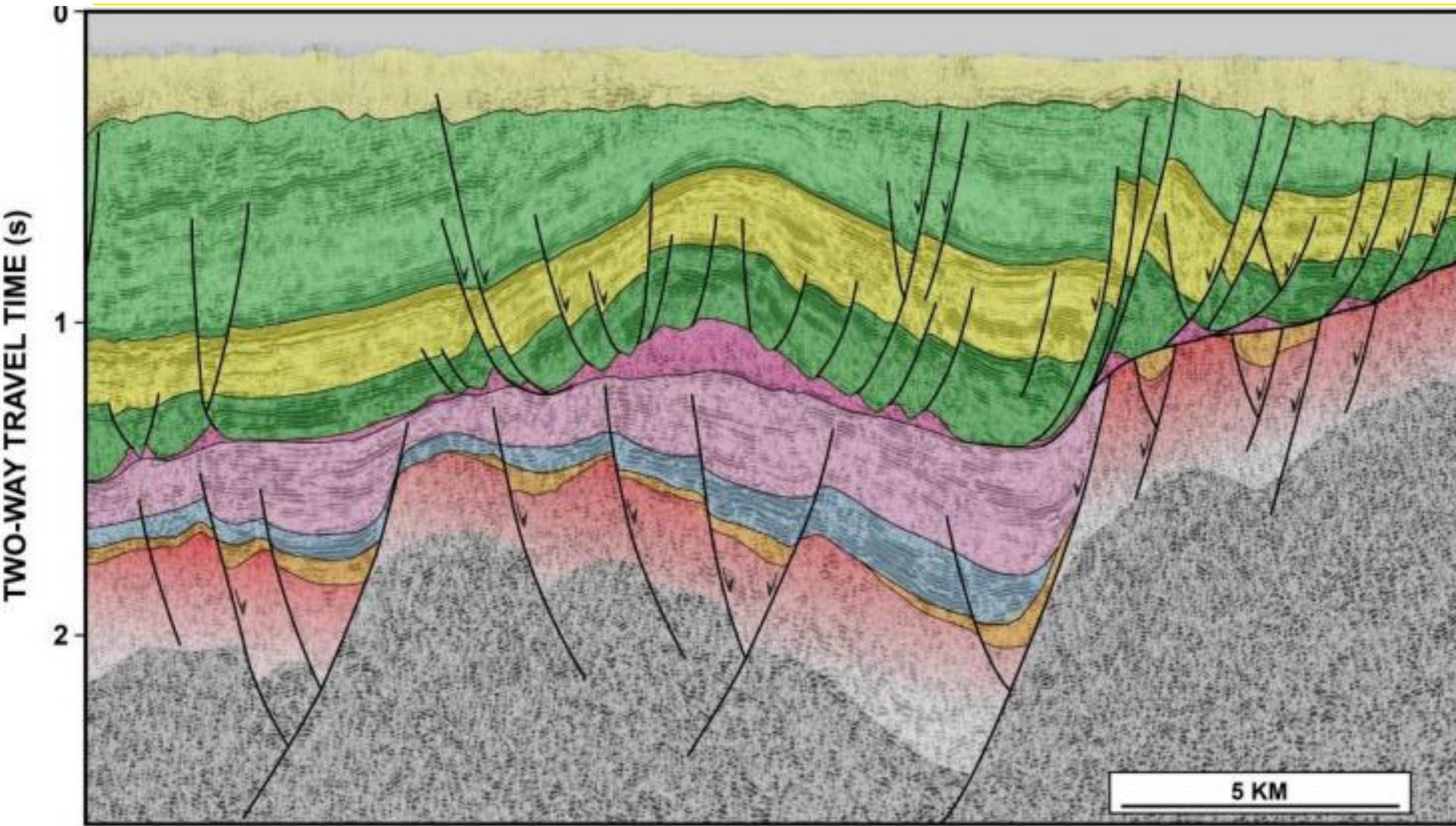


From Guardado et al., 1989

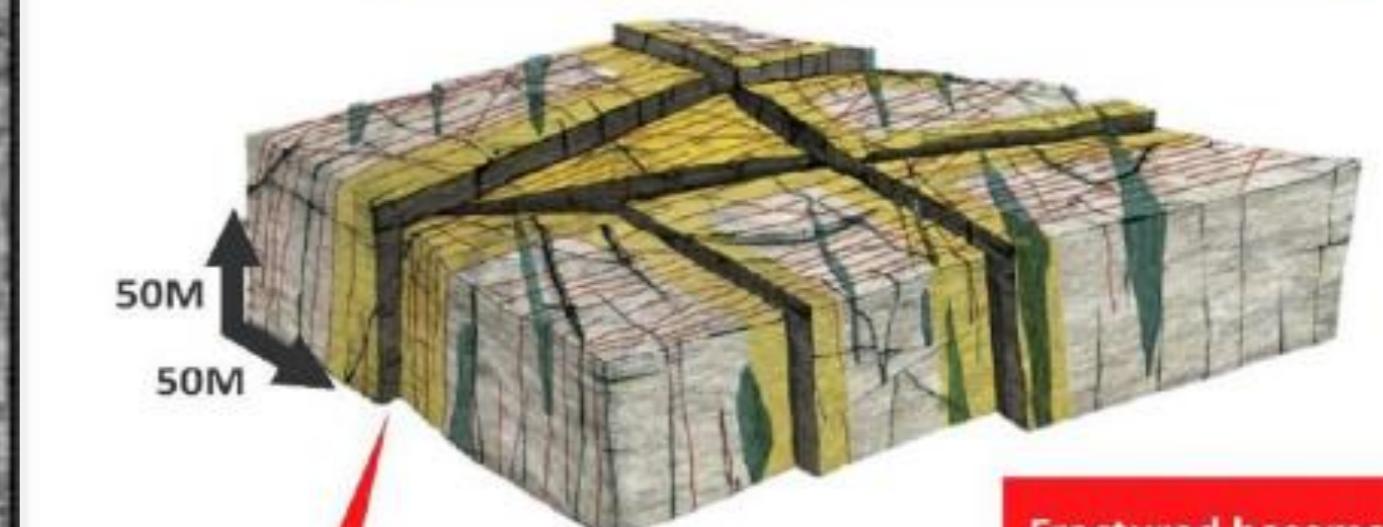
Figure 40—Seismic profile 53-436, Campos basin, illustrating structural pattern due to salt evacuation. Location shown on Figure 4.

Interpretation

Fracture Basement



Microfractures and joints are present throughout the fractured basement and fault zones



Fault zones
Represent pervasively fractured volumes of rock, that include preferentially enhanced aperture fractures and therefore improved reservoir characteristics. Fault zones are associated with seismically-resolvable faults

Fractured basement
The intervening host rock is pervasively fractured and also contributes to fluid flow

Seismic Data Interpretation

2. Interpretation

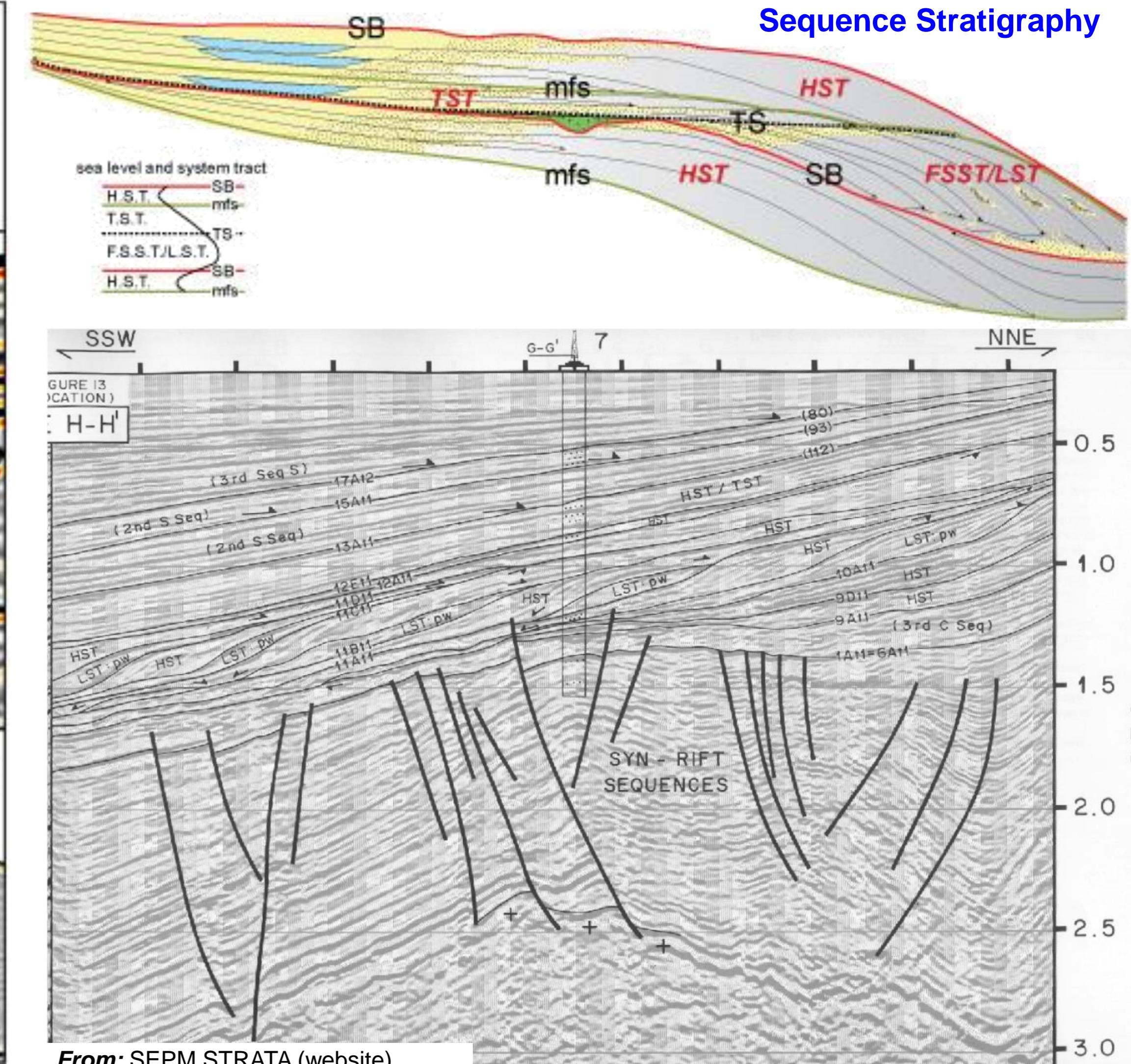
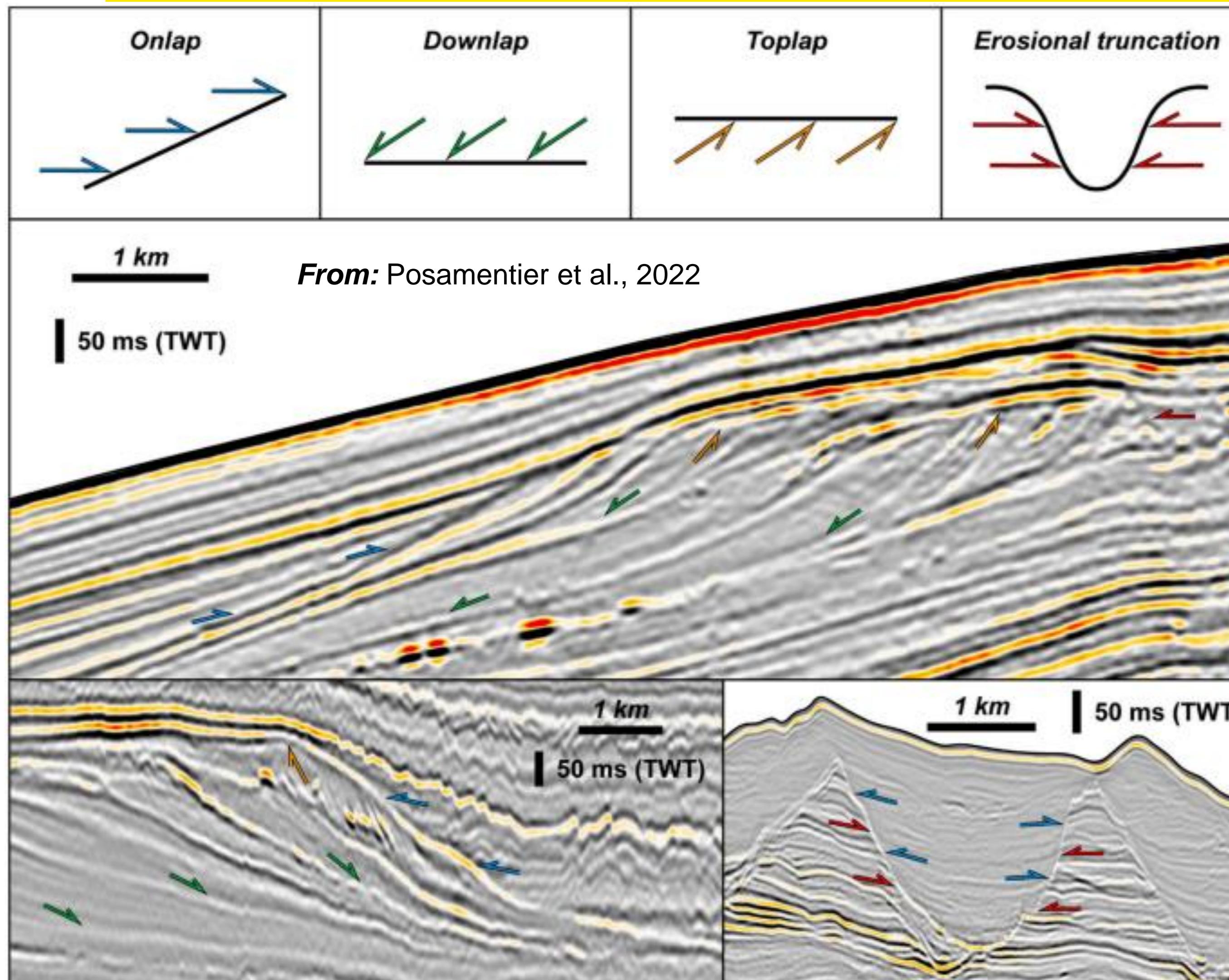
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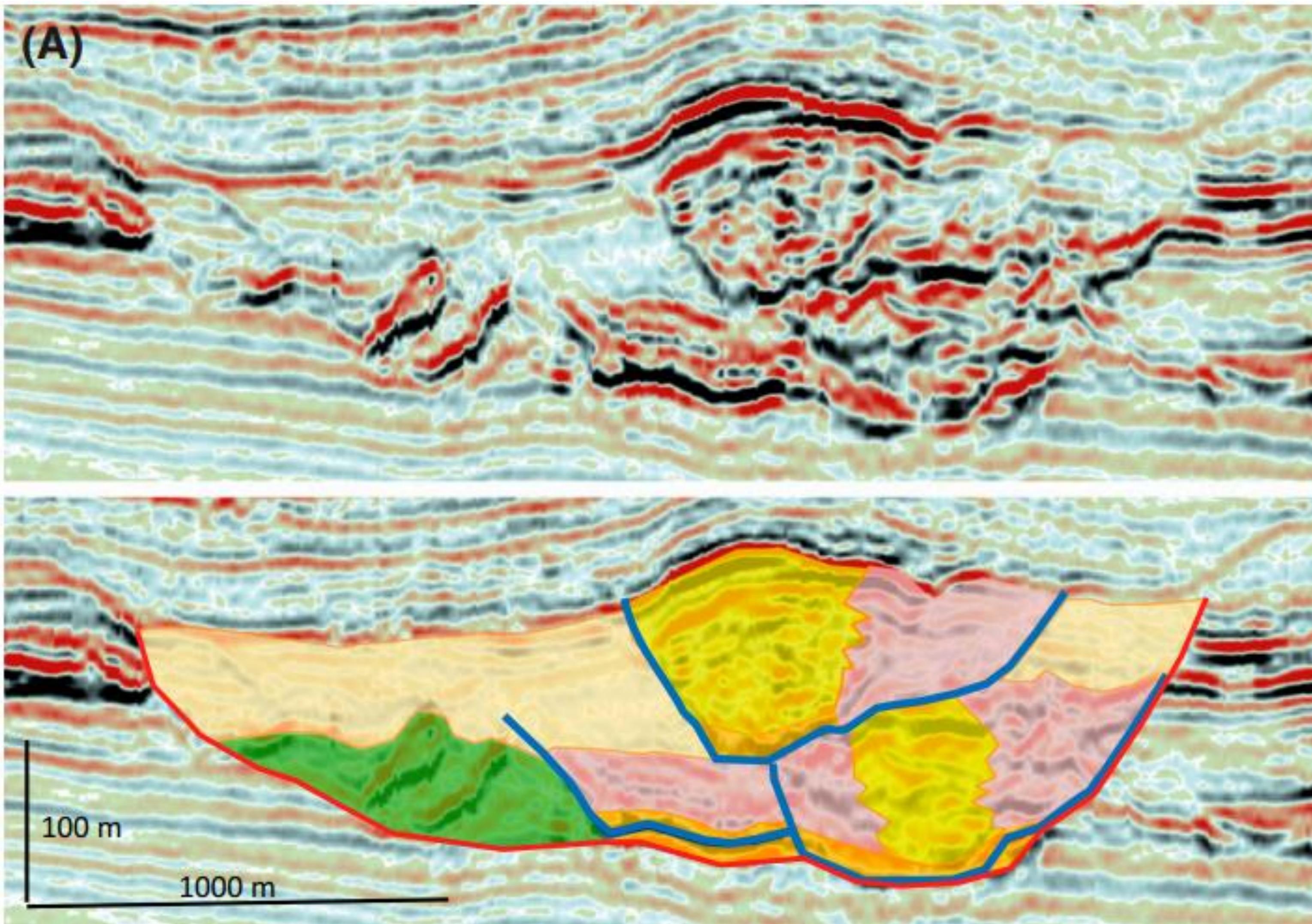
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Interpretation Stratigraphy



Interpretation

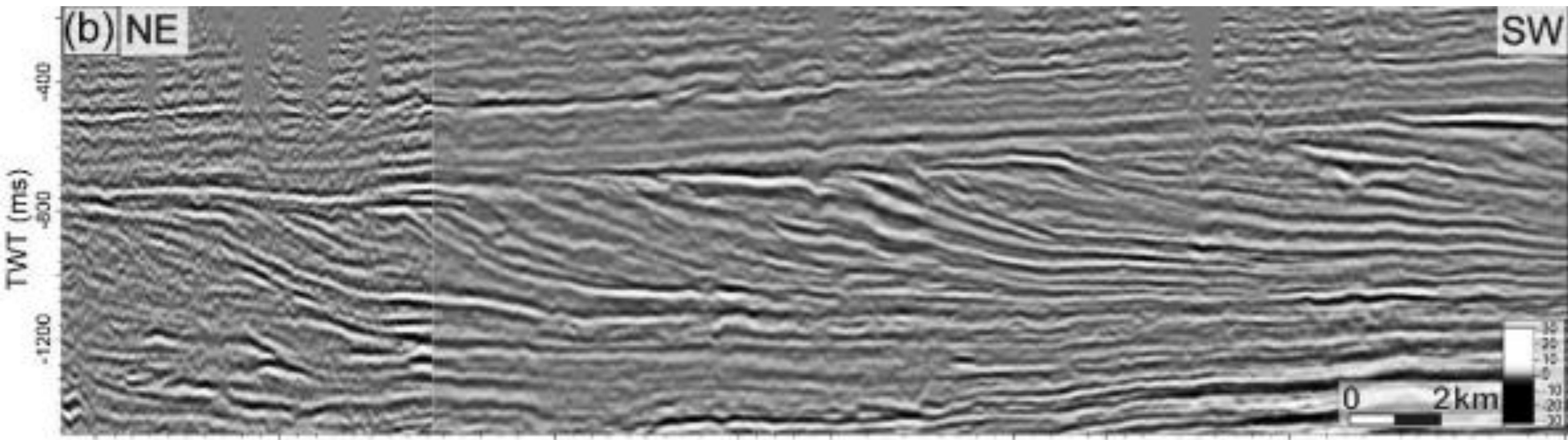
Sedimentary features: channels



From: Mayall and Kneller, 2021

Interpretation

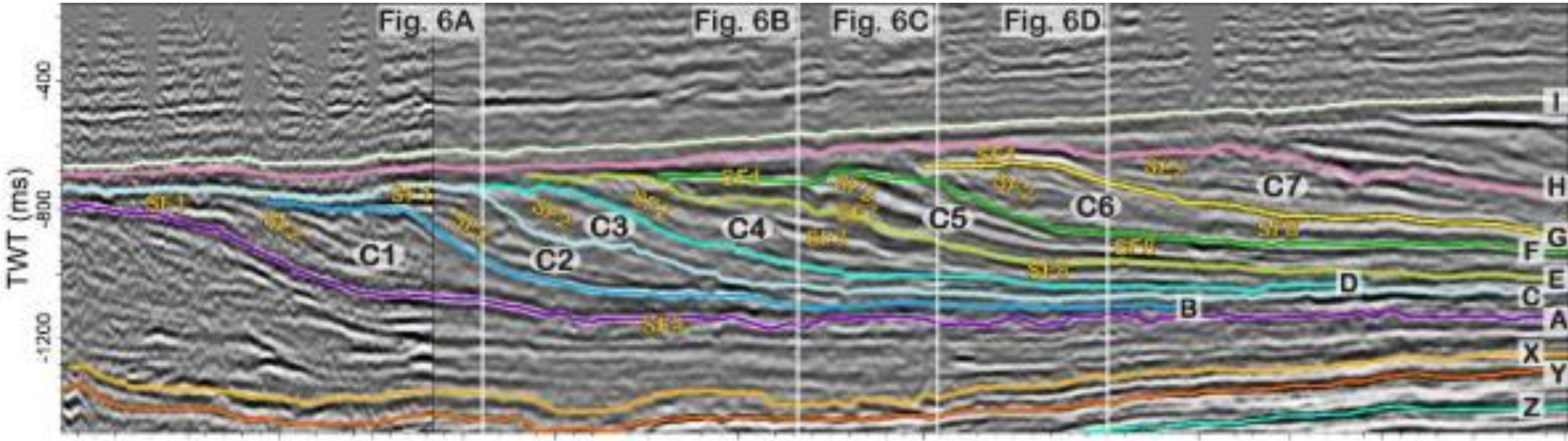
Sedimentary features: clinoforms



From: Fong-Ngern, 2016

Interpretation

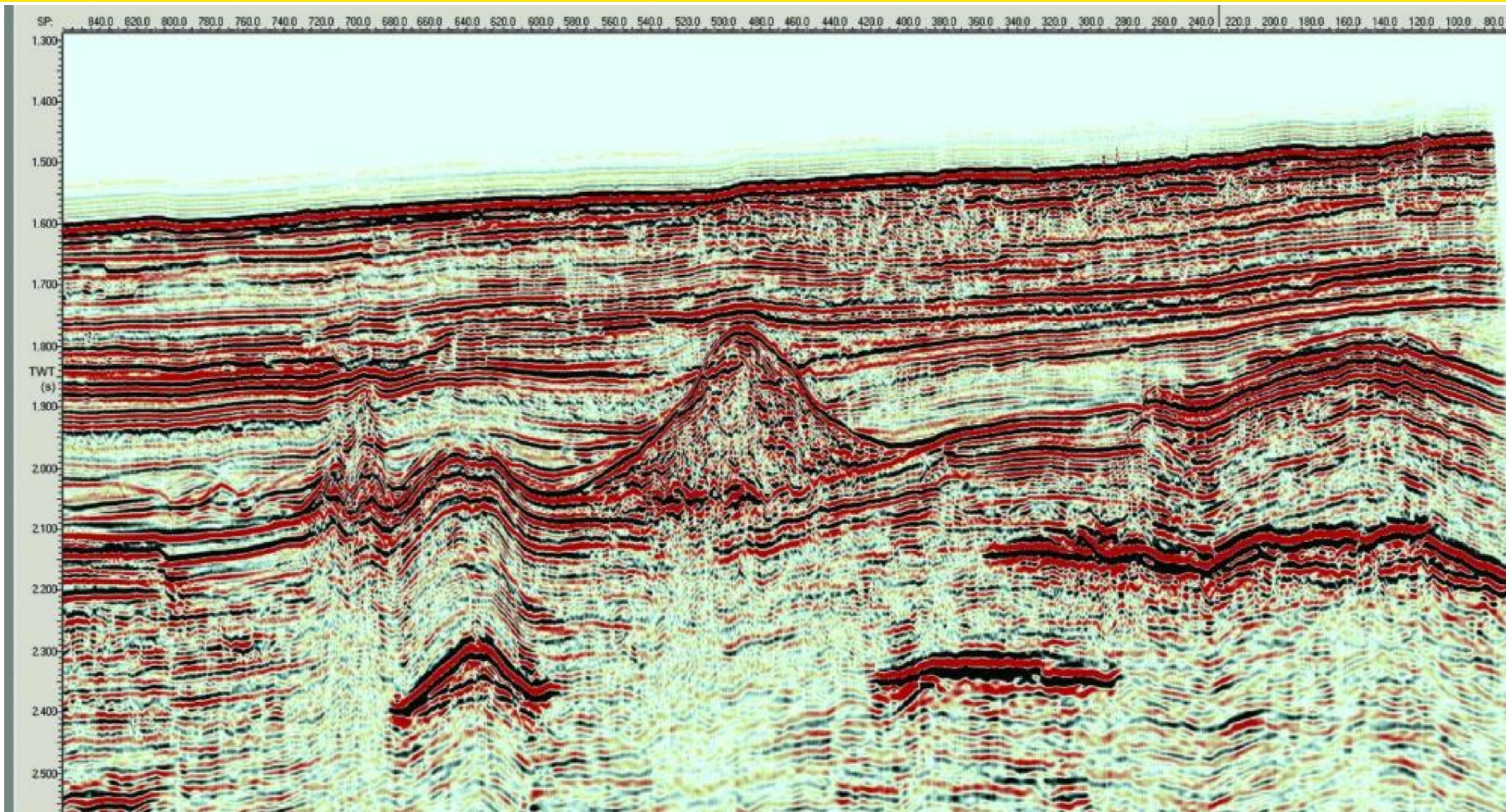
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From: Fong-Ngern, 2016

Interpretation

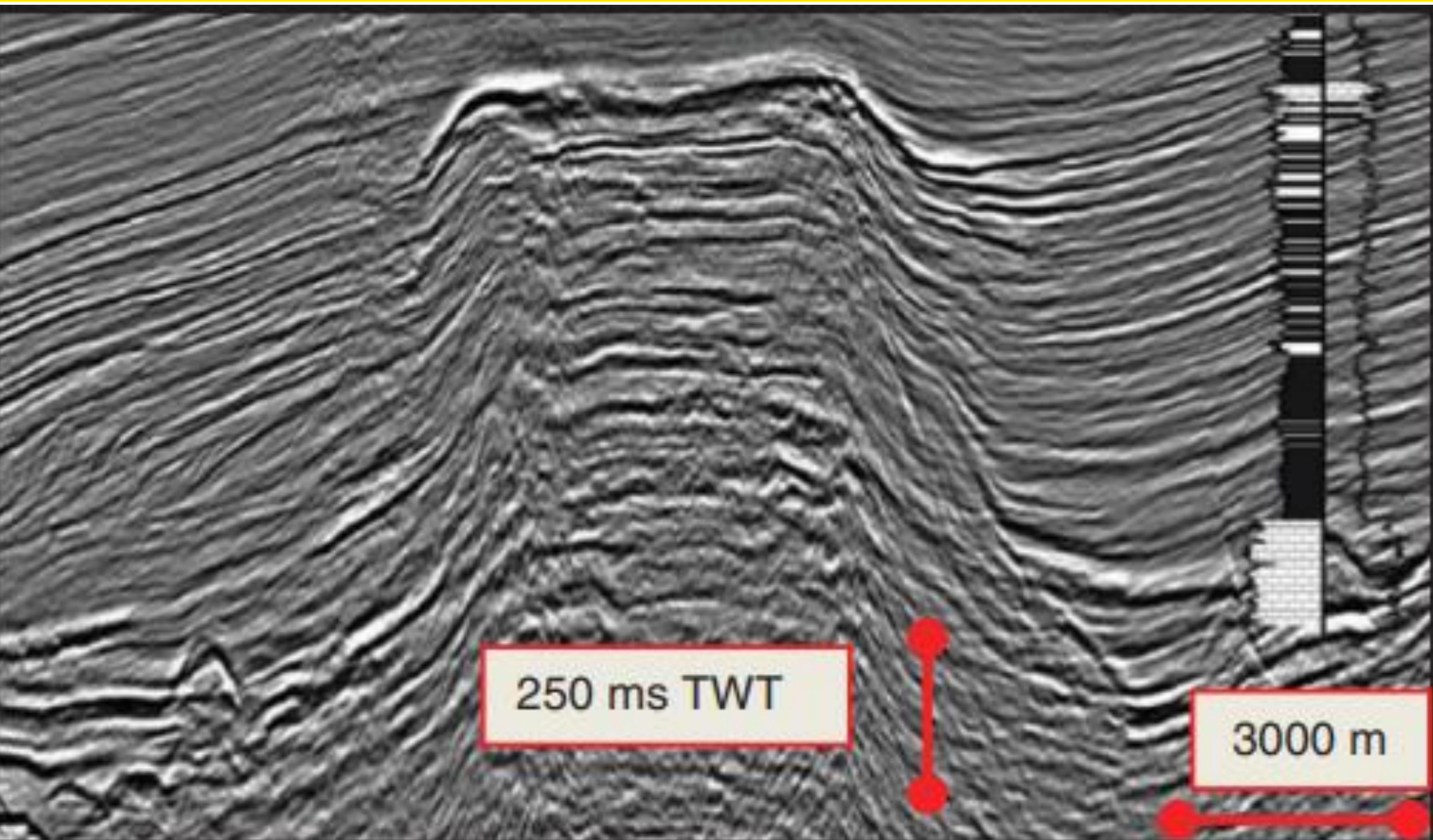
Volcanics



From: Virtual Seismic Atlas

Interpretation

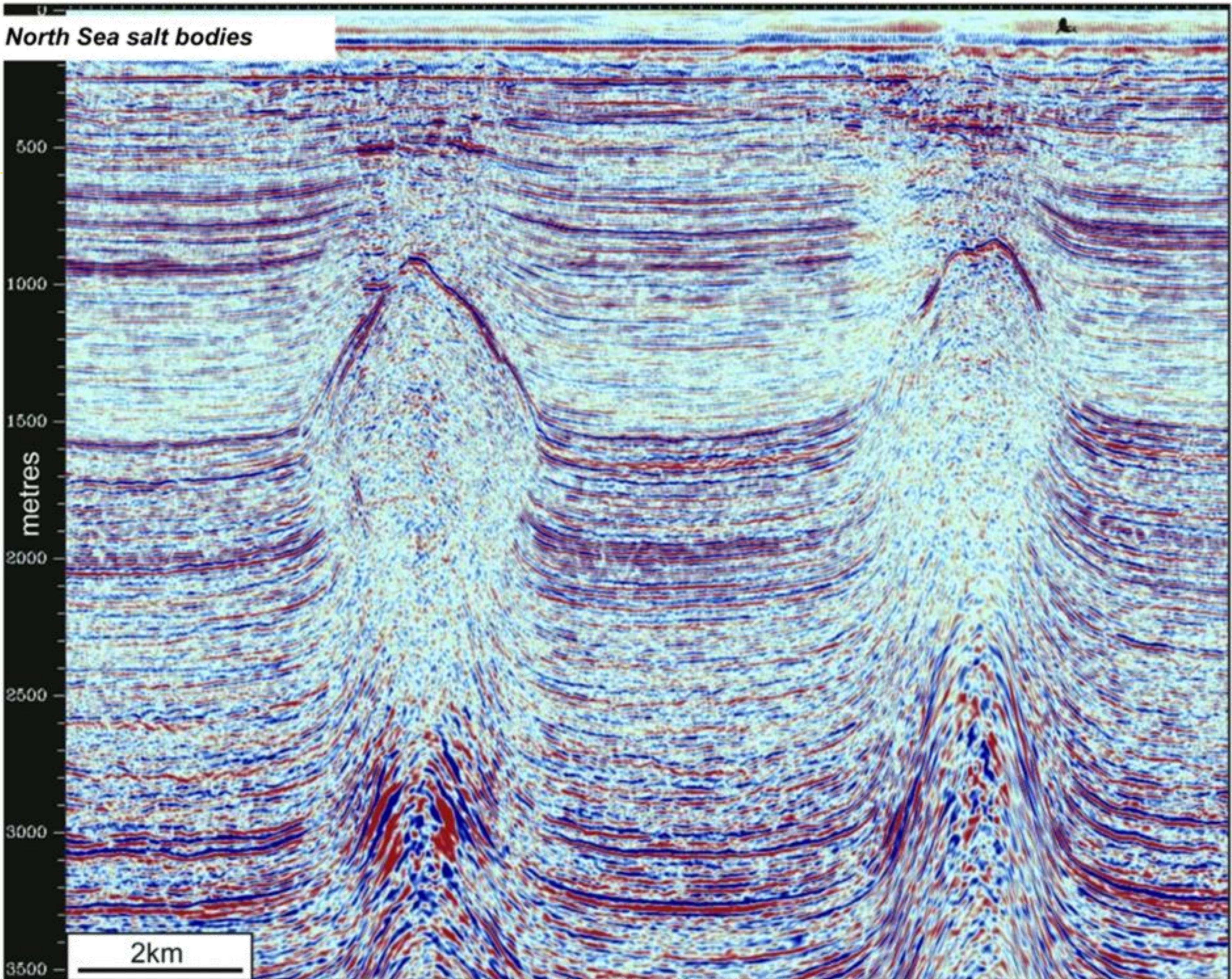
Carbonate build-ups



From: Badali et al., 2022

Interpretation

Salt diapirs

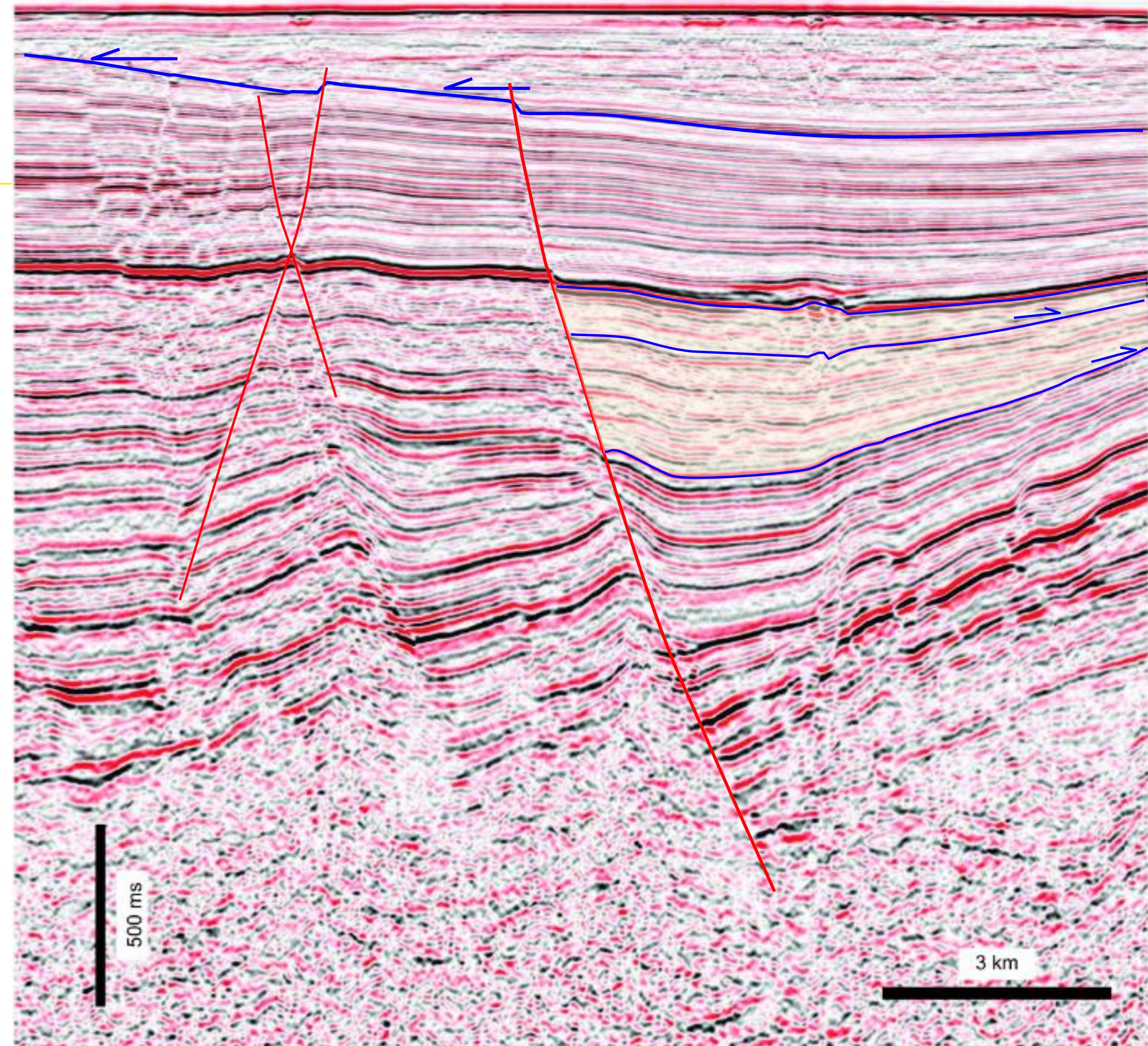


Interpretation

Complex Geology

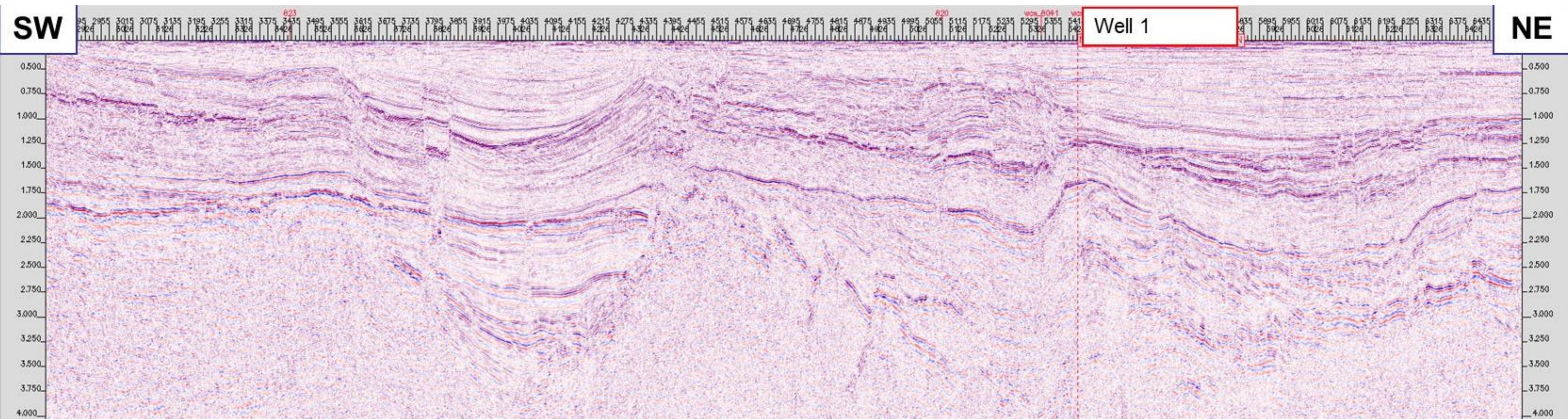
- At least 2 Fault trends
- Unconformities
- Sequences showing thickness changes

The interpretation of this kind of seismic line implies a regional understanding of the basin evolution through time.



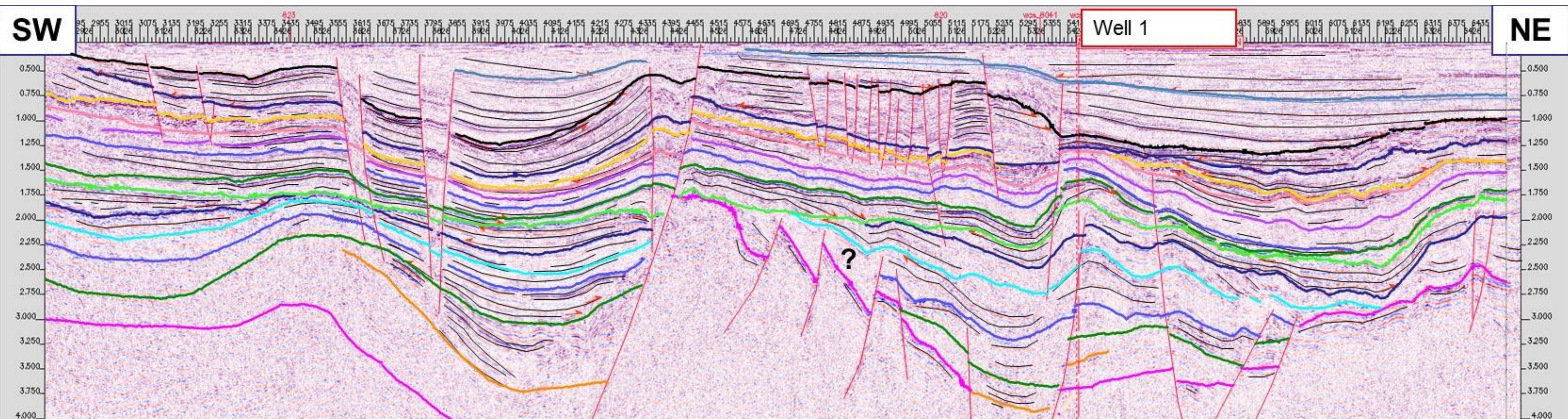
Interpretation

Basin scale Chrono-Stratigraphic Interpretation



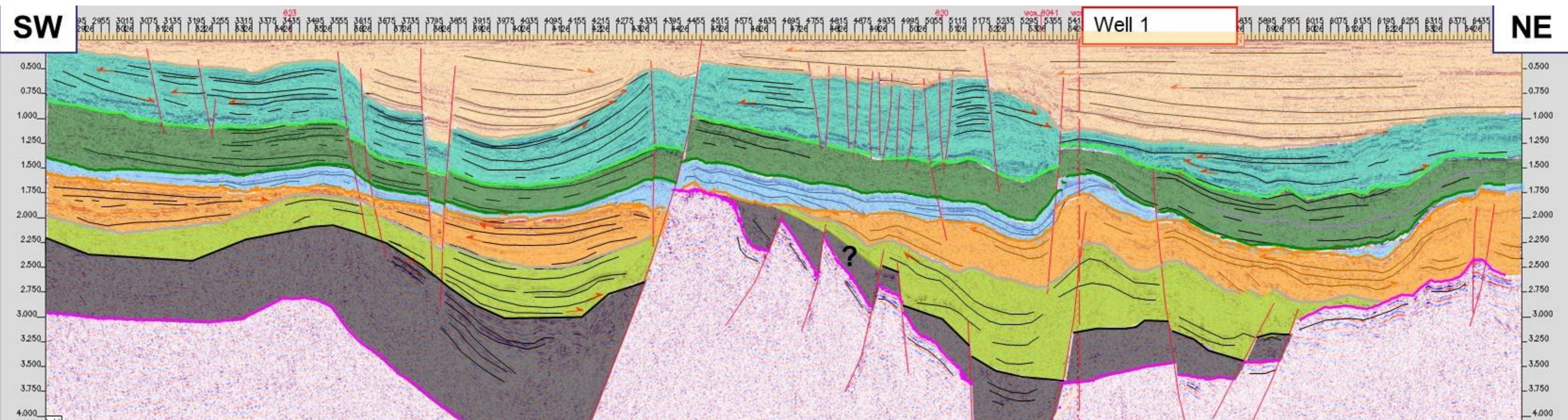
Interpretation

Basin scale Chrono-Stratigraphic Interpretation



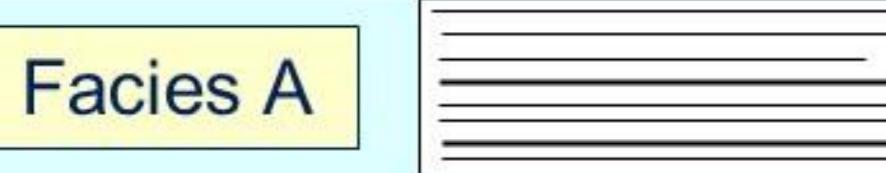
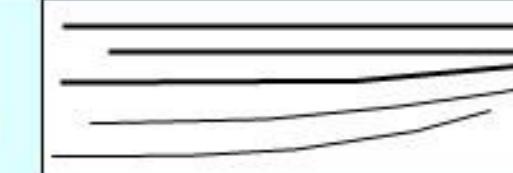
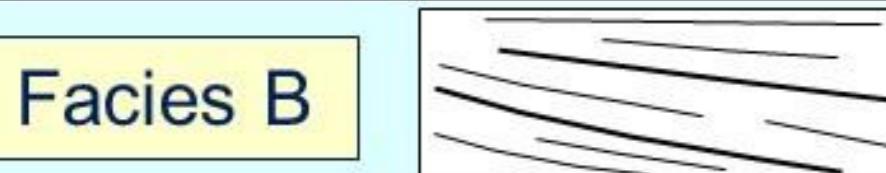
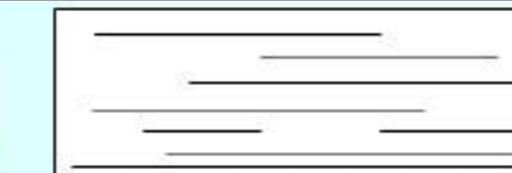
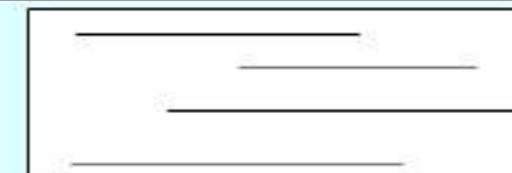
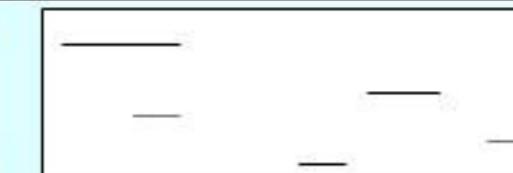
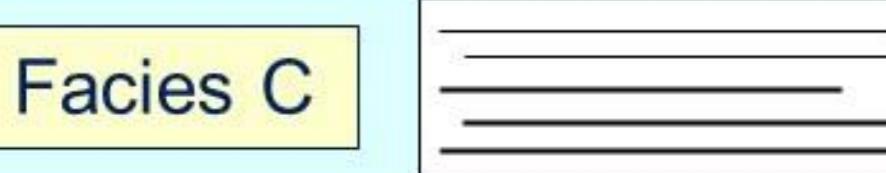
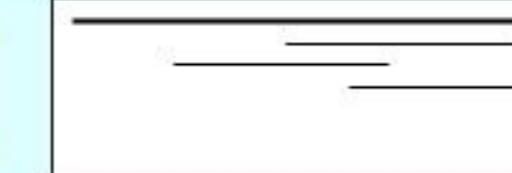
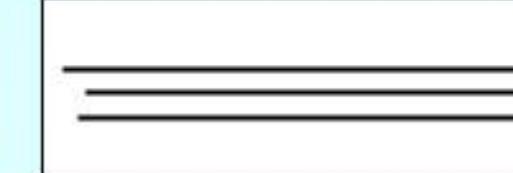
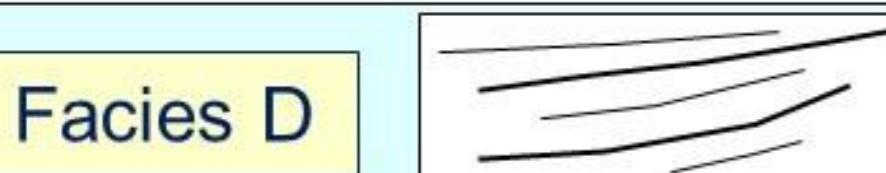
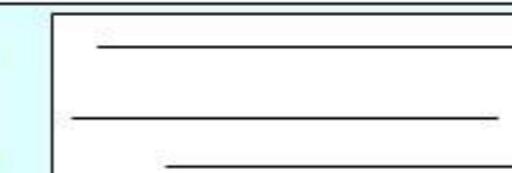
Interpretation

Main Seismo-Depositional Sequences



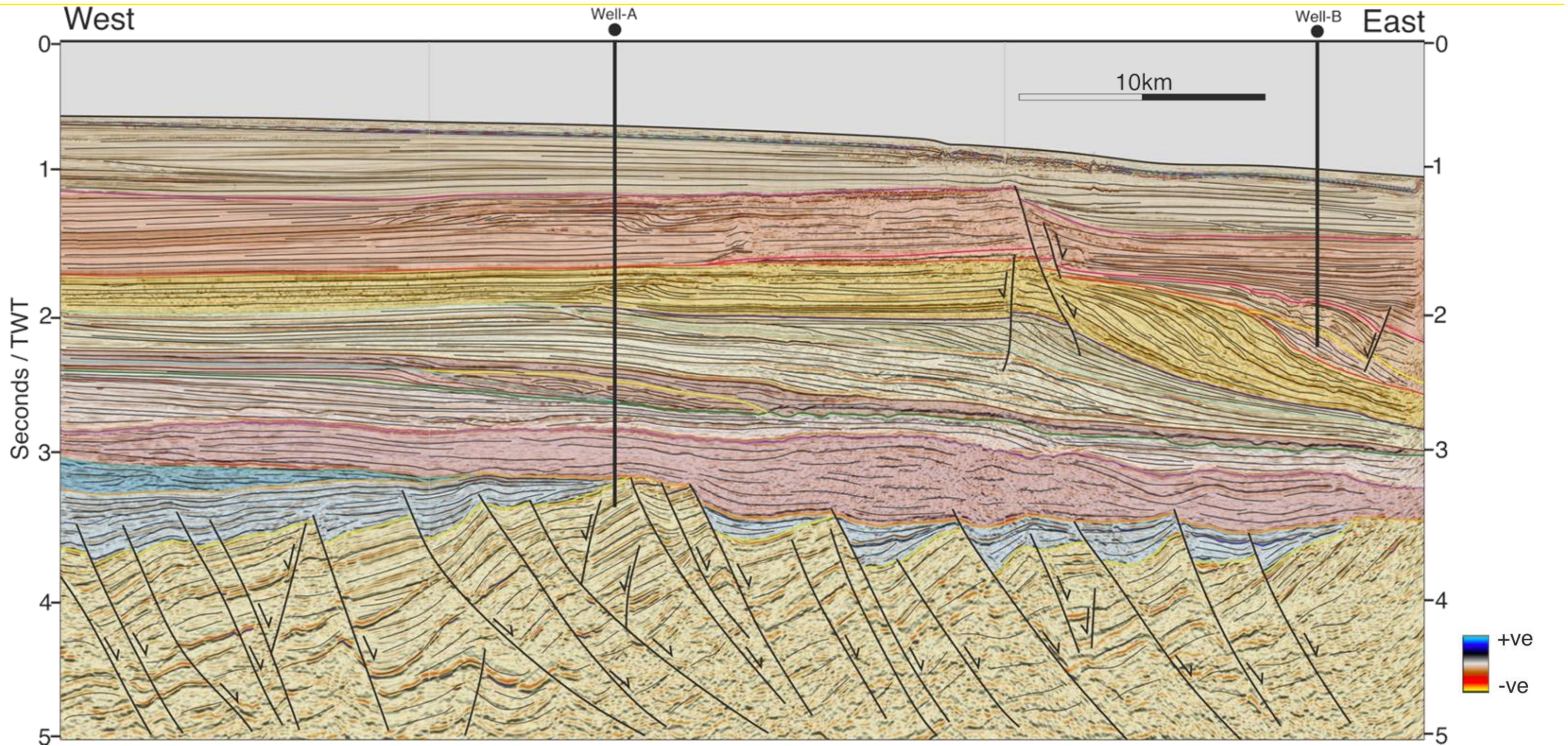
Interpretation

Seismic Facies

Facies A 	Facies E 	Facies I 	Facies O 
Tabular shaped, medium amplitude (locally high) reflections. Good continuity and high frequency.	Predominantly transparent. Locally medium amplitude discontinuous oblique reflections.	Predominantly transparent. Locally high amplitude discontinuous reflections.	Lenticular shaped, low to medium amplitude reflections. Good continuity and high frequency reflections. High amplitude reflections in the upper part of the sequence.
Facies B 	Facies F 	Facies L 	Facies P 
Lenticular shaped infilling. Medium amplitude (locally high) reflections showing downlapping geometries. Good continuity and high frequency. In the upper part of the sequence reflections become planar and parallel.	Medium to low amplitude, medium continuity high frequency reflections.	Low to medium amplitude, medium continuity, medium frequency reflections.	Predominantly transparent. Locally medium amplitude reflections.
Facies C 	Facies G 	Facies M 	Facies Q 
Tabular shaped, medium to high amplitude reflections. Good continuity and medium frequency.	Predominantly transparent. Locally medium amplitude discontinuous reflections. High amplitude and good continuity single reflection in the upper part of the sequence.	Wavy-shaped, divergent reflections with high amplitude and poor continuity.	High amplitude, good continuity, low frequency reflections.
Facies D 	Facies H 	Facies N 	Facies R 
Lenticular shaped, medium to high amplitude reflections. Good continuity and medium frequency.	Medium amplitude, high continuity, low frequency reflections.	Channelised features with erosive bottom and high amplitude, good continuity infilling.	Reflection free.

Interpretation

Geoseismic cross-section



Seismic Data Interpretation

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- iii. **Geo-morphological features**

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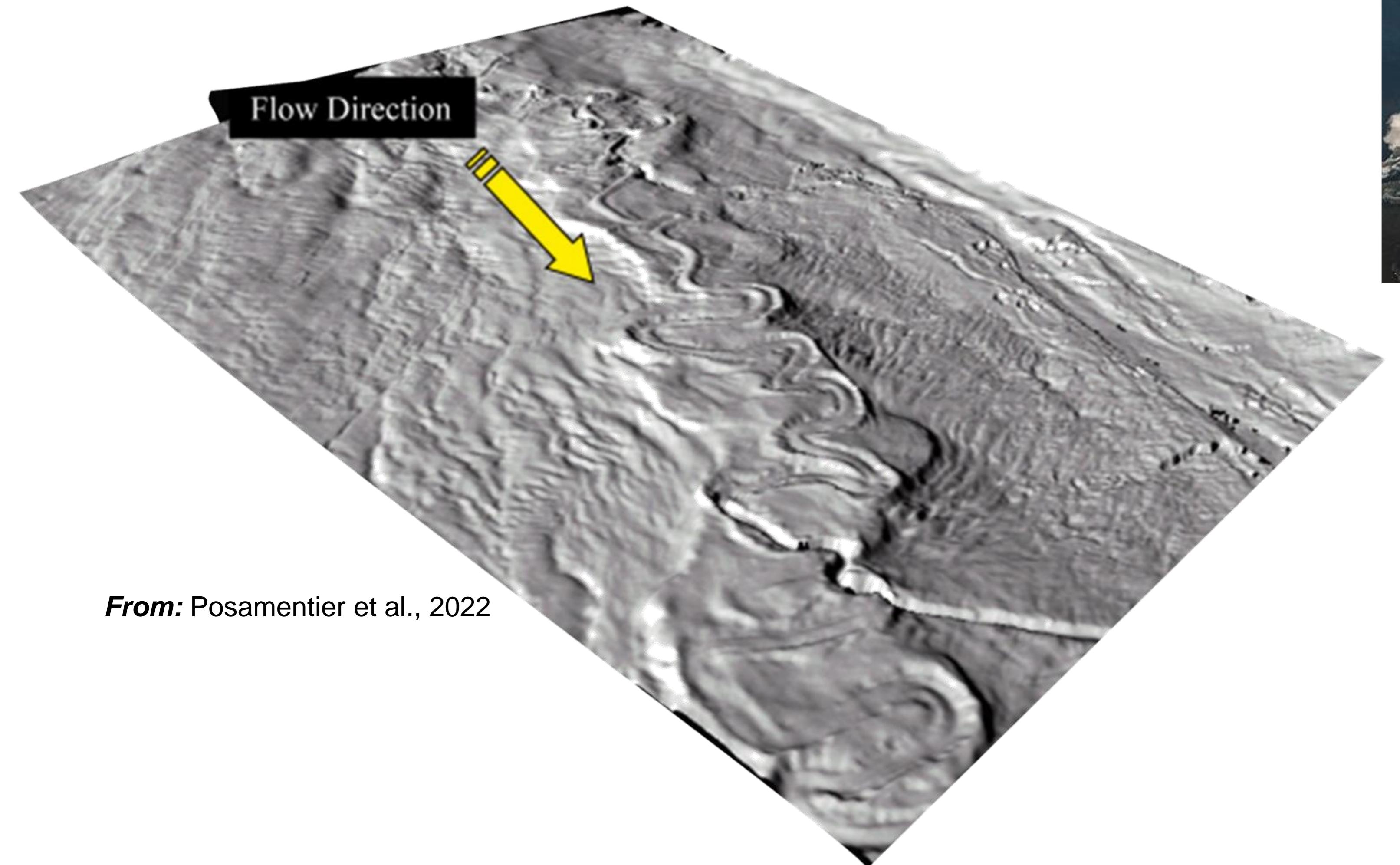
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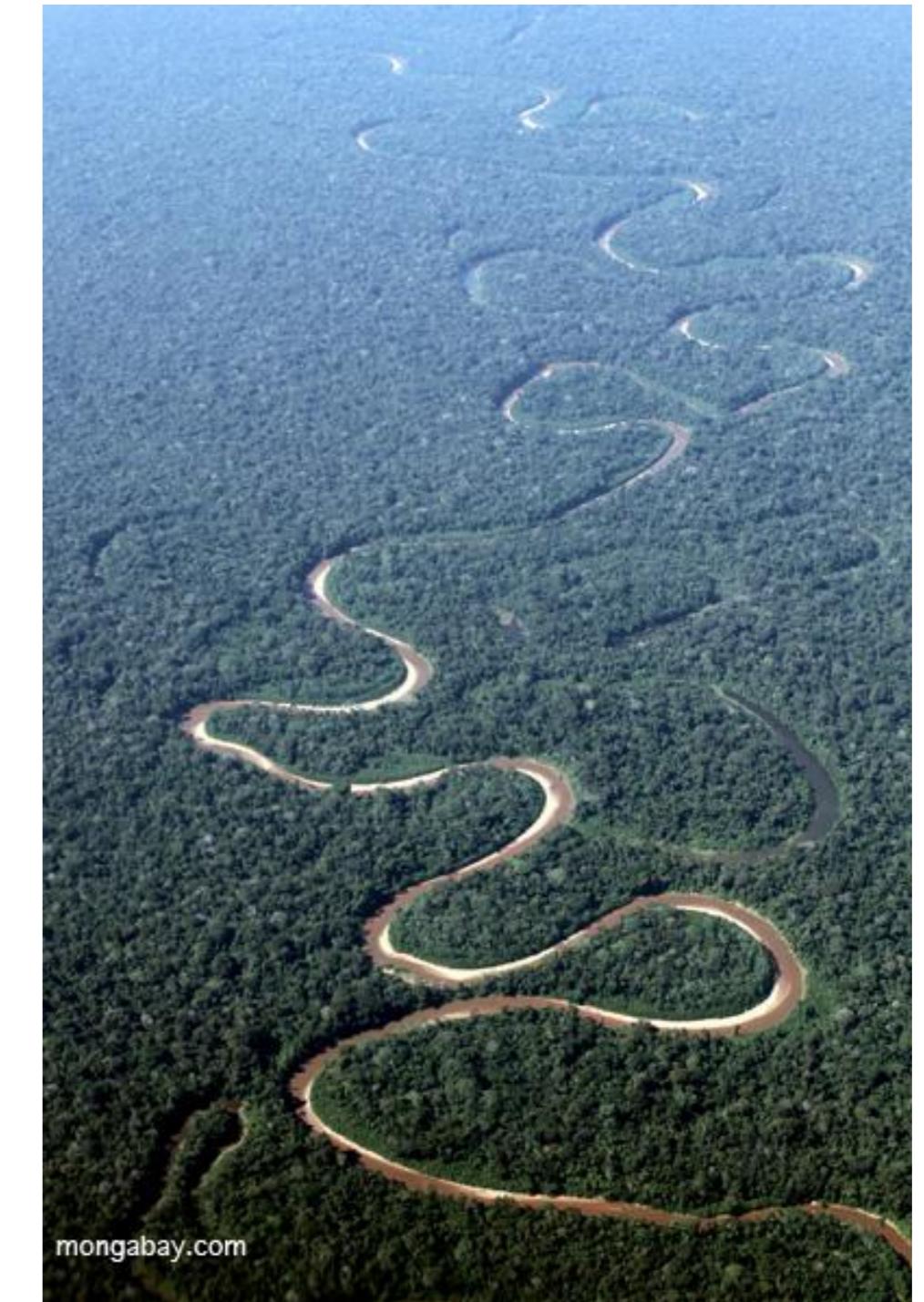
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Interpretation

Geo-morphological features



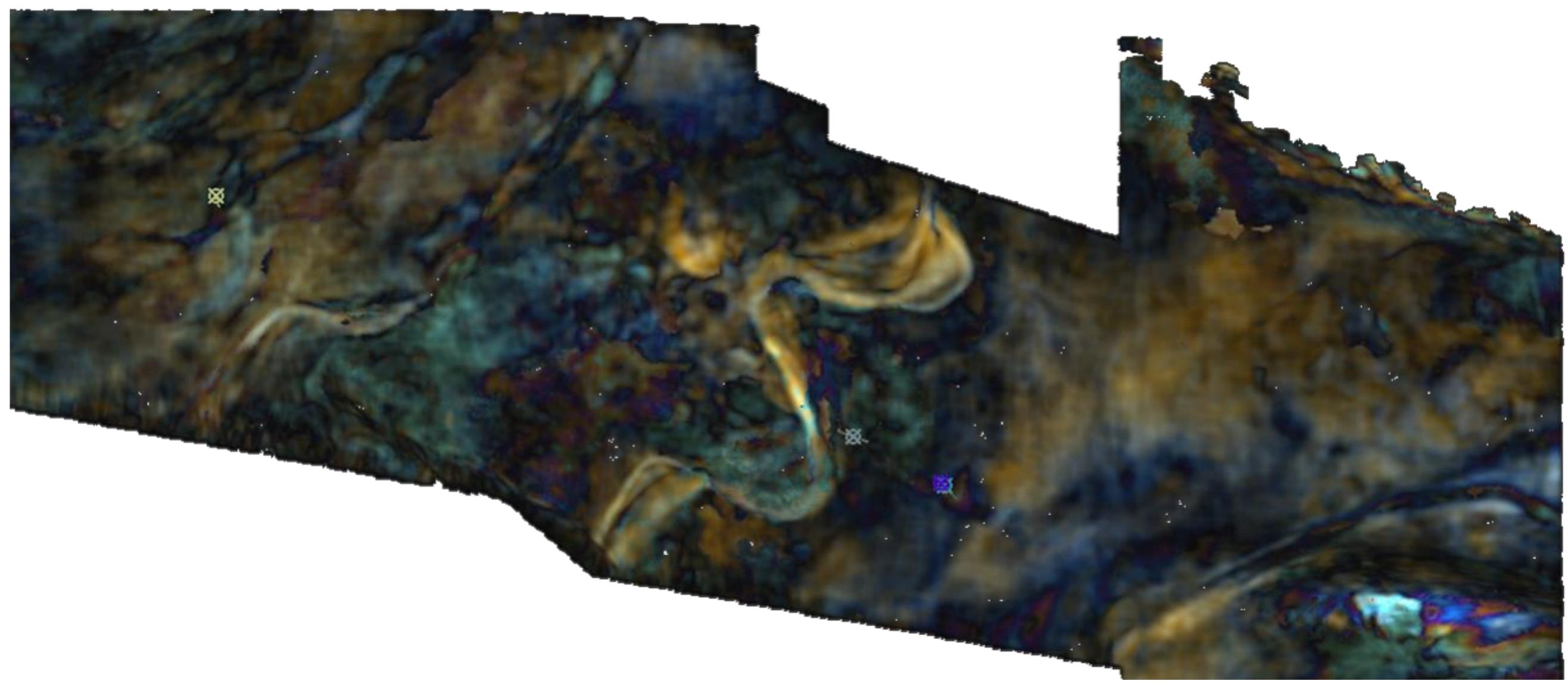
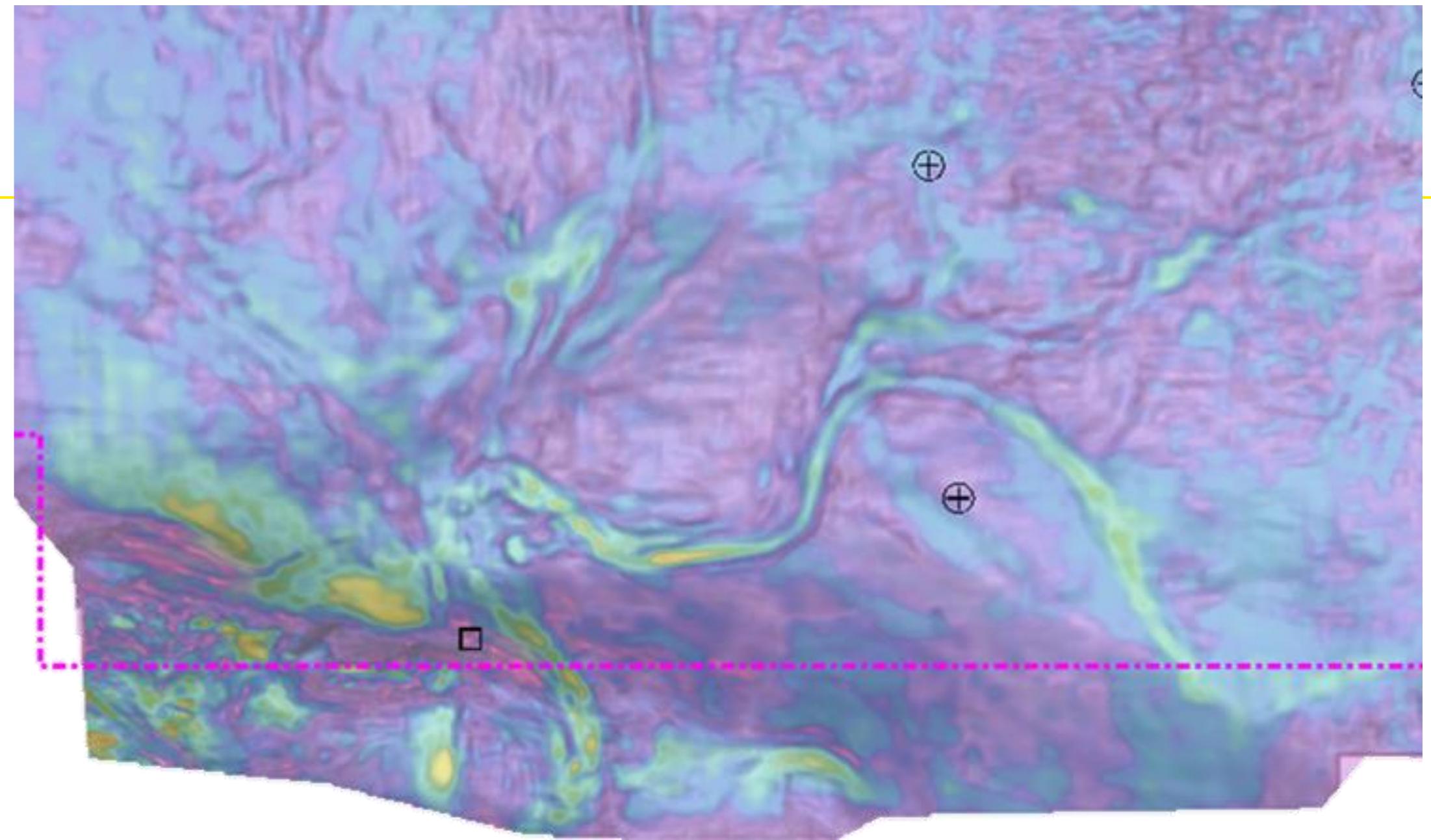
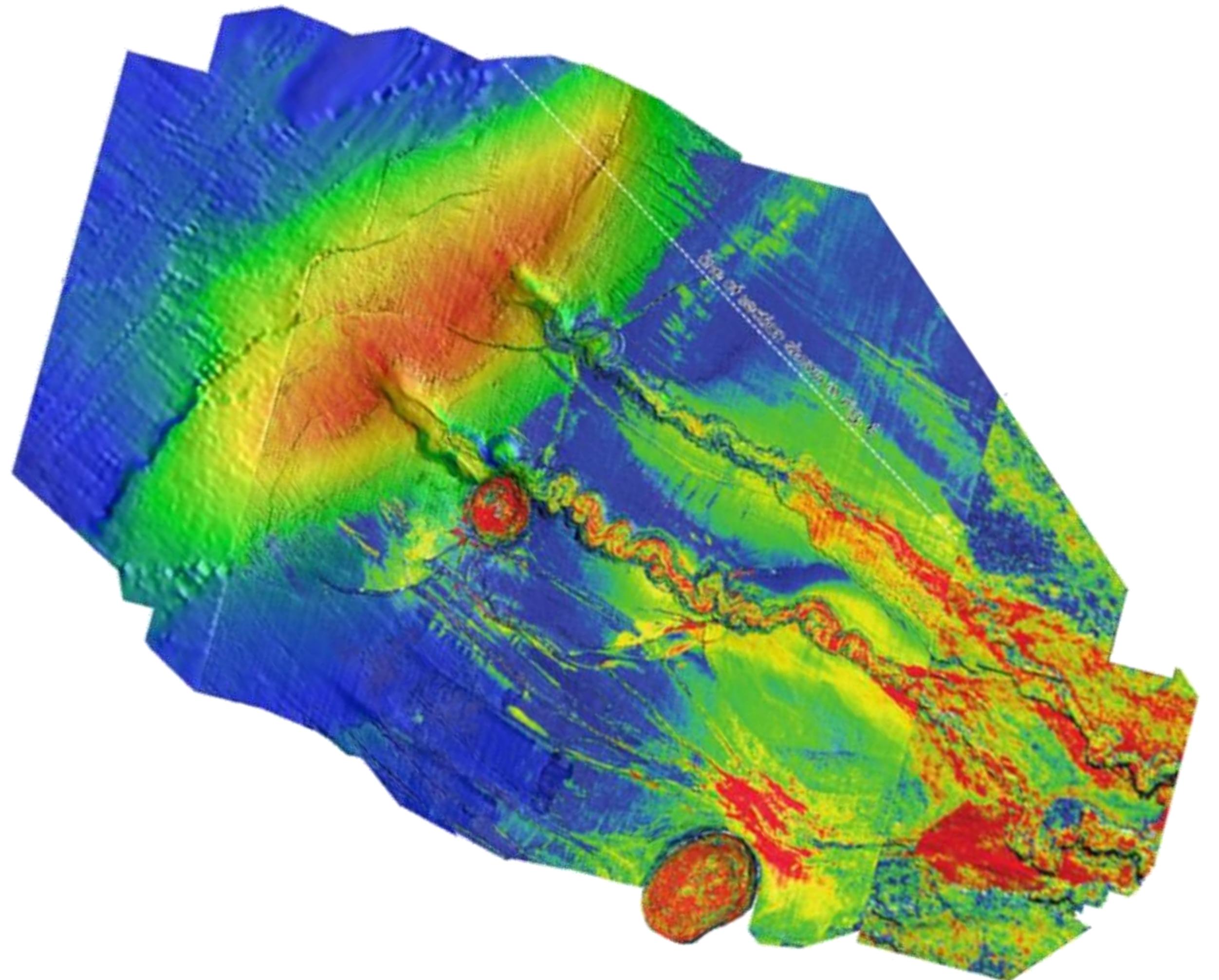
From: Posamentier et al., 2022



Meandering Rivers

Interpretation

Geo-morphological features



Interpretation

Geological Understanding: final remarks

“The best geologist is the one that have seen the most rocks”, Herbert Harold Read 1940

Geophysics without geological understanding can be misleading

At the end of the day as the old saying goes “Garbage-in, garbage-out”



Seismic Data Interpretation

2.b Interpretation workflow

1. Seismic Interpretation general concepts

- a. Seismic Reflection
- b. Well-to-Seismic Tie
- c. Depth conversion

2. Interpretation

a. Geological understanding

- i. Structural Settings
- ii. Stratigraphy
- iii. Geo-morphological features

b. Interpretation workflow

c. Interpretation Pitfalls

- a. We see only what we know
- b. Biases

3. Seismic Attributes

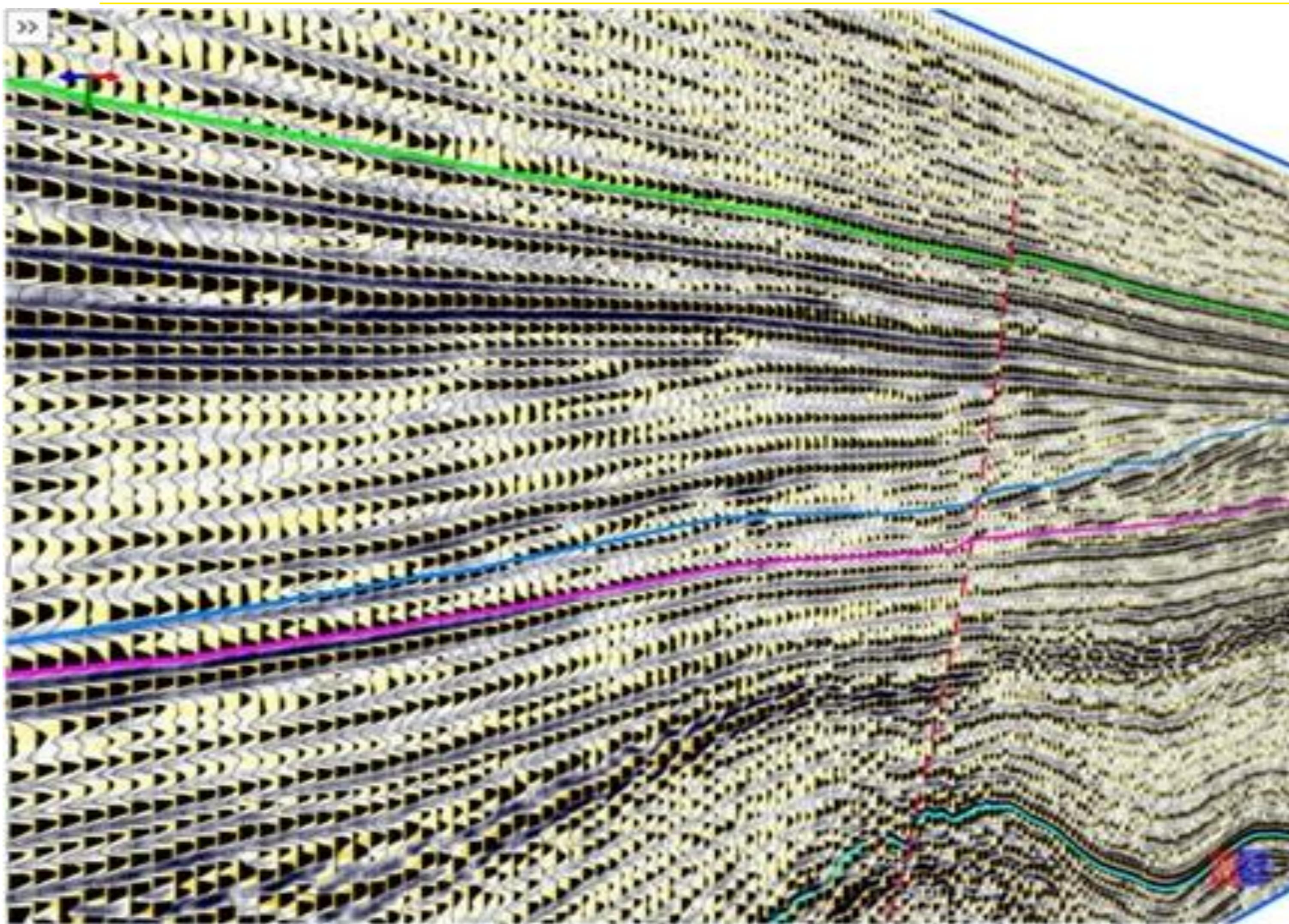
4. Seismic Interpretation for Geothermal

5. ML in Seismic Interpretation

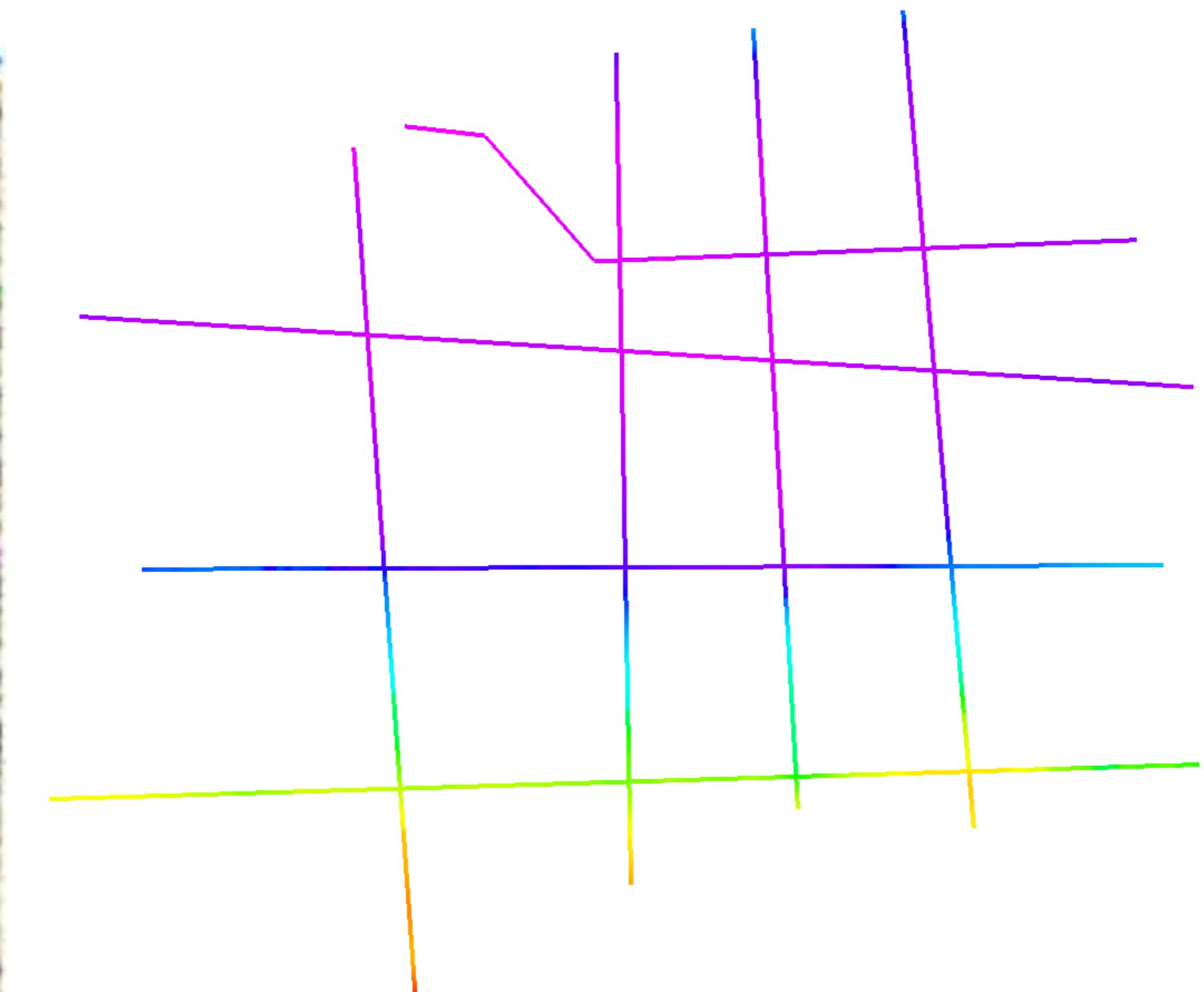
- a. Seismic Facies Clustering
- b. Supervised interpretation

Interpretation

2D Seismic Lines



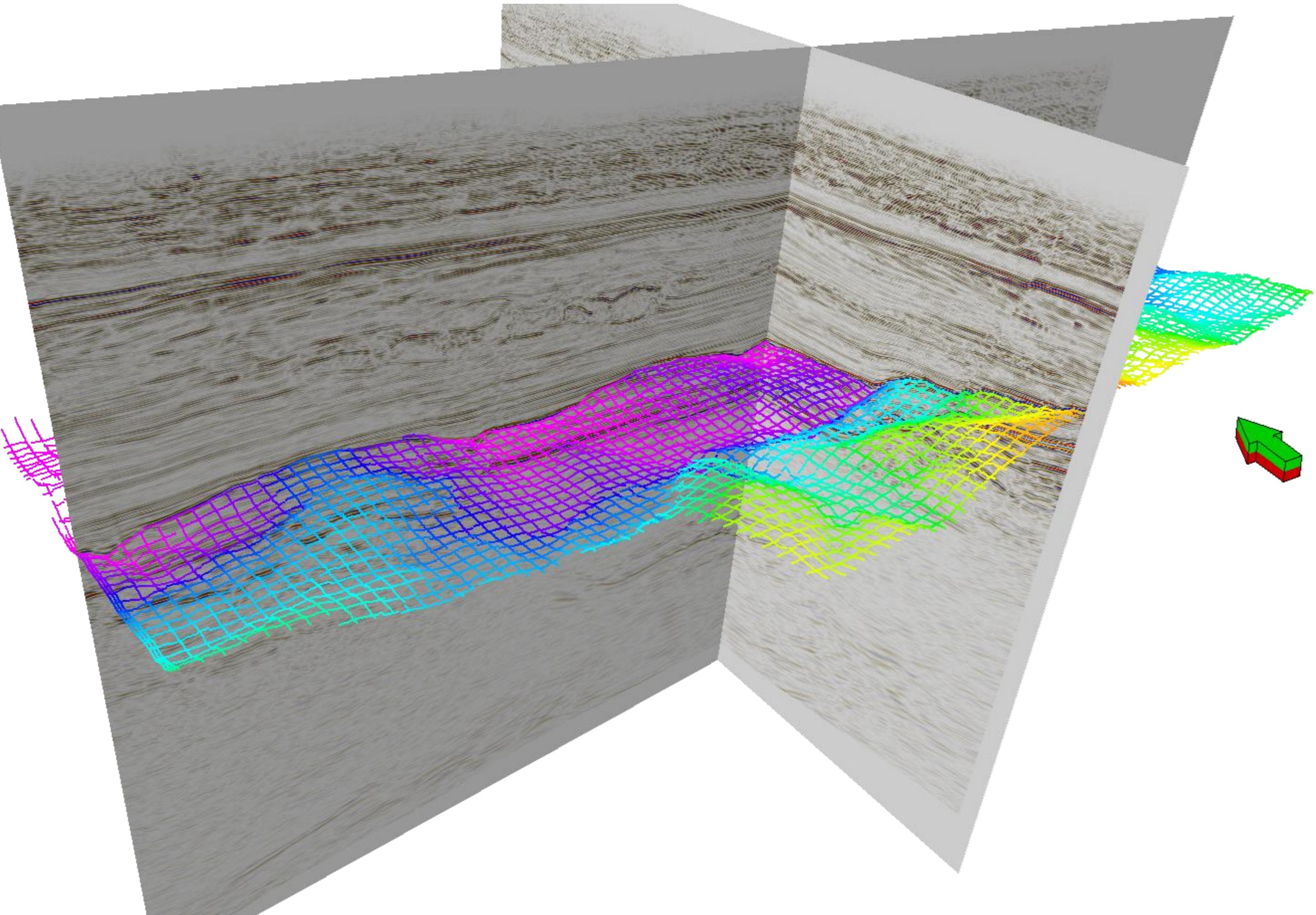
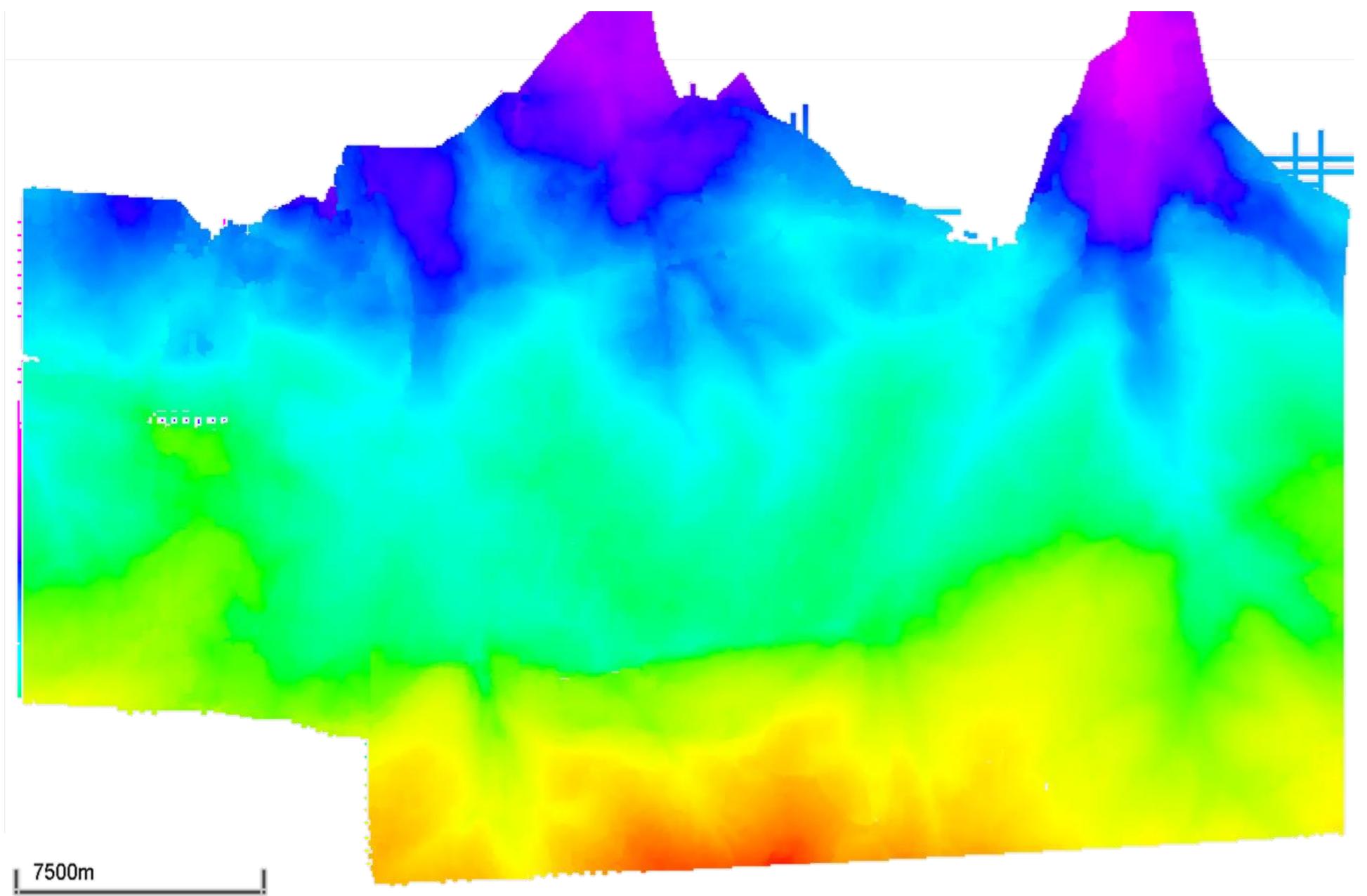
Irregular grid: it needs interpolation



Interpretation

3D cube, regular grid

- Regular grid every Nth IL and XL
- Infilling with Autotracking



Interpretation

Jump over the fault



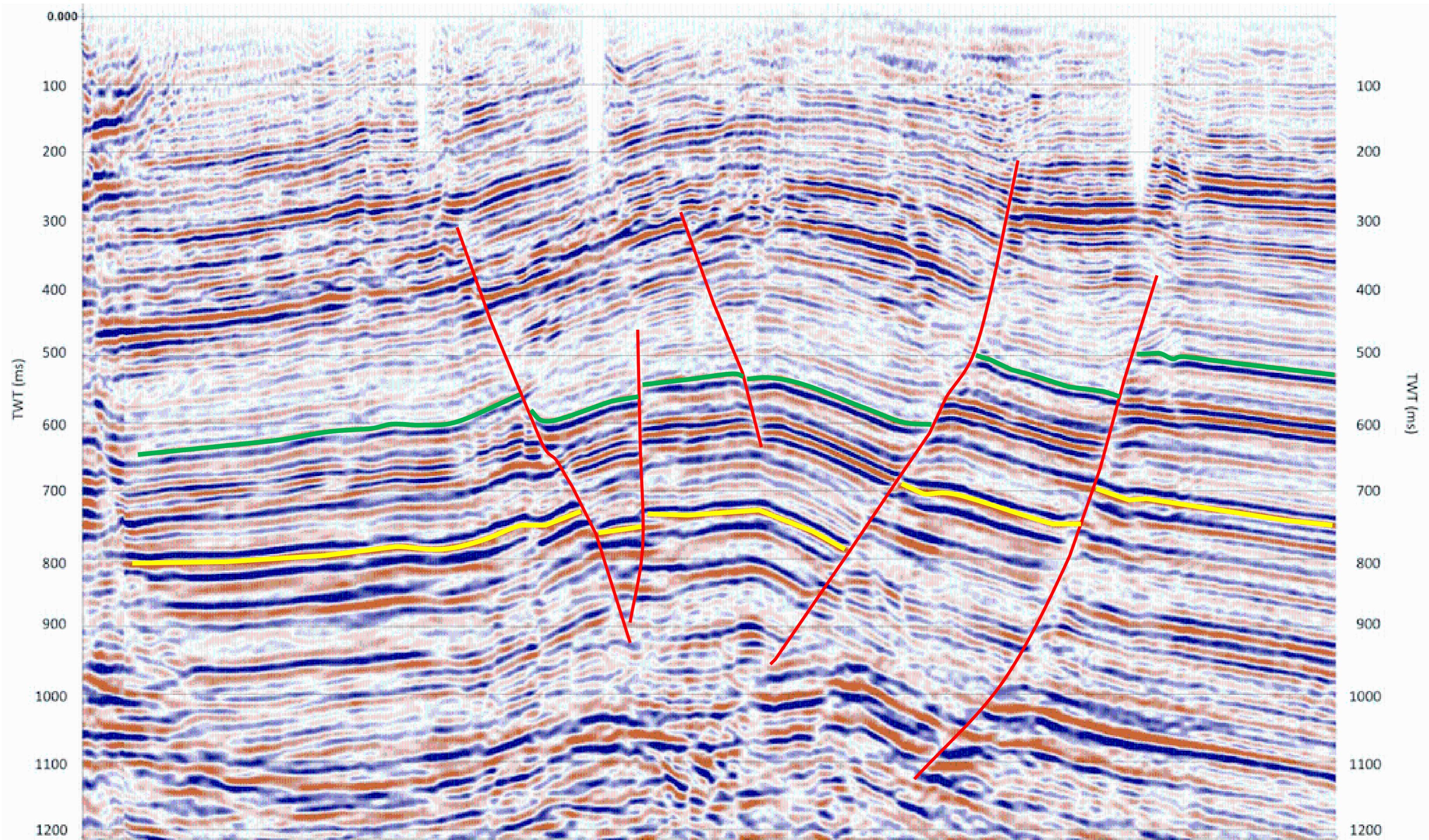
Interpretation

Jump over the fault



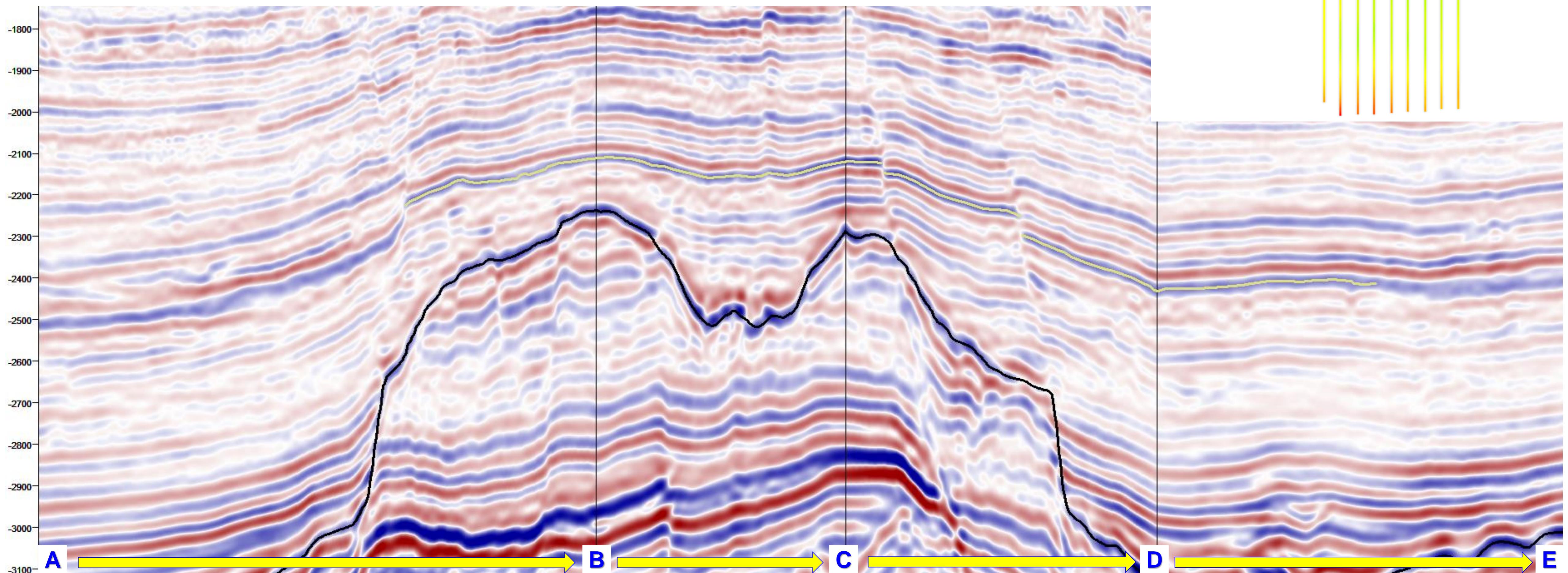
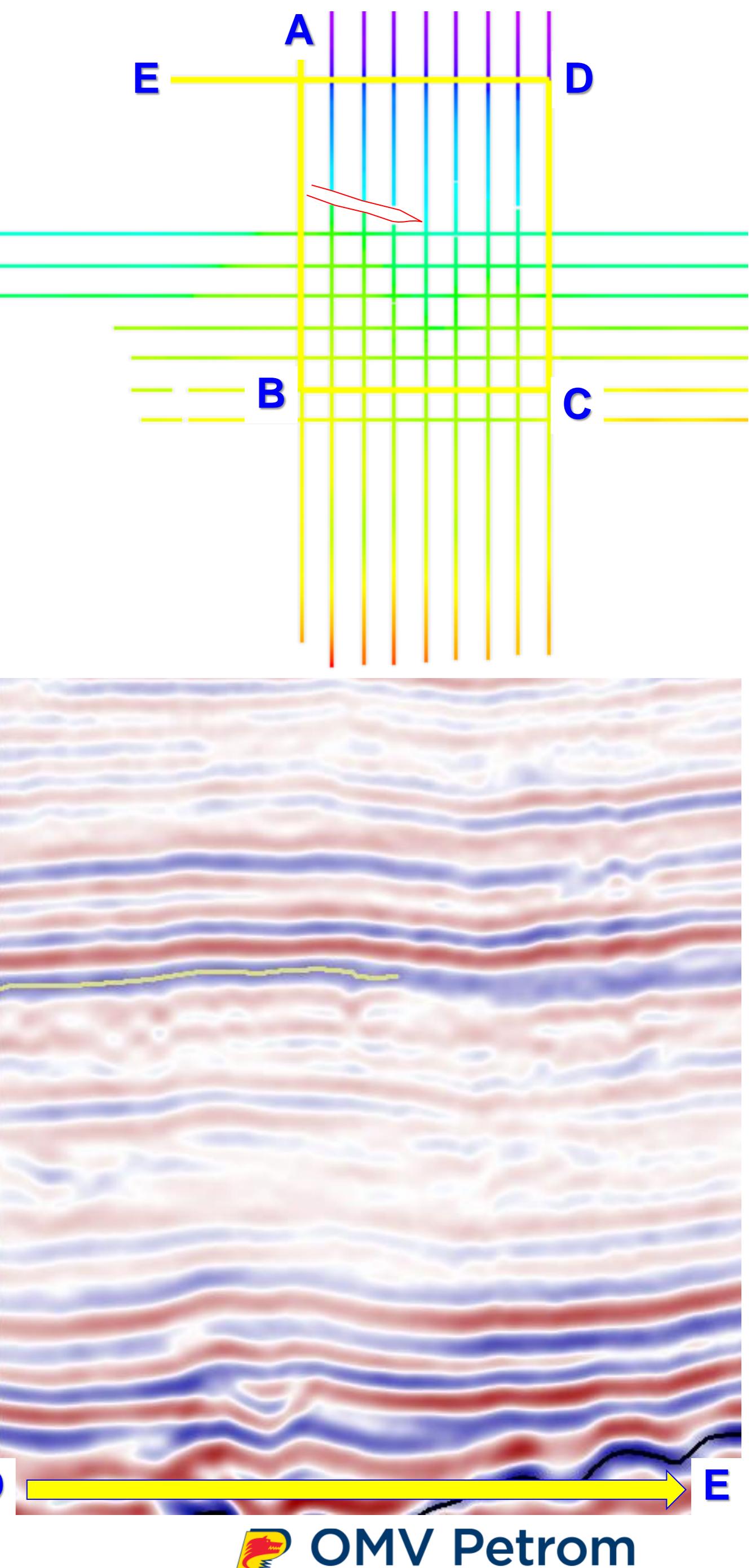
Interpretation

Jump over the fault



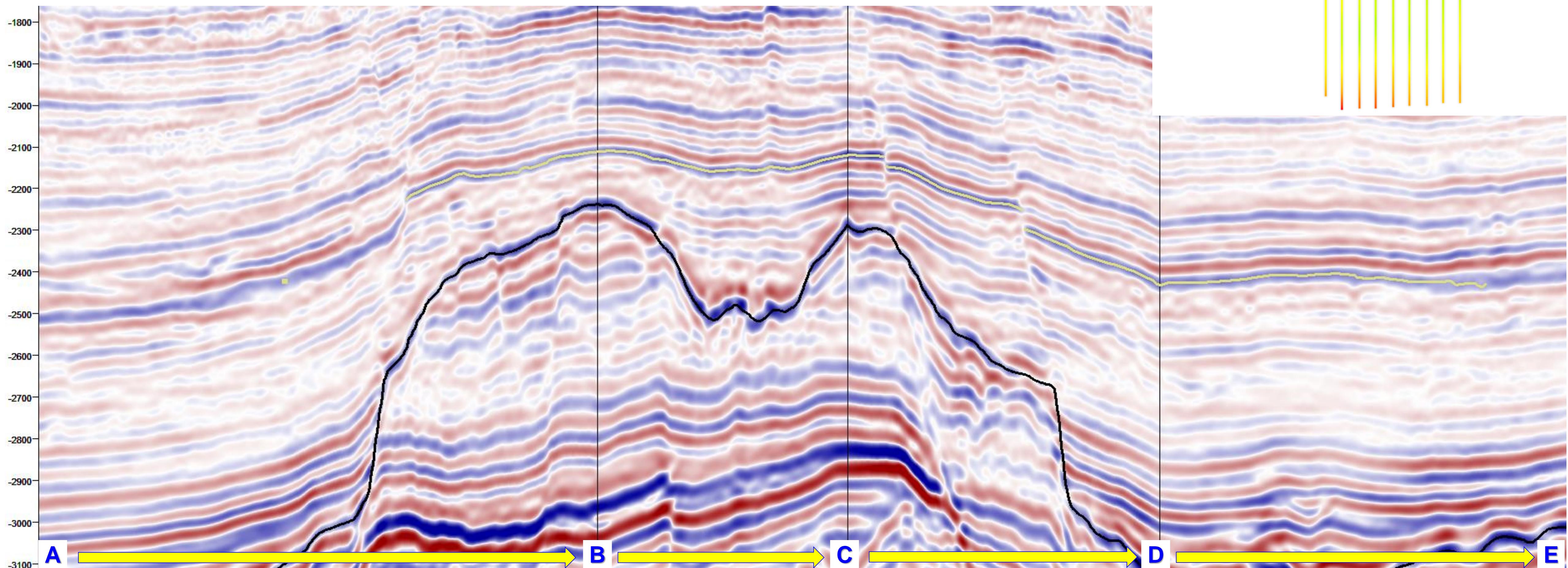
Interpretation

Jump over the fault



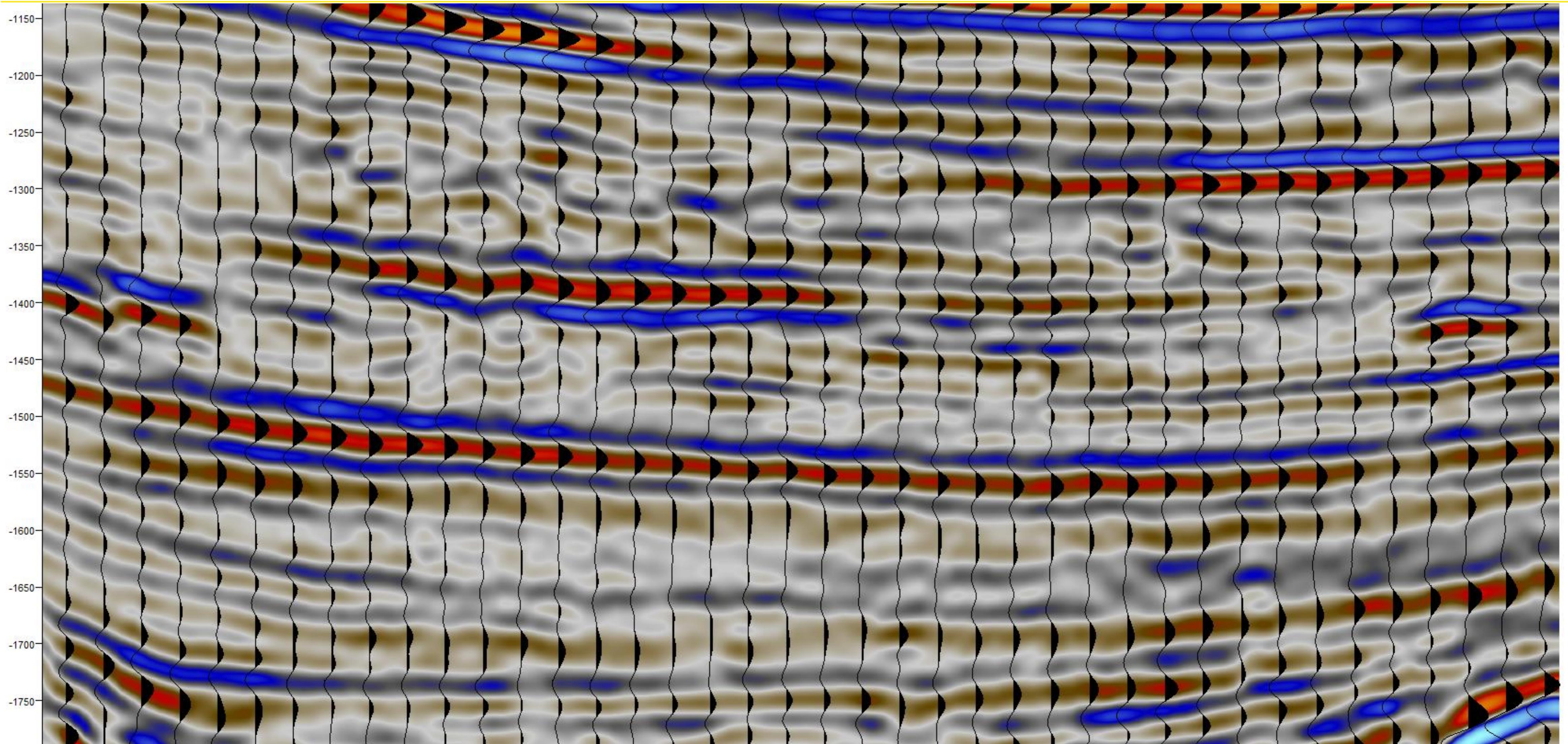
Interpretation

Jump over the fault

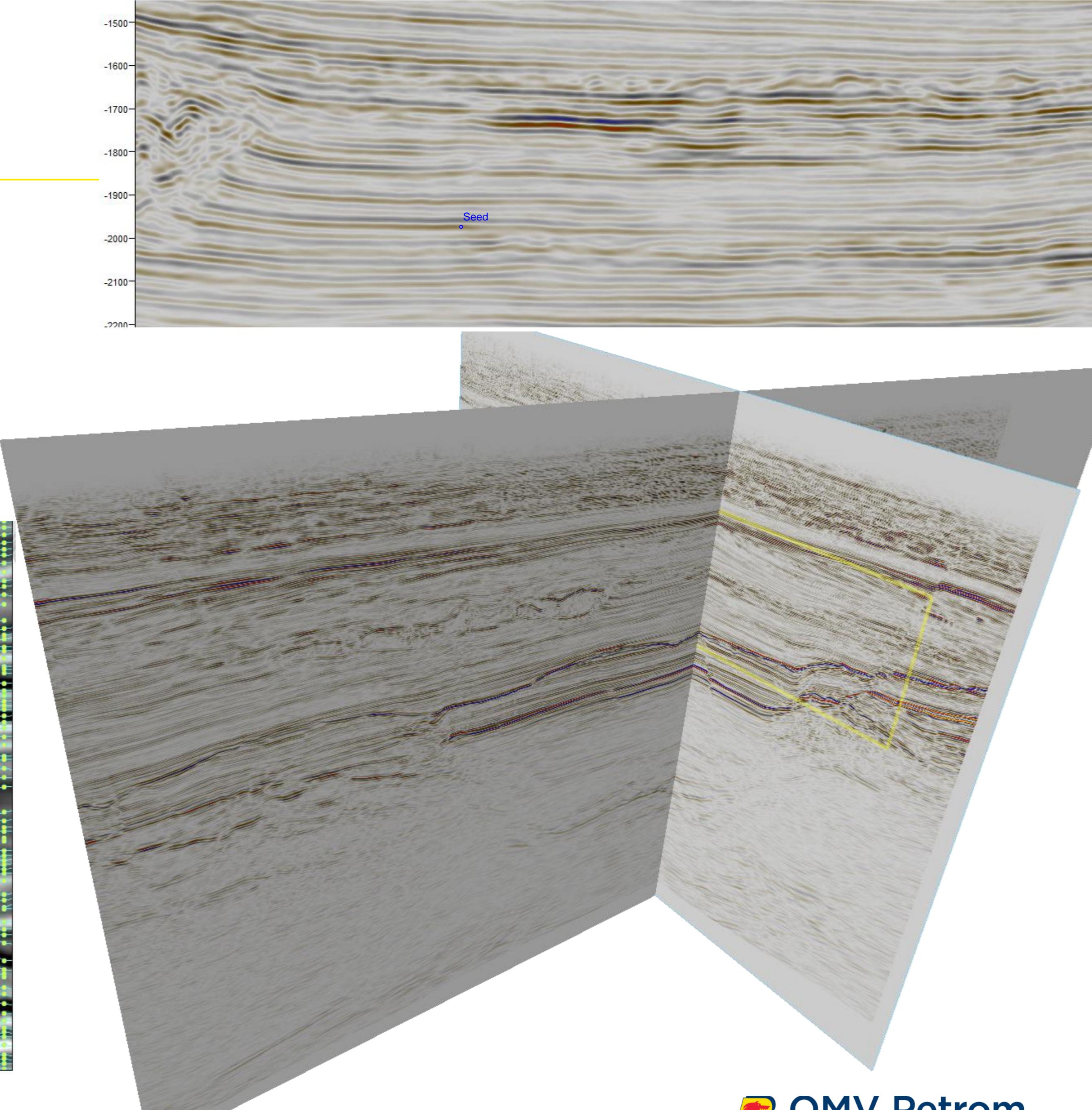
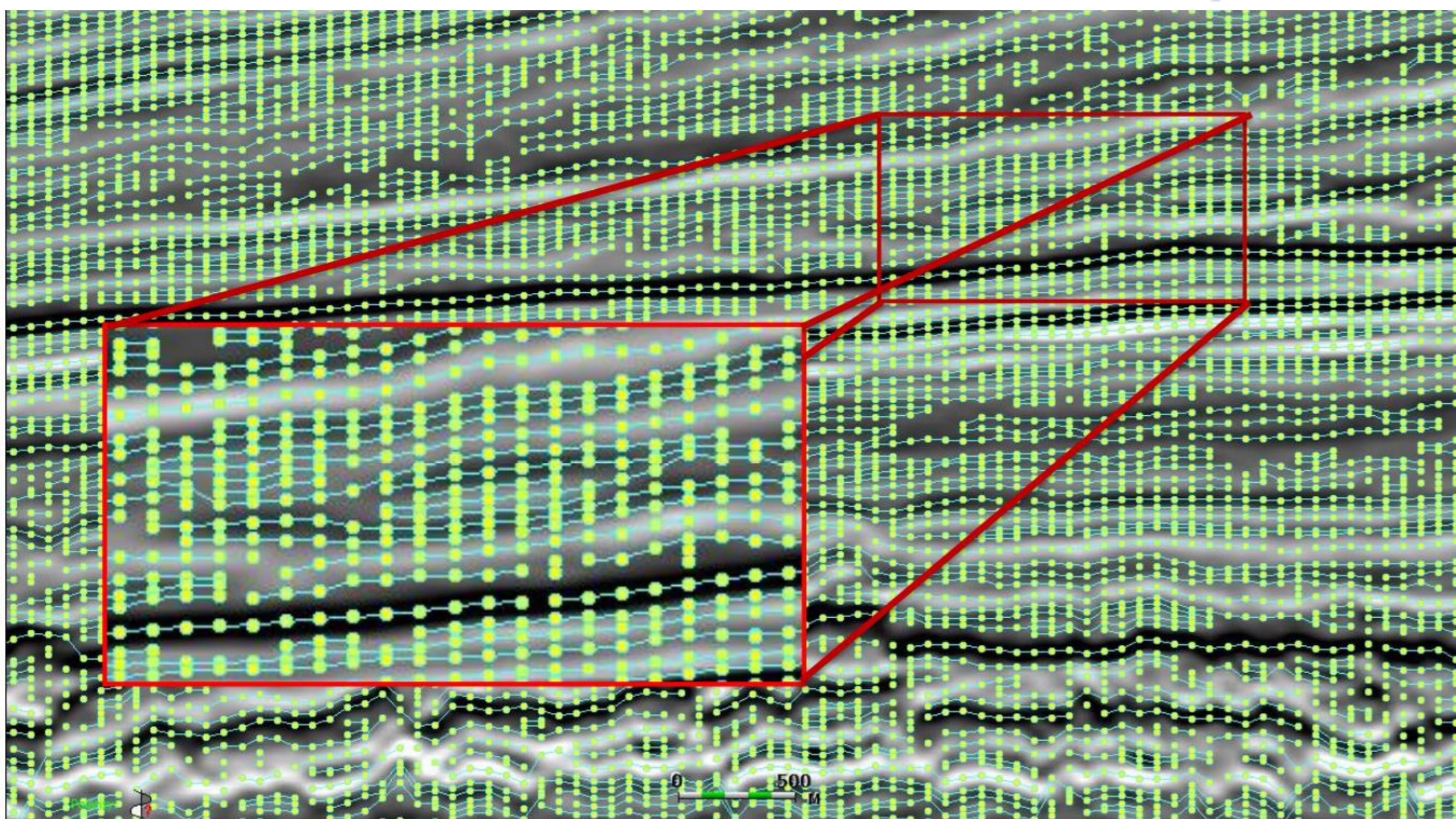
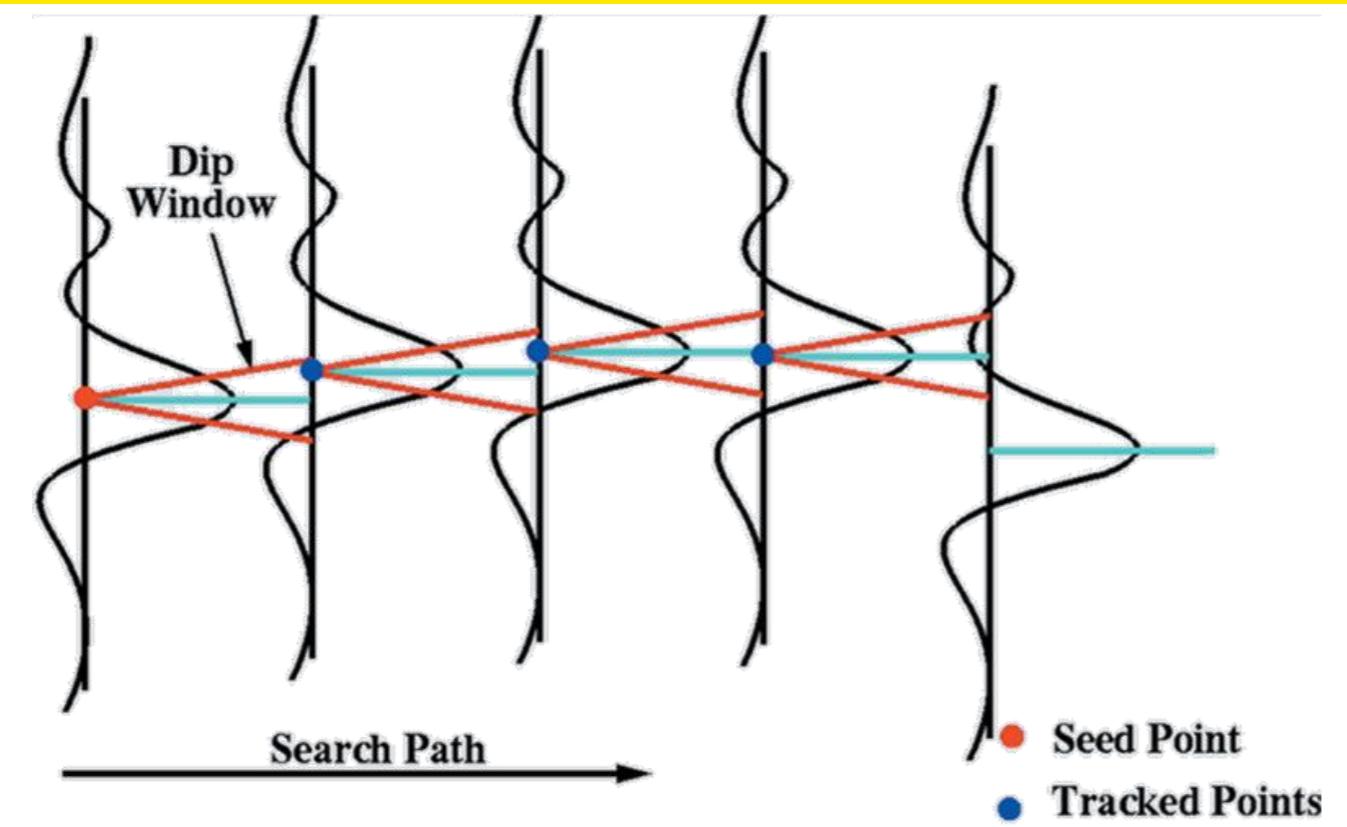
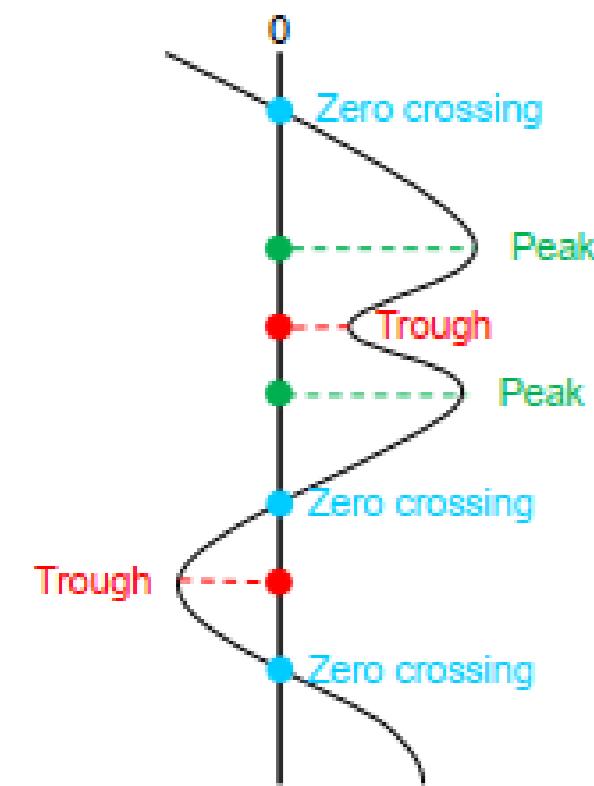


Interpretation

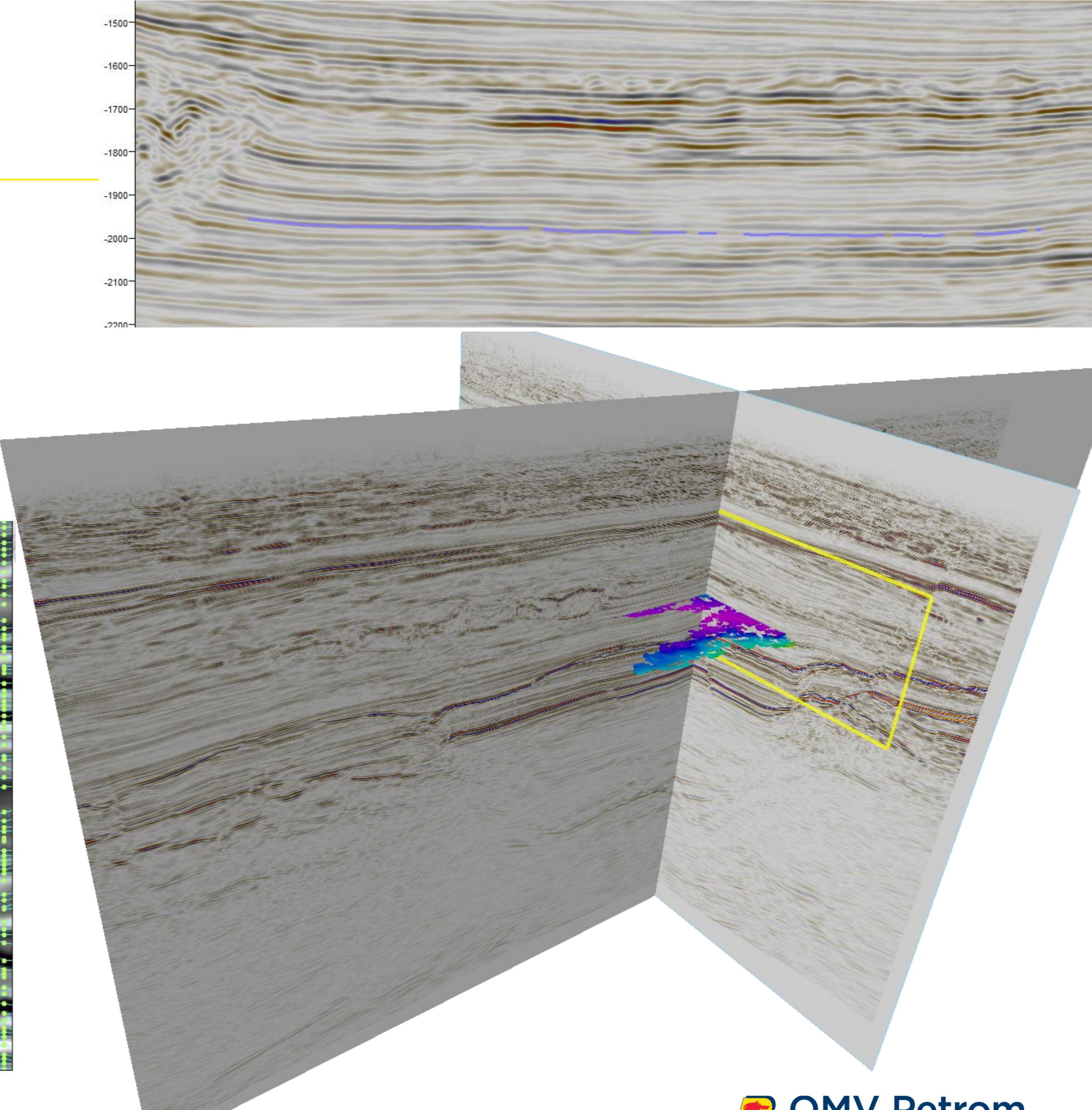
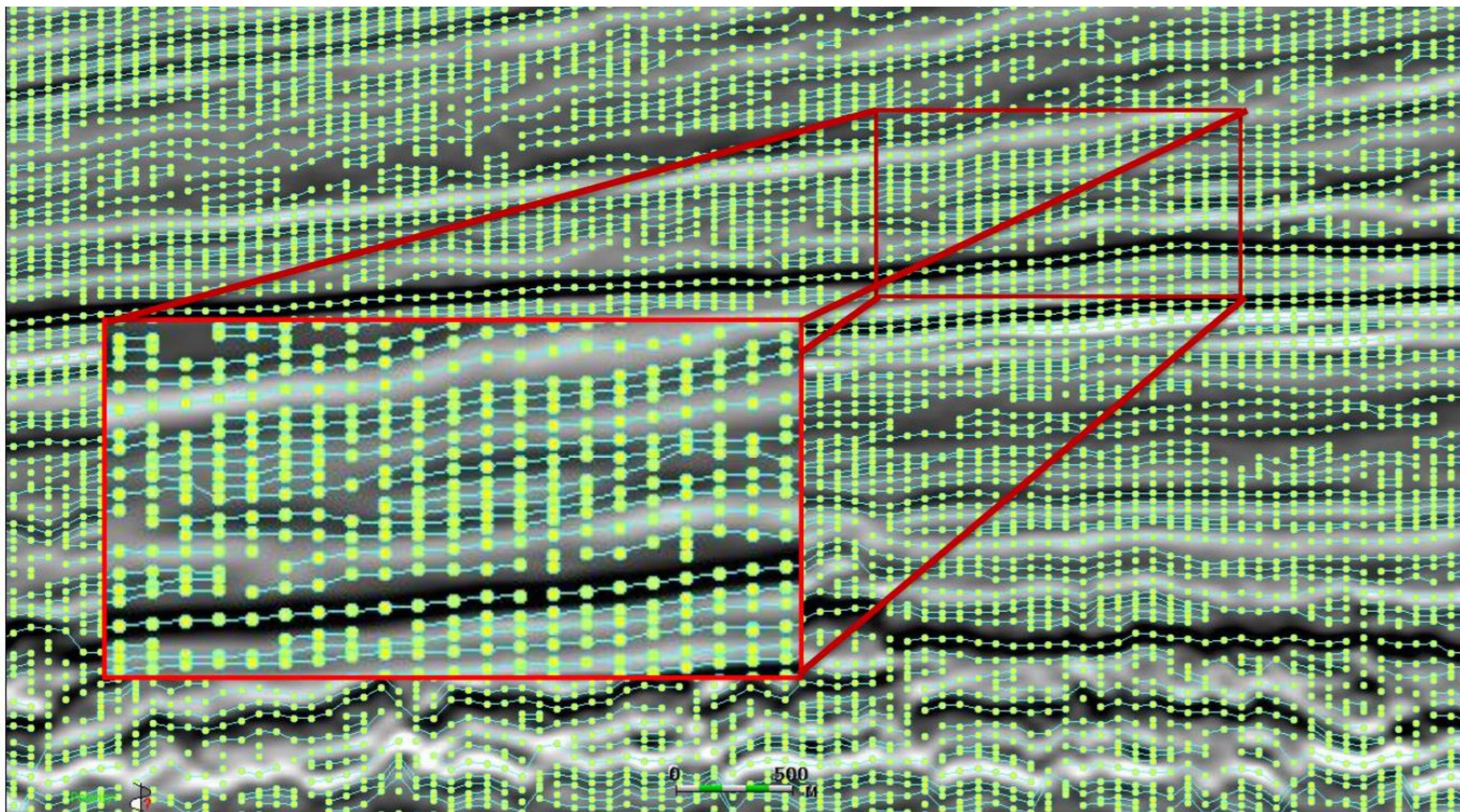
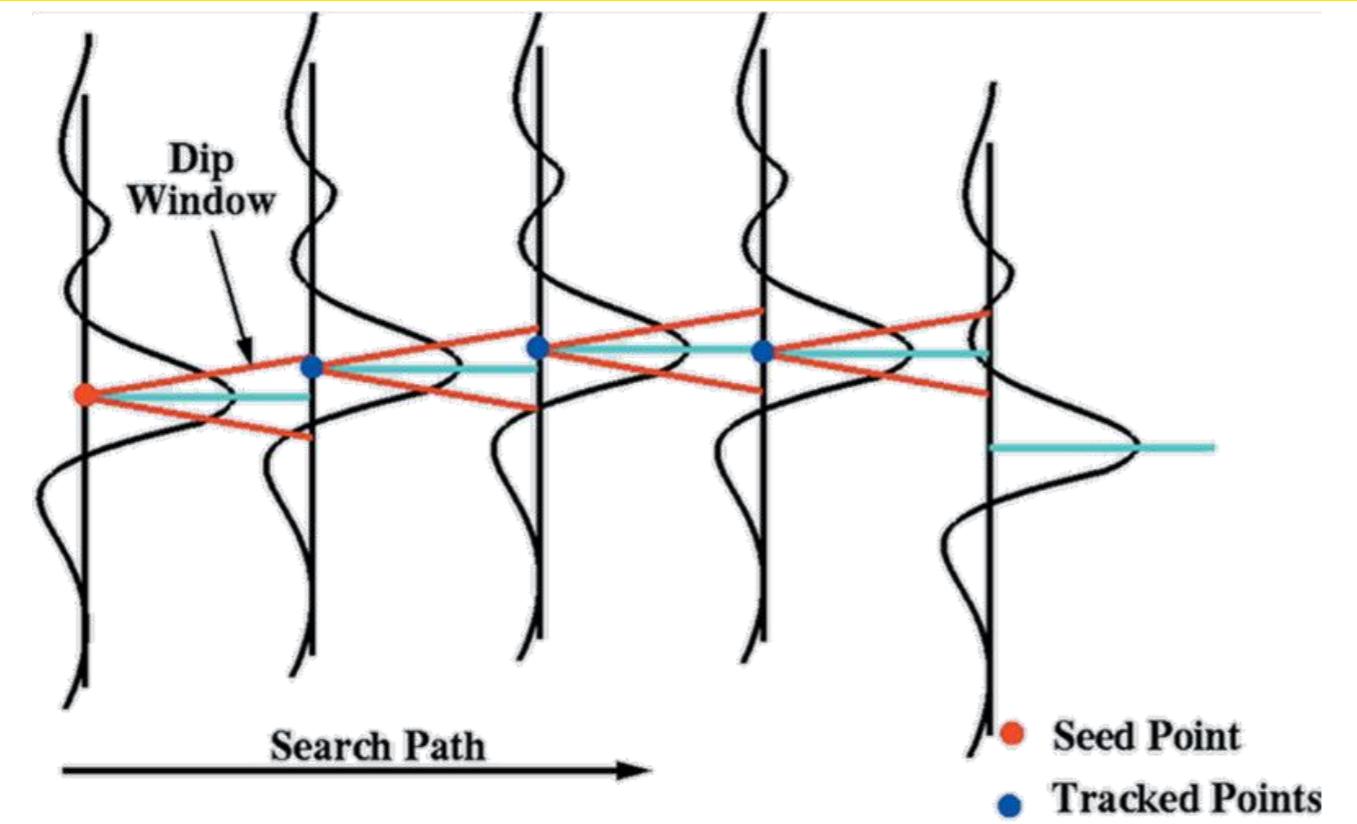
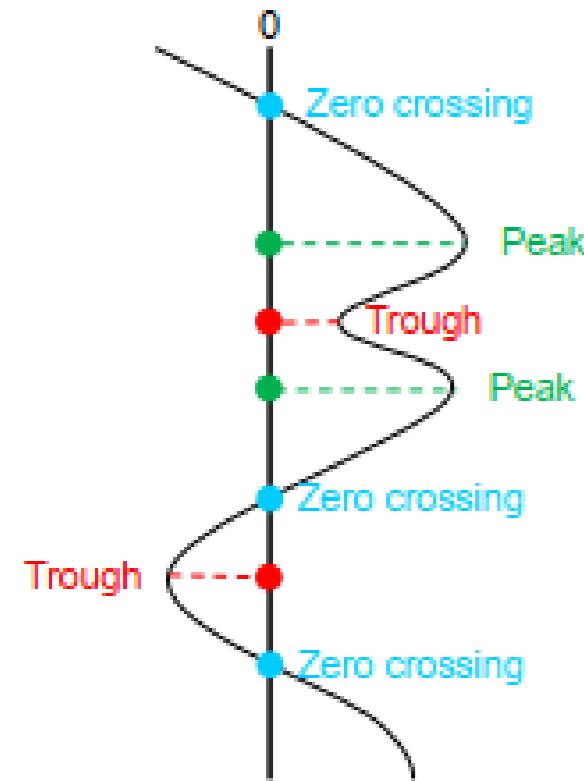
Autotracking



Interpretation Autotracking

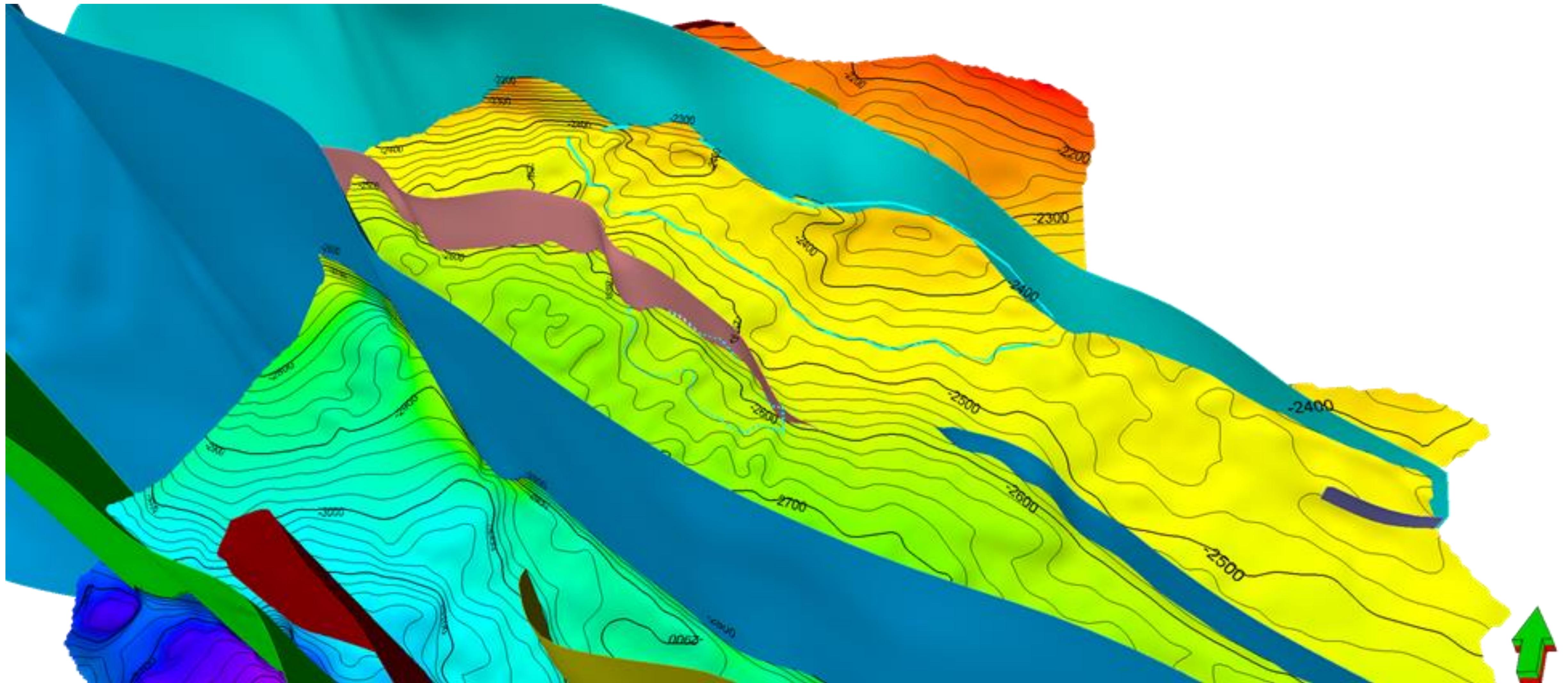


Interpretation Autotracking



Interpretation

Structural Framework



Seismic Data Interpretation

2.c Interpretation Pitfalls

1. Seismic Interpretation general concepts
 - a. Seismic Reflection
 - b. Well-to-Seismic Tie
 - c. Depth conversion

2. Interpretation

- a. Geological understanding
 - i. Structural Settings
 - ii. Stratigraphy
 - iii. Geo-morphological features
- b. Interpretation workflow

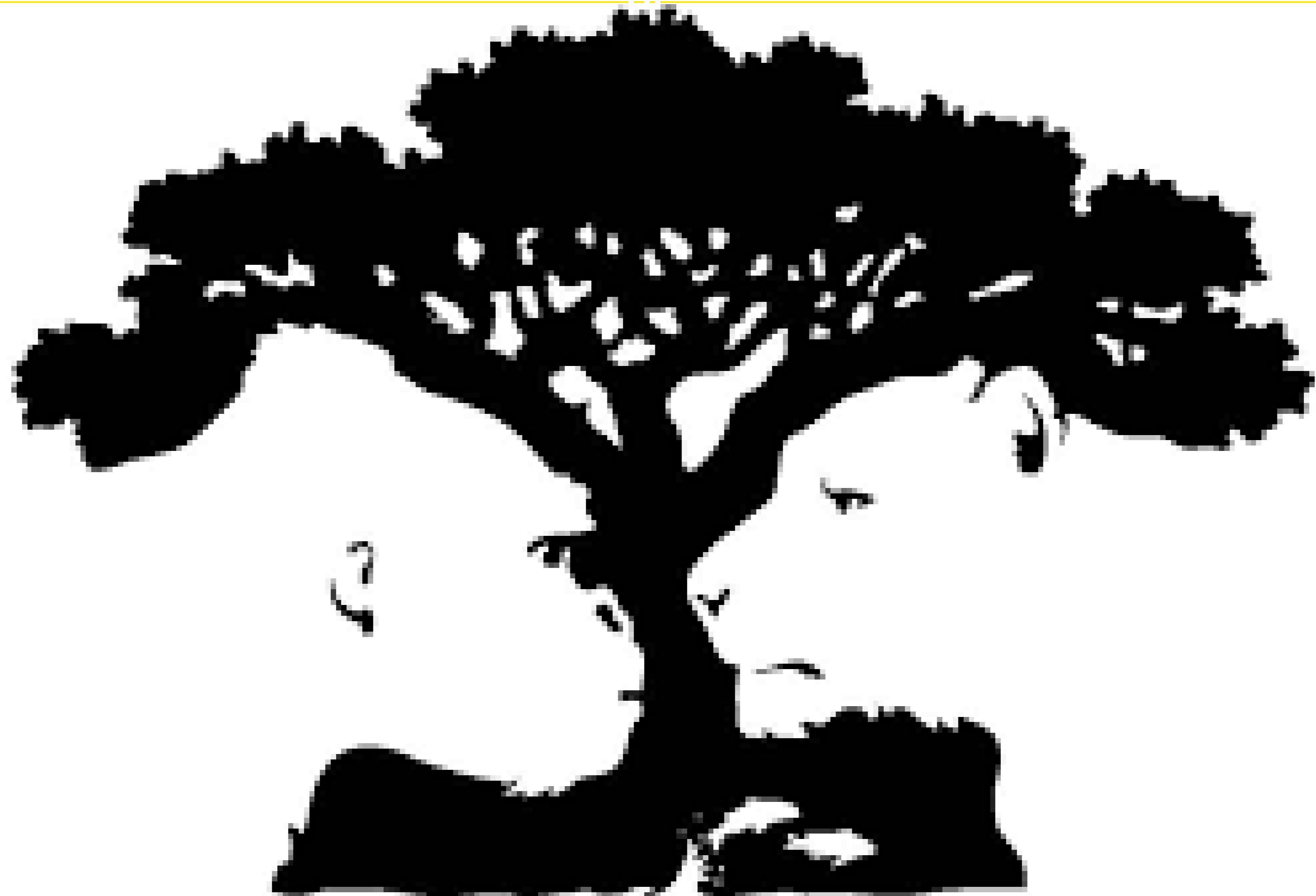
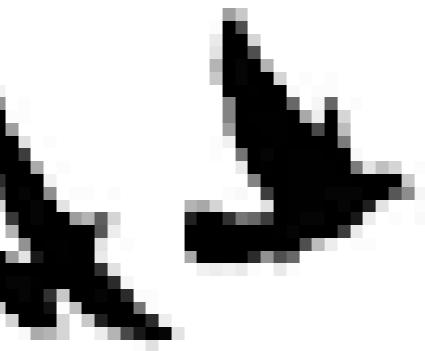
c. Interpretation Pitfalls

- a. We see only what we know
- b. Biases

3. Seismic Attributes
4. Seismic Interpretation for Geothermal
5. ML in Seismic Interpretation
 - a. Seismic Facies Clustering
 - b. Supervised interpretation

Interpretation

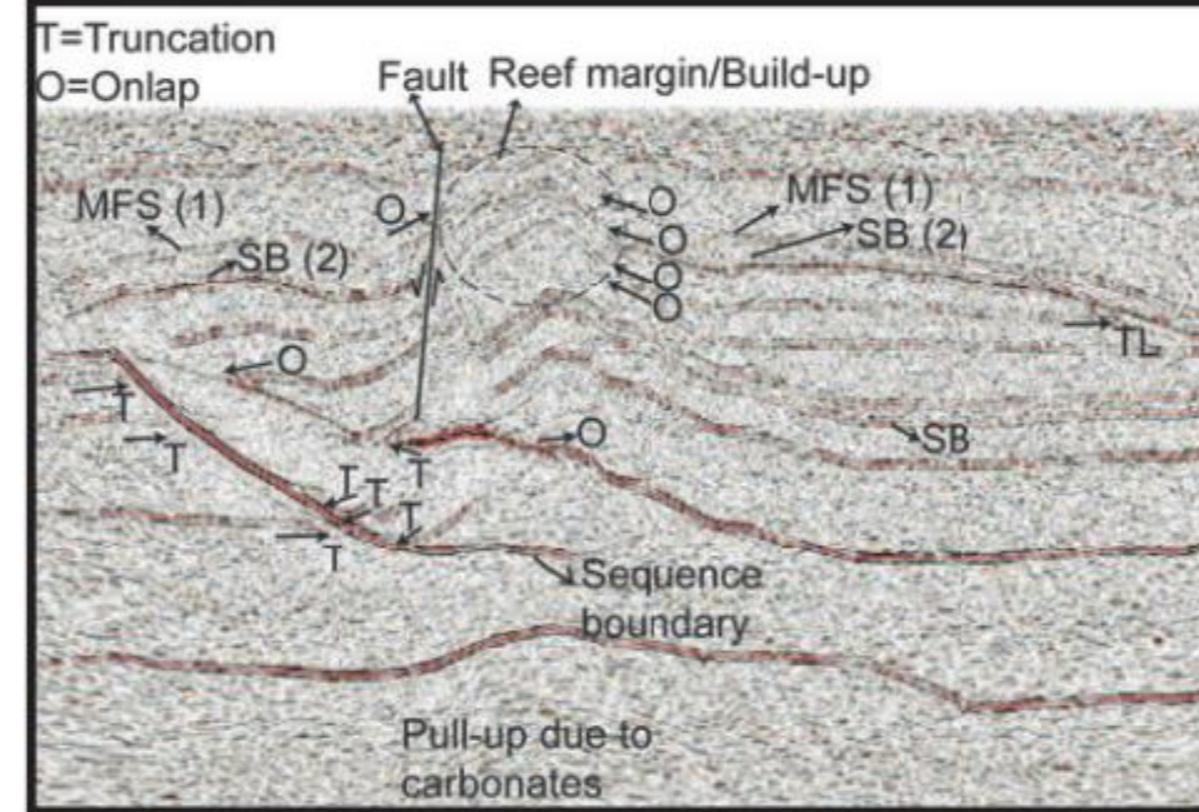
We see only what we know



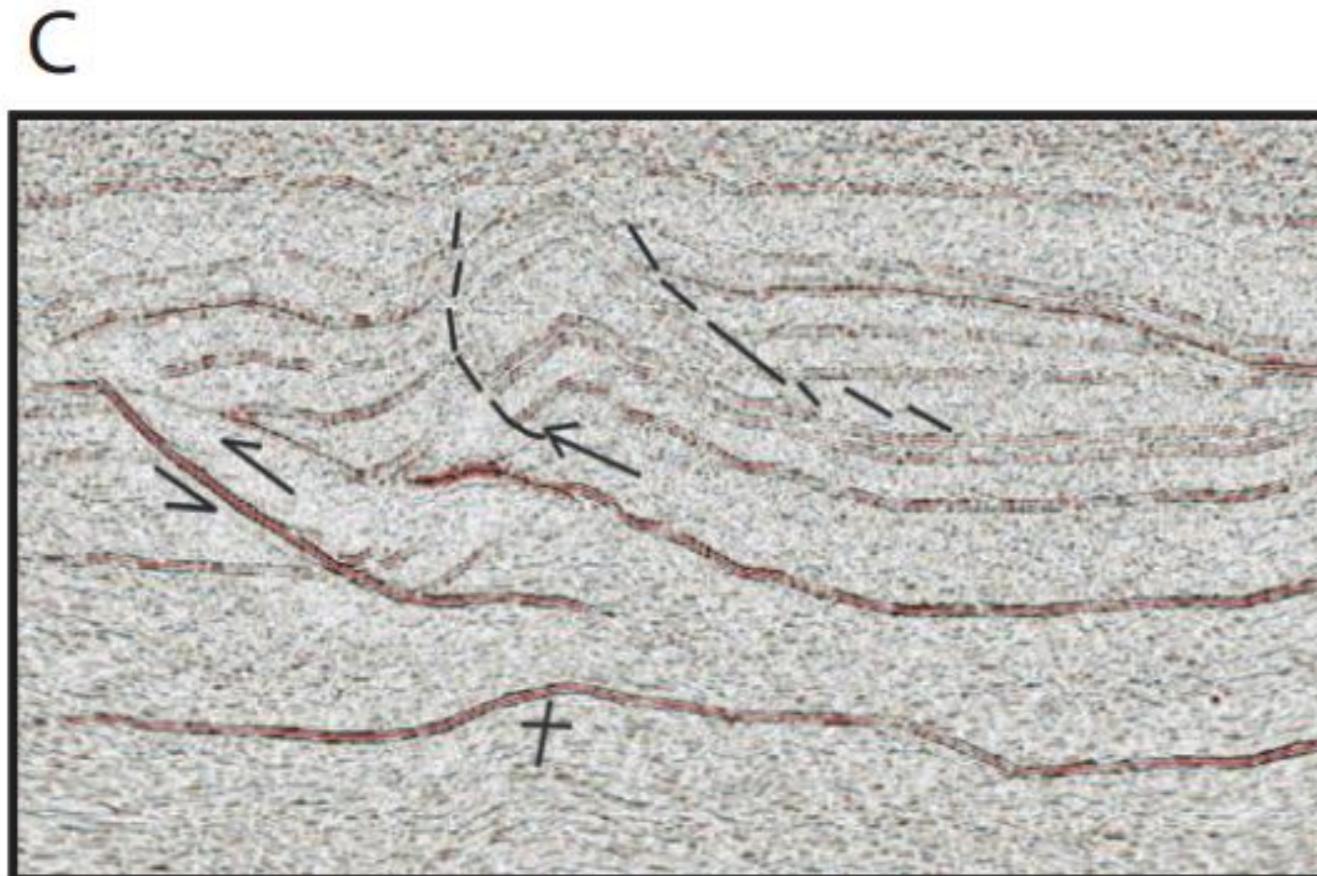
Interpretation Biases



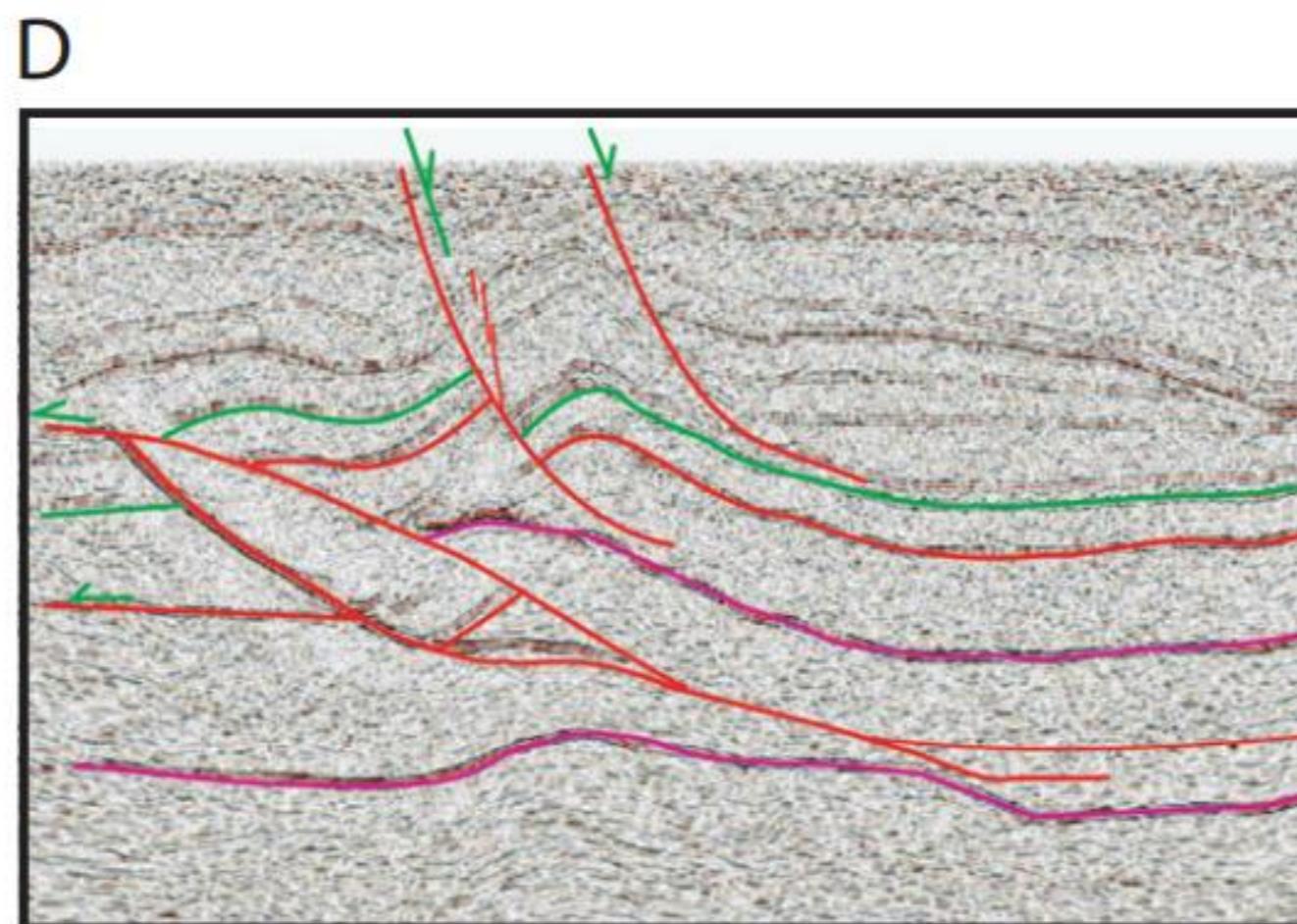
Student - PhD salt tectonics



Student - MSc sequence stratigraphy



+15 yrs - thrust expertise



+15 yrs - extensional expertise

From: Bond et al., 2007

Examples of different interpretations from interpreters with different years of experience and different expertise.

The goal of the study was to document the range of potential interpretations from a single data set and to test whether prior knowledge is important for interpretational outcomes.

412 Interpreters have been asked to interpret a Synthetic Seismic line created from a depth model (so that the authors knew the right answer).

Results:

- Only 21% of the participants interpreted the “correct” tectonic setting of the original model, and
- only 23% highlighted the three main fault strands in the image.
- Tectonic setting expertise seems to have influenced the concepts some participants brought to their interpretation.
- Participants with more experience (measured as number of years of experience) did not necessarily produce more “correct” answers.
- Apparently **type of experience is more significant than length of experience alone.**

Seismic Data Interpretation

3. Seismic Attributes

1. Seismic Interpretation general concepts
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 - c. Depth conversion
2. Interpretation
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 - b. Biases

3. Seismic Attributes

4. Seismic Interpretation for Geothermal
5. ML in Seismic Interpretation
 - a. Seismic Facies Clustering
 - b. Supervised interpretation

Interpretation

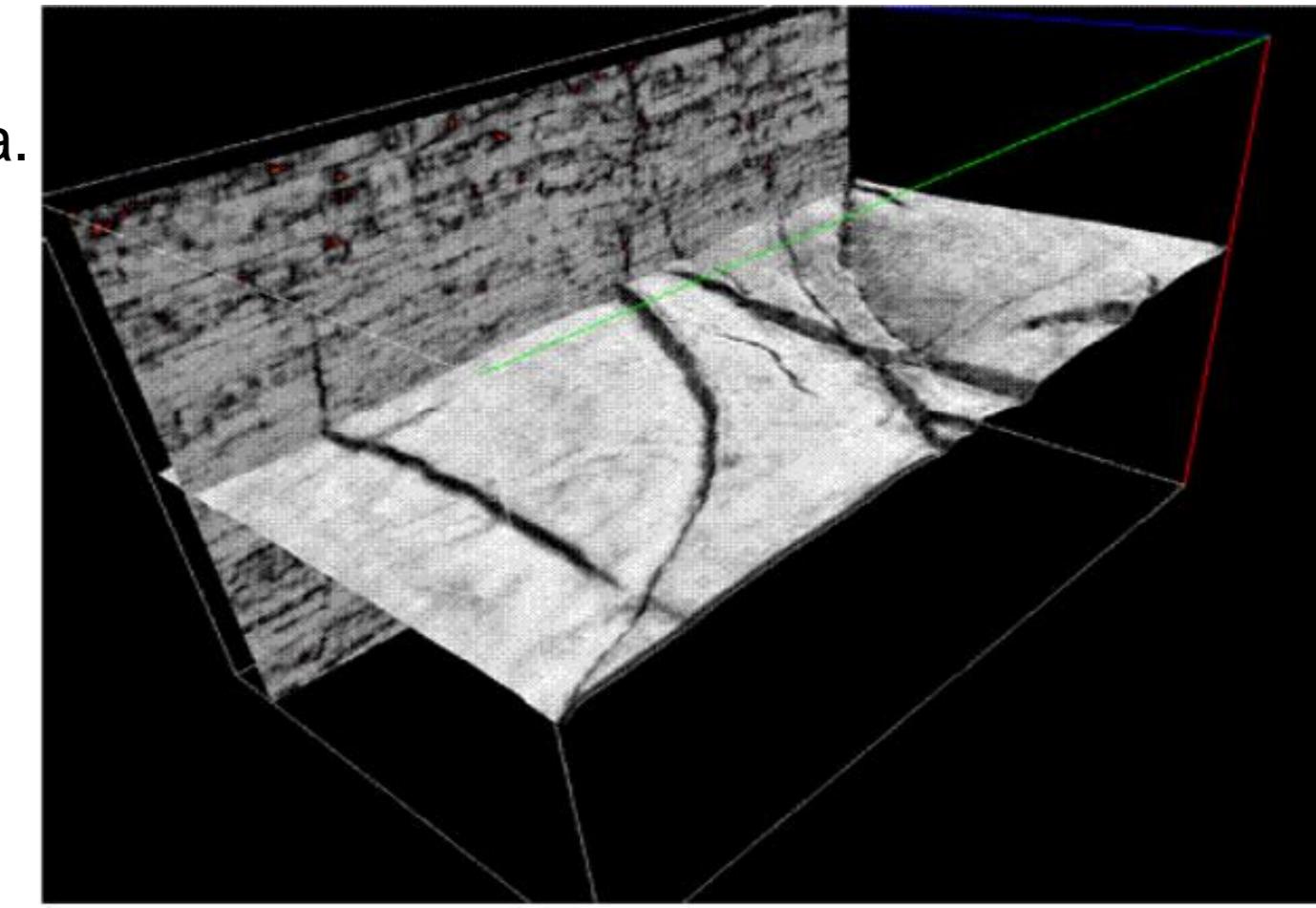
Seismic Attributes

A **seismic attribute** is a quantity extracted or derived from seismic data that can be analyzed in order to enhance information that might be more subtle in a traditional seismic image, leading to a better geological or geophysical interpretation of the data. Recently there has been a proliferation of Seismic Attributes, so much so that some authors warned that “**...many seismic attributes are redundant or useless and confuse seismic interpretation more than they help**”, Barnes (2007).

Three main families:

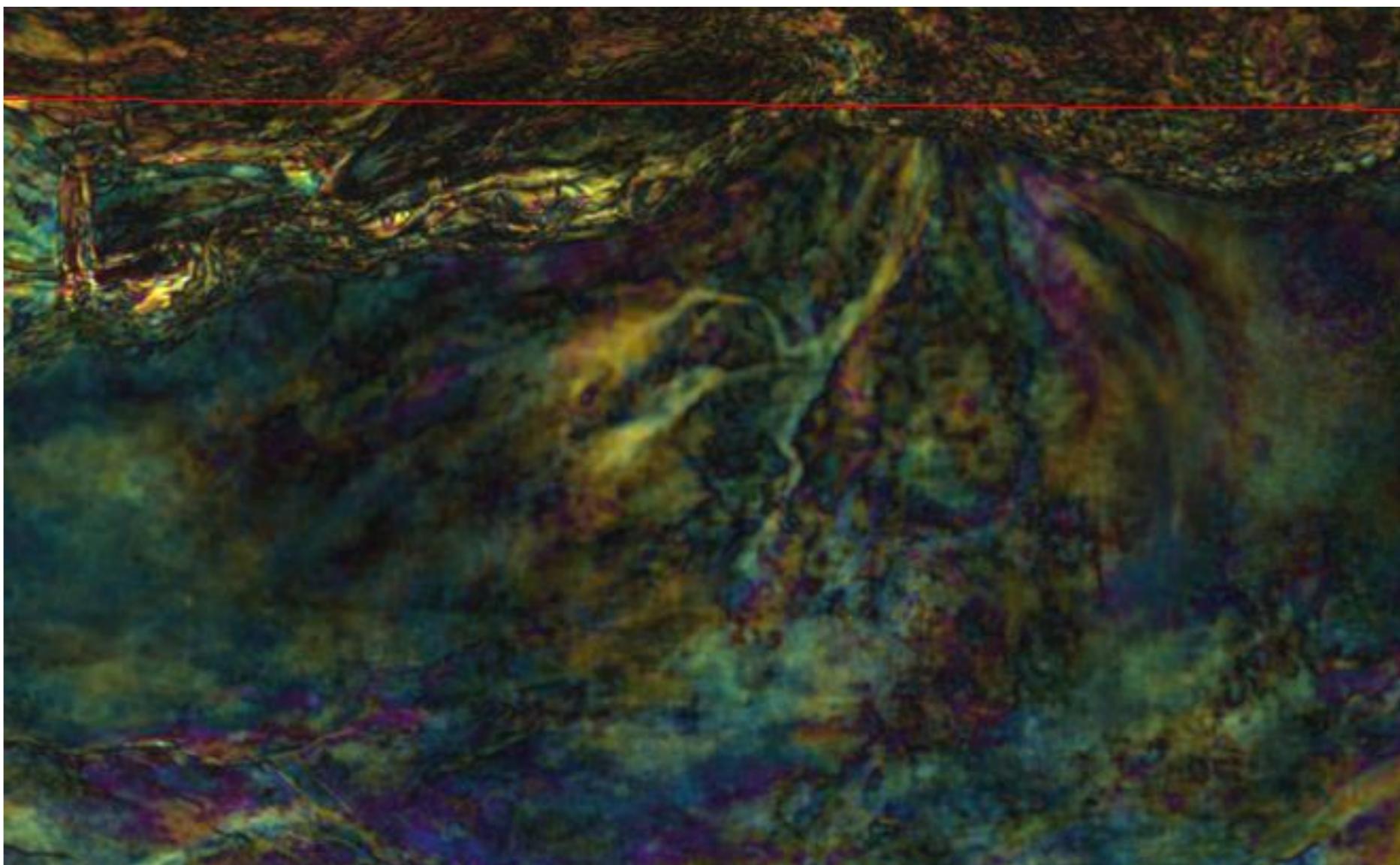
1) Structural Attributes: *they emphasize discontinuities in the seismic signal*

- Variance (Semblance, Continuity)
- Curvature
- Edge method
- Etc...



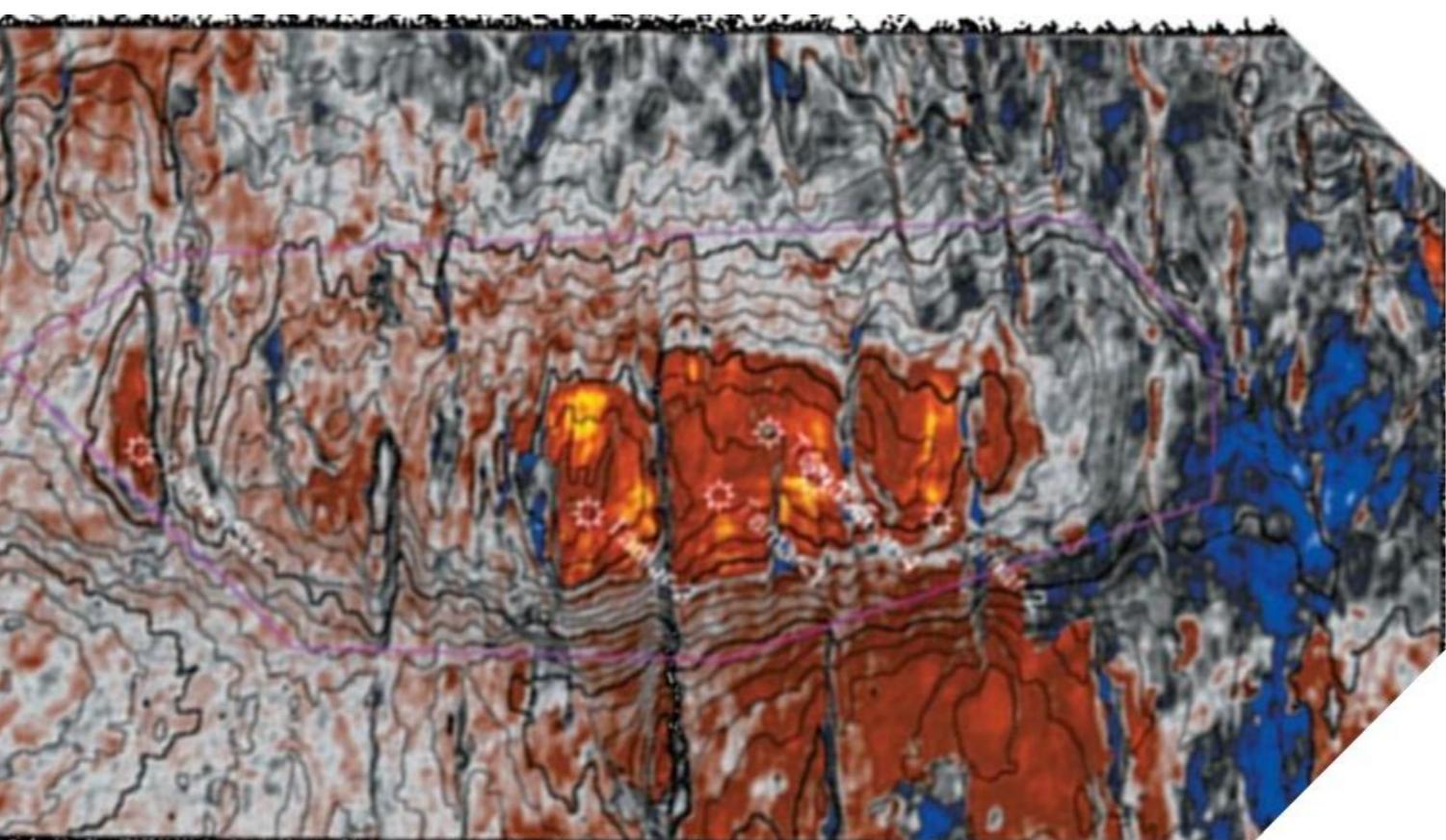
2) Lithological-Stratigraphic: *they are useful to highlight unconformity and/or depositional environment*

- Sweetness
- RMS Amplitude
- Spectral decomposition
- Etc...



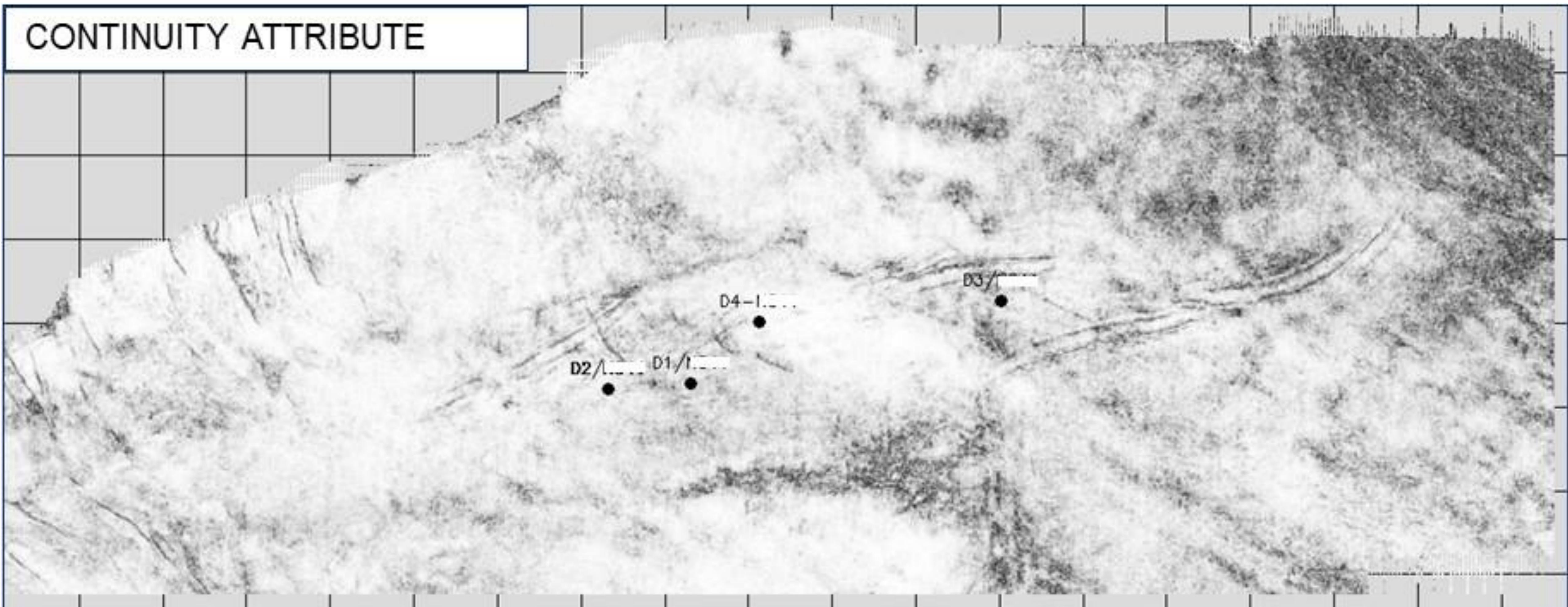
3) HC indicators: *They can indicate HC presence*

- RMS amplitude
- Envelope
- Reflection Intensity



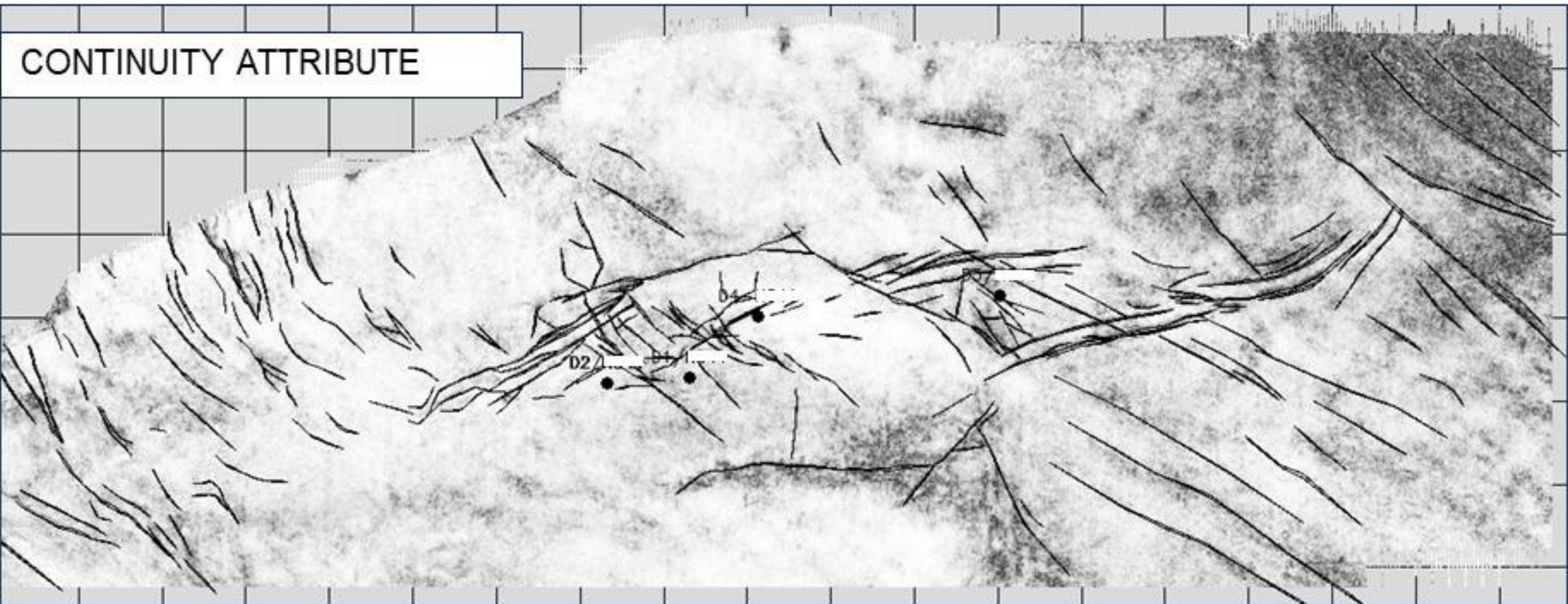
Interpretation

Fault interpretation



Interpretation

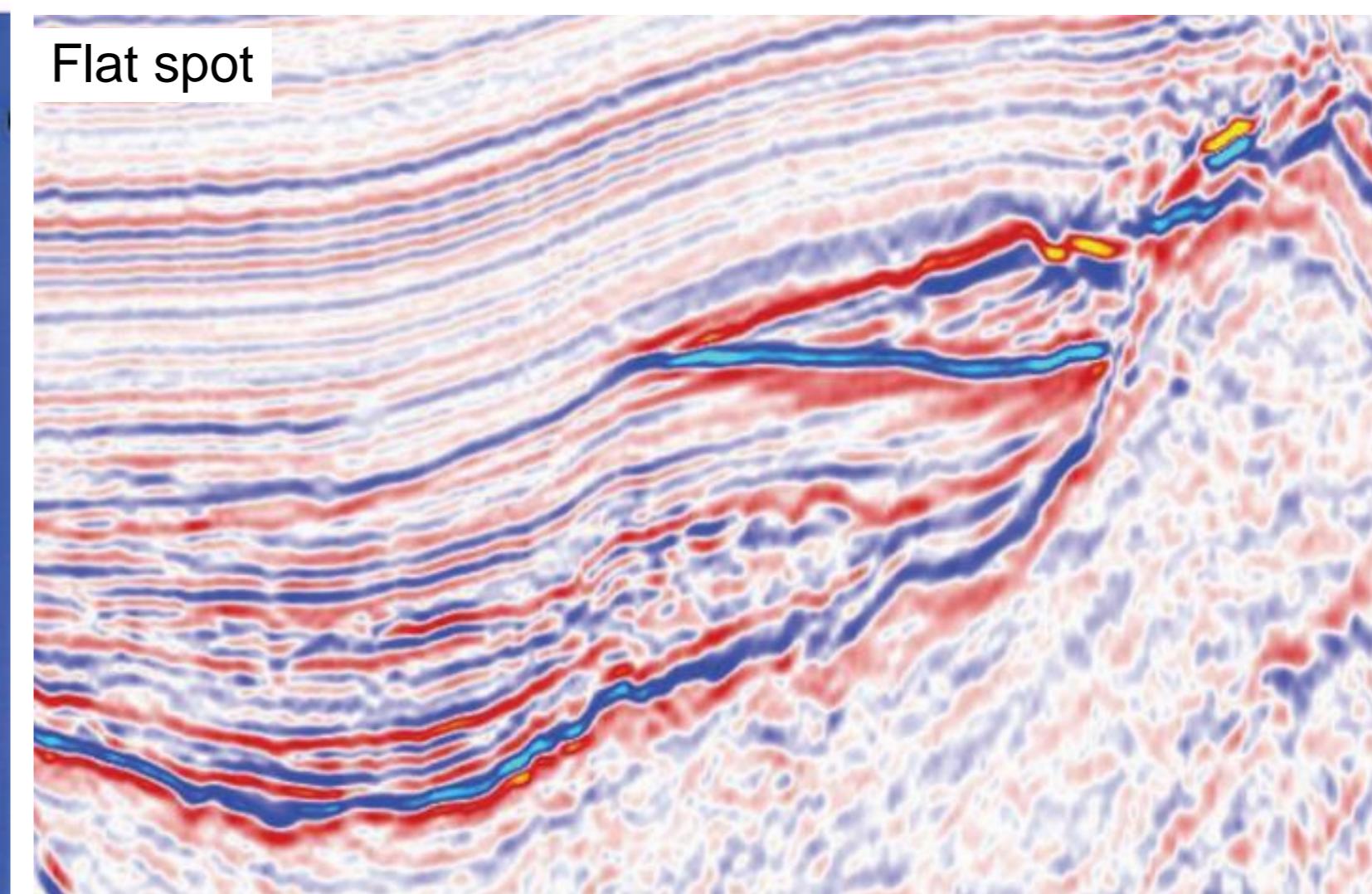
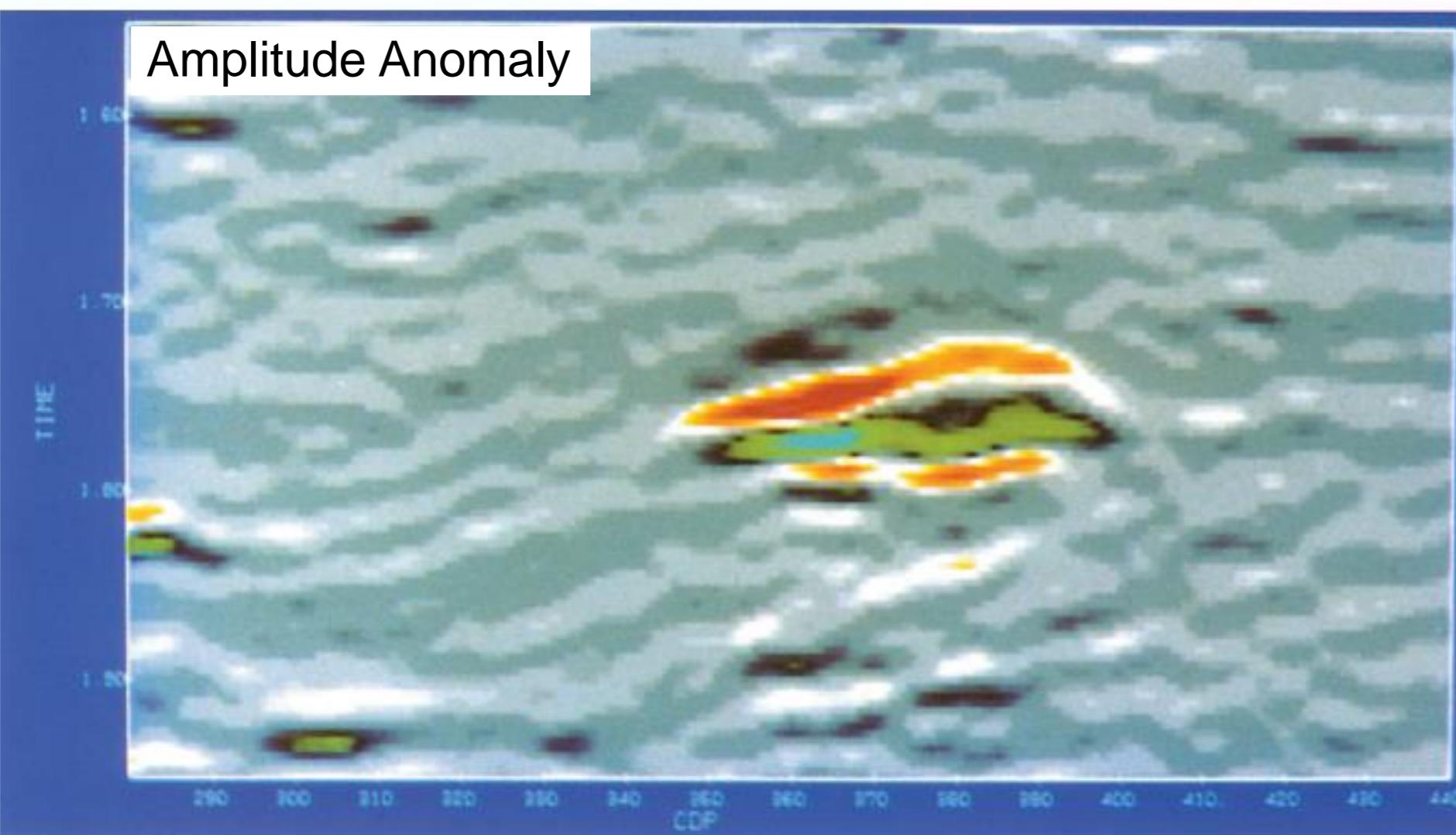
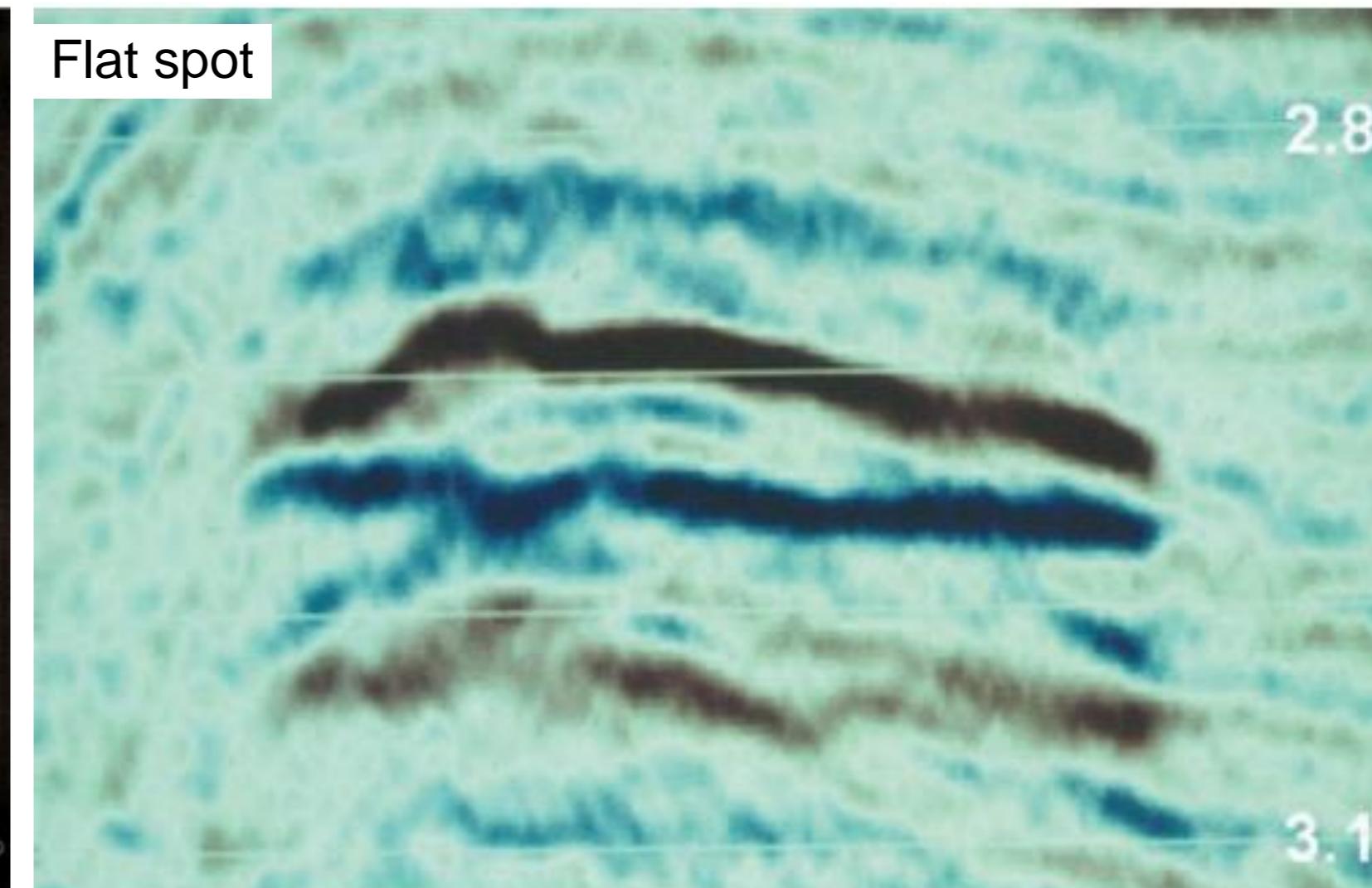
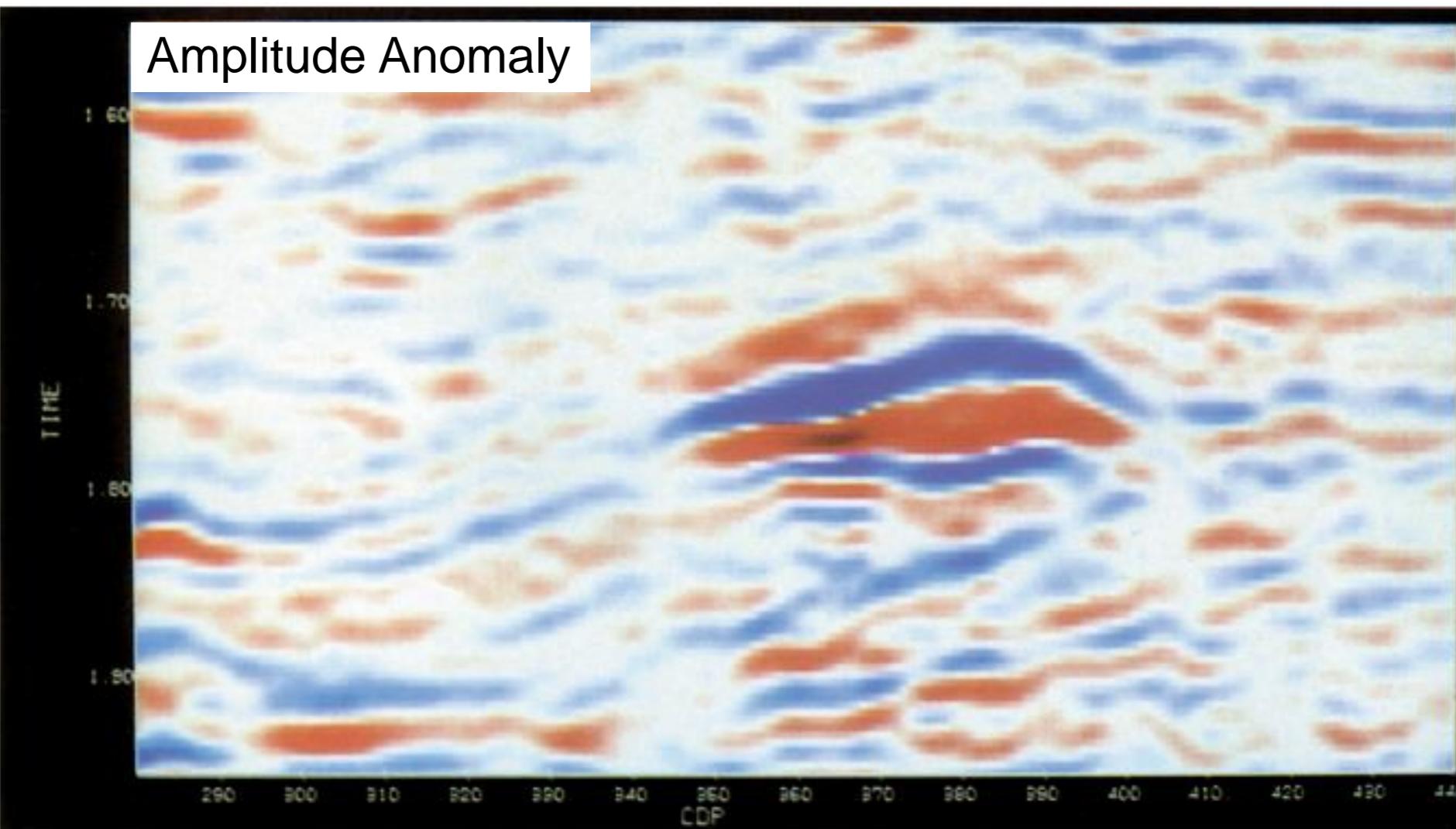
Fault interpretation



Interpretation

Direct Hydrocarbon Indicators (DHIs)

From: Brown (2011)



Interpretation

Derived Seismic Attributes (Seismic Inversion)

Layer 1

Velocity 1, Density 1 (v_1, ρ_1)

Incident
wave

Reflected
wave

Acoustic Impedance 1 = $v_1 \times \rho_1$

Interface

R = Reflection Coefficient

Velocity 2, Density 2 (v_2, ρ_2)

Transmitted
wave

Acoustic Impedance 2 = $v_2 \times \rho_2$

Layer 2

Low High

- Refl. Coeff. +

Seismic trace

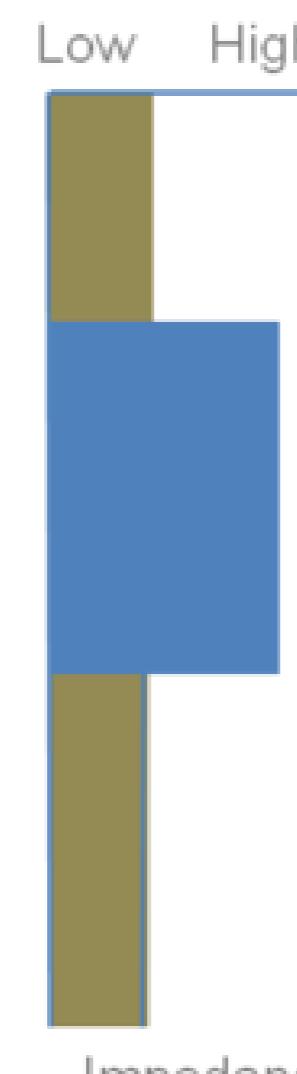
Many wiggle traces (seismic section)

$$R = \frac{(v_2 \times \rho_2) - (v_1 \times \rho_1)}{(v_2 \times \rho_2) + (v_1 \times \rho_1)}$$

Wavelet

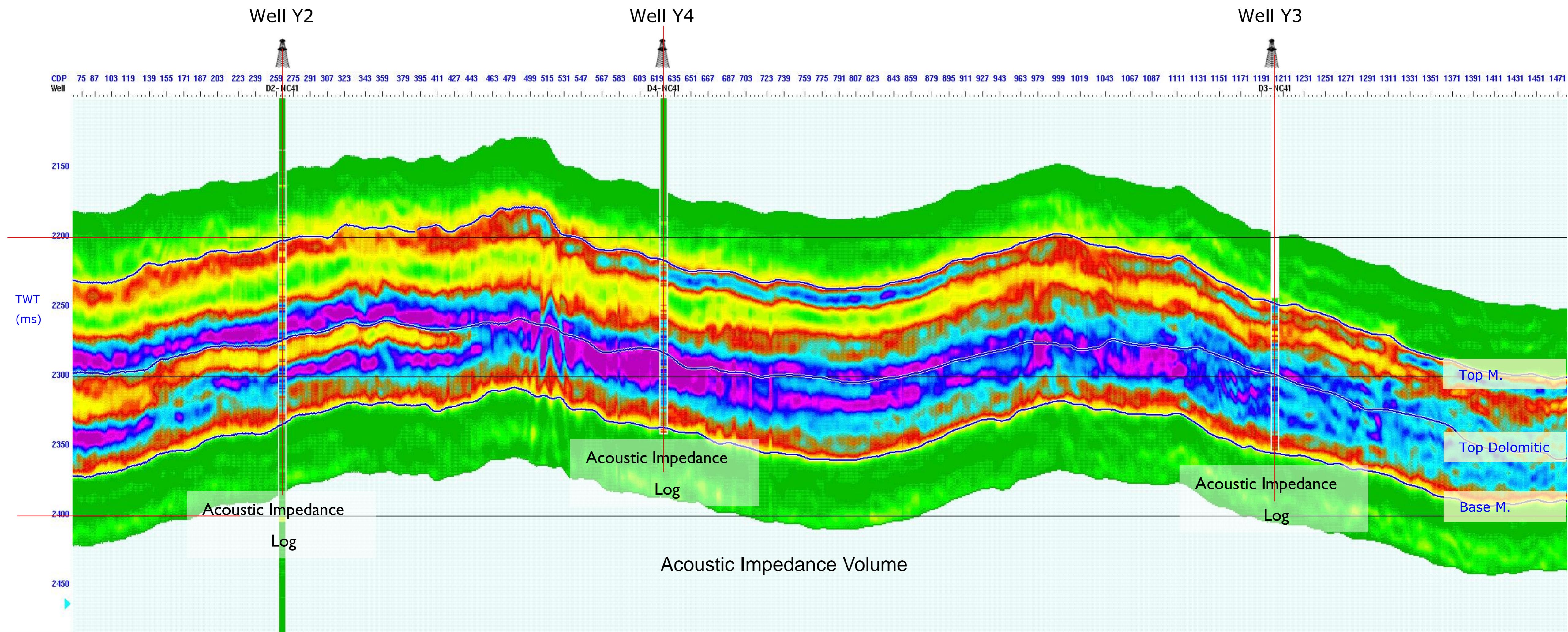
Sample interval

Wiggle trace



Interpretation

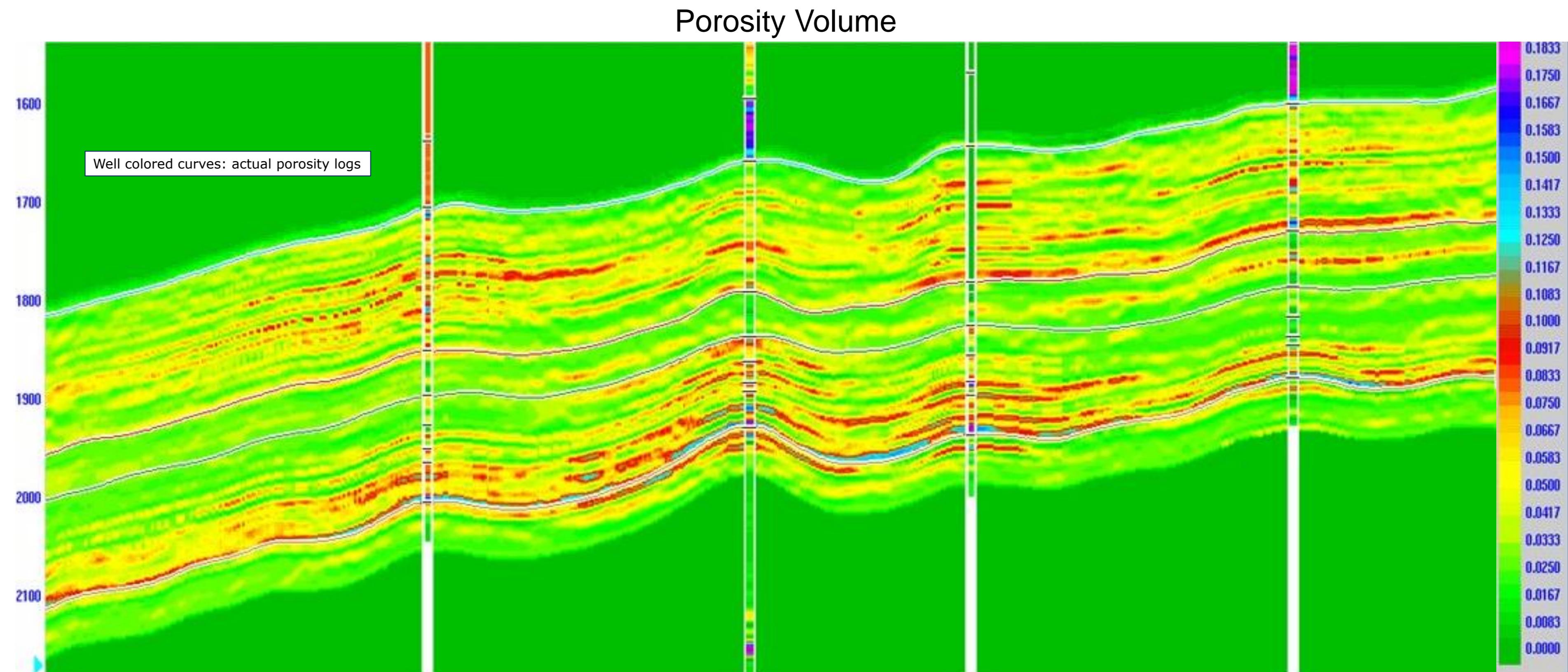
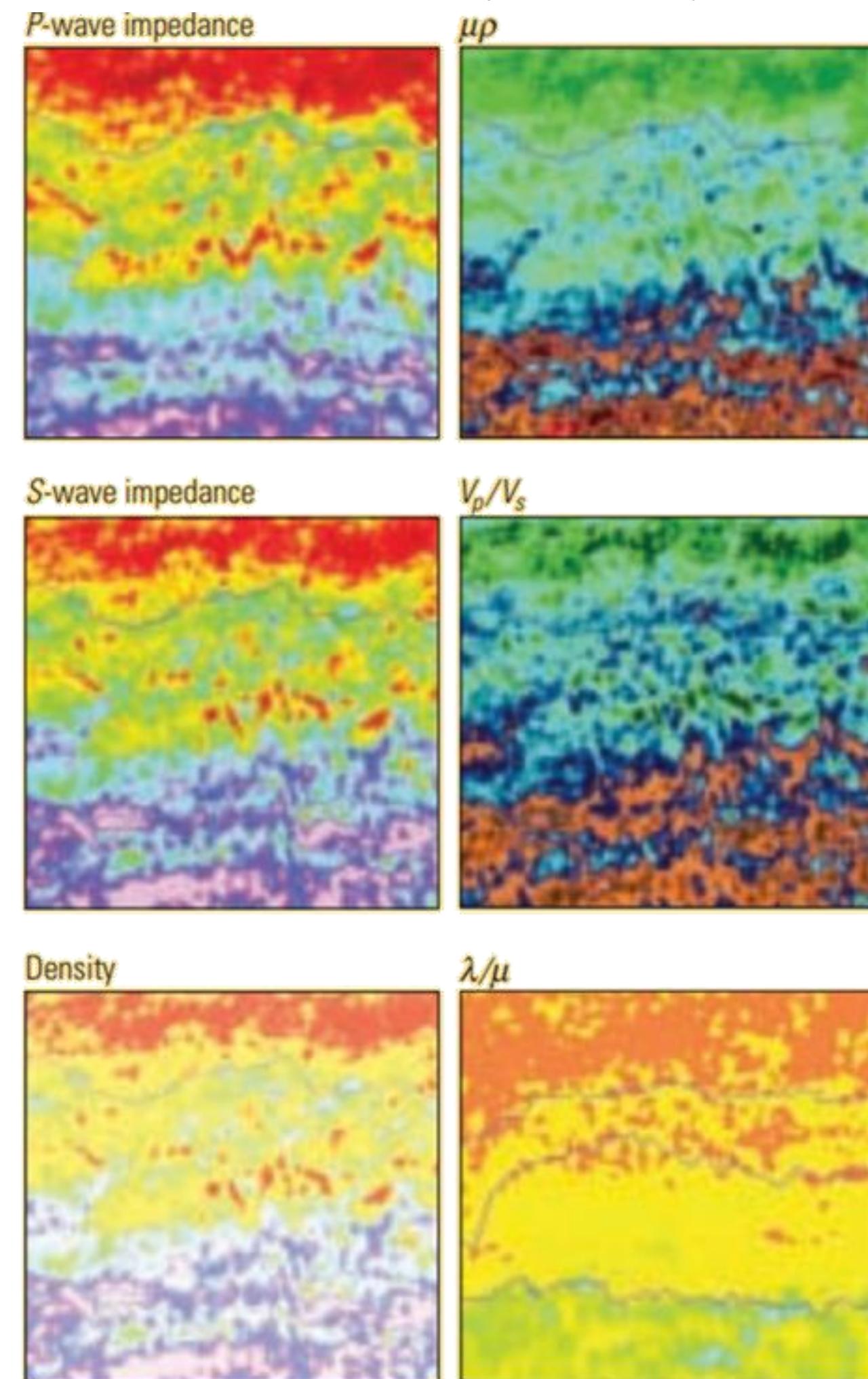
Derived Seismic Attributes (Seismic Inversion)



Interpretation

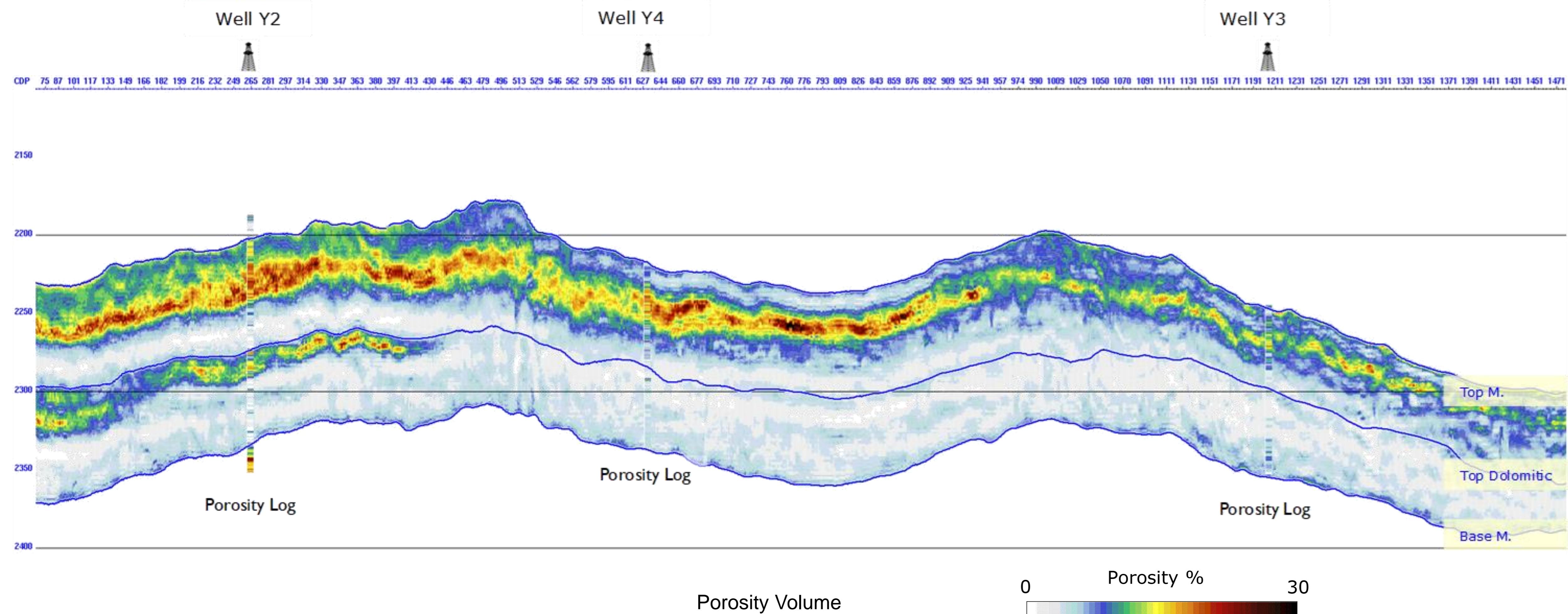
Derived Seismic Attributes (Seismic Inversion)

Seismic Inversion (Deliverables)



Interpretation

Calibration to Porosity



Seismic Data Interpretation

4. Seismic Interpretation for Geothermal

1. Seismic Interpretation general concepts

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- b. Well-to-Seismic Tie
- c. Depth conversion

2. Interpretation

- a. Geological understanding
 - i. Structural Settings
 - ii. Stratigraphy
 - iii. Geo-morphological features

- b. Interpretation workflow

- c. Interpretation Pitfalls

- a. We see only what we know
 - b. Biases

3. Seismic Attributes

4. Seismic Interpretation for Geothermal

5. ML in Seismic Interpretation

- a. Seismic Facies Clustering
- b. Supervised interpretation

Seismic Data Interpretation

Geothermal Energy Exploitation

Crucial Parameters:

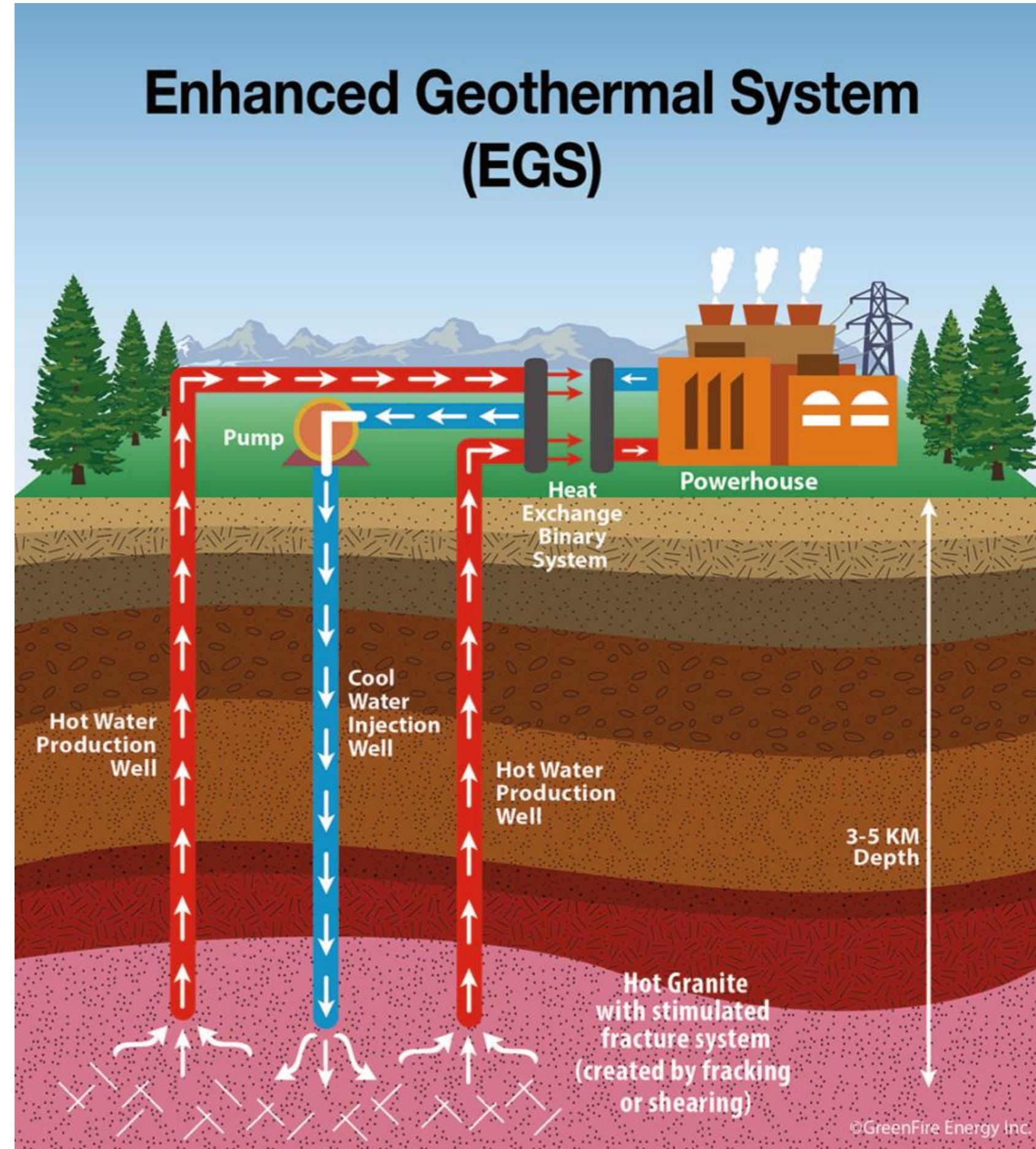
- a. Temperature
- b. Petrophysical properties of reservoir rocks
- c. Total dissolved solids (TDS)
- d. Fractures

Seismic Methods:

- a. Seismic Structural interpretation to define the reservoir volume (aquifer)
- b. Fault interpretation (to minimize drilling risks and to understand migration paths)
- c. Seismic Inversion (to assess the porosity of the rocks)

Main Issues:

- a. Onshore, so statics, velocity model, polarity



Seismic Data Interpretation

5. ML in Seismic Data Interpretation

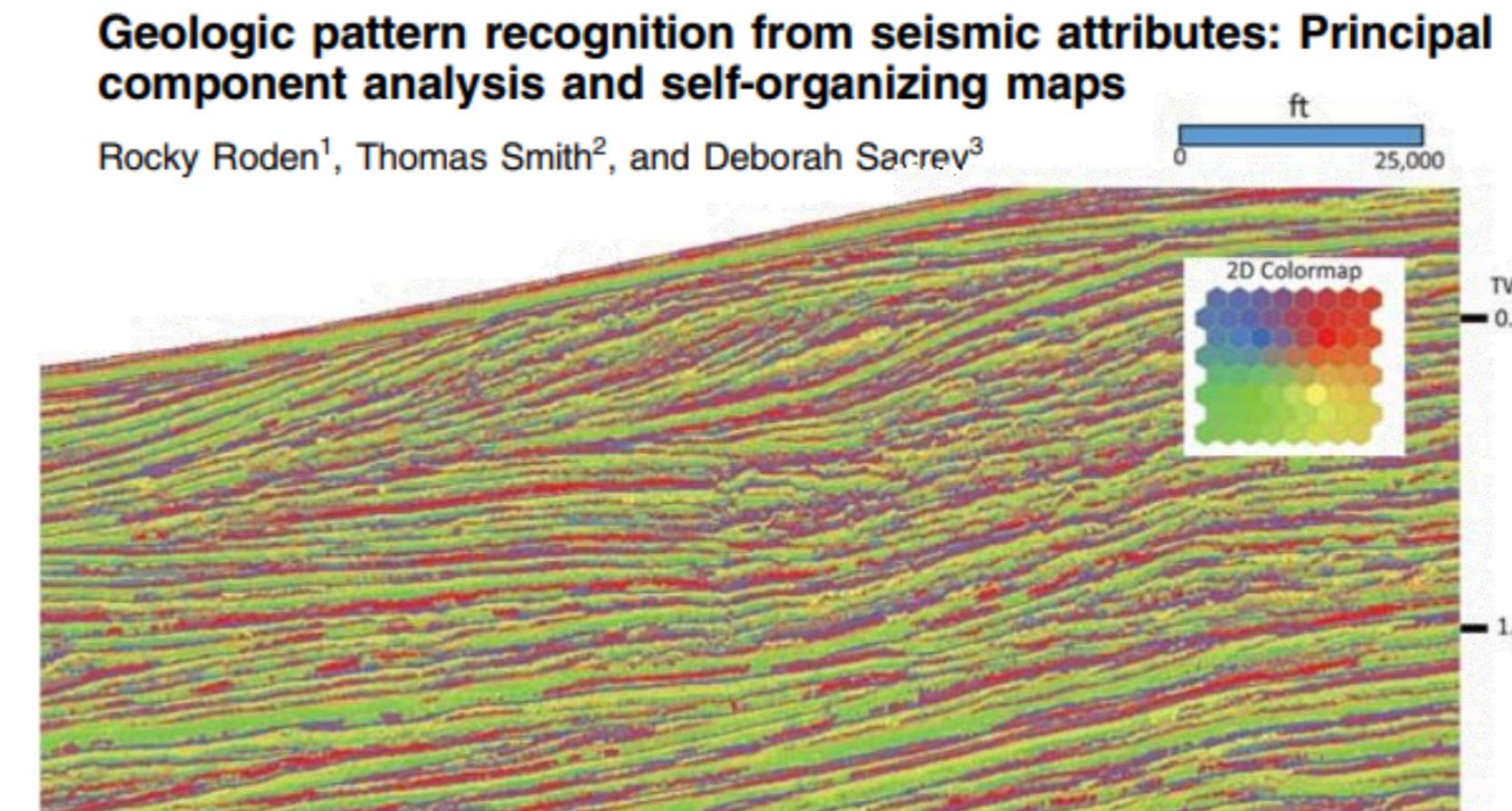
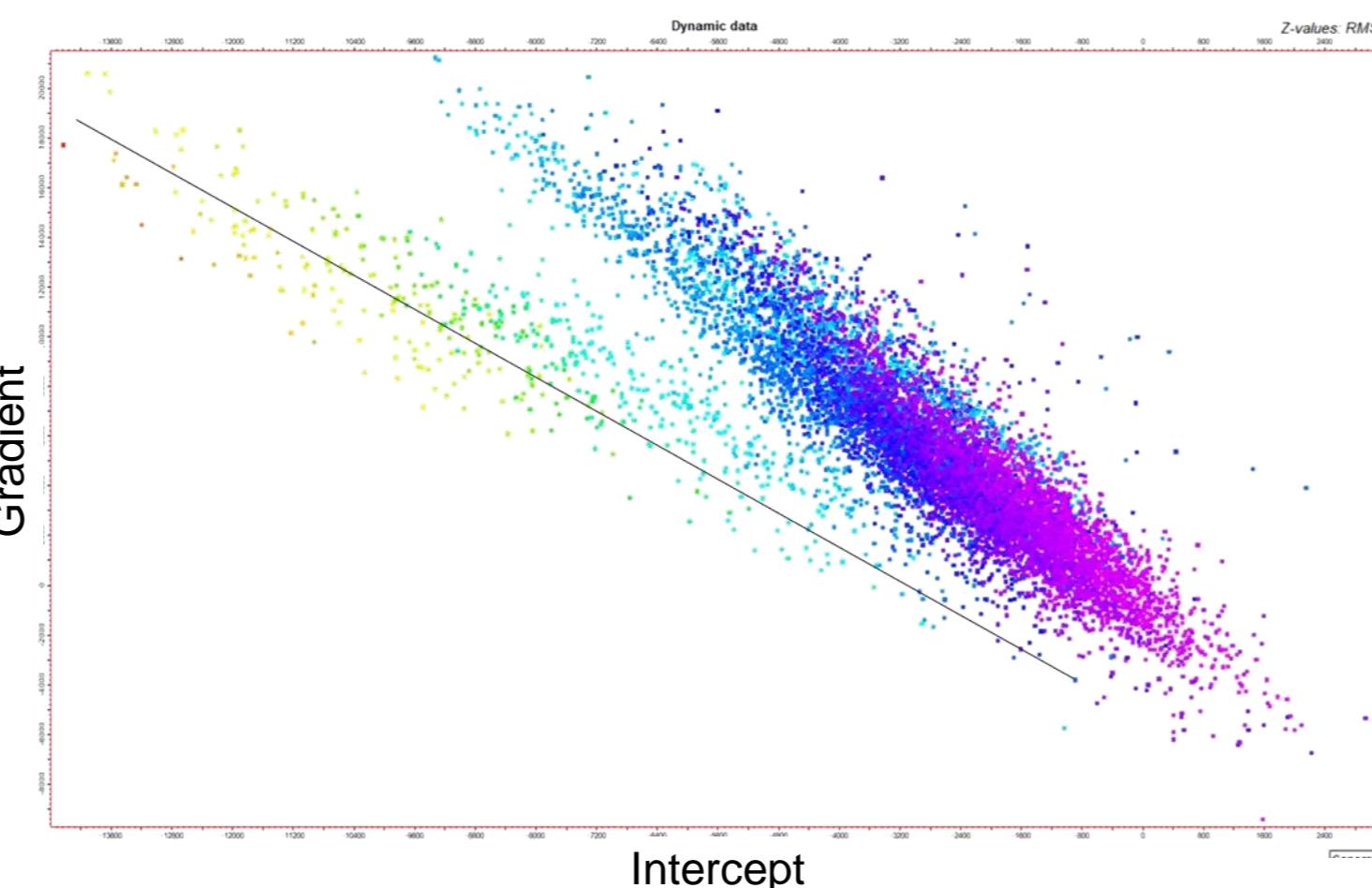
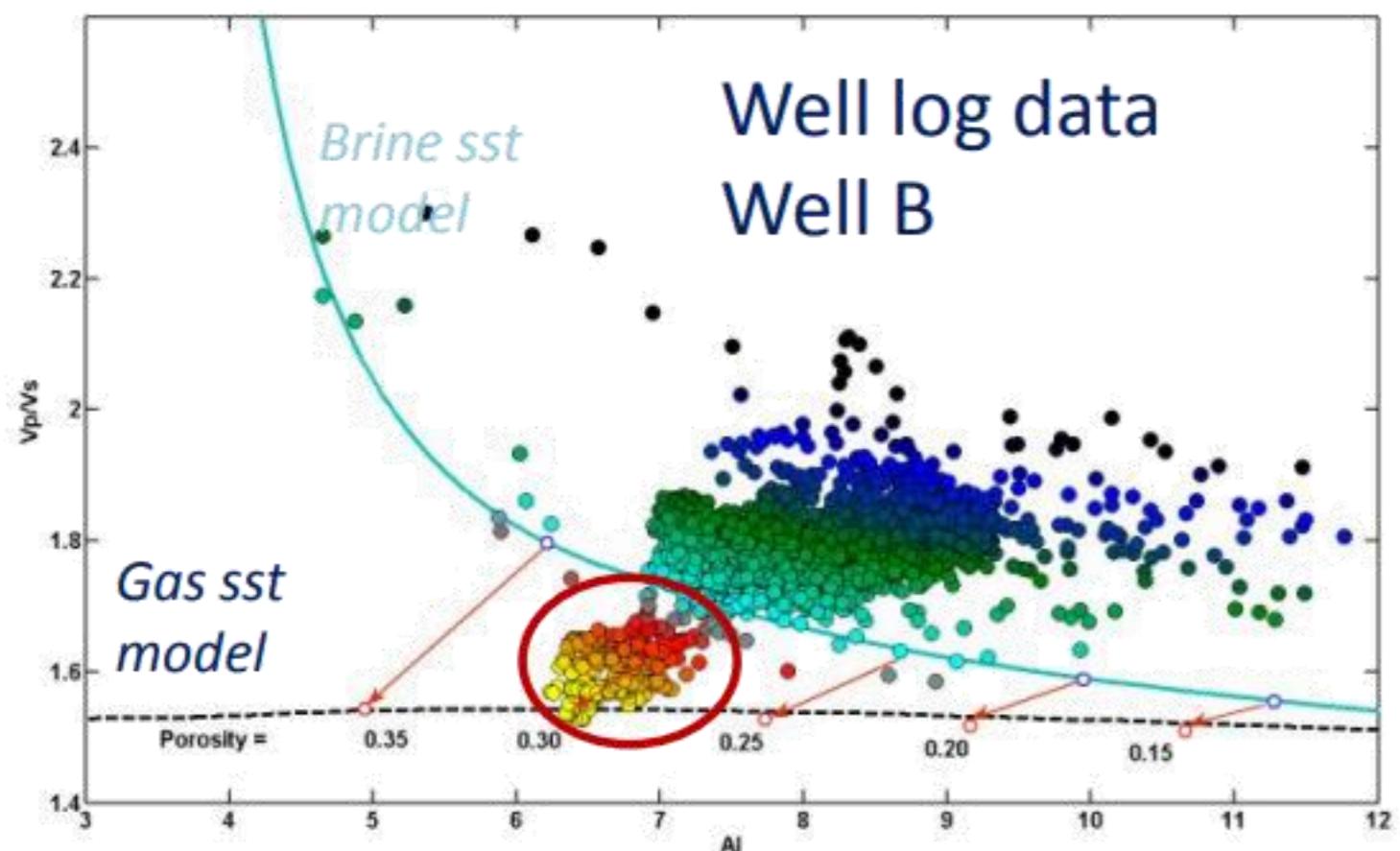
1. Seismic Interpretation general concepts
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4. Seismic Interpretation for Geothermal
- 5. ML in Seismic Interpretation**
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Seismic Data Interpretation

5. ML in Seismic Data Interpretation

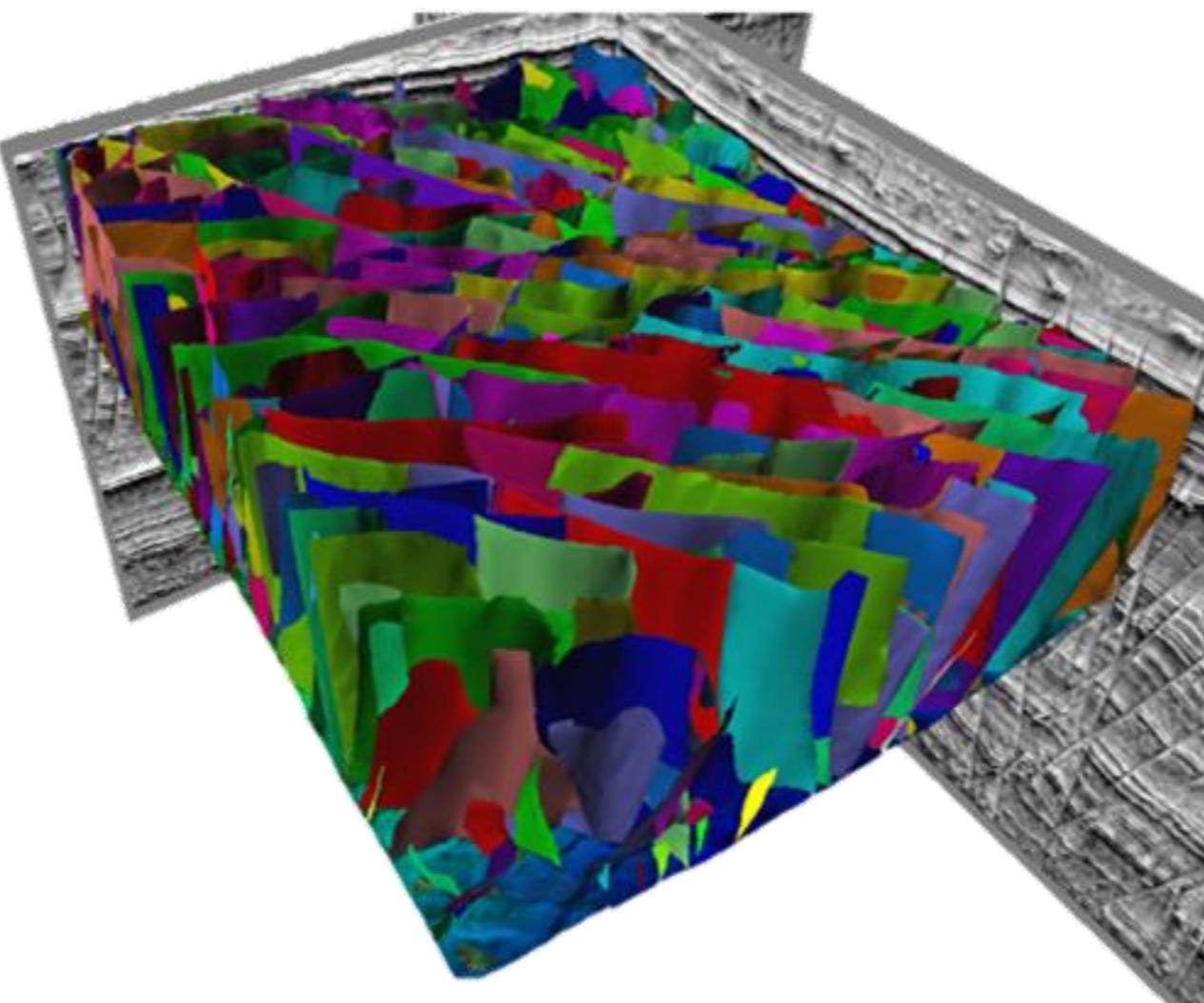
Two main approaches:

1) Clustering (unsupervised) – as geophysicists we have been doing this for ages



2) Deep Learning (supervised, interpretation)

- Automatic Fault extraction
- Horizon picking
- Salt Bodies Definition
- Etc...



Seismic Data Interpretation

Clustering

Many Seismic Attributes as input

In [7]: `df1.describe().transpose()`

Out[7]:

	count	mean	std	min	25%	50%	75%	max
(far-near)far	76297.0	-5.786031e+05	2.873776e+06	-3.289526e+07	-772663.13	-154209.02	257929.06	12609810.00
far-near	76297.0	3.004215e+03	2.262688e+03	-4.527140e+03	1370.93	2731.87	4423.61	14047.59
Gradient	76297.0	5.533468e+03	4.117813e+03	-9.428280e+03	2651.97	5079.96	8085.29	21682.78
Intercept	76297.0	-2.966421e+03	1.988745e+03	-1.422762e+04	-3925.64	-2681.89	-1660.25	3398.02
InterceptGradient	76297.0	-4.113261e+07	5.399059e+07	-5.127301e+08	-57111268.00	-21171642.00	-5388891.50	85893632.00
PImp	76297.0	6.473687e+06	1.630162e+05	5.967443e+06	6332898.50	6496215.00	6613183.50	6827914.00
PolProd	76297.0	-8.866563e+04	9.471527e+04	-9.078793e+05	-116415.75	-71607.19	-33137.16	348322.94
RMS	76297.0	1.700021e+03	1.059891e+03	8.637000e+01	1005.97	1496.30	2121.14	8900.62
Sweetness	76297.0	3.888598e+02	2.655760e+02	1.530000e+00	231.10	346.24	472.32	2231.48
VpVs	76297.0	2.144117e+03	3.925854e+01	1.998640e+03	2111.75	2138.08	2169.35	2226.94

What attribute to use?

- Feature selection
- What those features mean (geological understanding)
- Dimensionality reduction (PCA)

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Q&A



Italian Section



Netherlands Section



London Section



Romanian Section



Croatian Section



Central Ukraine Section



Geothermal Technical Section



Data Science and
Engineering Analytics
Technical Section

ENERGY

Geo Hackathon

Society of Petroleum Engineers

www.spehackathon-eu.com

#DatafyingEnergy



SPE Europe Region

