Frequency-Dependent Seismic Stratigraphy for High-Resolution Interpretation of Depositional Sequences*

Hongliu Zeng[1]

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[1]BEG, University of Texas at Austin, Austin, TX (hongliu.zeng@beg.utexas.edu)

Abstract

Seismic interpretation of stratigraphy and sedimentology is frequency or scale dependent. Classic seismic stratigraphy utilizes reflection patterns to identify depositional sequences and stratigraphic relationships. Further analysis of seismic facies (shape, configuration, amplitude, and continuity) leads to interpretation of lithology, facies, and depositional history of sequences. For study of large-scale sequences (hundreds of meters) where details are not crucial, this approach is highly effective. For high-resolution interpretation of depositional sequences (meters to tens of meters), however, details are key, and seismic-interpretation strategy should be changed accordingly.

Seismic events are a function of wavelet (frequency and phase) and acoustic impedance (AI) profile. Seismic interferences, or amplitude and frequency tuning effects, determine occurrence of seismic events and relationships among these events or seismic facies. By adjusting seismic frequency and phase, one can intentionally modify seismic facies to a certain degree. For high-resolution study, this adjustment may help optimize interpretation by reconditioning seismic events such that they selectively show thickness and AI distribution, stratigraphy, or depositional facies, depending on one's purpose.

Tests on model and field data clearly reveal the value of frequency-dependent seismic stratigraphy in reservoir-level interpretation of sequences. For example, an erosional surface (e.g., an incised valley) or a lithofacies of certain thickness may occur on a section only in a selected frequency band but "disappear" in other bands. A thin, lowstand deltaic system may be observed as high amplitude/ high-continuity facies in low-frequency bands but as low-amplitude/low-continuity facies in high-frequency bands. Broadbanded seismic traces tend to correlate better with wireline lithology/porosity logs in wells, especially when thickness and AI have significant lateral changes, whereas narrow-banded traces seem more closely to follow stratal surfaces. As a result, use of the multiple-band display would reduce ambiguity of geologic interpretation and risk in drilling.

References

Hentz, T. and H. Zeng, 2003, High-frequency Miocene sequence stratigraphy, offshore Louisiana; cycle framework and influence on production distribution in a mature shelf province: AAPG Bulletin, v. 87/2, p. 197-230.

Zeng, H., 2007, Seismic imaging for seismic geomorphology beyond the seabed; potentials and challenges, *in* R.J. Davies, H.W. Posamentier, L.J. Wood, and J.A. Cartwright (editors) Seismic geomorphology; applications to hydrocarbon exploration and production: Geological Society (London) Special Publication 277, p. 15-28.

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Hongliu Zeng
Bureau of Economic Geology
Jackson School of Geosciences
The University of Texas at Austin

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Outline

Frequency dependency of:

1. Seismic events
2. Seismic facies
3. Interpretation of stratigraphy, depositional systems, and reservoirs

Factors that control appearance of sequences and seismic facies

1. Reflection interference patterns (what seismic events and architectures look like)
2. Thin-bed tuning
    - *Thickness tuning*
    - *Frequency tuning*

Thickness tuning and frequency tuning

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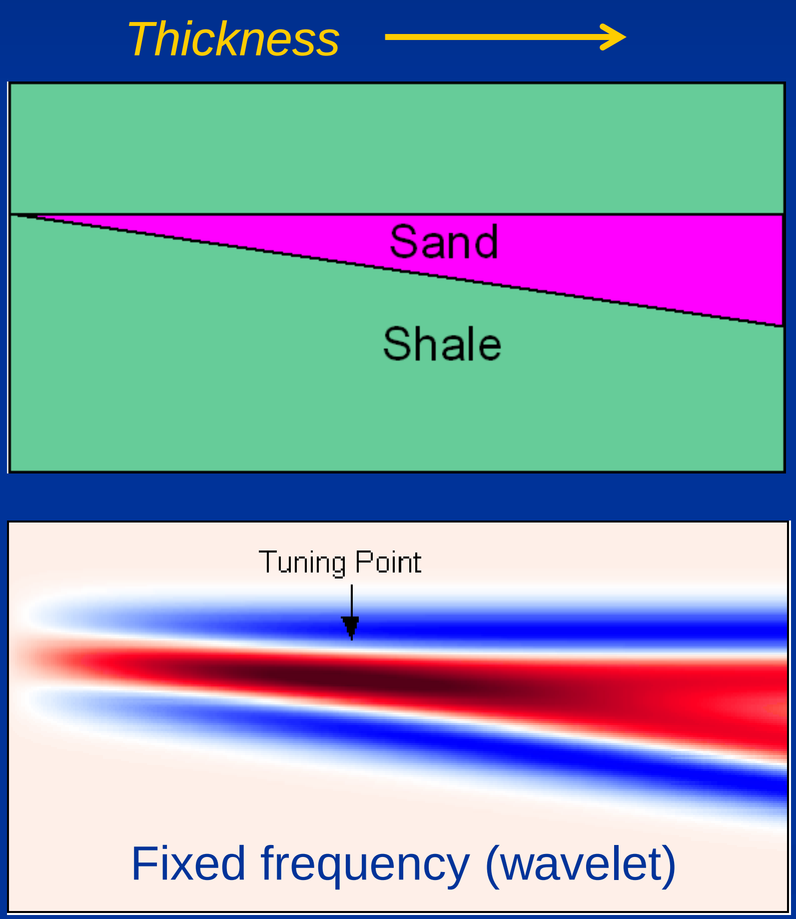
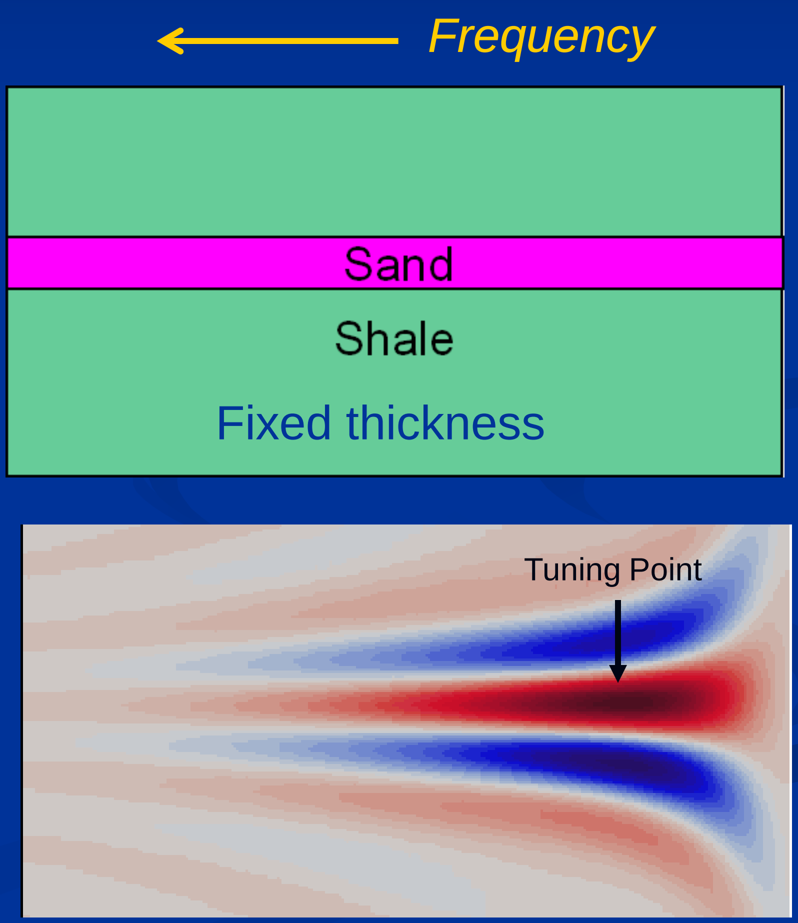
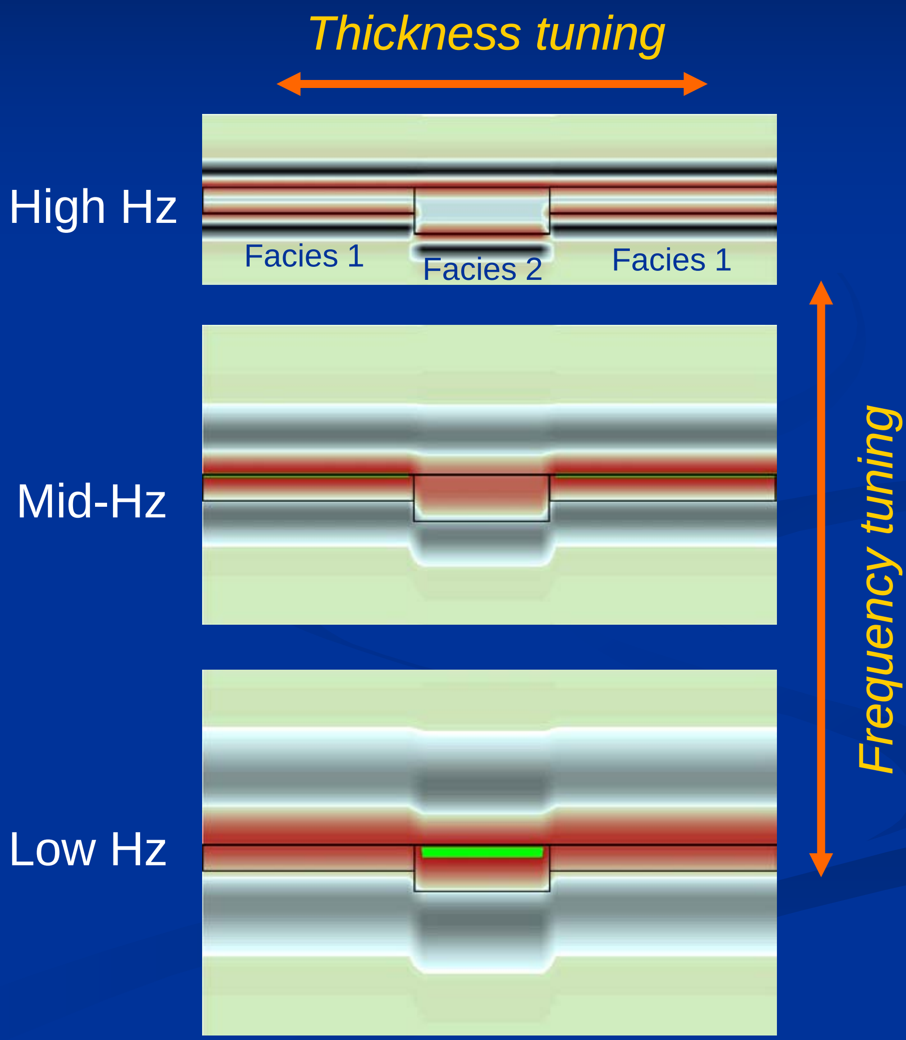
Thickness tuning



Frequency tuning



Reflection pattern and amplitude as a function of both thickness and frequency

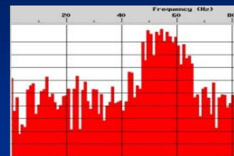


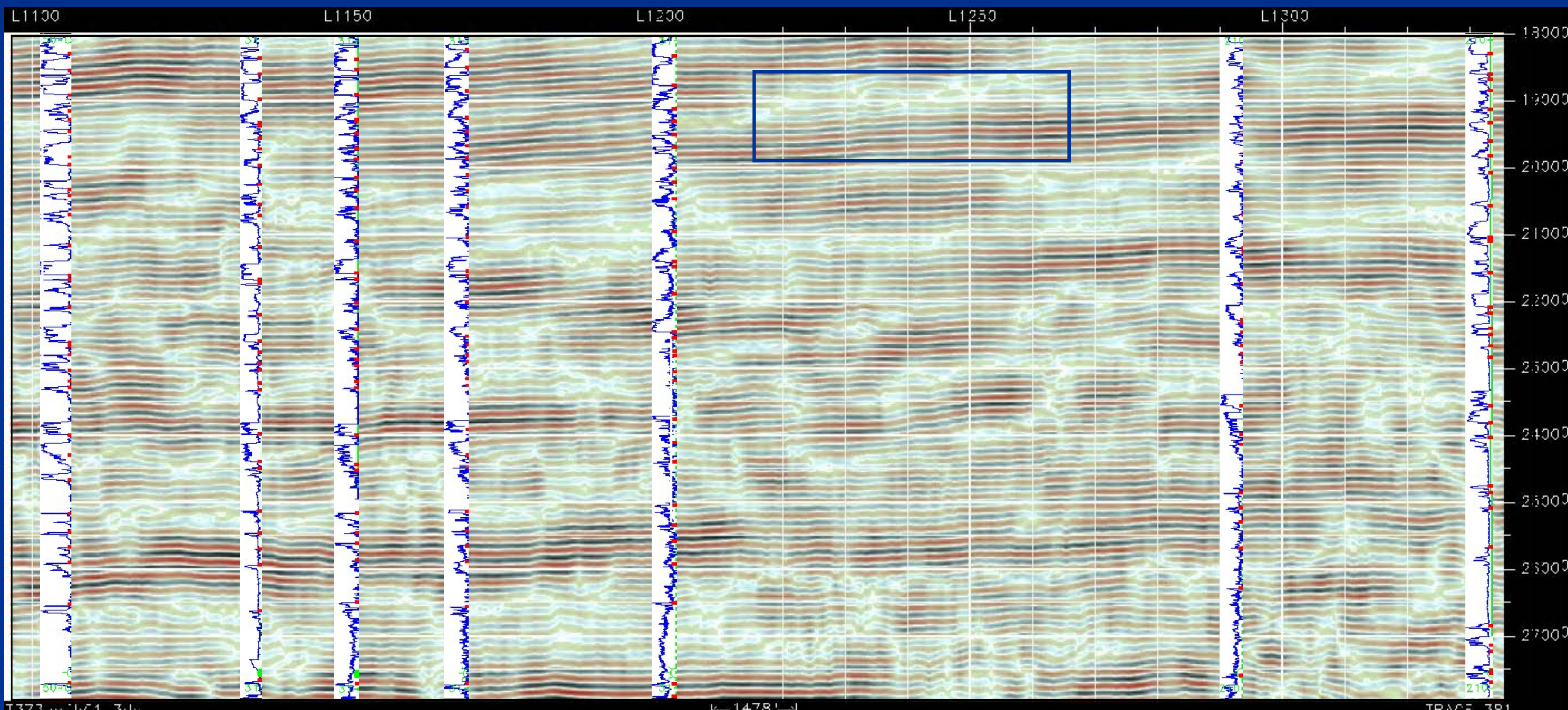
Factors that control frequency tuning

1. Predominant frequency
2. Bandwidth

Predominant frequency vs. seismic
(30–55 Hz)

30 Hz

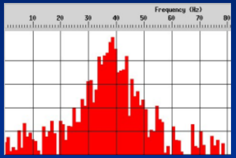


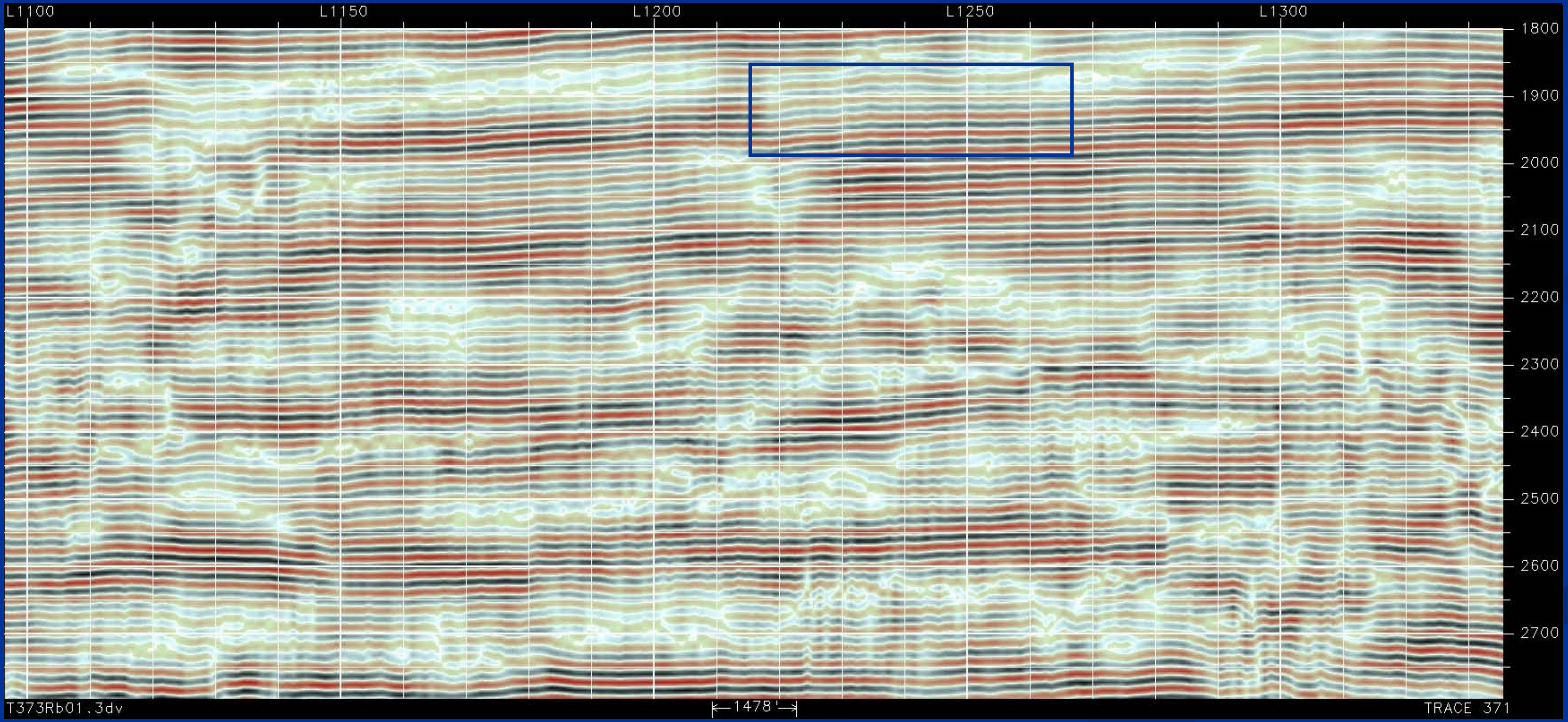


1 km

Bandwidth vs. seismic (same predominant frequency)

Band 1—poststack





1 km

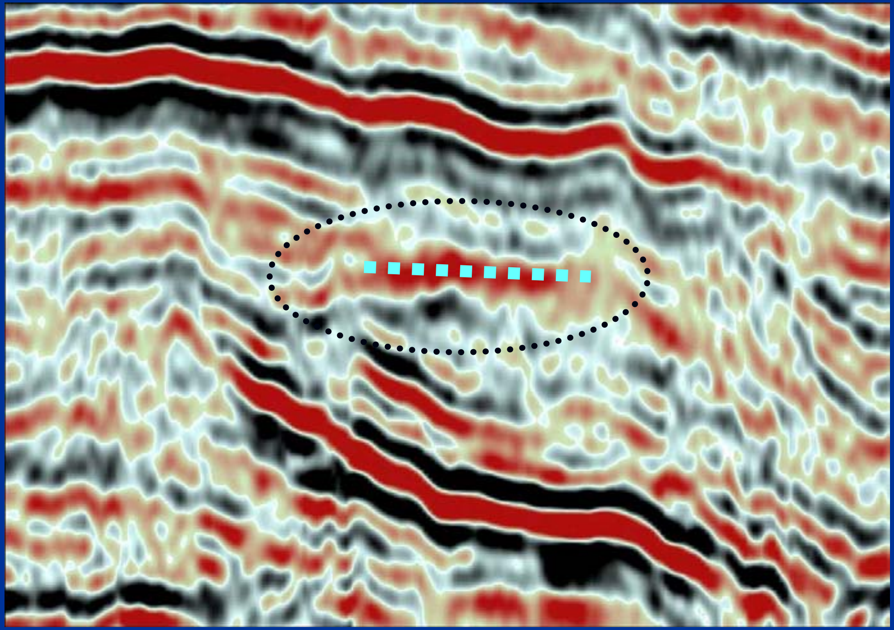
Consequences of frequency dependency

1. *Time transgression:* a seismic event may or may not follow geologic time surfaces

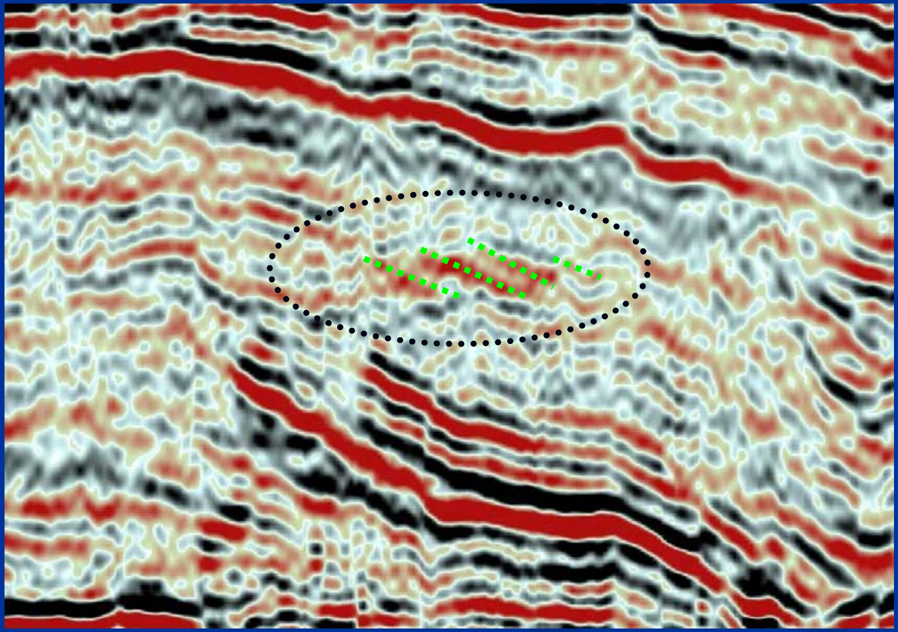
2. *Uncertainty of seismic facies:* changes in frequency (not geology!) may lead to different seismic facies

Frequency dependency of geologic time-line

Low frequency--lithofacies



High frequency—time units

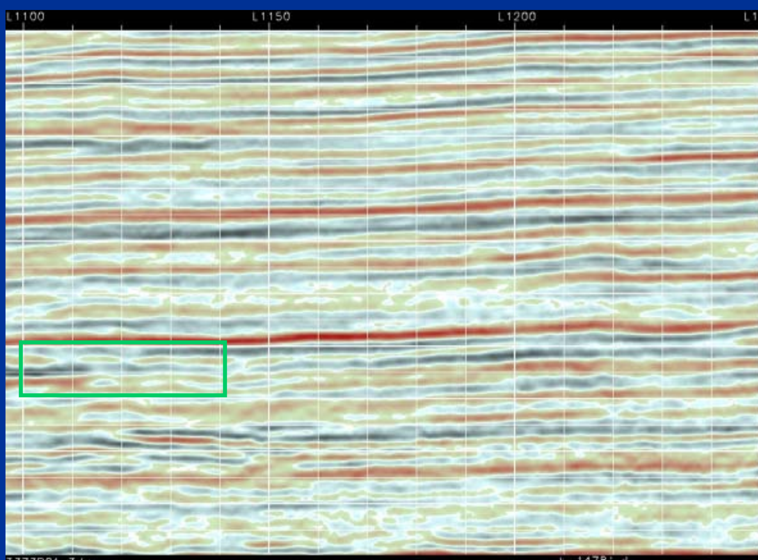


500 m

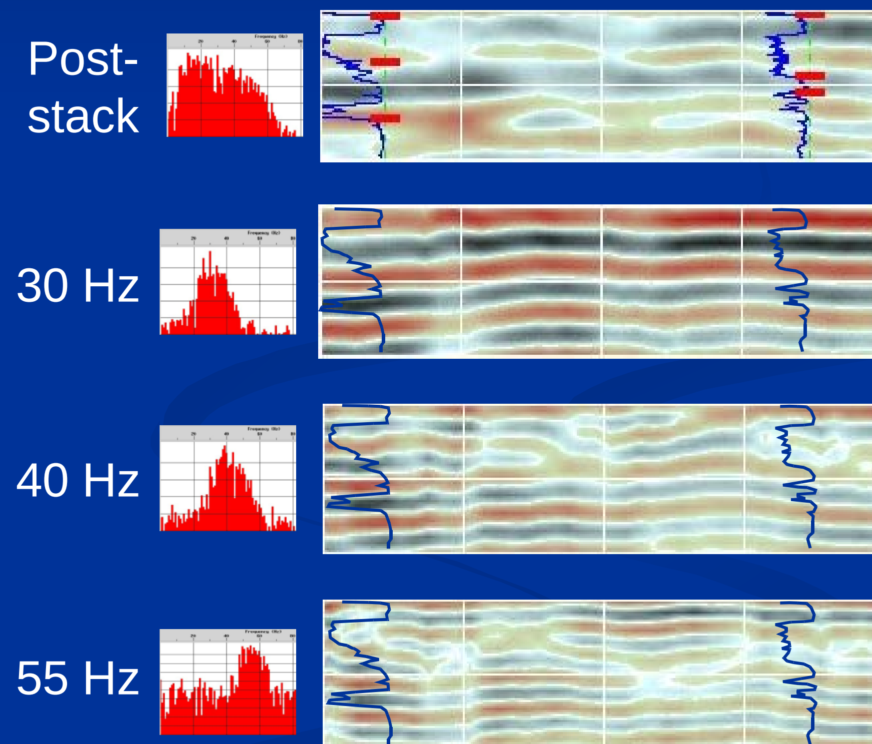
50 ms

Frequency dependency of seismic facies

Poststack



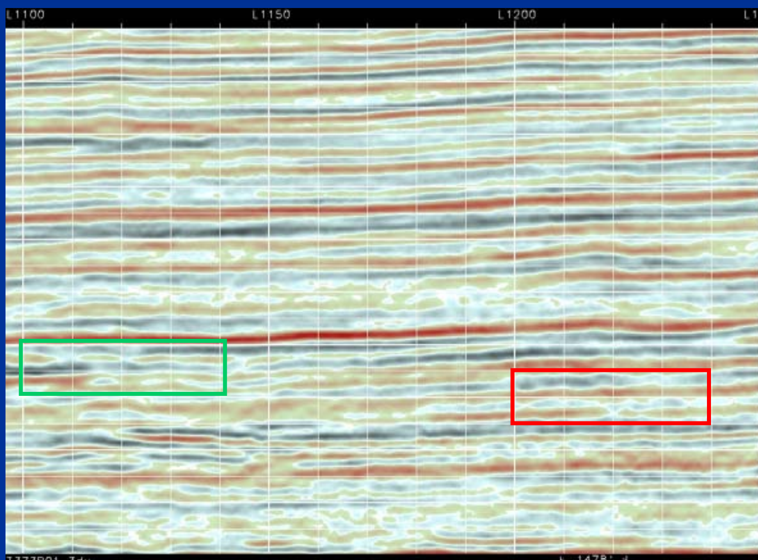
1 km



500 m | 50 ms

Frequency dependency of seismic facies (cont.)

Poststack



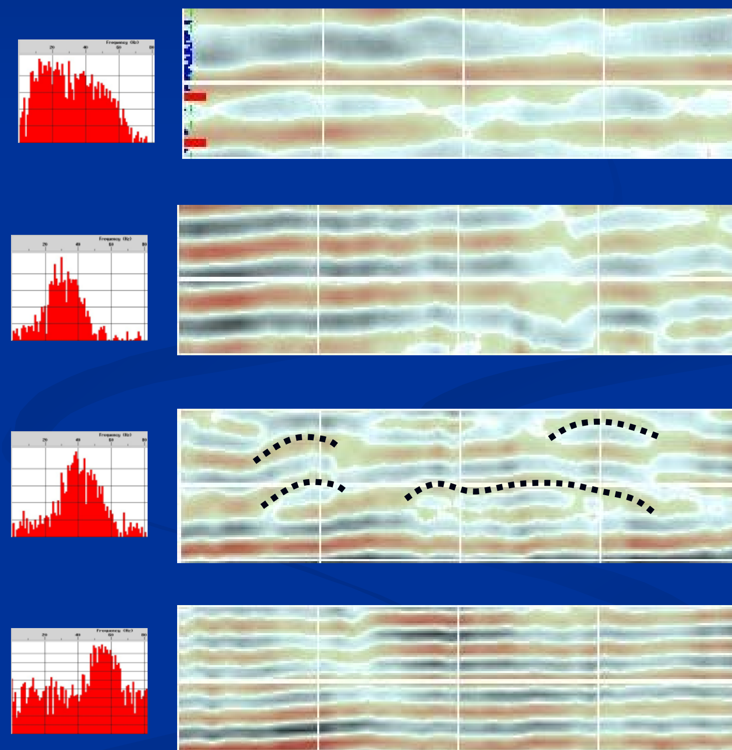
1 km

Post-
stack

30 Hz

40 Hz

55 Hz



500 m

50 ms

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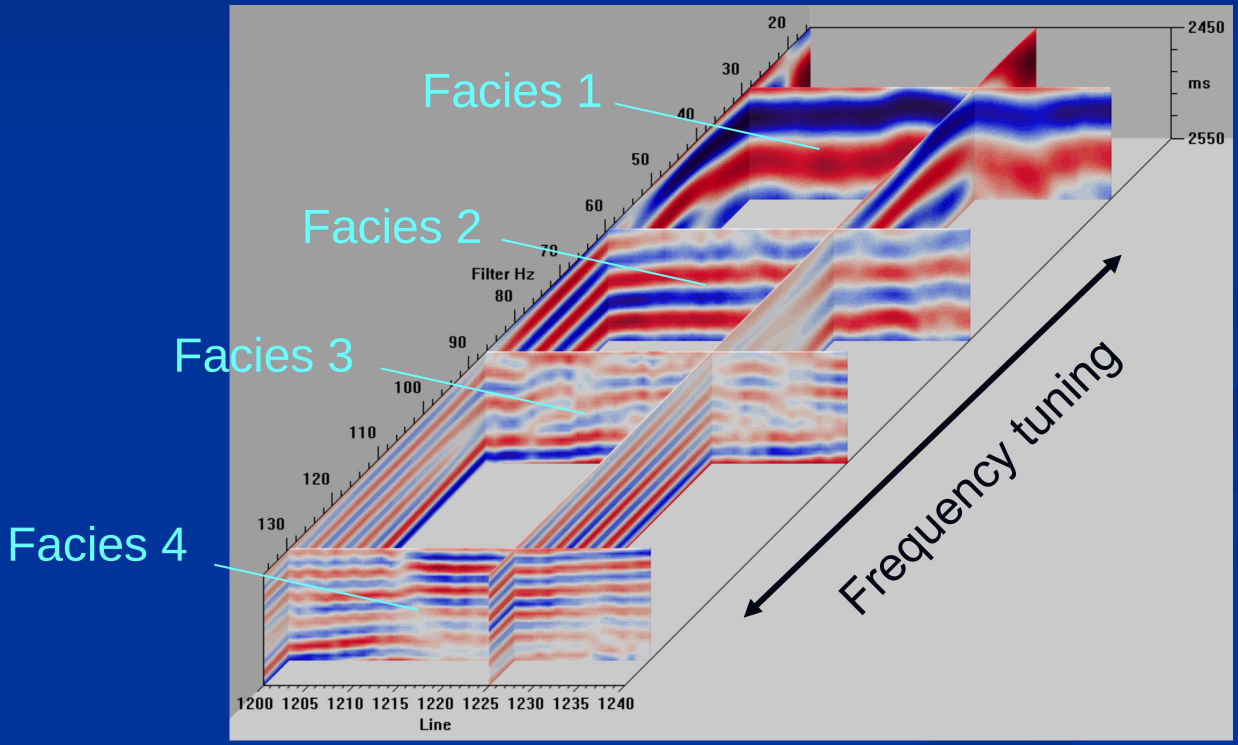
Seismic facies: selective imaging governed by thickness/frequency tuning



Thickness tuning

Tools for selective imaging

Amplitude-versus-frequency (AVF)
Simple form: panel filtering

- Digital filtering (FFT and others)
- Spectral decomposition
- Wavelet transform

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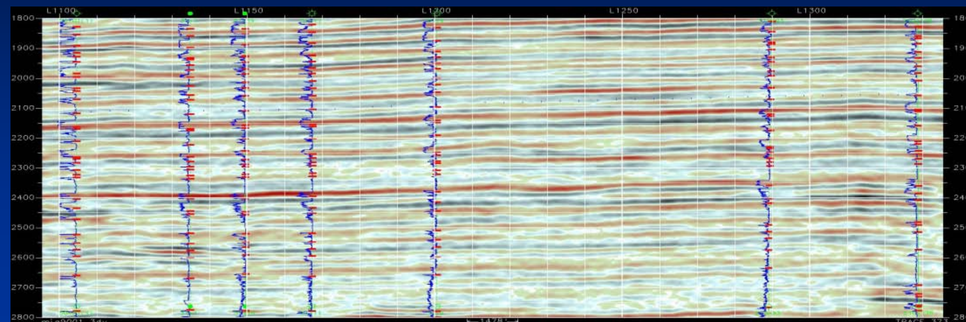
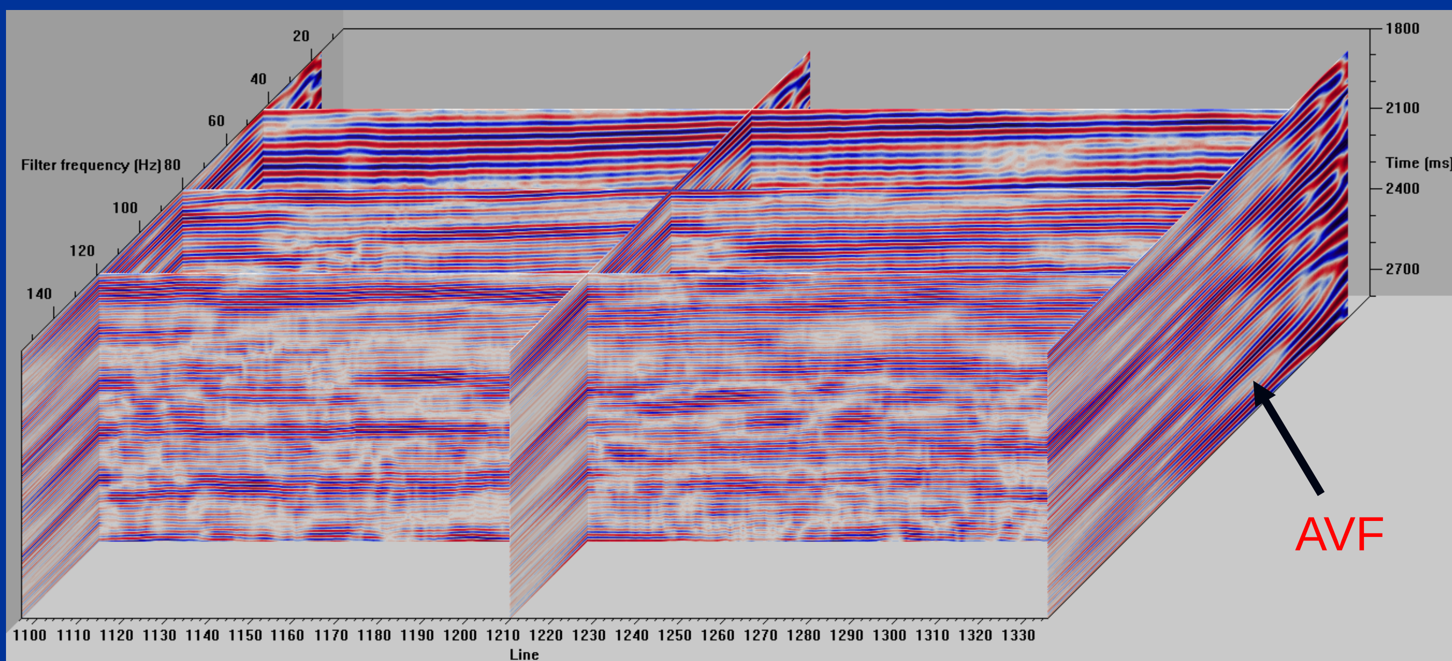
Expand data to a new dimension!

2D
↓
3D



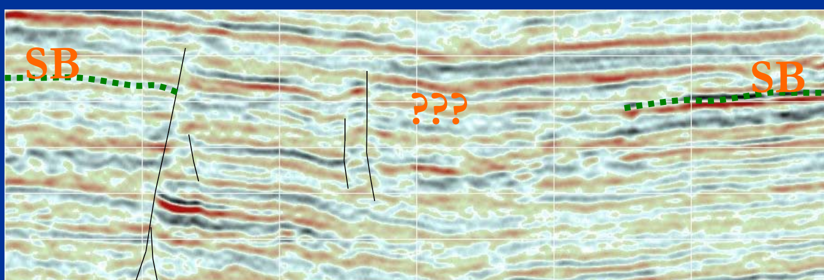


Application: selective imaging of:

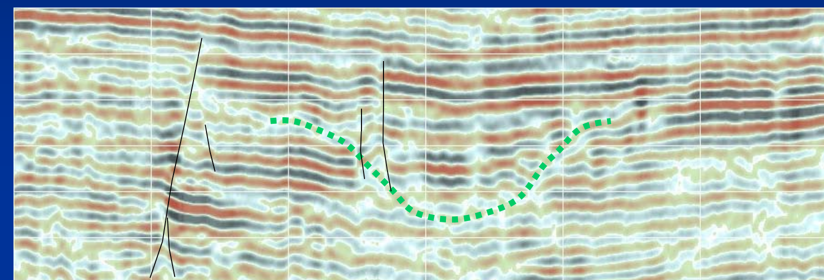
1. *Geologic-time surfaces*
2. *Seismic sedimentology/geomorphology*
3. *Seismic facies* for geobody
4. *High-freq. sequence stratigraphy*

1. Scan for erosional surface (SB)

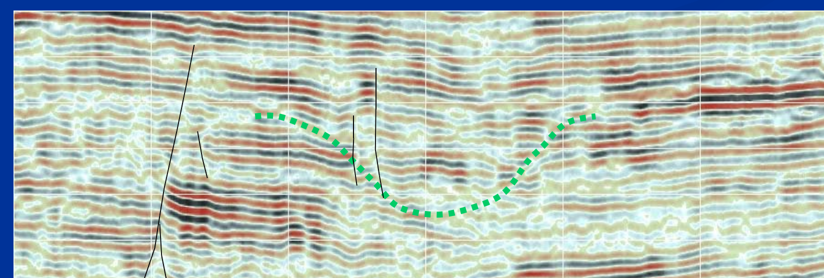
Poststack



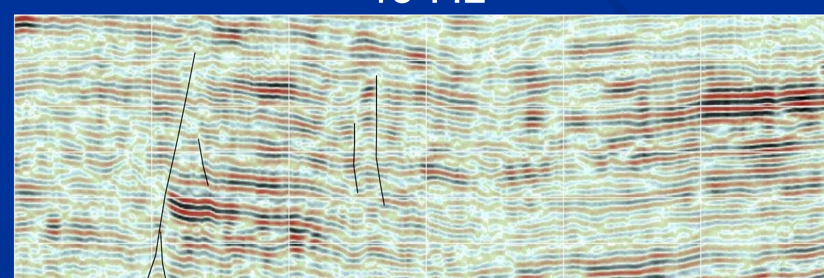
20 Hz



30 Hz

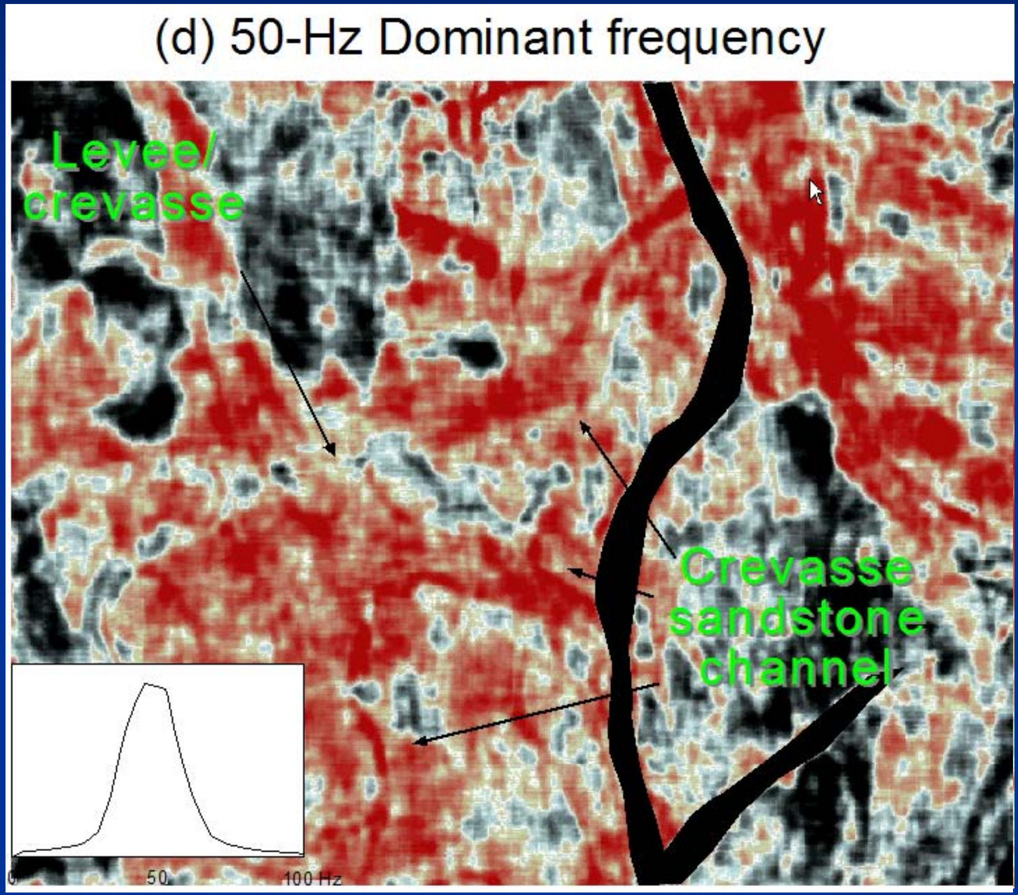


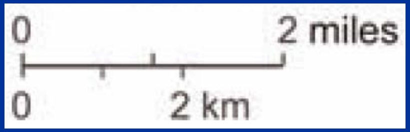
40 Hz



500 m | 100 ms

2. Seismic sedimentology (stratal slice)

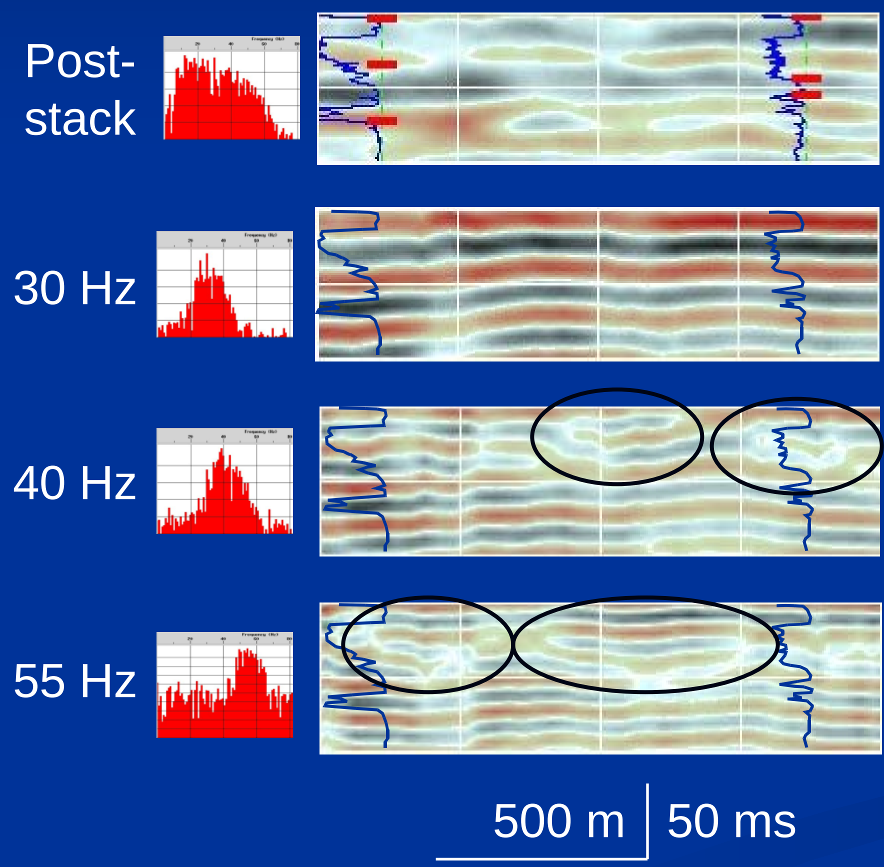




Tuning thickness
20 m
16 m

Zeng (2007)

3. Seismic facies for identifying depositional elements

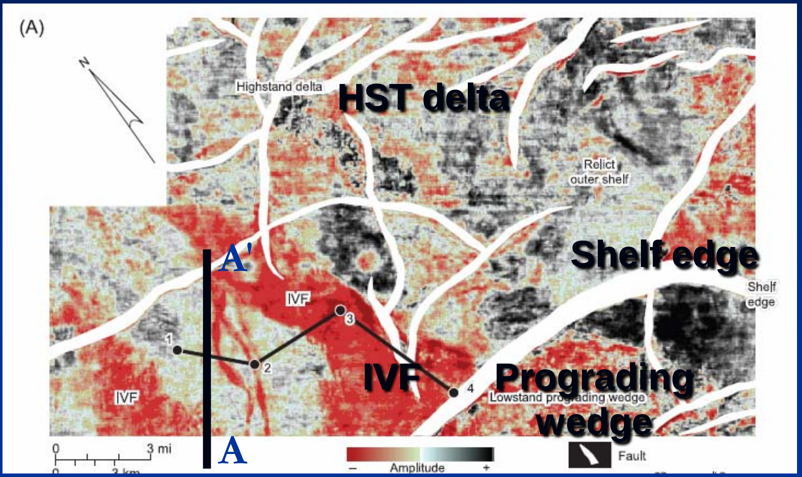


Log pattern:
Upward-coarsening, deltaic sediments

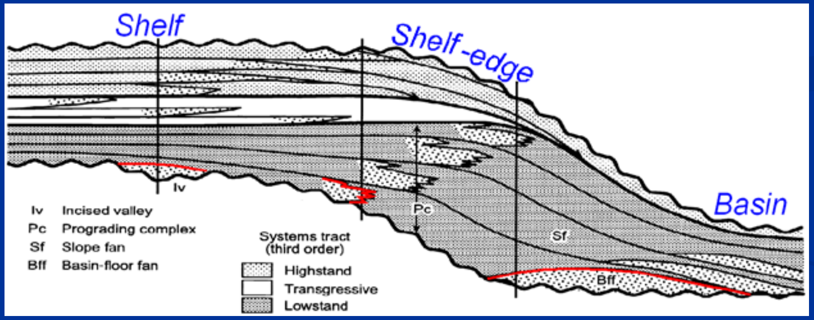
Expected seismic facies:
Clinoforms, lobes, channel form

4. Sequence Stratigraphy: shelf edge

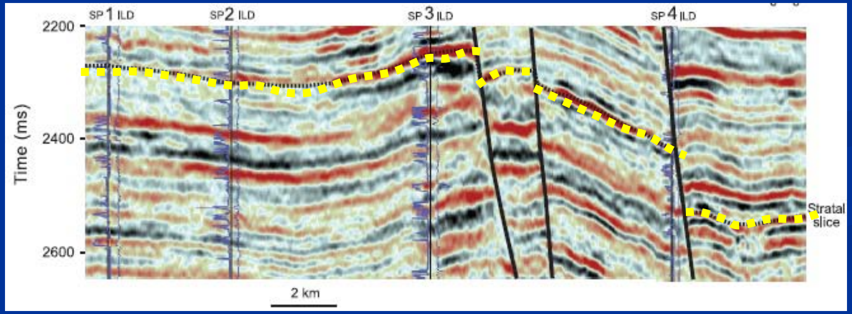
Systems tracts on stratal slice



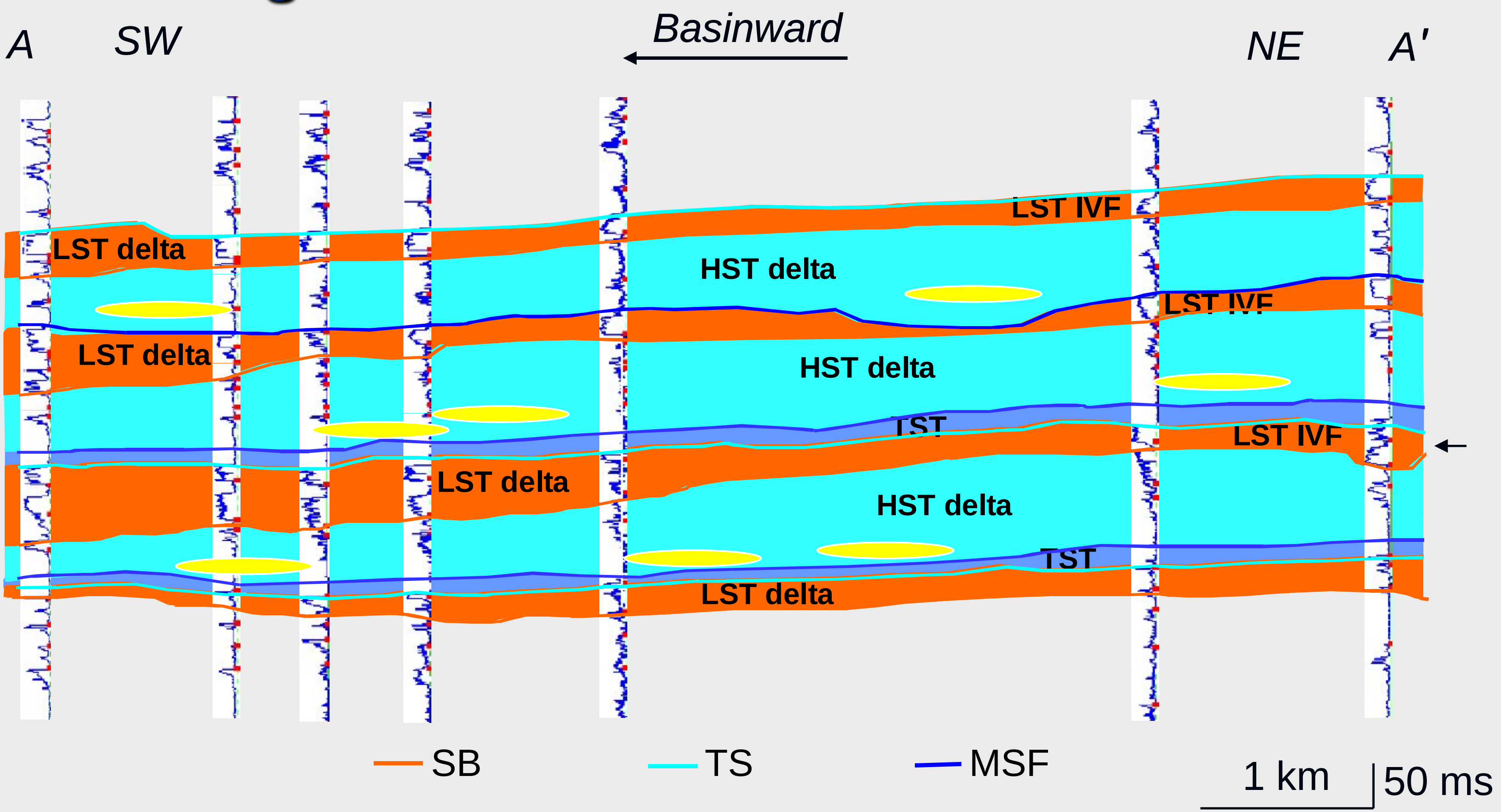
Sequence model
(Hentz & Zeng 2003)



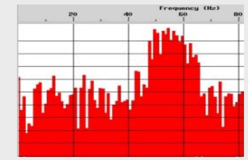
Seismic correlation



High-frequency sequences/systems tracts: wireline-log correlation

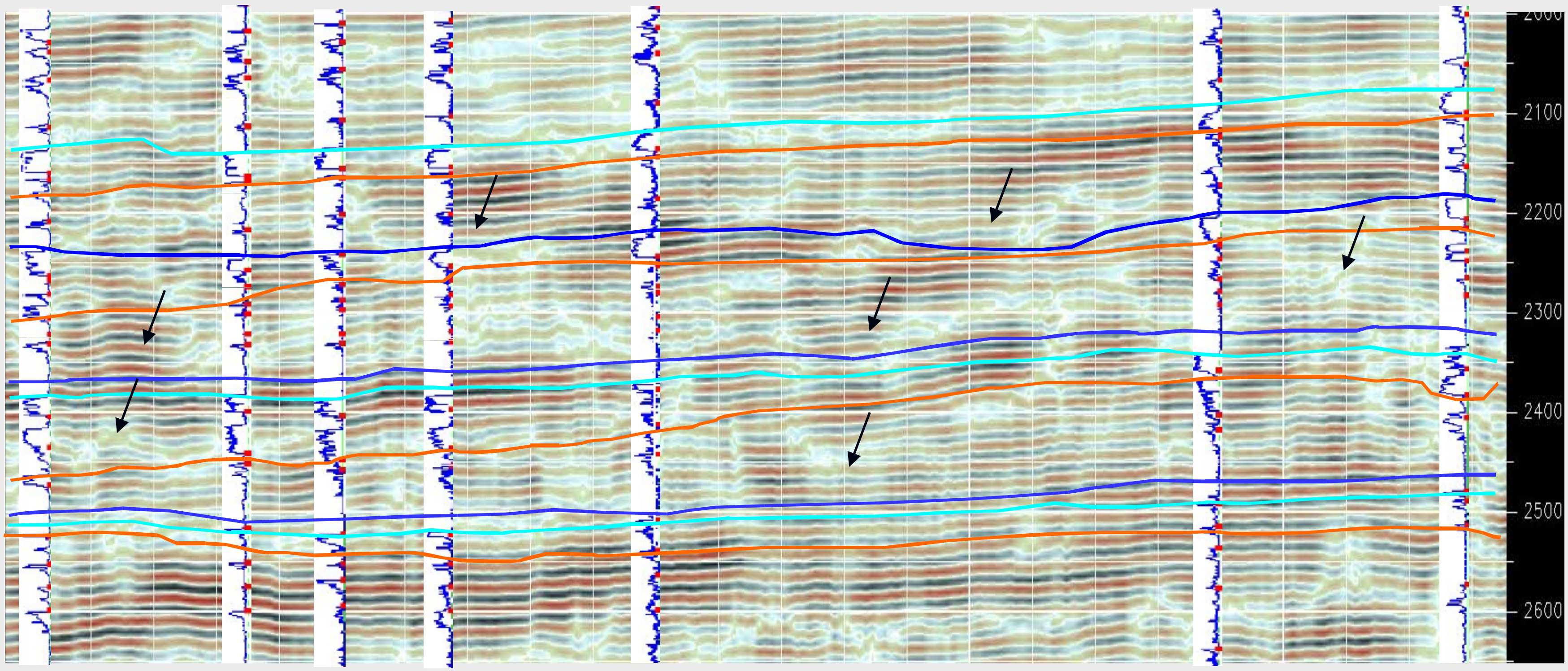


High-frequency sequences/systems tracts: verified by seismic



Poststack

Basinward



Conclusions

1. Seismic tuning includes thickness tuning and frequency tuning. *Frequency tuning is underutilized*.

2. Both seismic events (surfaces) and seismic facies are frequency dependent.

3. Seismic stratigraphy is incomplete (half done) if its frequency dependency has not been studied.

Challenges and future work

1. Frequency dependency as a function of lithology, rock properties, and water saturation
2. Frequency dependency of seismic attributes
3. Better data processing and interpretation tools

Acknowledgments

1. Texaco Inc. (now Chevron) provided well/seismic data

2. Landmark Graphics provided seismic interpretation software