Revitalizing Seismic Facies Analysis*

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Abstract

In sedimentary basins worldwide, numerous 2D seismic lines and 3D seismic volumes have been acquired for hydrocarbon exploration and development. However, seismic stratigraphic interpretation is traditionally based on physical appearance of stacked and migrated reflection events. As presented in a series of papers in AAPG Memoir 26 in 1977, Vail and his colleagues showed how reflection configurations, external geometry, and statistical characteristics of amplitude, frequency, continuity, etc., could infer depositional systems. Nonetheless, the interpretations are largely geologic model driven, and the results are deemed to be qualitative and non-unique for the lack of lithological identification of sedimentary rocks in the system. In practice, well calibration could provide lithofacies information near well sites, which, however, is difficult to populate in long distance.

A quick and efficient interpretation of lithology on the basis of rock impedance model is the key to improve seismic facies analysis. To understand how a seismic signal responds to thin-bedded depositional elements in the context of impedance stacking pattern is essential; it is a function of thickness, wavelet phase, and frequency. Basic methods include (1) adjusting wavelet phase for the best fit between seismic traces and a wireline log-measured sandstone unit without seismic inversion; typically -90° phase trace is our choice because it provides symmetrical waveforms for a seismically thin bed and thus has the best correlation with wireline lithologic logs (e.g., gamma ray), and (2) performing frequency recomposition to expand the range of sandstone thickness imaging of seismic events by detuning amplitude from the single tuning point at a quarter wavelength. As a result, new seismic profiles can either keep as wiggle trace form with lithological labeling, which is familiar to geologists, or be displayed in RGB color-blended sections for more lithofacies details.

With a proper software tool, the methodology has a potential to revitalize seismic facies analysis by making use of millions of idled seismic lines for renewed exploration efforts. Examples from marine (GOM) and non-marine (Bohai Basin in China) basins will be presented.

Selected References

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Revitalizing Seismic Facies Analysis

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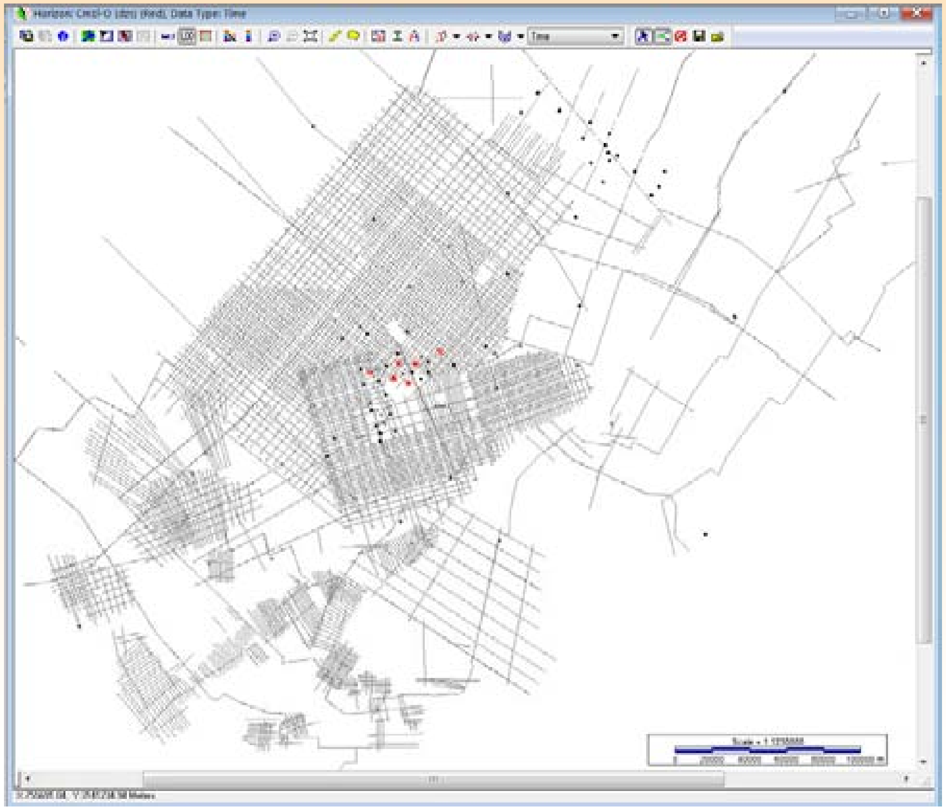
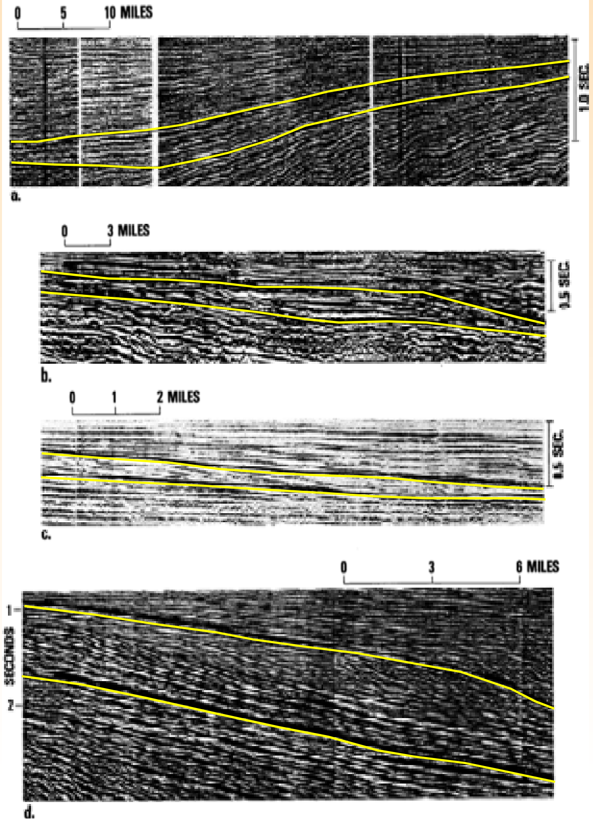
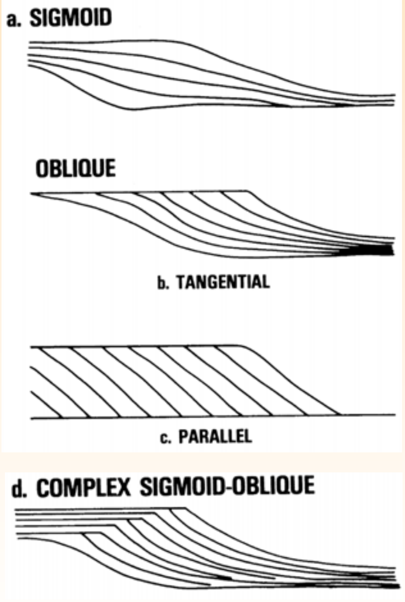
Seismic facies analysis: go beyond structural mapping





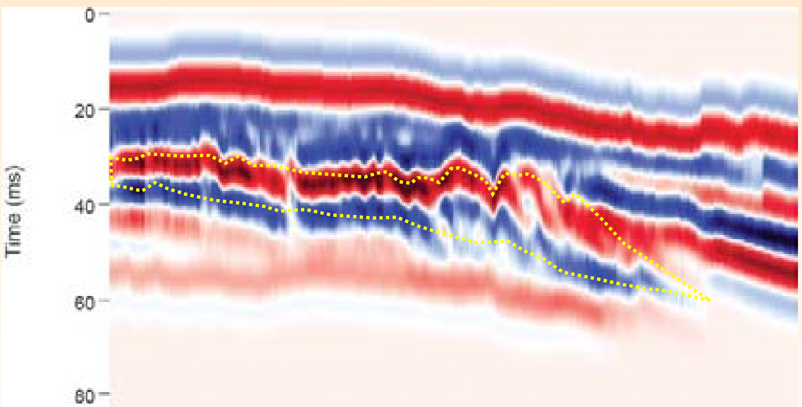


(Mitchem et al., 1977)

What is seismic facies?

- Seismic facies are mappable three-dimensional seismic units whose parameters differ from adjacent units.

–Modified from Wikipedia



1. External geometry (thickness)
2. Internal parameters (configuration, continuity, amplitude, frequency, etc.)

- According to Vail et al. (1977), seismic facies is the seismic expression of depositional facies.

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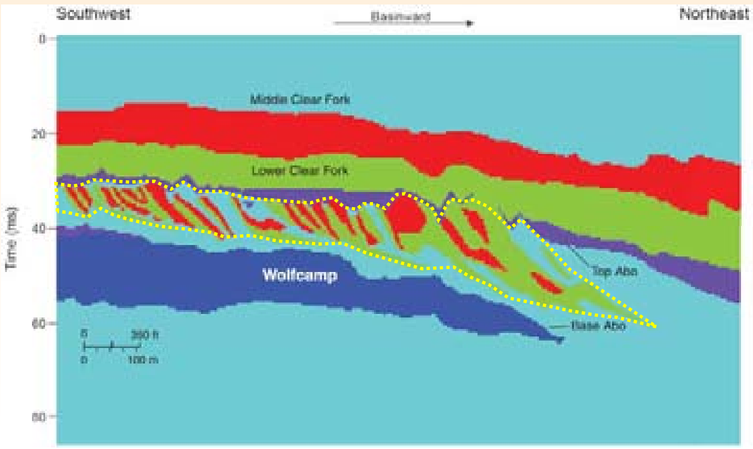
Ideally, depositional facies (lithofacies) should have three components if seen from a seismic section

1. Lithology
2. Geometry (thickness)
3. Stacking pattern (progradational, retrogradational, aggradational, termination, etc.)

Grainstone/packstone/mudstone
5 – 20 m
Clinoform



(Zeng and Kerans, 2013)

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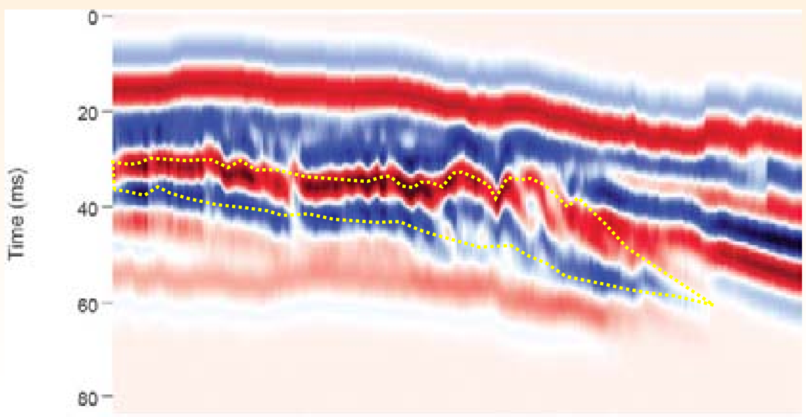
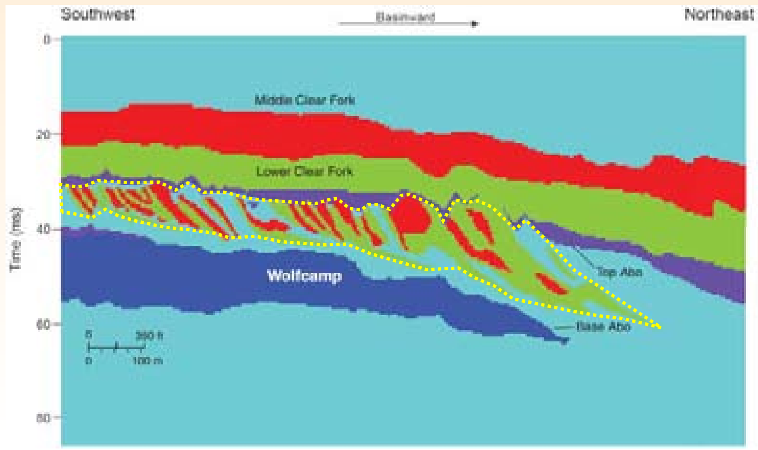
Current status of seismic facies analysis

1. Lithology → depend on geologic model and drilling data
2. Geometry (thickness) → hard to see, except above resolution
3. Stacking pattern → reflection, not necessarily facies pattern

Seismic section



Geologic section



(Zeng and Kerans, 2013)

Current status of seismic facies analysis

1. Seismic facies ≠ depositional facies
2. To improve the interpretation, key is to add lithologic information to seismic facies
3. However, how to *effectively and cheaply* convert seismic attributes to lithology and thickness remains a challenge

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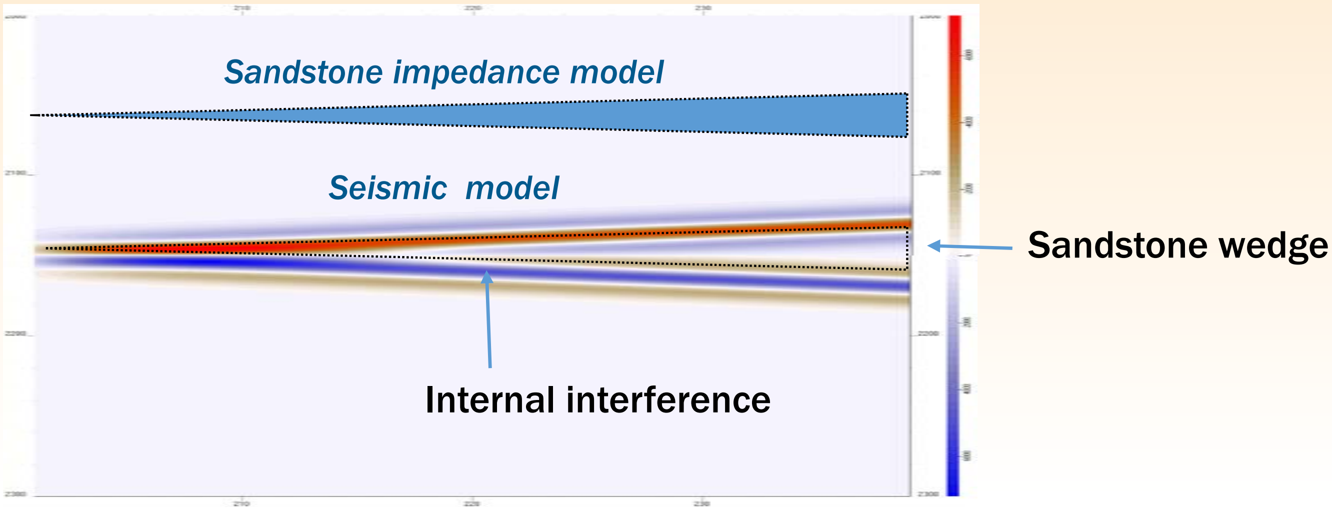
Major difficulties in seismic facies imaging

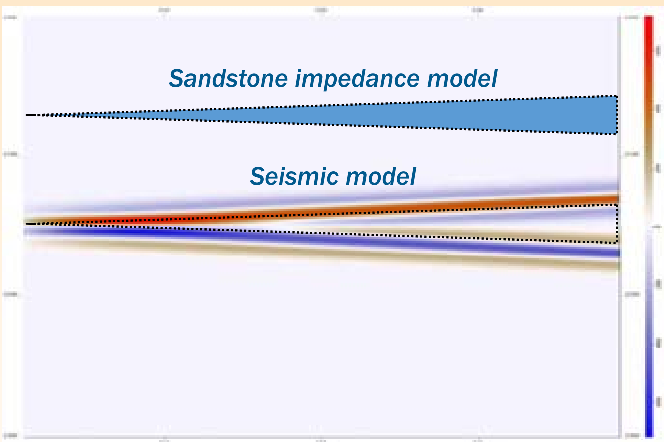
1. Zero-phase data reveal reflectivity, not impedance (lithology).
2. Internal seismic interferences may be mis-interpreted as stratigraphic terminations (unconformity, toplap, etc.)

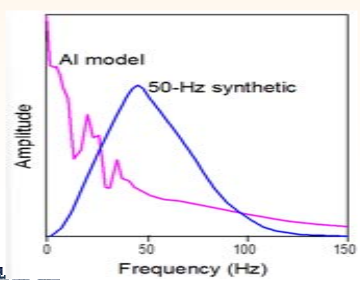
Wedge model



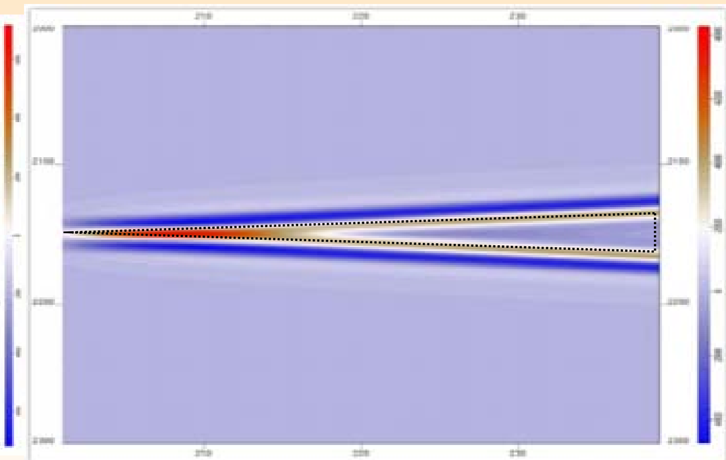
New workflow:
to dig lithology/thickness information from old 2D data

Original data (zero phase)

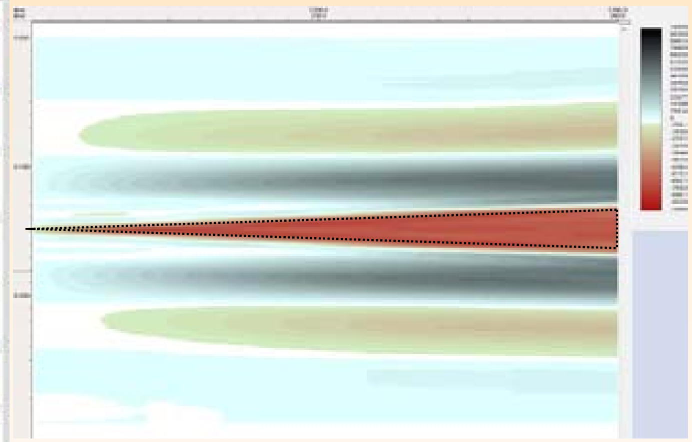


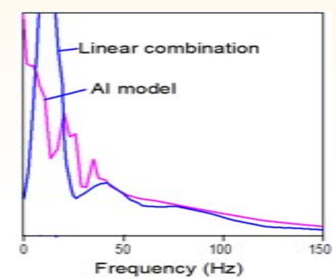


1. Tie seismic event partially to lithology



2. Tie seismic event to sand body





New methodology (Zeng, 2017 Interpretation)

1. Phase adjustment to -90° for relative impedance (lithology)
2. Frequency recomposition (recombination) to view geobodies *beyond dominant frequency* for wider thickness range

Frequency recomposition (recombination)

Define a new seismic attribute by a linear combination of multiple frequency panels:

$$s_{new}(t) = a_1 s_1(t) + a_2 s_2(t) + a_3 s_3(t)$$

where a_1 through a_3 are user-defined artificial constants for low, moderate, and high frequency panels S_1(t) through S_3(t)

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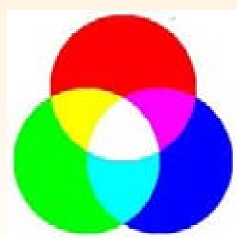
Frequency recomposition in RGB color domain

$$s_{new}(t) = a_1 s_1(t) + a_2 s_2(t) + a_3 s_3(t)$$

$N_r = I_r * 255$ $N_g = I_g * 255$ $N_b = I_b * 255$

RGB triplet pixel

N_r = low freq. (thick)

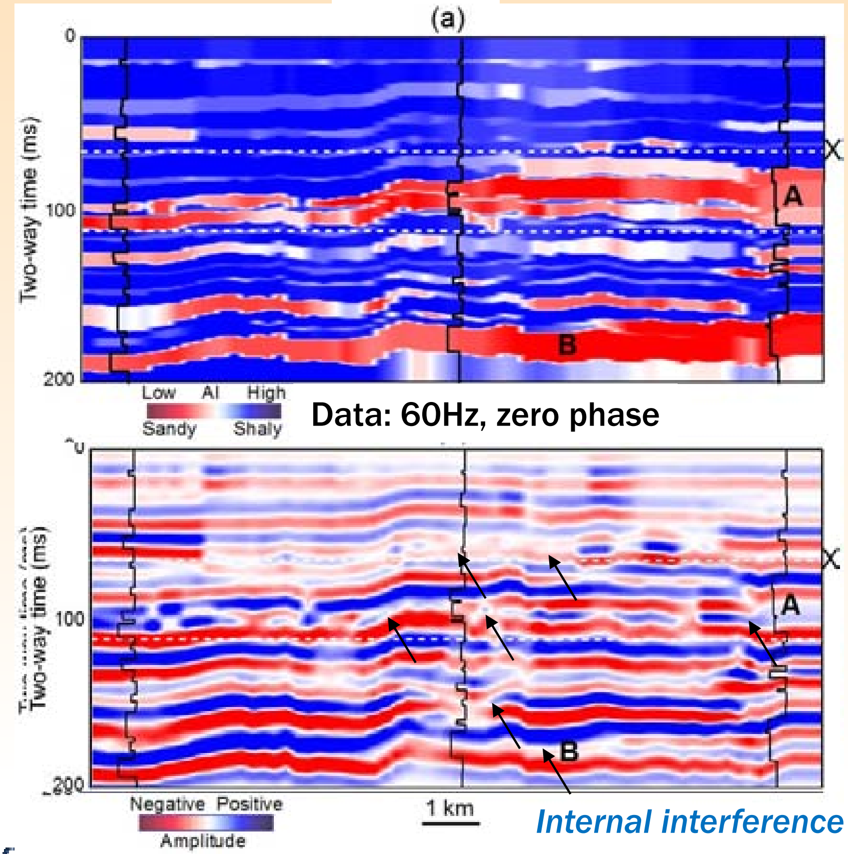


N_g = intermediate freq. (moderate)

N_b = high freq. (thin)

Realistic, interfingerred sand/shale model

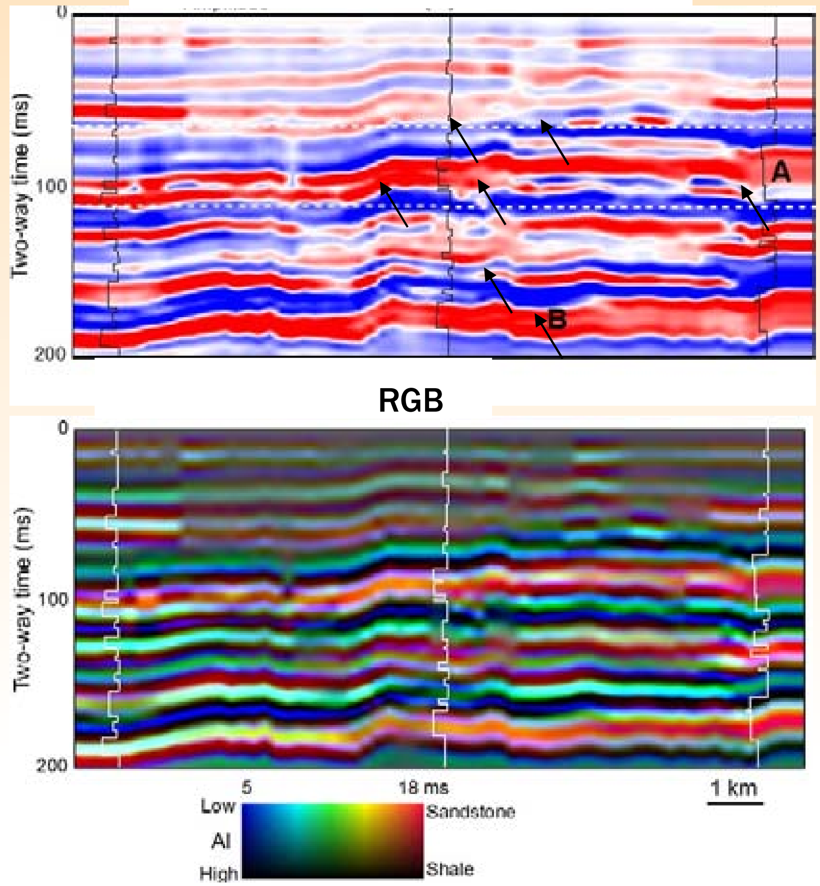
AI model



Data: 60Hz, zero phase

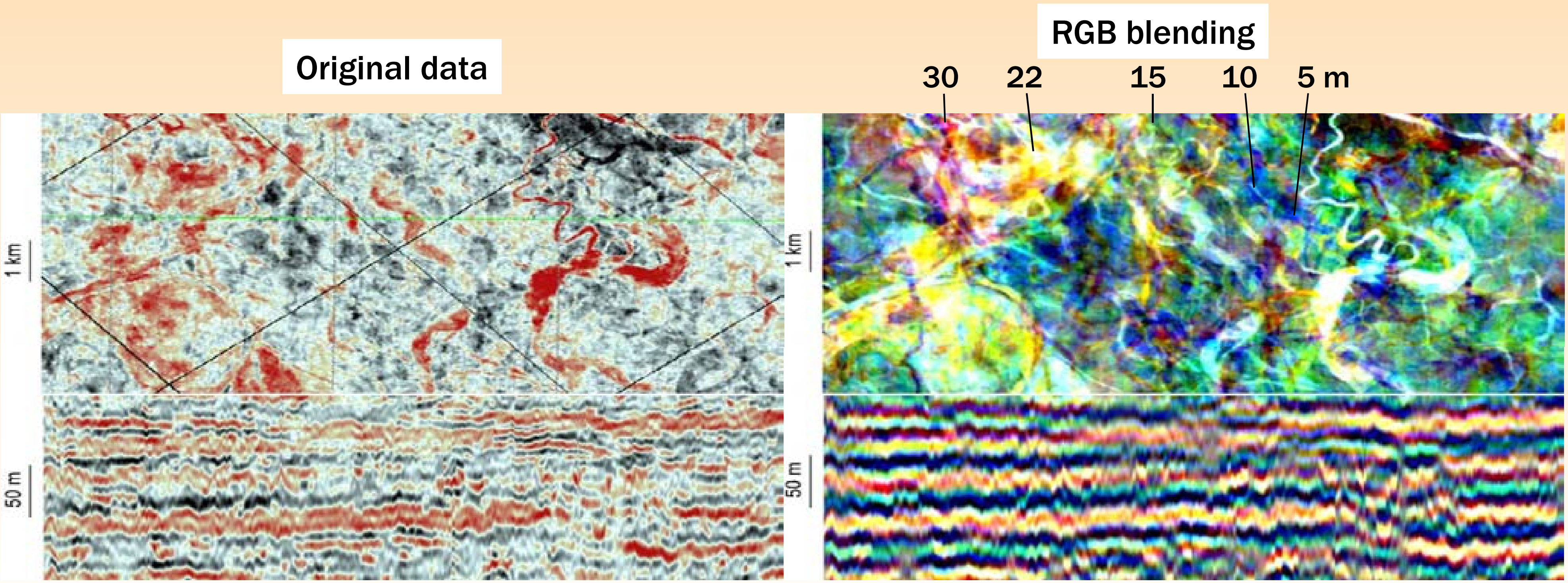
Internal interference

Linear combination of three panels

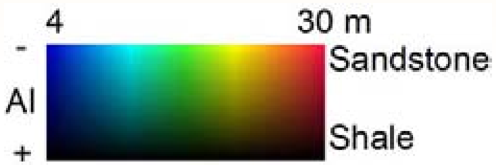


RGB

Expected improvement in 3D



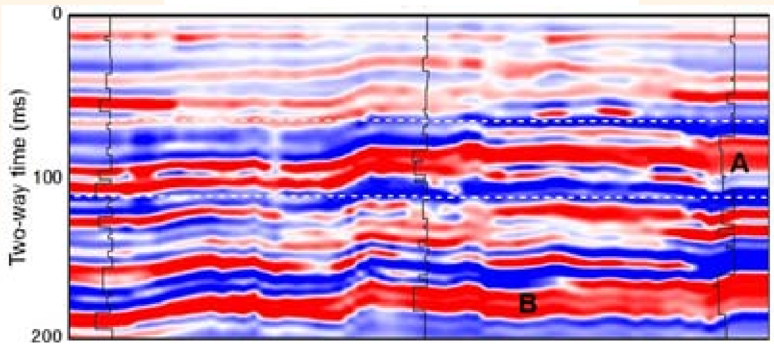
- V -- reflection vs. geometry/stratigraphy
- H -- reflectivity vs. thickness



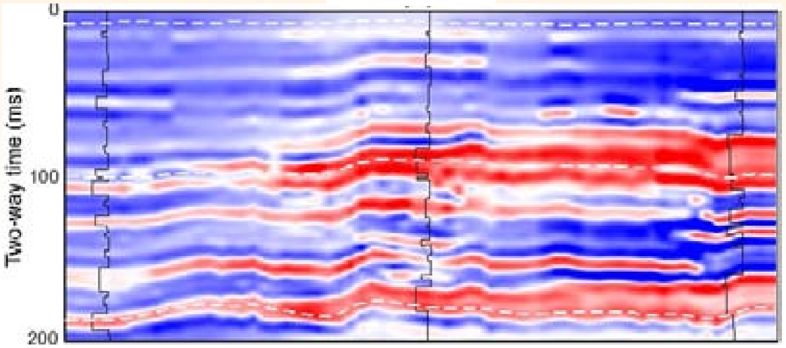
Why seismic inversion is not a solution?

1. A good inversion needs well data for low-frequency velocity model (many 2D lines are not tied to well)
2. Inversion involves significant cost/time; hard to do to numerous 2D lines
3. Inversion generates *derivative* data that are not familiar to stratigraphers and sedimentologists

New and simplified approach



Inversion



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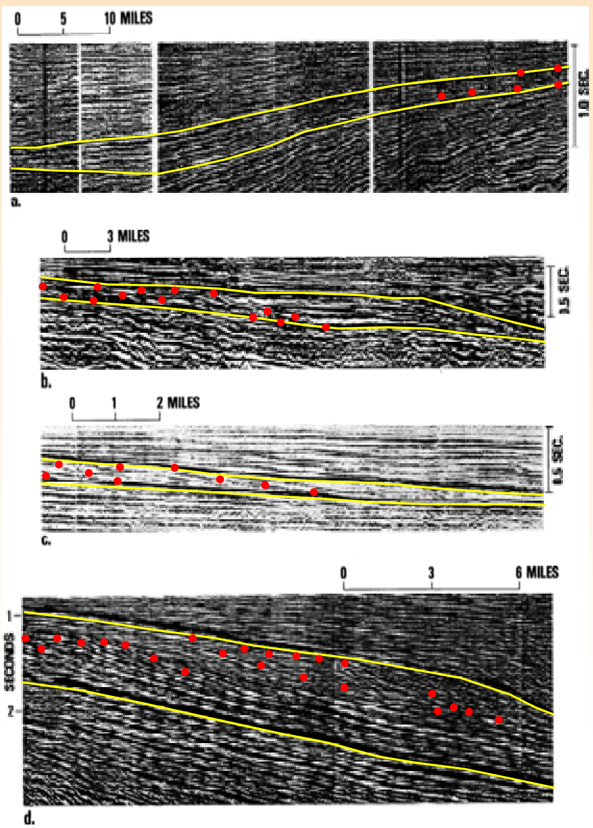
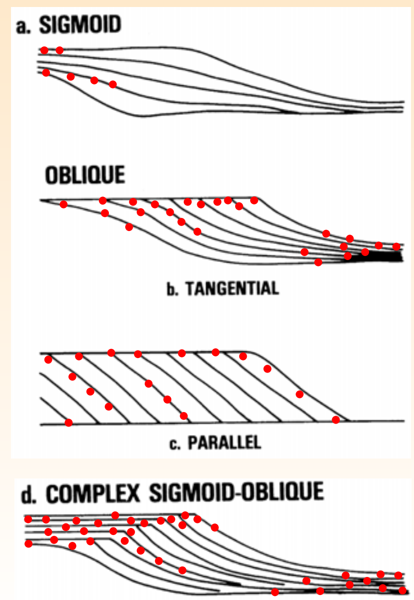
For 2D data, we want to revitalize seismic facies analysis by adding lithofacies component





(Mitchem et al., 1977)

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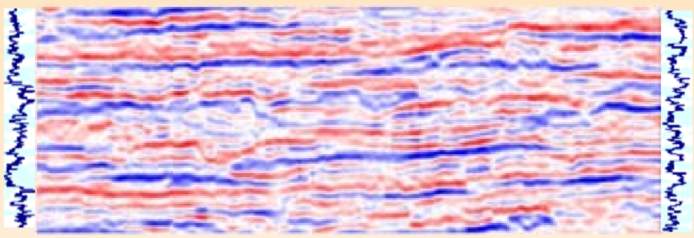
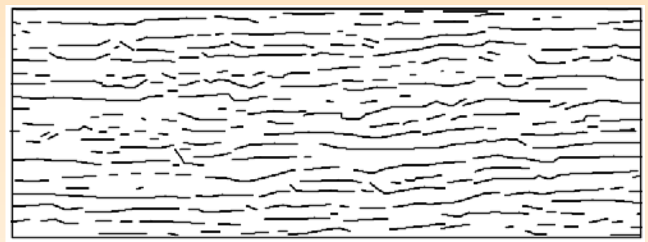
An example of fluvial seismic facies

Data | **Interpretation** | **Seismic facies**

gamma

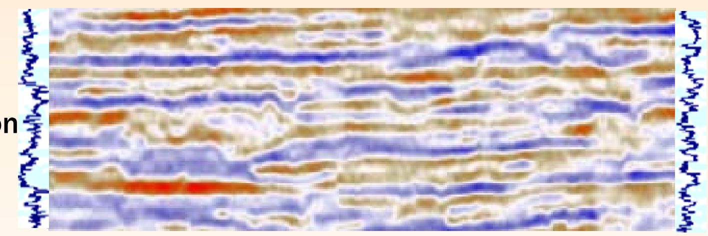
Poststack

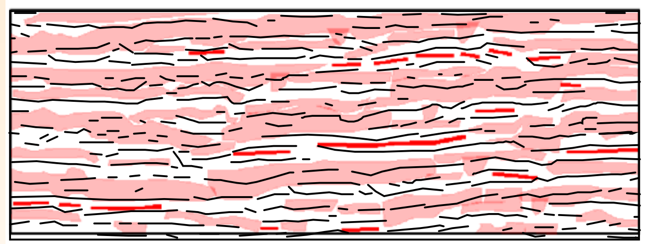




Sub-parallel, variable amplitude/continuity

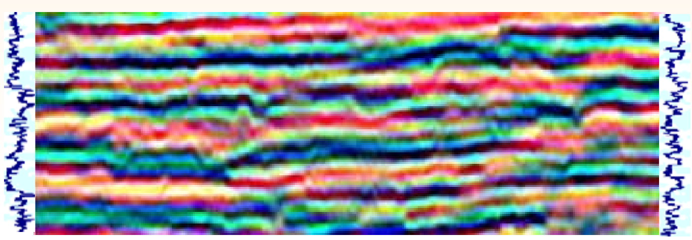
Recombination

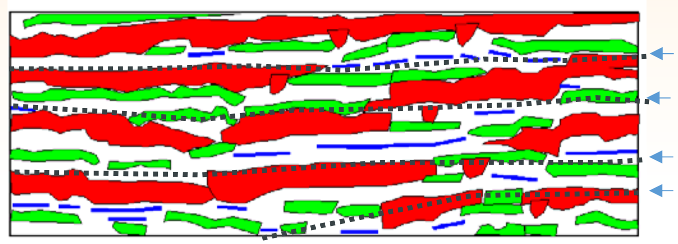




Sub-parallel stacking of discontinuous thick and thin sandstones

RGB





+ thickness cycle (facies unit)

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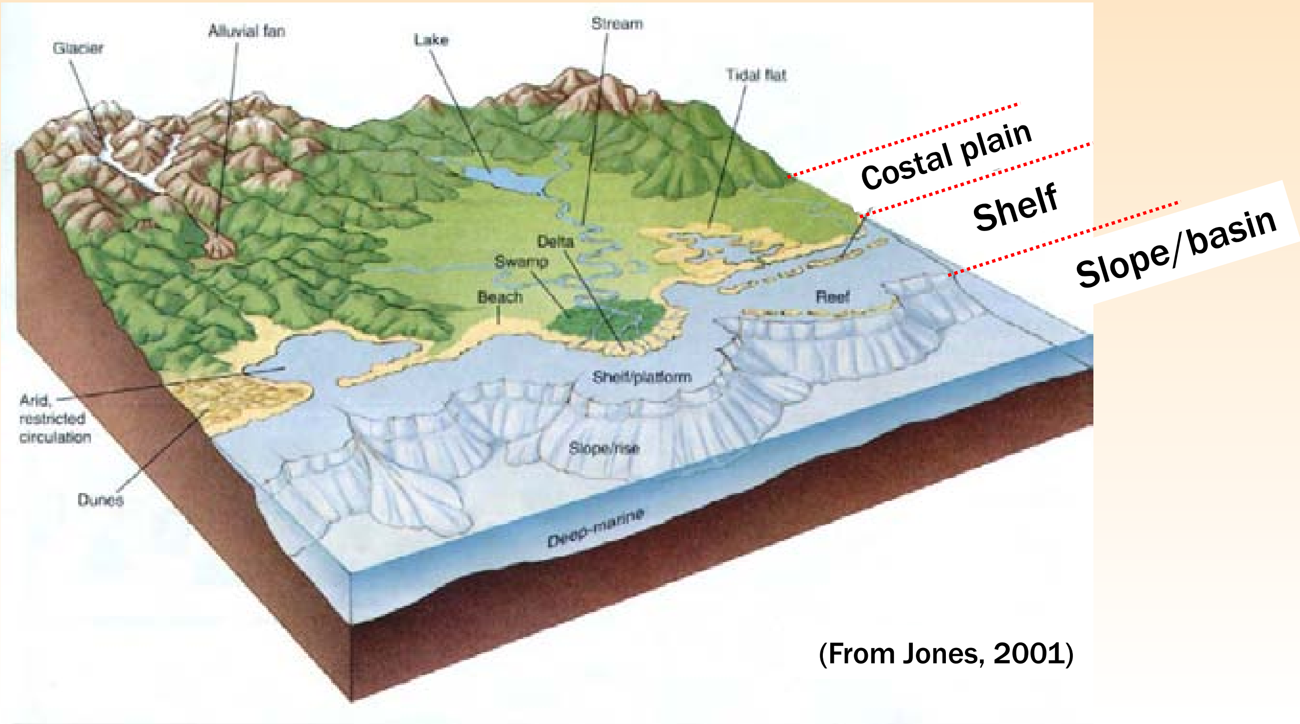
Passive margin: depositional settings



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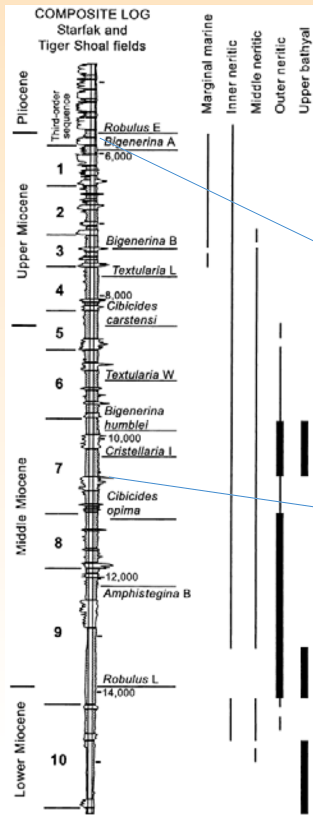
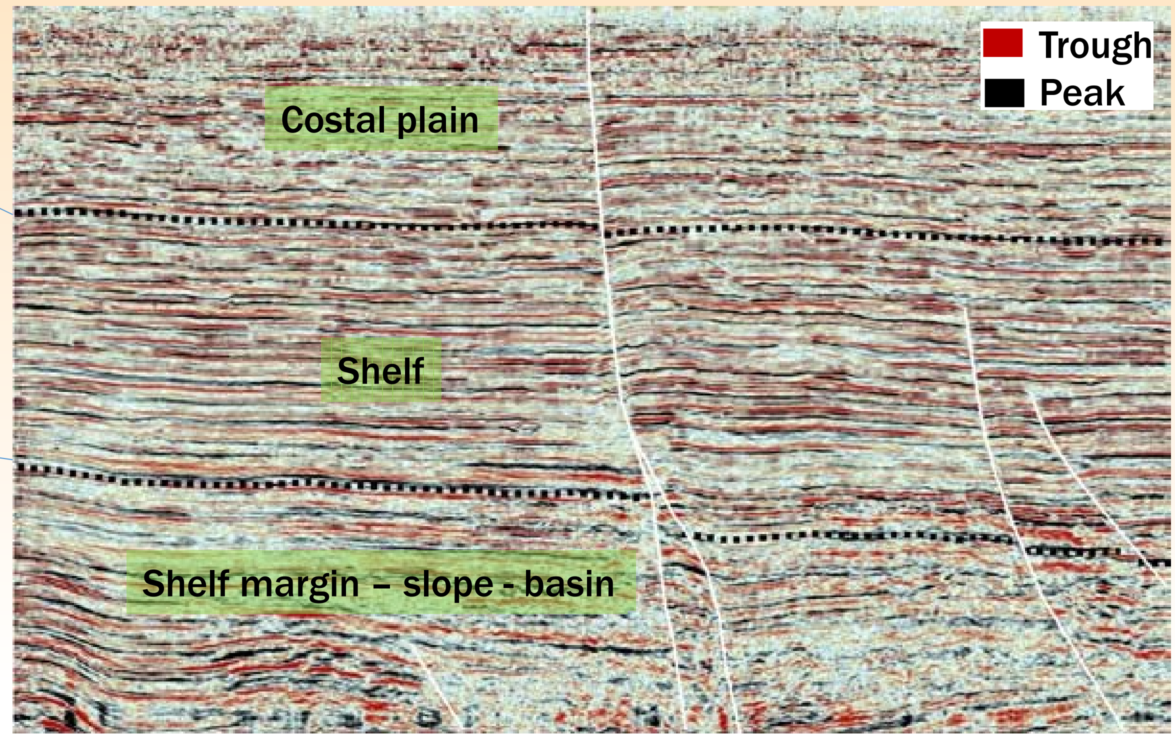
Passive margin: offshore Louisiana (Miocene–Pliocene)

(Hentz and Zeng, 2003)



Poststack



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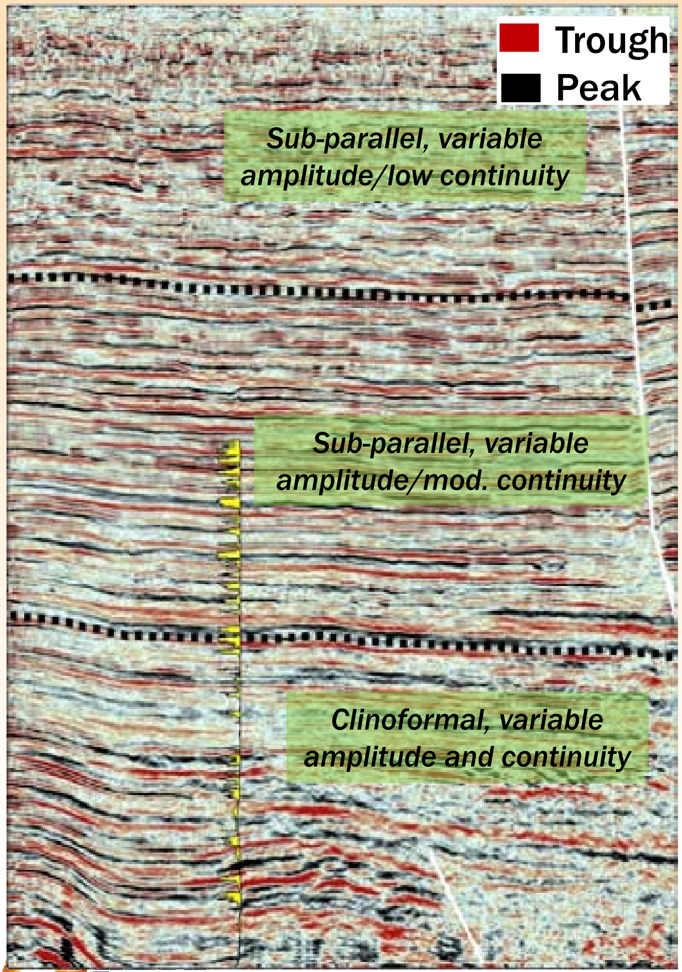
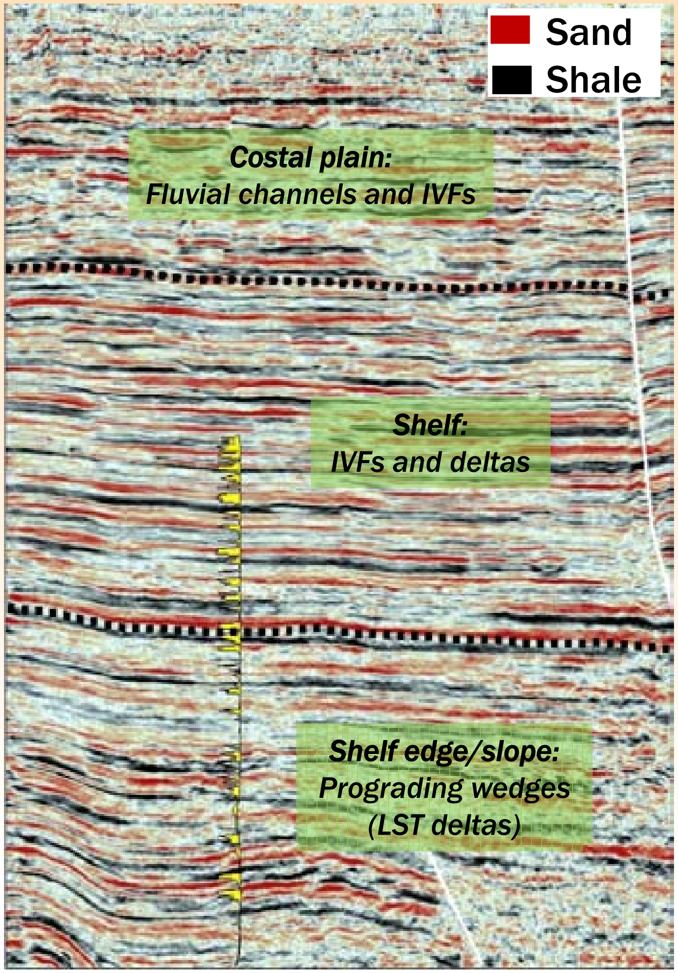
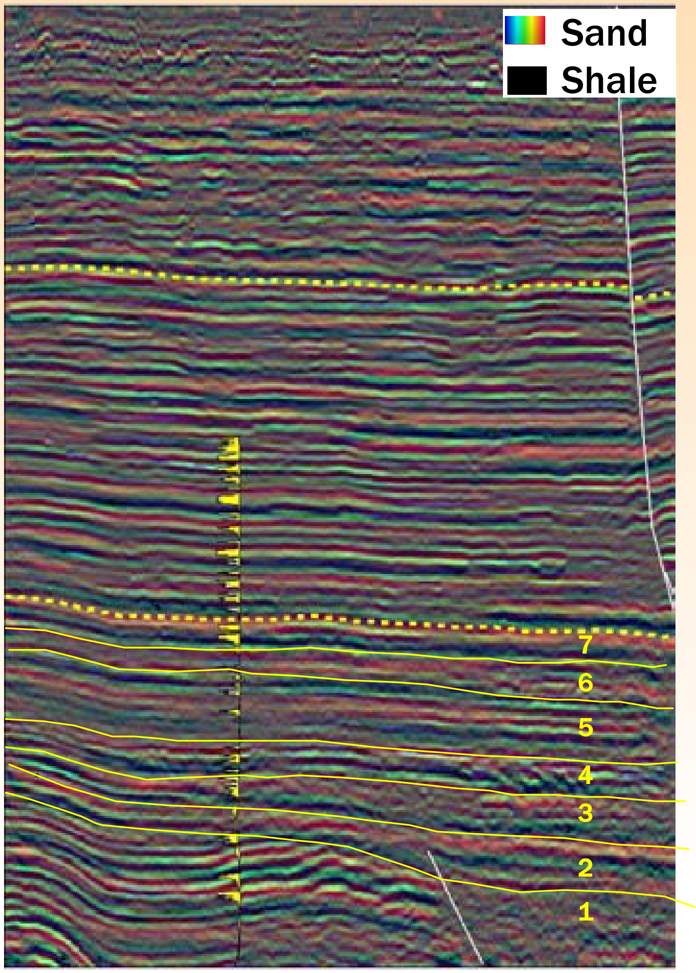
Poststack



Recombination



RGB



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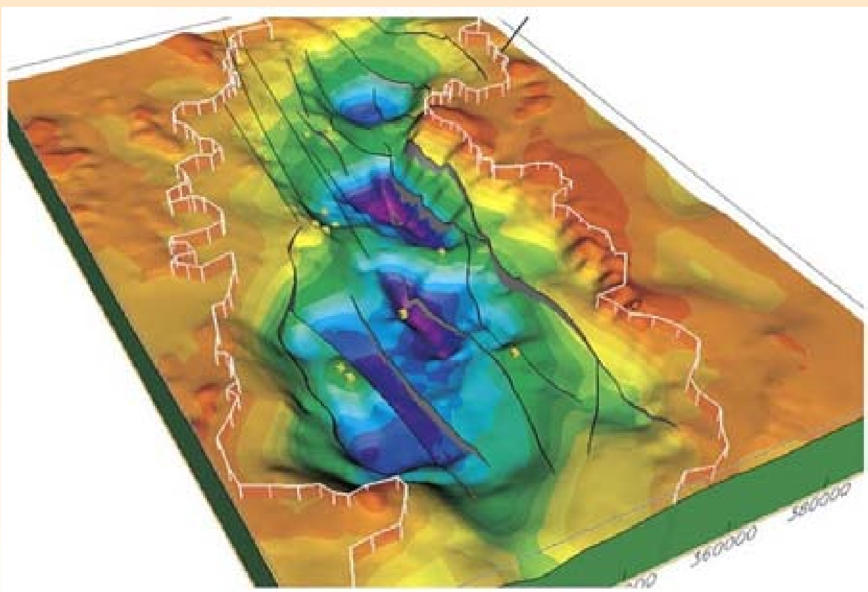
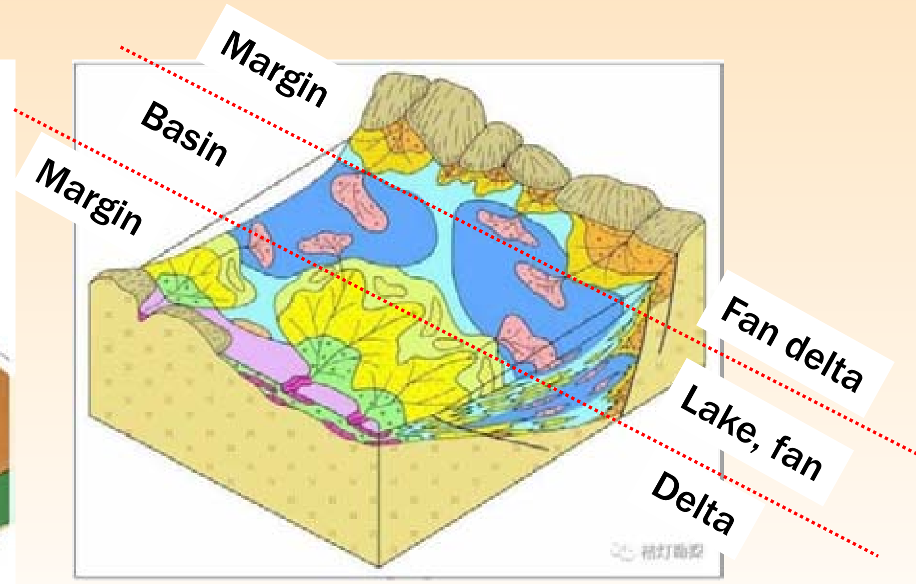
Faulted lacustrine basin: depositional settings





(From Ji, 2015)

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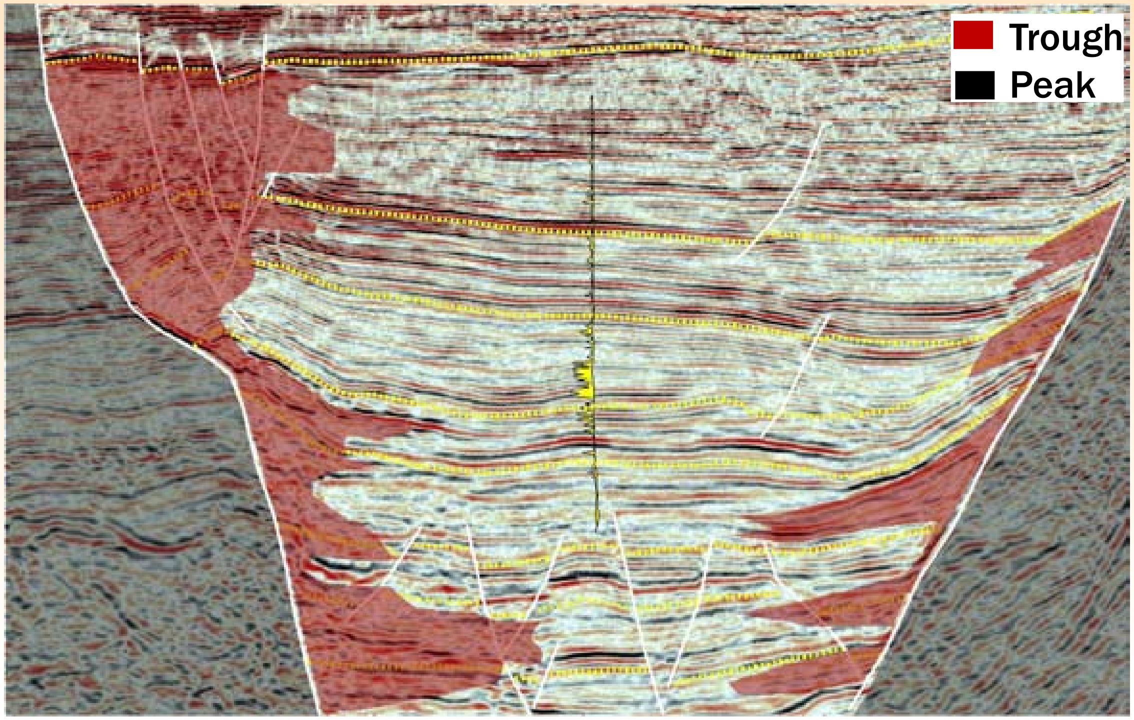
Faulted lacustrine basin: Tertiary, North China

Poststack



Delta

Fan delta

Subaqueous fan
or alluvial fan

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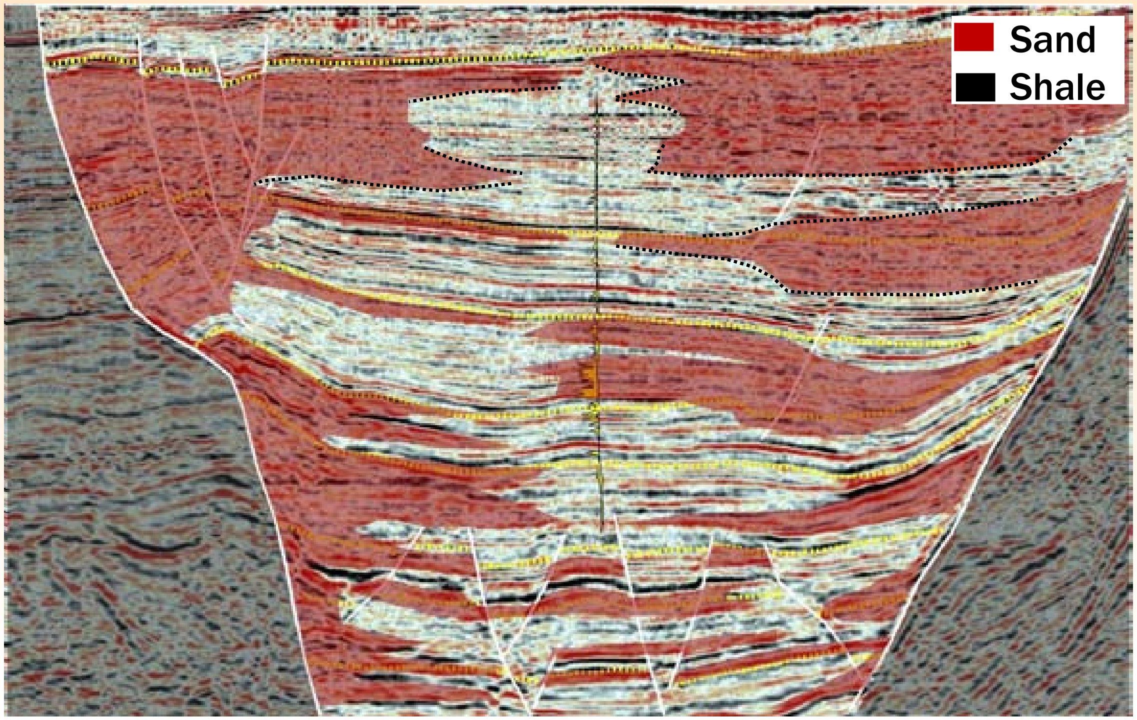
Faulted lacustrine basin: Tertiary, North China

Recombination



Delta

Fan delta

Subaqueous fan
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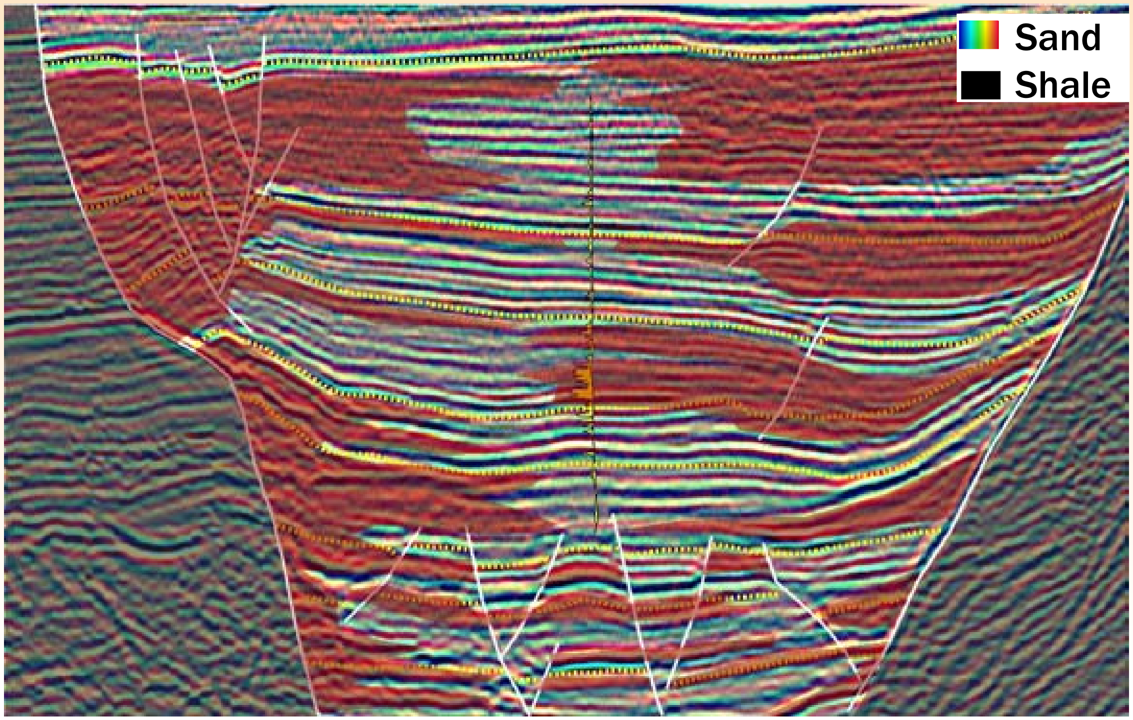
Faulted lacustrine basin: Tertiary, North China

RGB



Delta

Fan delta

Subaqueous fan
or alluvial fan

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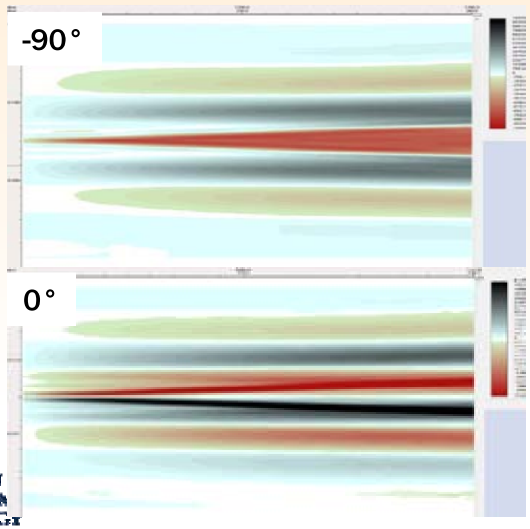
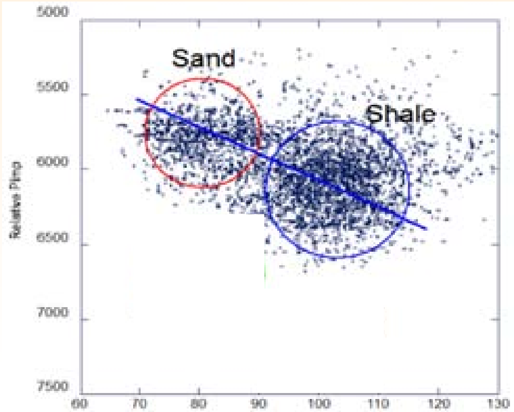
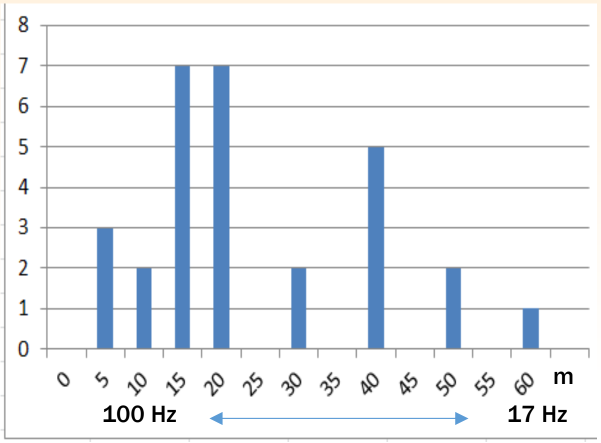
Precautions

1. Seismic data have to be -90° phased (relative Impedance log)
2. Sandstone and shale have to have enough impedance contrast
3. Have knowledge of sandstone thickness distribution (from well data or geologic model) so that frequency panels can be made properly







Conclusions

1. It's *impedance* ! (in relative sense)
2. It's *nonderivative* (designed for stratigrapher/sedimentologist users)
3. It's *fast and cheap*
4. It's *easy to manipulate without wells* (however, you do need to have geologic experience)
5. Hopefully, it's a tool to *revitalize* seismic facies analysis.

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Thanks