



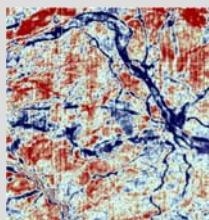
# Seismic-Sedimentologic Interpretation of Thin Sandstones 薄互层砂岩的地震沉积学解释

Hongliu Zeng

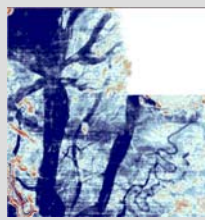
BEG, University of Texas at Austin

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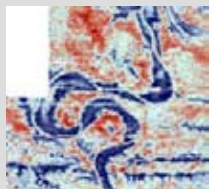
## Amplitude stratal slices and depositional systems 振幅地层切片和沉积体系



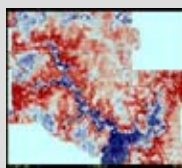
*A distributary channel system.*



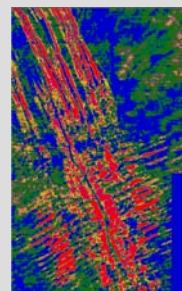
*Coastal plain and incised valley.*



*Meander loops.*



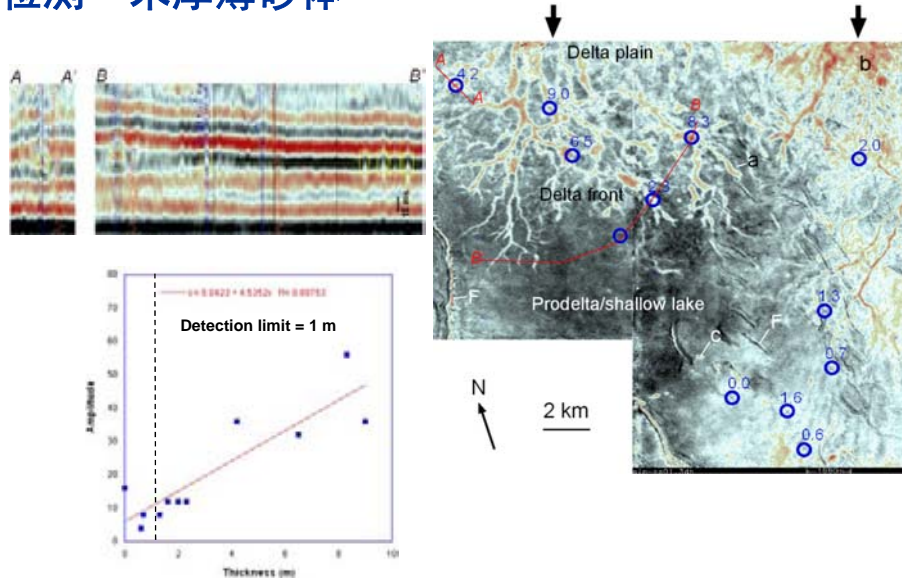
*A tidal-dominated shore zone  
(tidal flat and tidal delta).*



*A slope-fan system.*

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## Detection of 1-m thin beds 检测一米厚薄砂体



## Dilemma of seismic resolution 地震分辨率悖论

- How to understand the "resolution" of below-resolution thin beds using stratal slices?  
如何理解用地层切片“分辨”低于地震分辨率的薄砂体？
- Below-resolution sampling causes confusion  
低于分辨率采样引起认识上的混乱
- Must introduce the concept of spatial resolution  
需要引入地震空间分辨率的概念



## Concepts of seismic resolution and detection (Sheriff, 2002)分辨率和检测率概念

- **Resolution limit:** For discrete seismic reflectors, the minimum separation so that one can ascertain that more than one interface is involved. (Sheriff, 2002)
- Commonly accepted resolvable limit is Rayleigh resolution limit, or  $\lambda/4$ .
- **Detection limit:** The minimum thickness for a bed to give a reflection that stands out above the background. Often of the order of  $\lambda/25$ .

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## Proposed concepts of spatial seismic resolution空间分辨率

- Seismic resolution is directional; **Horizontal resolution** equals **vertical resolution**. (Lindsey, 1989)
- **Spatial resolution:** both vertically and horizontally resolved.
- **Oneway resolution**单向分辨率: Either vertically or horizontally resolved but not being resolved in the other direction.

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## Status of seismic resolution:分辨率状态 Four possible reservoir geometry models

| Type 1  | Type 2  | Type 3  | Type 4  |
|---|---|---|---|
|  |  |  |  |
| $\lambda : \lambda$   | $\frac{\lambda}{8} : \lambda$   | $H : V = \lambda : \frac{\lambda}{8}$   | $\frac{\lambda}{8} : \frac{\lambda}{8}$   |
| $\lambda = \text{wavelength}$   |   |   |   |
| Spatially resolved  | Oneway Resolved (vertical)  | Oneway Resolved (horizontal)  | Spatially unresolved  |

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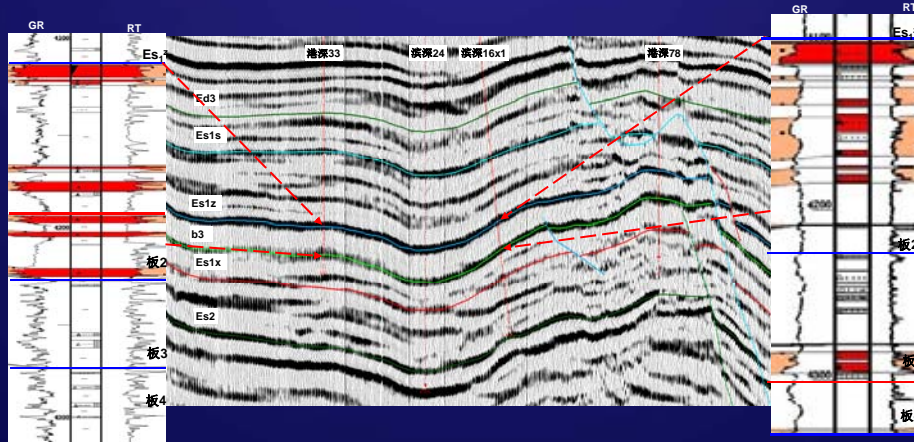


## Status of seismic resolution: wave-equation modelling (migrated data)

| Type 1  | Type 2  | Type 3  | Type 4  |
|---|---|---|---|
|  |  |  |  |
| $\lambda : \lambda$   | $\frac{\lambda}{8} : \lambda$   | $H : V = \lambda : \frac{\lambda}{8}$   | $\frac{\lambda}{8} : \frac{\lambda}{8}$   |
| Spatially resolved  | Oneway Resolved (vertical)  | Oneway Resolved (horizontal)  | Spatially unresolved  |

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## Challenge #1: 一个同相轴含多个砂体 Multiple thin sandstones in a single event

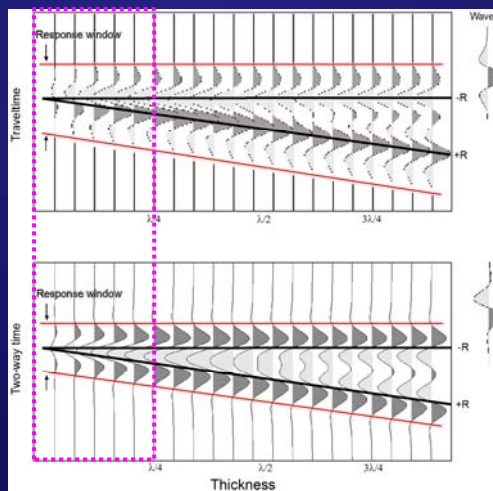


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## Challenge #2: Large response window 地震响应时窗大于砂体厚度

Zero phase

90° phase



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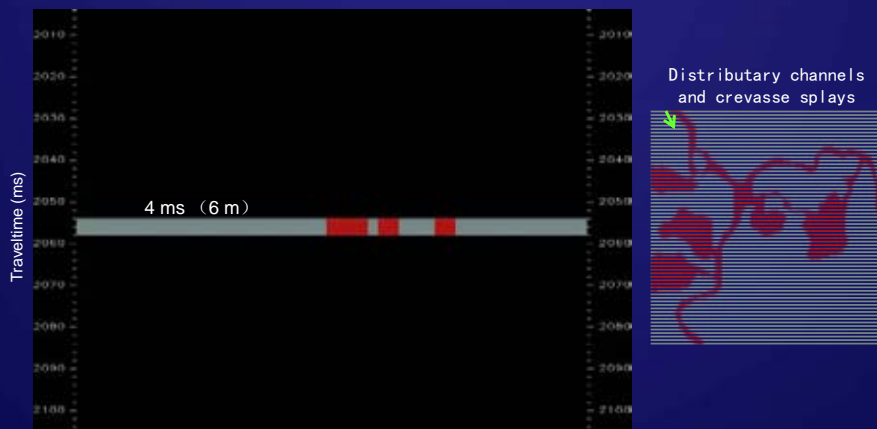


## Large response window: a double-edged sword 双刃剑

- Bad: reduce vertical resolution and introduce heavy interferences.  
降低分辨率，加重地震波干涉
- Good: preserve unique waveform for thin-bed prediction.  
保存特殊波形，有利薄层预测



## Simple model: thin sand in shale 简单模型：单层薄砂体



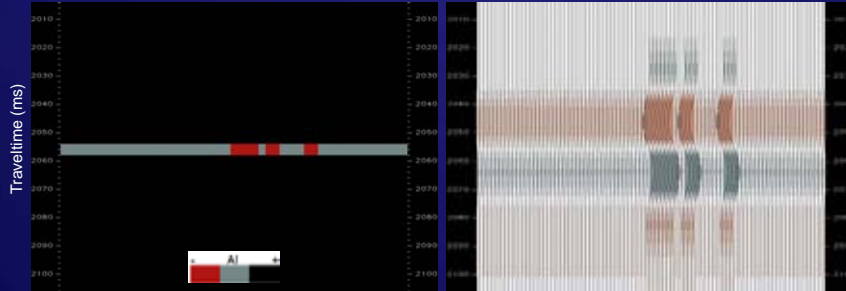
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# Simple model: synthetic volume (zero phase, 25-Hz dominant frequency)



Acoustic Impedance

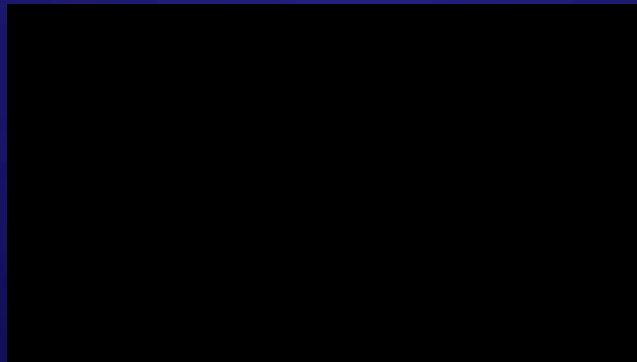
Waveform



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# Waveform in stratal-slice movie 用地层切片分析薄层波形

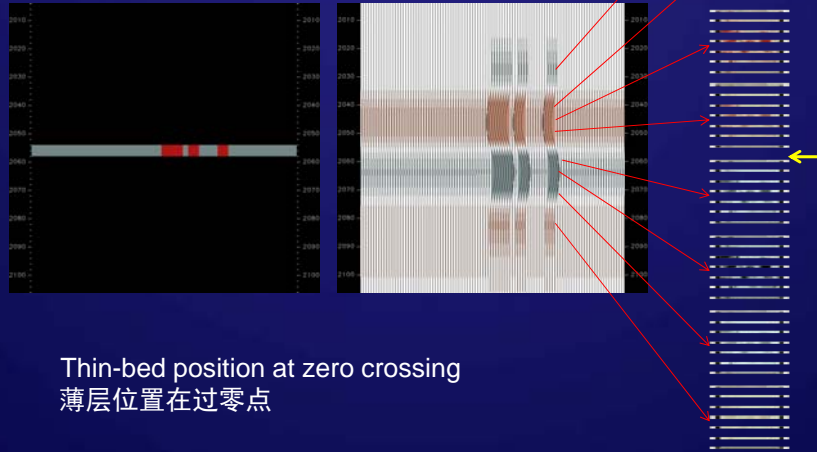


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## Waveform recovered with stratal slices (zero-phase wavelet)

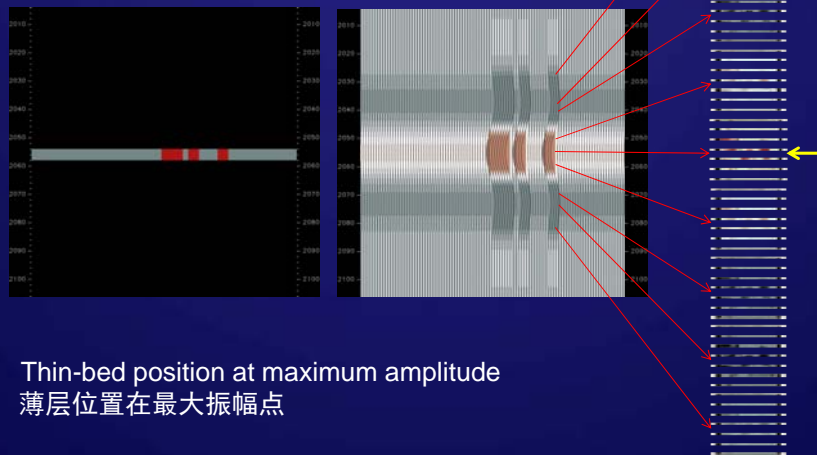


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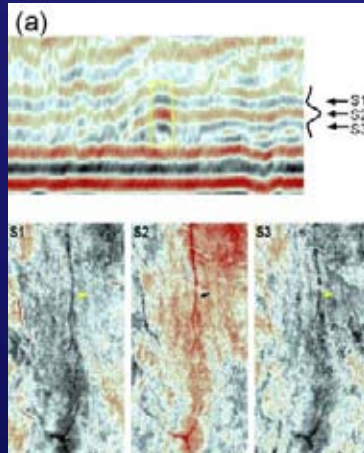
## Waveform recovered with stratal slices (90° wavelet)



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# A field-data example (90° phase)



Sand body image #1 (sidelobe)  
 Sand body image #2 (max amp, center of sand)  
 Sand body image #3 (sidelobe)

Recognizable only on stratal slices!

# Complex model 复杂模型: interbedded thin sandy units and shale interlayers 多砂体



Fluvial channel (LST)



A

IVF/floodplain (LST)



B

Delta plain (HST)



C

Delta plain (HST)



D

Delta (HST)



E

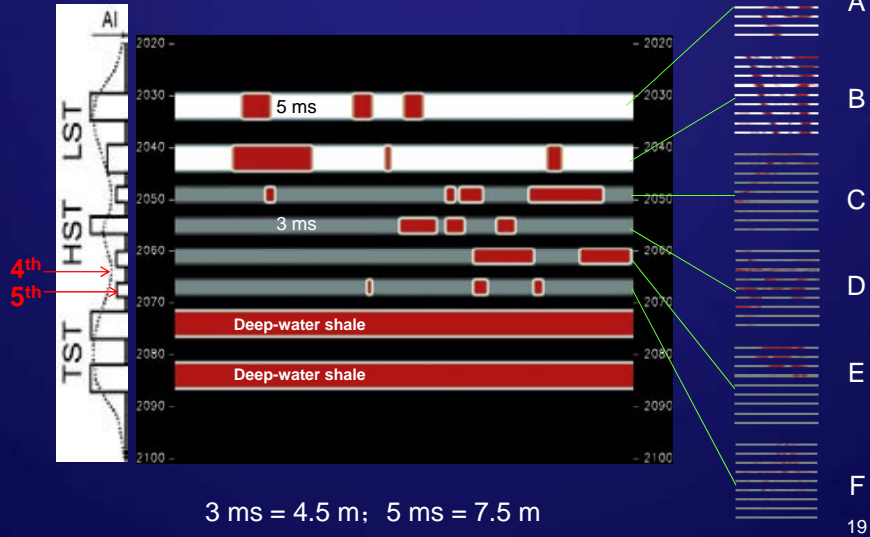
Delta (HST)



F

# Complex model: impedance/sequences

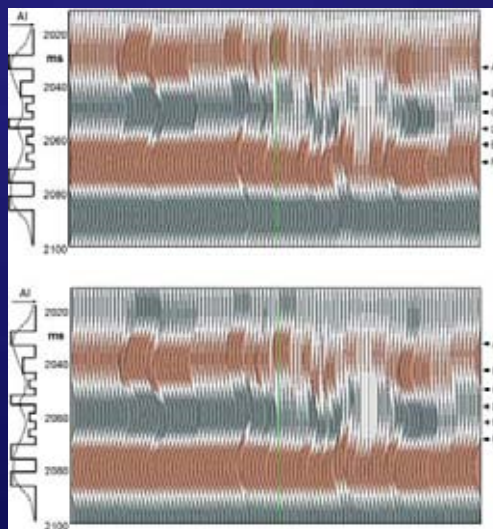
波阻抗/层序



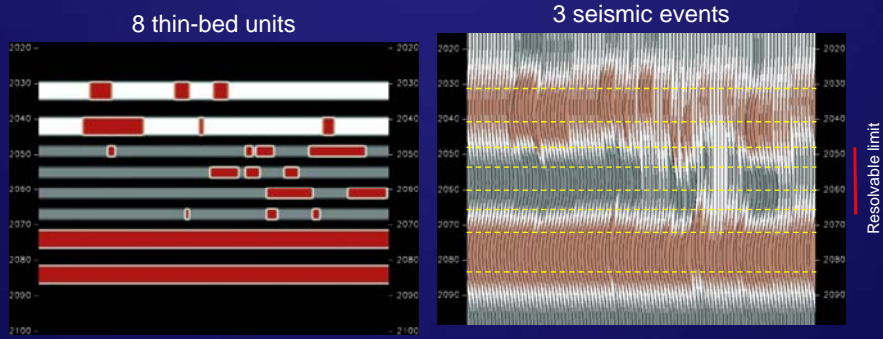
# Complex model: synthetic seismic (25-Hz dominant frequency)

Zero phase

90° phase

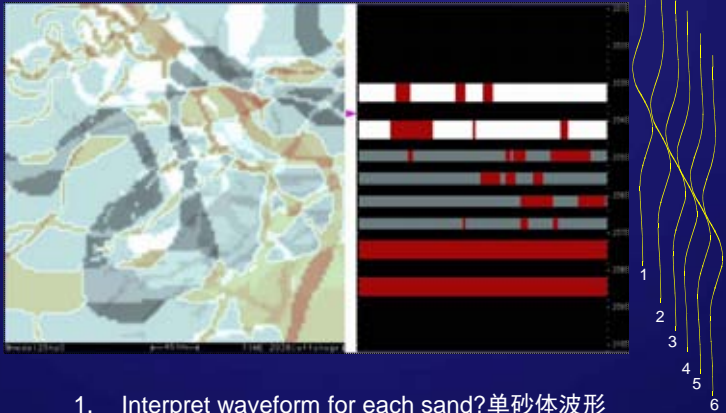


**Thin-bed units are not adequately represented by seismic events**  
 同相轴不能充分代表所有薄砂体



At least 8 slices are needed to represent 8 thin beds, which requires a sample rate much smaller than resolution limit!  
 至少需要8个切片代表8个砂体，采样率大大小于分辨率

**Waveforms in stratal slice movie?**  
 用地层切片能识别薄层波形吗

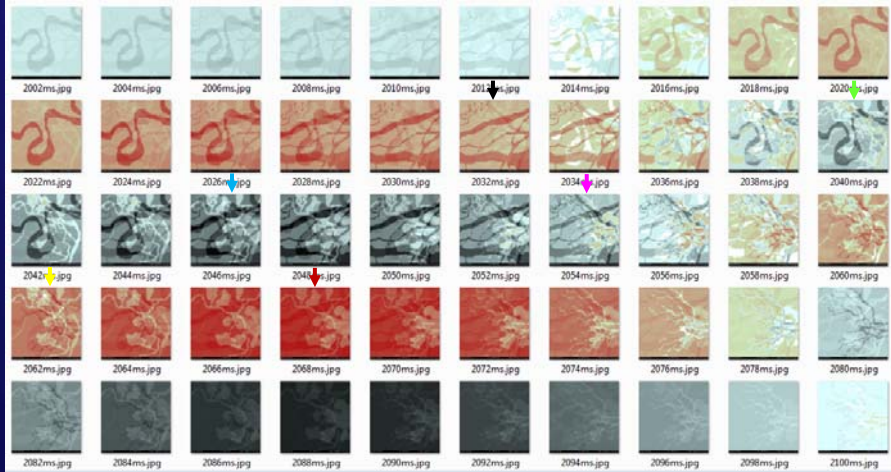


1. Interpret waveform for each sand? 单砂体波形
2. Determine position of each sand? 单砂体位置
3. Reveal depositional history? 沉积史

# Interpret thin-bed waveform and position (zero phase)

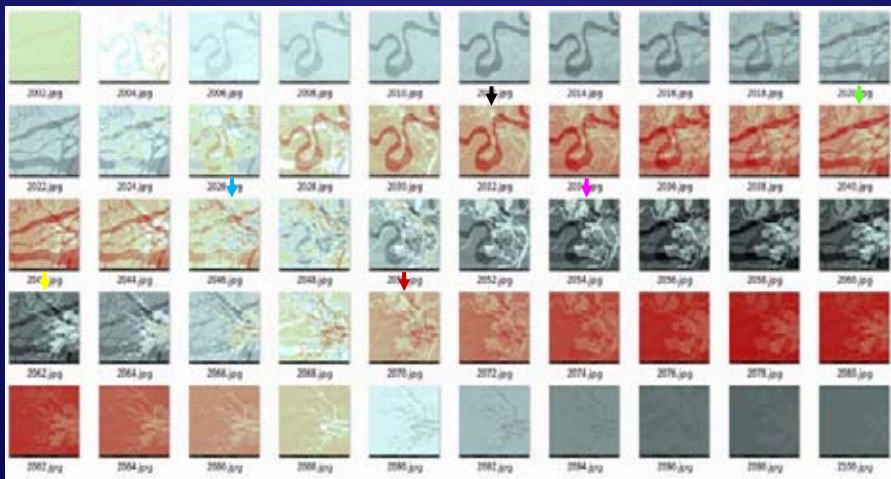


Top



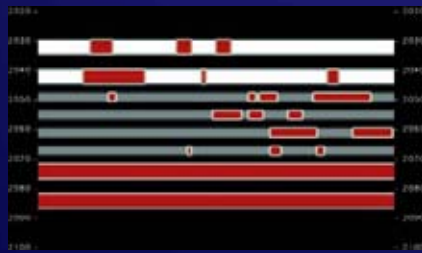
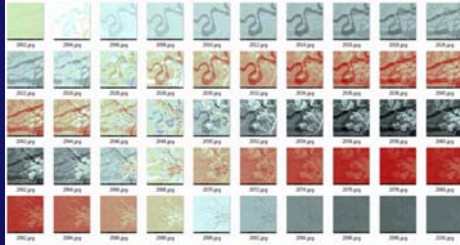
Base  
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# Interpret thin-bed waveform and position (90° phase)



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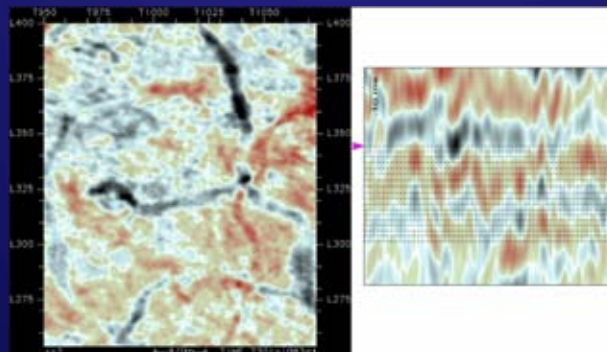
## Some control factors for thin-bed imaging 控制因素



- Wavelet phase (waveform symmetry)  
子波相位 (对称性)
- Geomorphology  
地貌识别难易程度
- Thickness (sandstones and shale interlayers)  
厚度 (砂体和泥岩夹层)
- Position (number of sources of interference)  
砂体空间位置

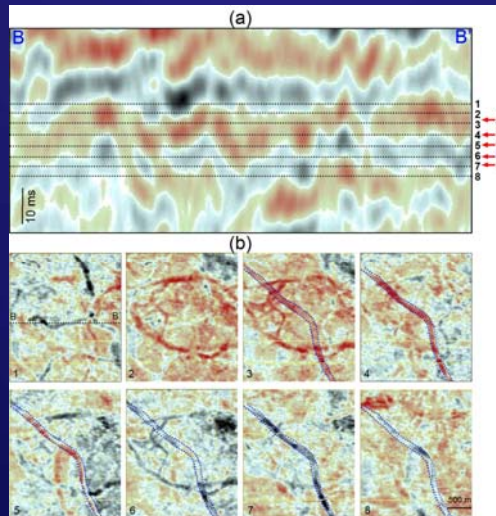
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## Field-data example: Songliao Basin, China (50 Hz, zero phase)实例



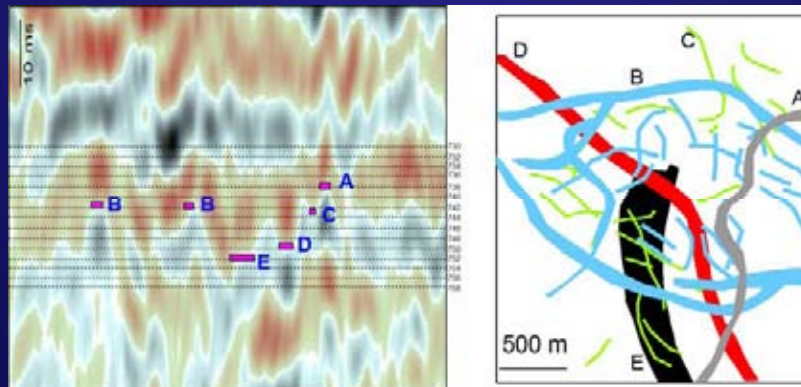
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## Field-data example: Songliao Basin, China (50 Hz, zero phase)



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## Field-data example: Songliao Basin, China (50 Hz, zero phase)



5 sands in 20 ms (30 m), or average  $\lambda/24$  thick sand beds

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## Conclusions结论

1. Stratal slice (that may or may not follow seismic events) is an effective platform to visualize thin depositional systems at detectable limit (up to 1 m). 地层切片（同相或不同相）可有效显示薄层沉积体系（最薄一米）
2. There is a need to expand the definition of seismic resolution. Oneway resolution is a useful concept to understand thin-bed imaging. 有必要扩展地震分辨率定义。单向分辨概念有利于理解薄层成像
3. Models demonstrate that thin beds can be predicted by waveforms with unique seismic geomorphologic patterns in Wheeler domain. 模拟实验证实wheeler（地层切片）域的独特地震地貌模式可用于预测薄层
4. Field-data example shows that up to 3 interbedded fluvial channel sand bodies can be interpreted in a single seismic event. 实例研究证实在一个地震同相轴内可识别最多3个砂体