

Seismic Geomorphology of Carbonate Reservoirs in the Upper Permian Changxing and Lower Triassic Feixianguan Formations, Northern Sichuan Basin, Southwest China*

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Abstract

During the late Permian to early Triassic period, a northwest-southeast-extending deepwater trough developed in northern Sichuan Basin, southwest China, which was named the 'Kaijiang-Liangping Trough' (Wang et al., 2006). To the southwest, the trough was surrounded by a rimmed carbonate platform. Our study area is located in the platform and trough junction, covering features of the platform, platform margin, slope and the deepwater trough from southwest to northeast. The lower Triassic Feixianguan Formation shoal oolitic carbonates on the platform margin constituted the most excellent reservoirs in the area.

In the study, a 3-D seismic survey with an area of about 1,050 km² were interpreted by using an integrated seismic stratigraphic and geomorphological analysis procedure, aimed to investigate the lateral occurrence and vertical evolution of the sedimentary geomorphological elements. Well logs from two exploration wells were used for horizon calibration by well-to-seismic tie.

Through seismic sequence analysis, six sequence boundaries and nine maximum flooding surfaces were recognized, which classified the Feixianguan Formation into five sequences and nine systems tracts. The five sequences were named SQ1 to SQ5 upwards, respectively. Except for the lowermost sequence (SQ1), in which only a transgressive systems tract was developed, each of the other four sequences consisted of a lower transgressive systems tract and an upper highstand systems tract.

Several methods were utilized to reconstruct the occurrence and evolution of the sedimentary geomorphological elements, including horizon flattening, horizon slicing, stratal slicing, and multi-attribute neural-network-based seismic facies classification. The results suggested that the study area was characterized with the rimmed platform to the southwest and the deepwater trough to the northeast

before the deposition of Feixianguan Formation. From SQ 1 to SQ 4, the carbonate platform gradually prograded northeastwards to the trough as a response to an overall falling of relative sea level. As a result, a set of prograding clinoforms were developed. During the late stage of Feixianguan Formation deposition (SQ5), the trough was gradually filled, and the study area evolved into a gentle northeast-dipping ramp, on which evaporative tidal flat environments developed. As the reservoir with the most potential, the oolitic shoal facies on the platform margin were delineated.

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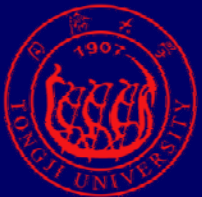
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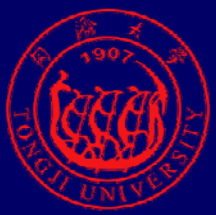
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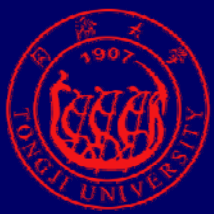
2. Geophys. Prospecting Co., Chuanqing Drilling Eng. Co., Ltd., CNPC, Chengdu, China

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Outline

- Methodology
- Geological background
- Seismic sequence analysis
- Seismic facies analysis
- Seismic geomorphological analysis
- Geological models for reservoir prediction
- Summary



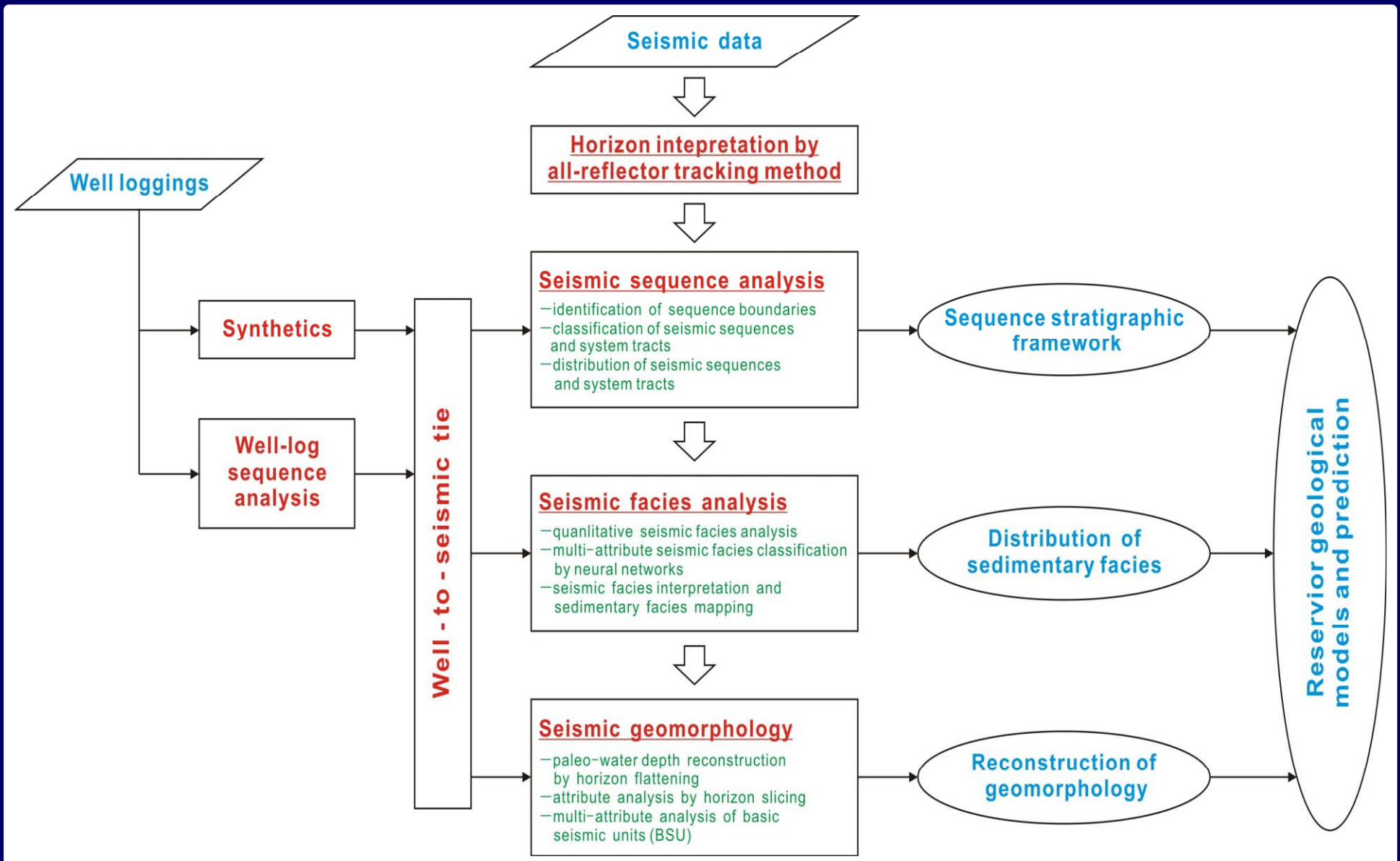
Methodology

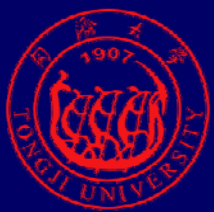
- **Seismic sequence stratigraphy** (Vail et al., 1977; Van Wagoner et al. 1987; Posamentier and Vail, 1988) and **seismic geomorphology** (Posamentier, 2000, 2007) are milestones in the evolution of seismic interpretation techniques.



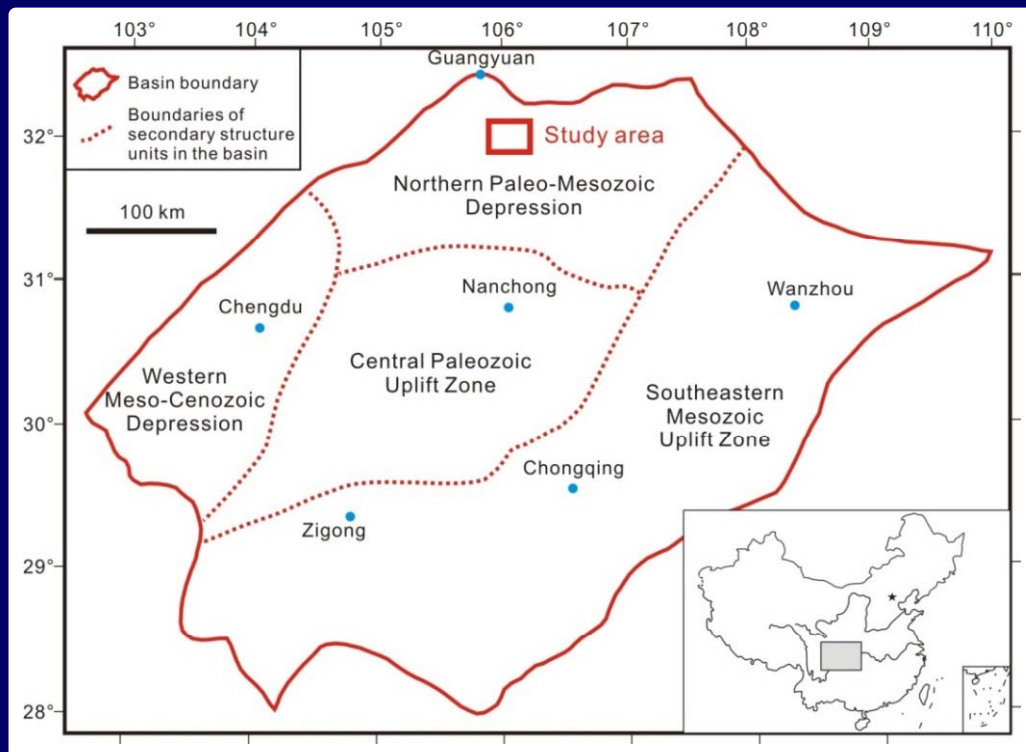
Methodology

- Integrated seismic stratigraphic and geomorphological interpretation based on all-reflector tracking method (Zhong et al. 2010)





Geologic Background: Tectonic elements and stratigraphy



Major tectonic units
in Sichuan Basin,
SW China

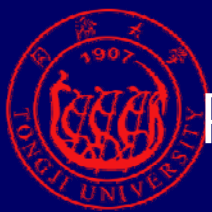
Stratigraphy of
Sichuan Basin
(Ma et al. 2006)

Stratigraphy			Lithology	Thickness	Source rocks	Reservoirs
Erathem	System	Formation				
Mesozoic	Cretaceous			0~2 000		
		Penglaizheng Fm.		650~1 400		
	Jurassic	Suilin Fm.		340~500		
		Saximiao Fm.		600~2 800		
		Ziliujing Fm.		200~900		
		Xujiahe Fm.		250~3 000		
	Triassic	Leikoupo Fm.				
		Jialinjiang Fm.		900~1 700		
		Feixianguan Fm.				
		Changxing Fm.				
Paleozoic	Permian	Longtan Fm.				
		Maokou Fm.				
		Qixia Fm.		200~500		
		Liangshan Fm.				
	Carboniferous	Huanglong Fm.		0~500		
	Silurian			0~1 500		

Studied intervals

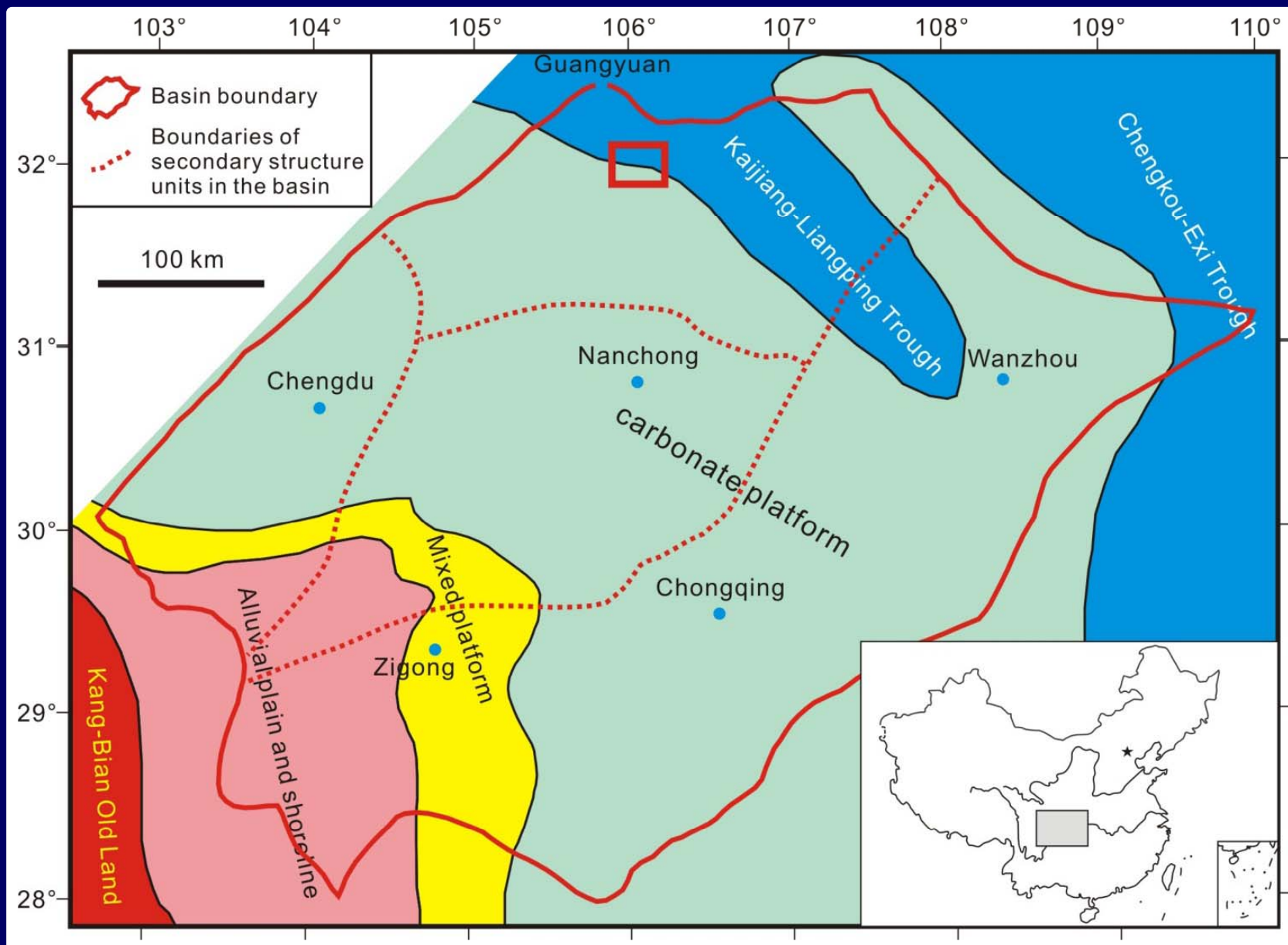
Nonmarine clastic
succession

Marine clastic and
carbonate succession

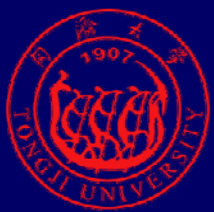


Geologic Background:

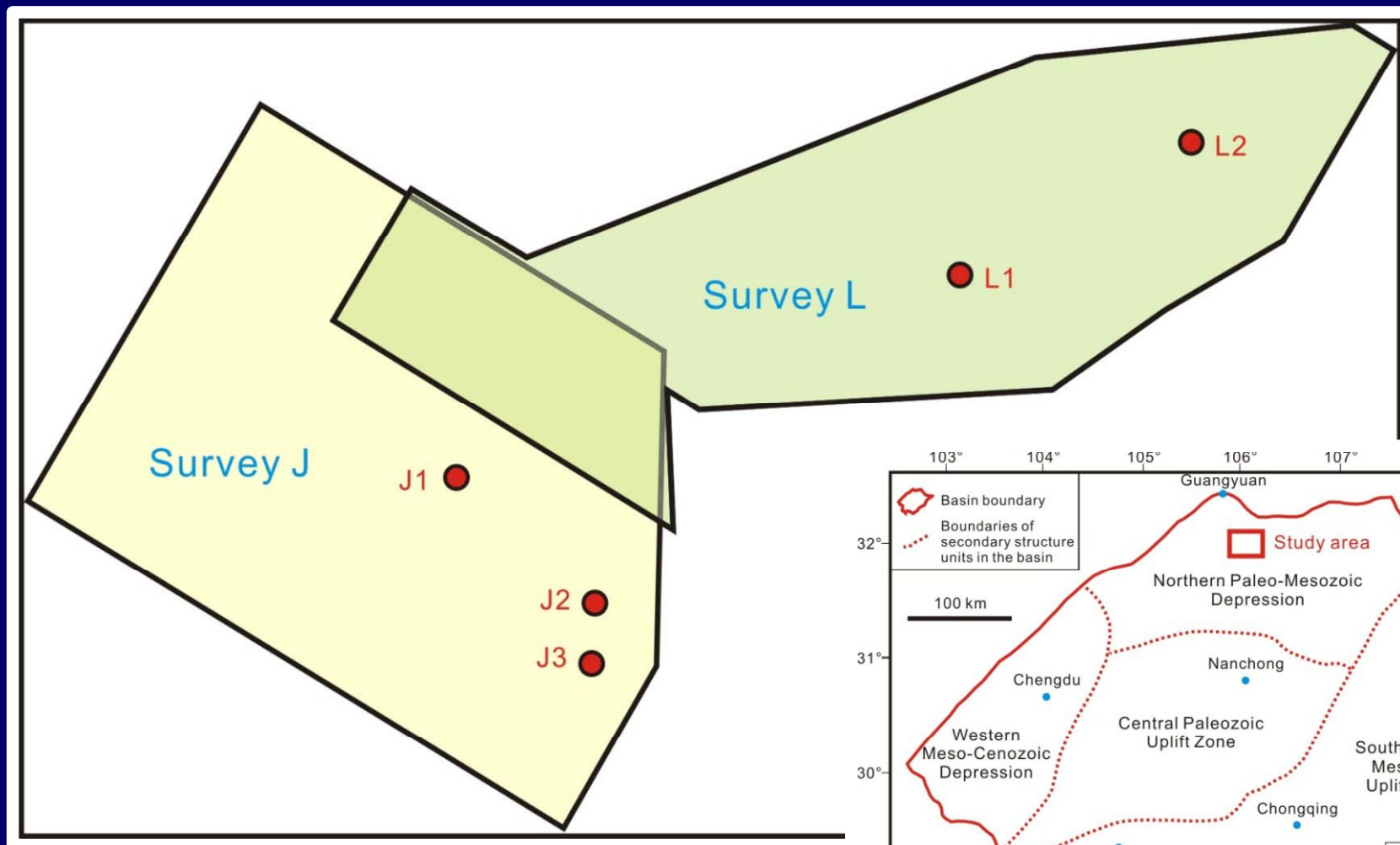
Paleogeographic map in Late Permian to the earliest Early Triassic in Sichuan Basin



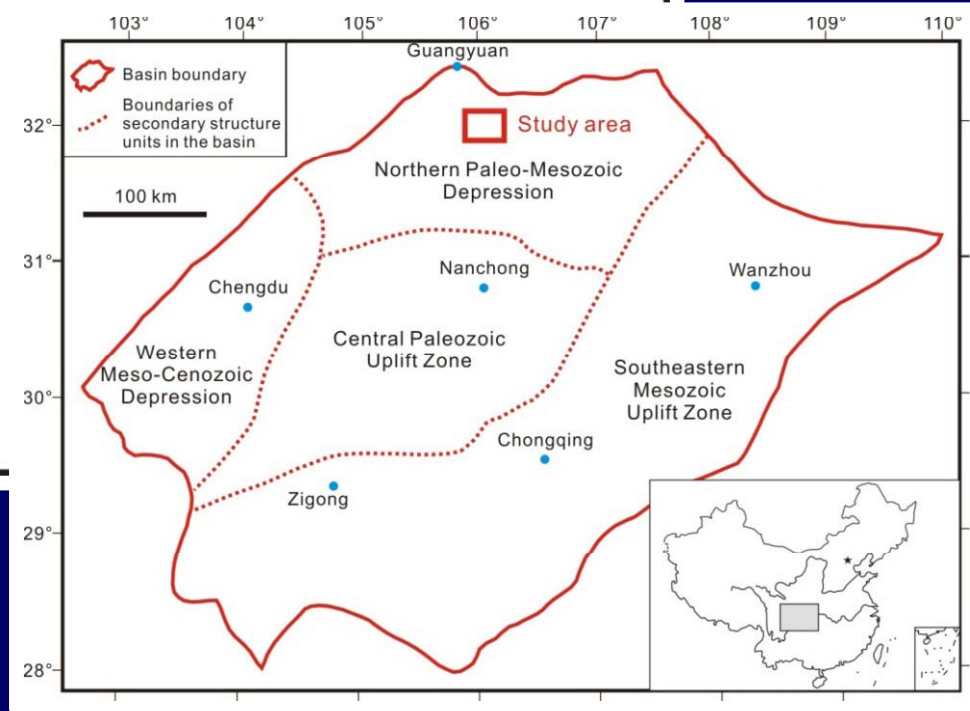
(Compiled from Wang et al., 2002; Ma et al., 2006; Wang et al., 2009; He and Luo, 2010; Zou et al., 2011)



Data Set



Survey J: 1150 km²
Survey L: 1046 km²
Total area: 1986 km²

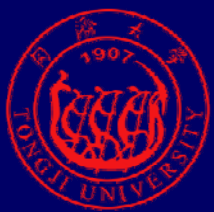




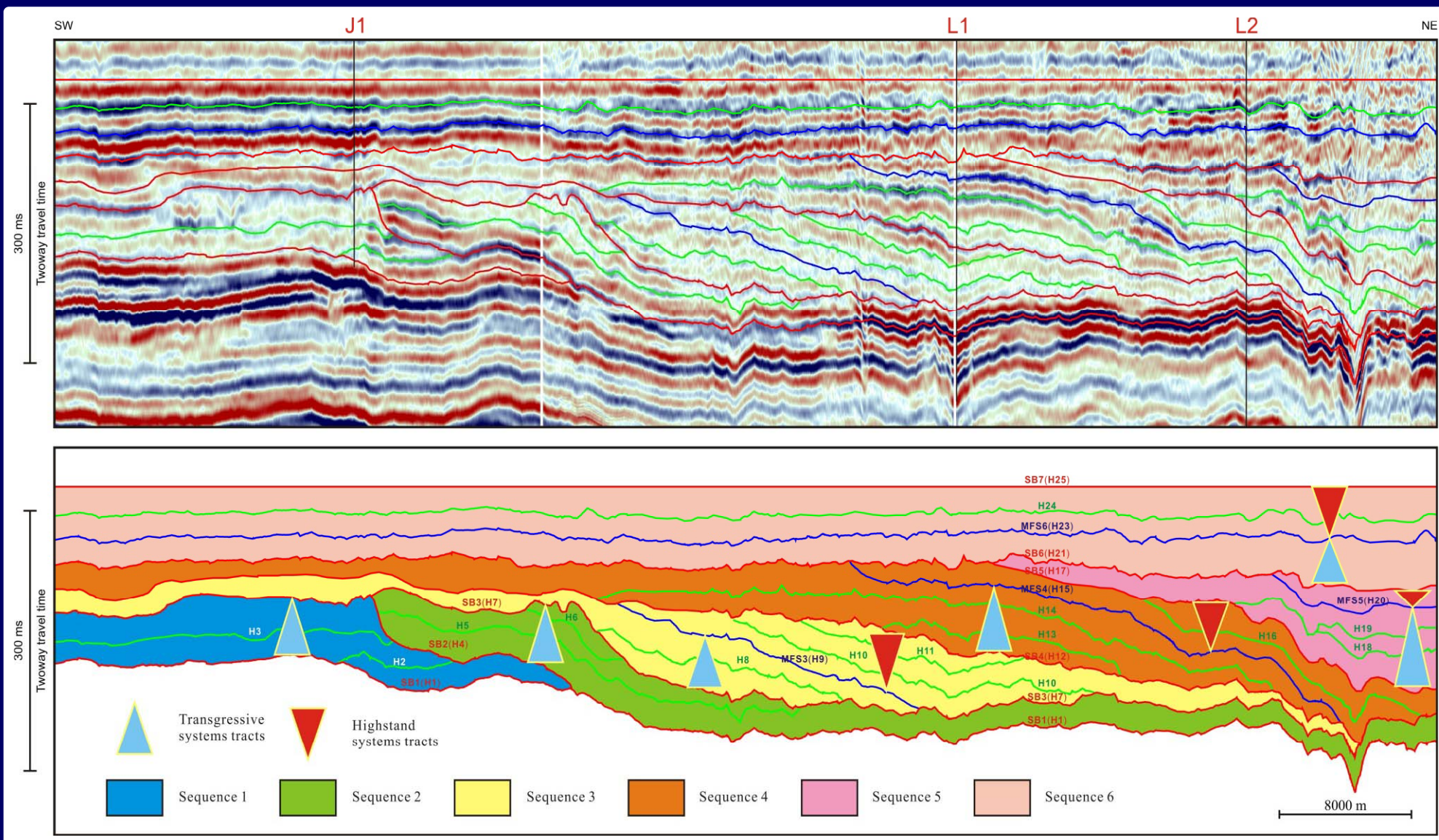
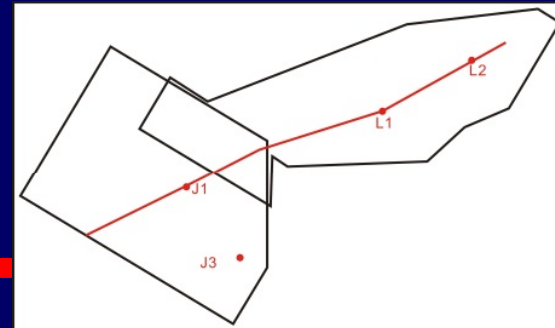
Seismic Sequence Analysis

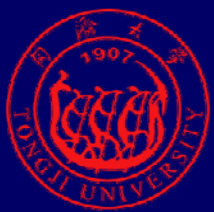
- 25 horizons were tracked; and 6 sequences, 10 systems tracts, and 24 basic seismic units (BSU) were defined.
- A 'BSU' is a seismic unit bounded by two adjacent horizons obtained by using our 'all-reflector tracking' method, which comprises the smallest isochronous seismic unit that can be constructed by direct horizon picking.

Seismic horizons	Seismic sequence stratigraphic classification					Corresponding litho-stratigraphic units							
	Seismic stratigraphic boundaries	Basic seismic units	Systems tracts	Sequences	Composite sequences								
H25	— SB7 —	BSU24	HST6	Sequence 6	Composite sequence 3	Members 3 & 4	Lower Triassic Feixianguan Formation						
H24		BSU23											
H23	— MFS6 —	BSU22	TST6										
H22		BSU21											
H21	— SB6 —	BSU20	HST5	Sequence 5	Composite sequence 2	Member 2							
H20	— MFS5 —	BSU19	TST5										
H19		BSU18											
H18		BSU17											
H17	— SB5 —	BSU16	HST4	Sequence 4				Composite sequence 2	Member 2				
H16		BSU15											
H15	— MFS4 —	BSU14	TST4										
H14		BSU13											
H13		BSU12	HST3	Sequence 3		Composite sequence 2				Member 1			
H12	— SB4 —	BSU11											
H11		BSU10	TST3										
H10		BSU9											
H9	— MFS3 —	BSU8	TST2	Sequence 2					Composite sequence 2		Member 1		
H8		BSU7											
H7	— SB3/MFS2 —	BSU6	TST1		Sequence 1							Composite sequence 1	Upper Permian Changxing Formation
H6		BSU5											
H5		BSU4	TST1										
H4	— SB2/MFS1 —	BSU3											
H3		BSU2	TST1	Sequence 1	Composite sequence 1			Upper Permian Changxing Formation					
H2		BSU1											
H1	— SB1 —												

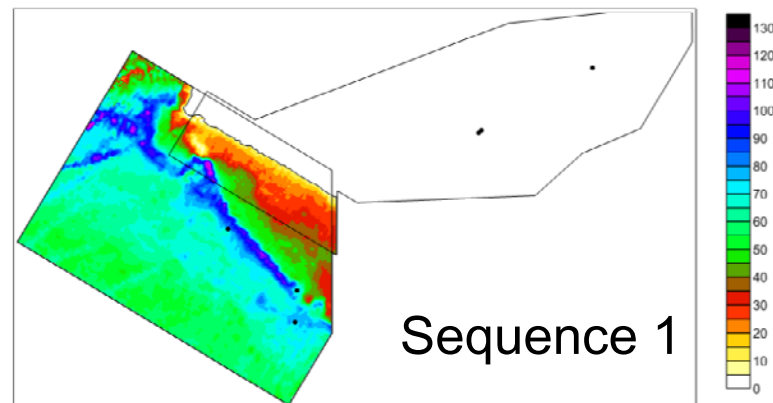
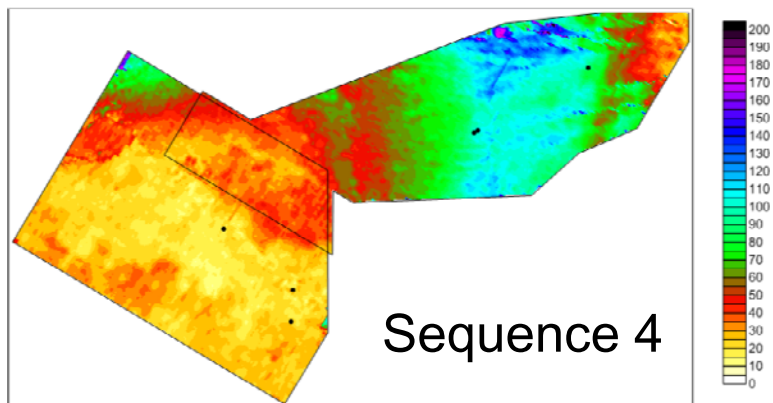
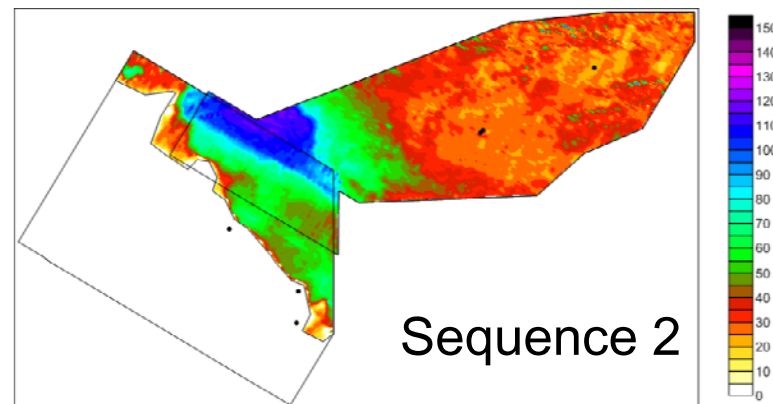
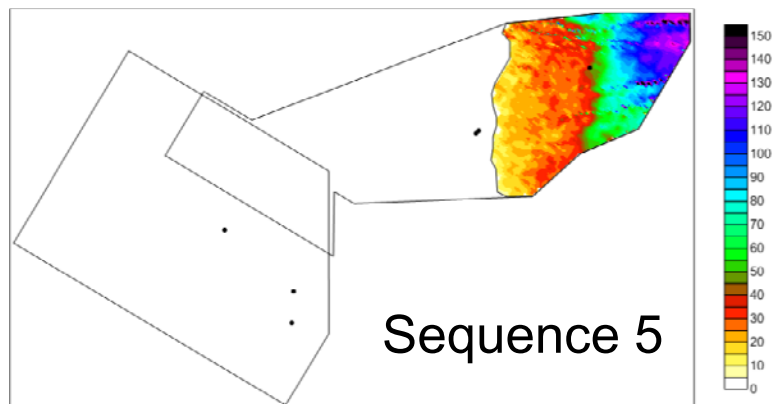
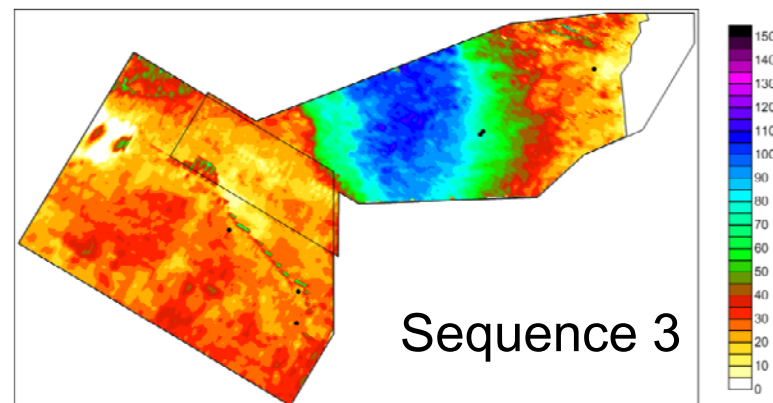
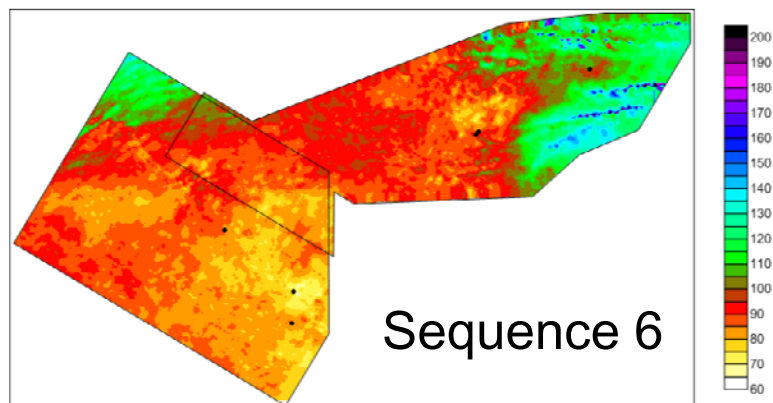


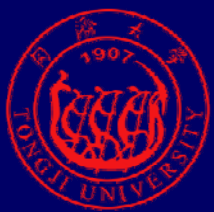
Seismic Sequence Analysis





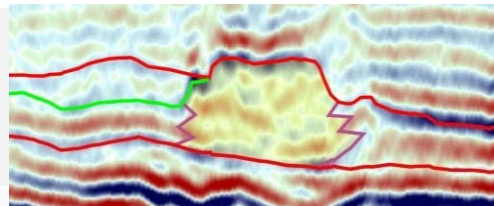
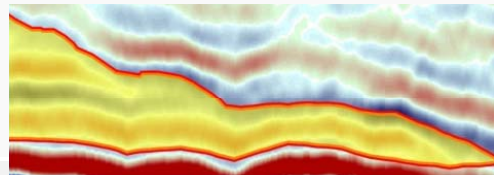
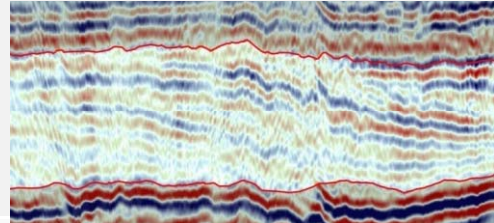
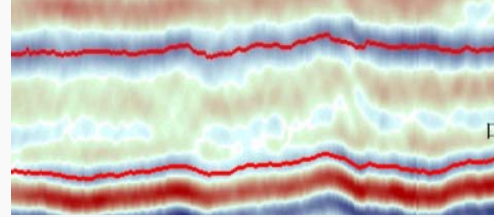
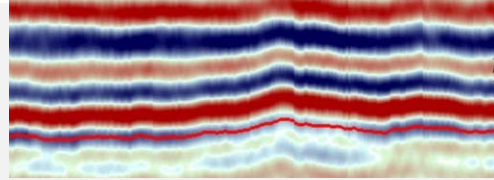
Seismic Sequence Analysis: Isopach maps (TWT) of the sequences

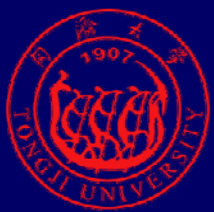




Seismic Facies Analysis:

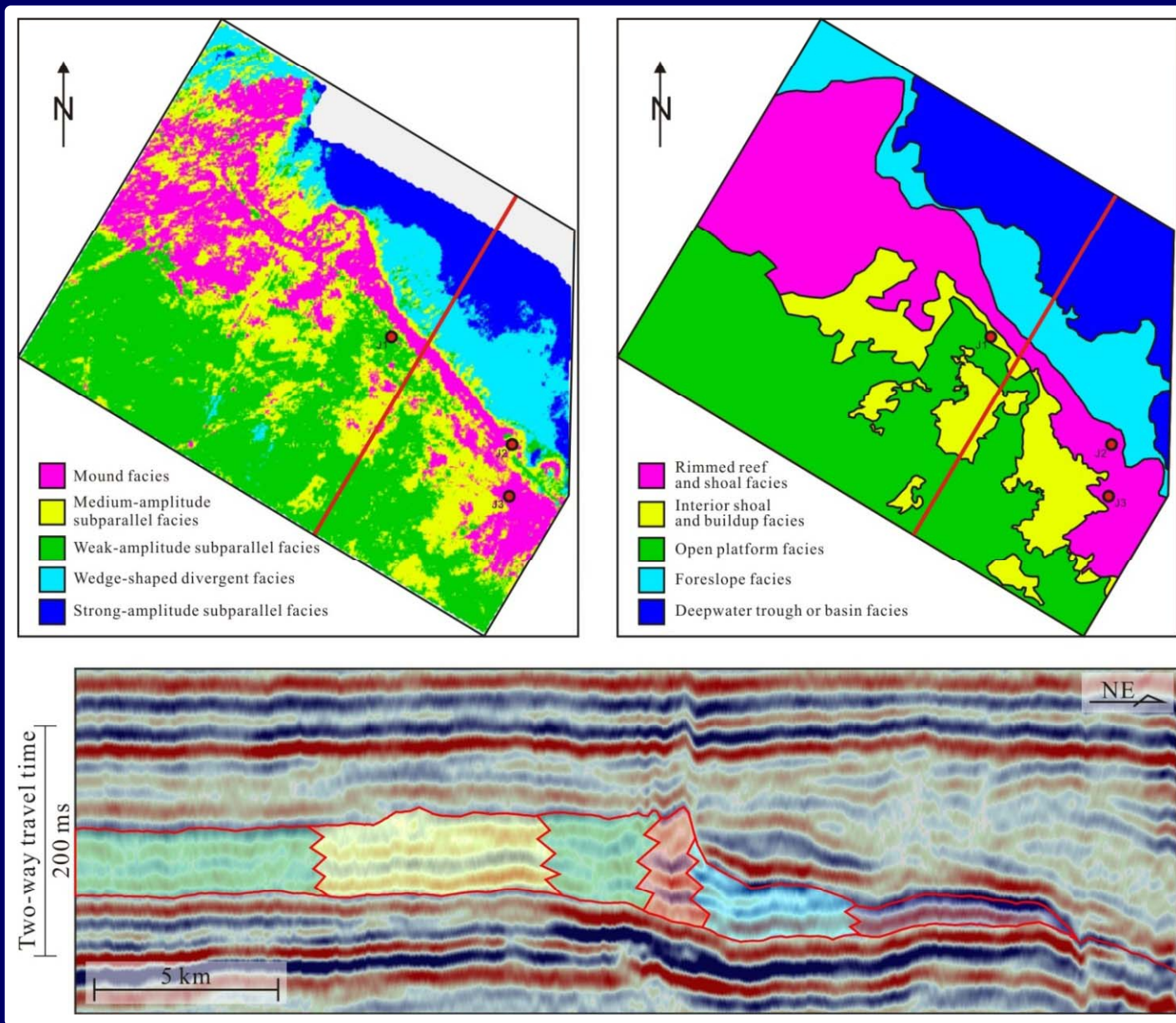
Types and characteristics of seismic facies

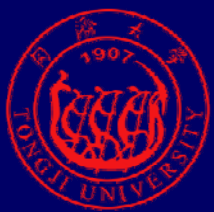
No.	Facies types	Reflection characteristics	Sedimentary environments	Seismic expressions
1	Mound facies	Mound geometry, chaotic to weak reflection configurations	Marginal reefs	
2	Wedge-shaped, divergent facies	Wedge-shaped, divergent units, bounded by strong reflections	Platform slope	
3	Prograding clinoform facies	Low to medium amplitude; Sigmoid, oblique, and complex sigmoid-oblique clinoforms	Prograding platform margin	
4	Parallel to sub-parallel facies	Low to medium amplitude, low to medium continuity, parallel to sub-parallel configuration	Platform interior (restricted to open platforms)	
		High amplitude, high continuity, parallel to sub-parallel configuration	Basin (trough)	



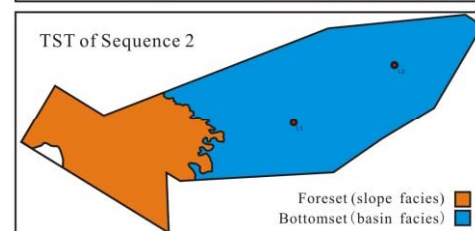
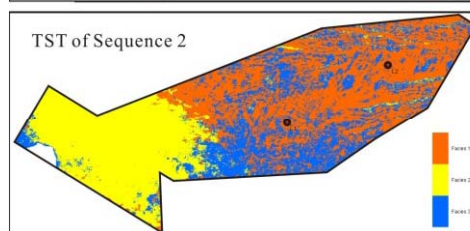
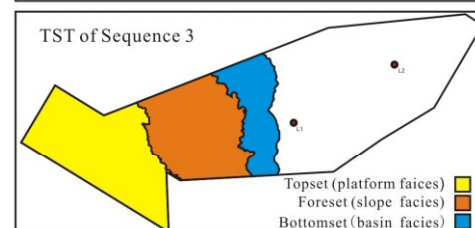
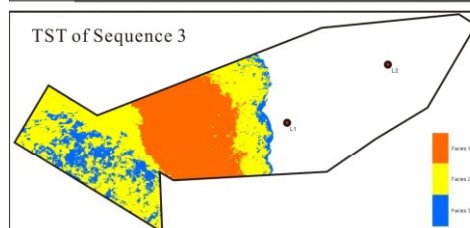
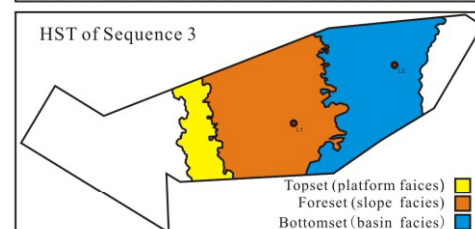
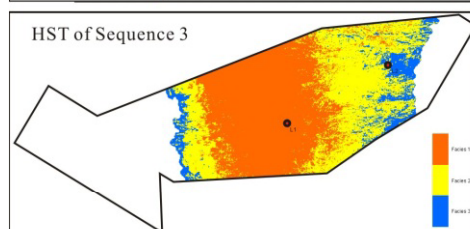
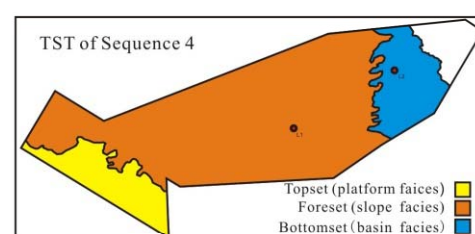
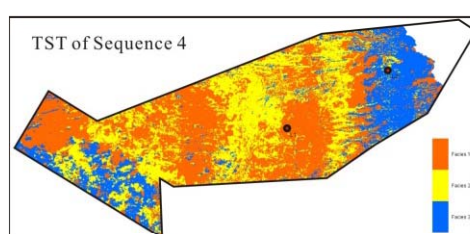
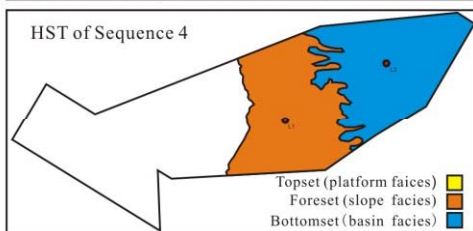
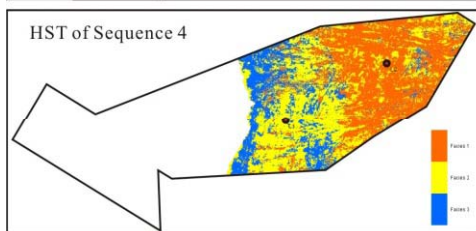
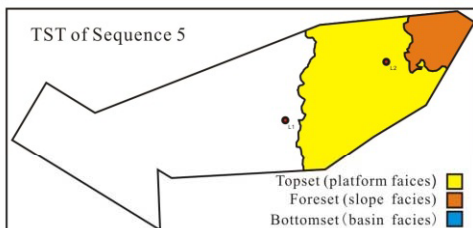
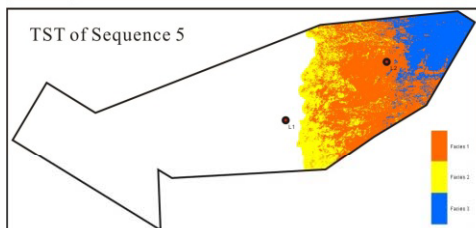
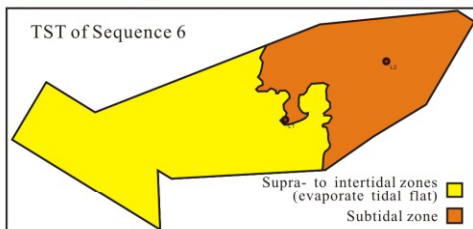
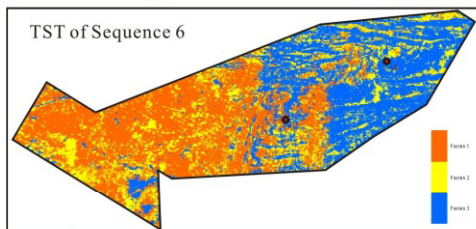
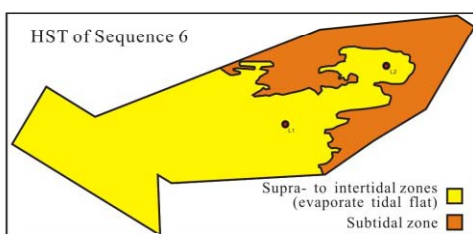
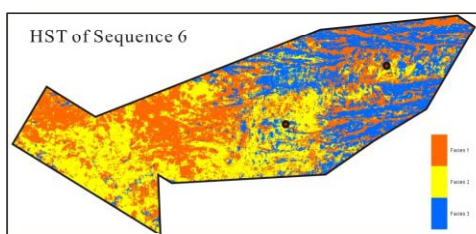
Seismic Facies Analysis: Seismic facies mapping & interpretation

Seismic facies
and
corresponding
sedimentary
facies maps of
sequence 1
(upper Permian
Changxing
Formation)

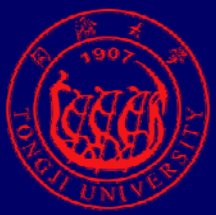




Seismic Facies Analysis: Seismic facies mapping & interpretation

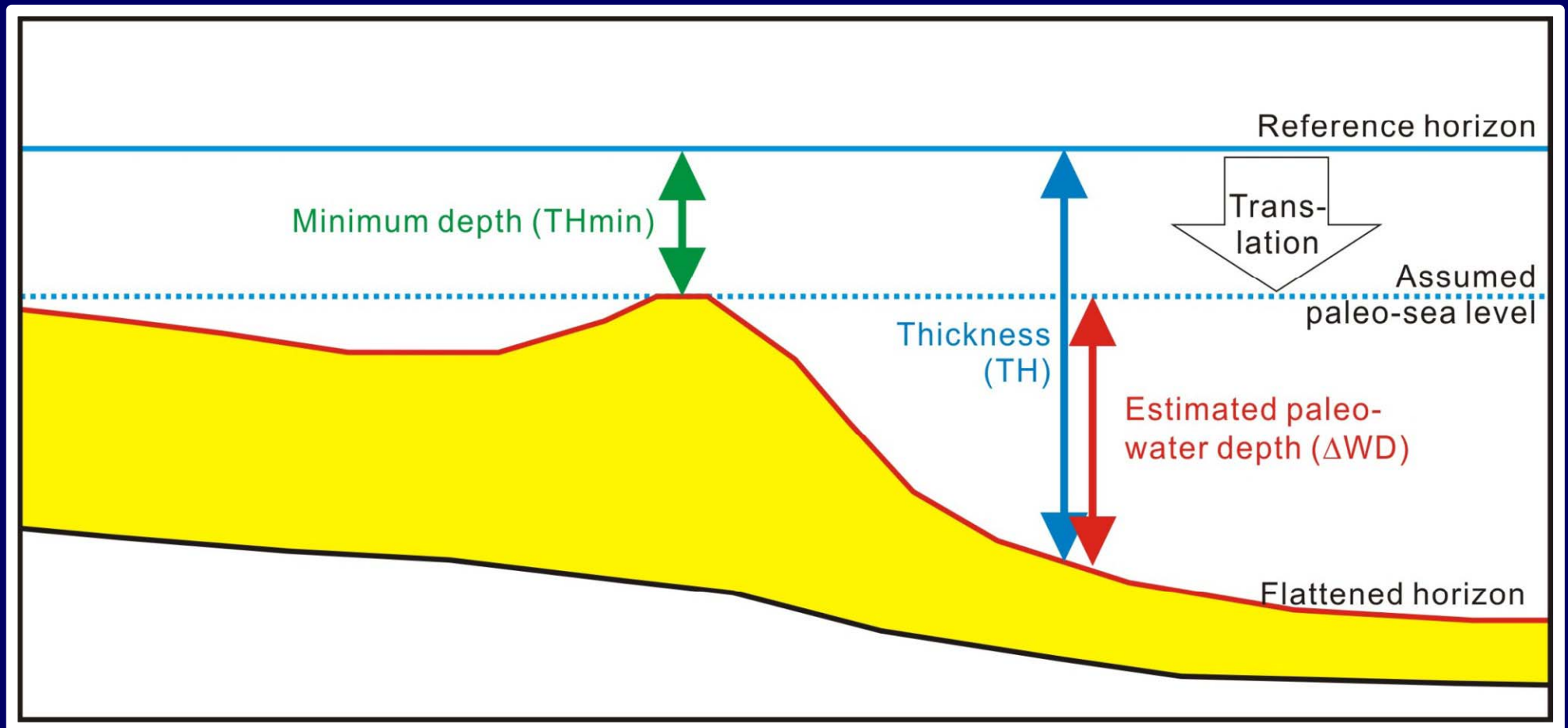


Seismic facies and corresponding sedimentary facies maps of different systems tracts in sequences 2 to 6 (lower Triassic Feixianguan Formation)

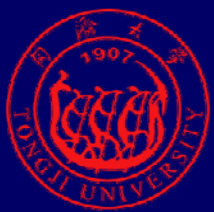


Seismic Geomorphology: Method 1 - Horizon flattening

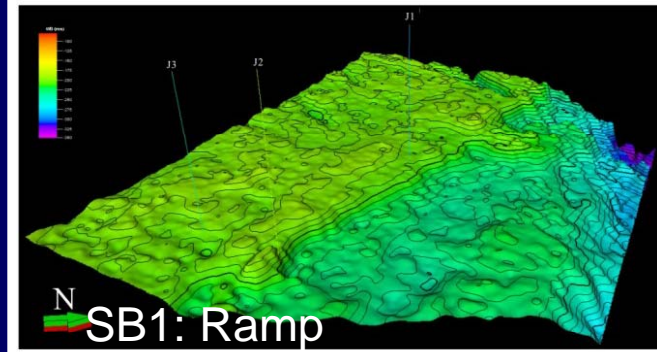
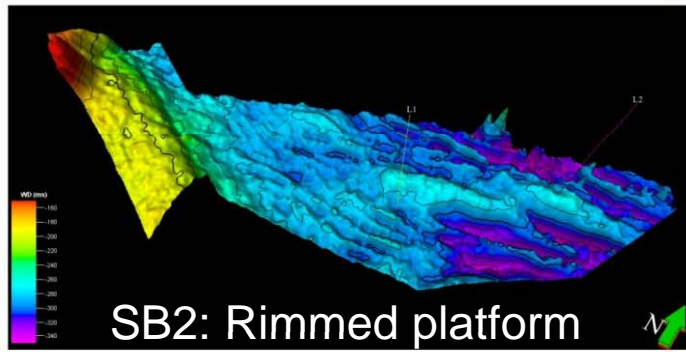
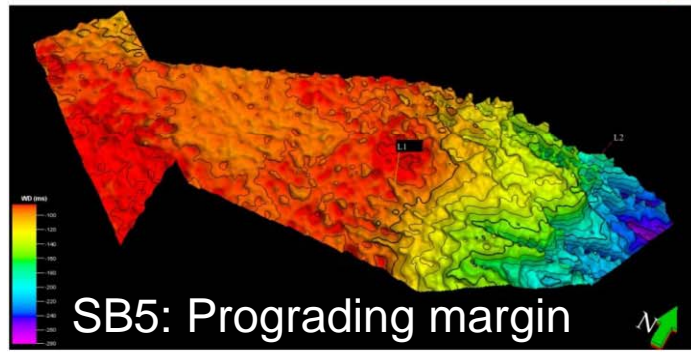
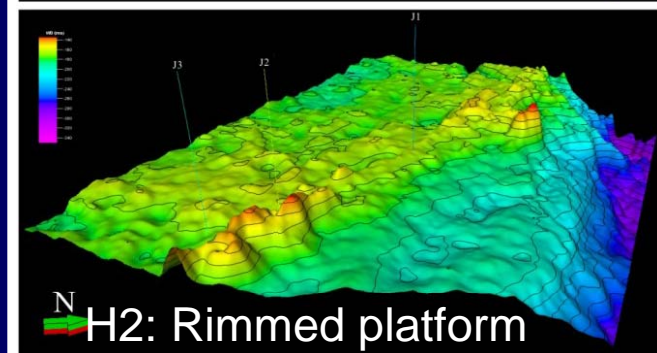
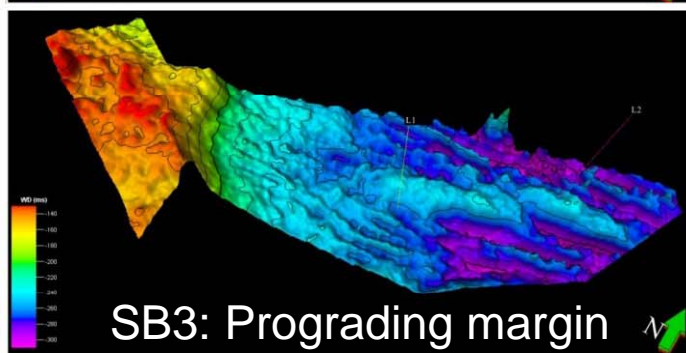
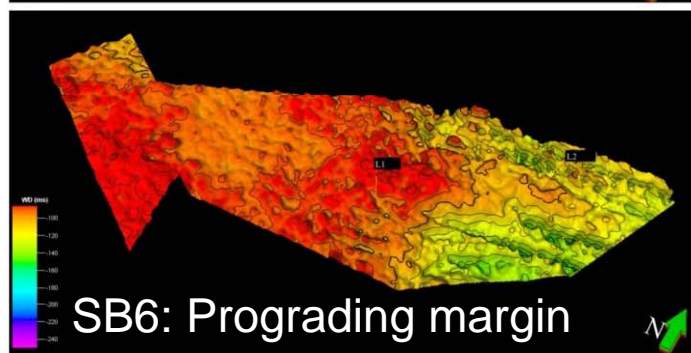
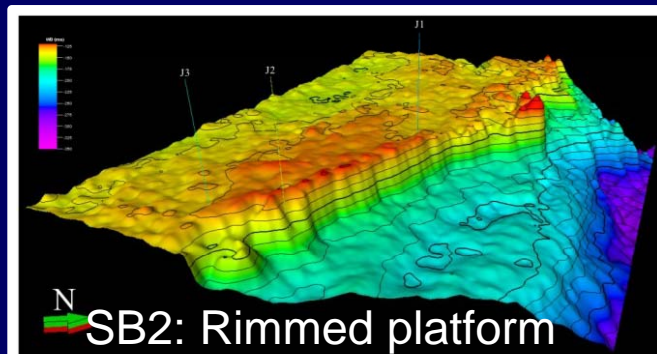
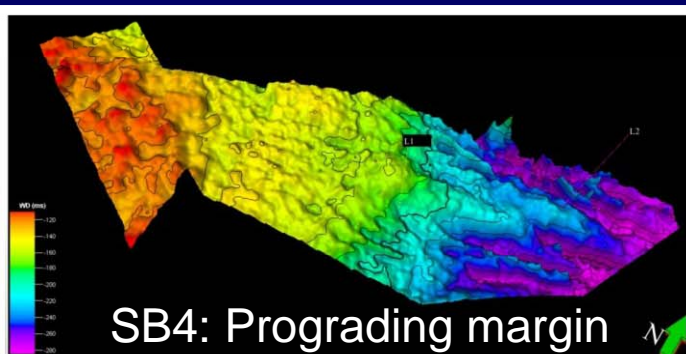
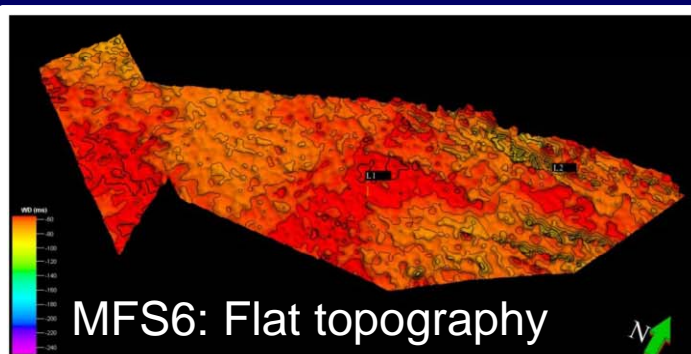
Paleo-water depth estimation by horizon flattening



$$\Delta WD = TH - THmin$$

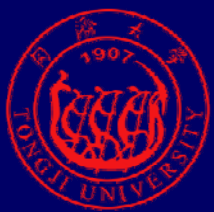


Seismic Geomorphology: Method 1 - Horizon flattening

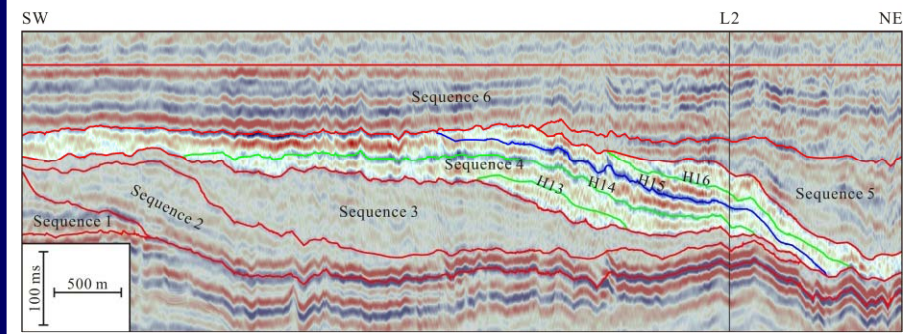
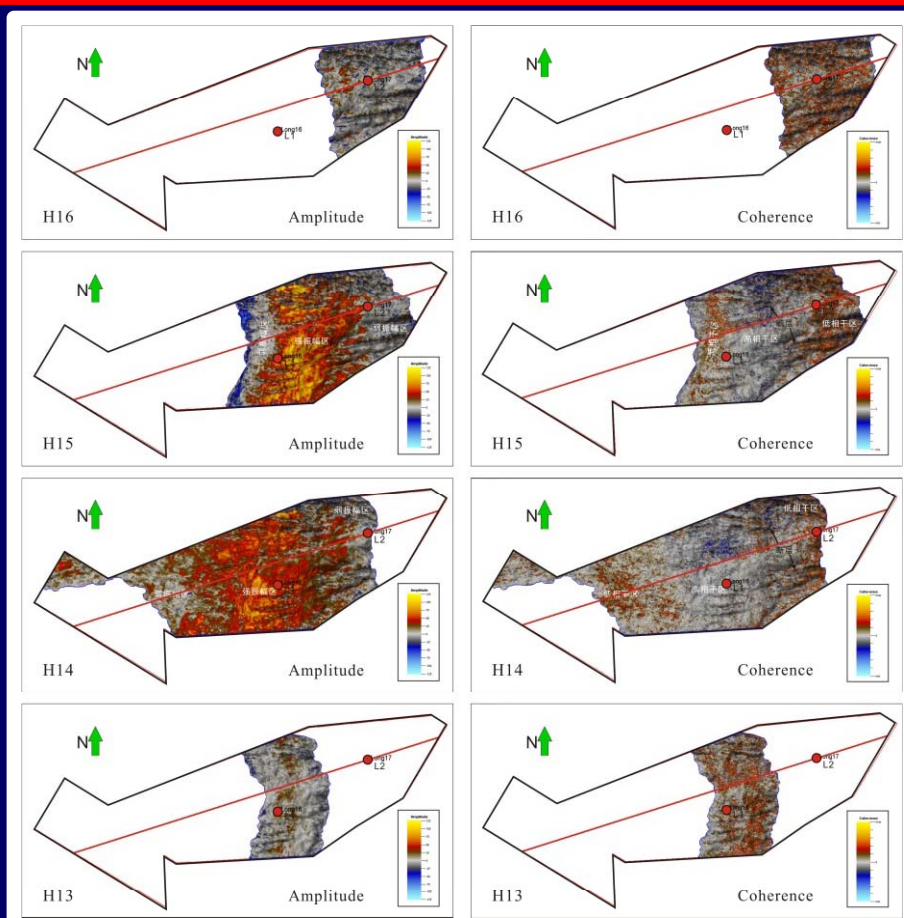
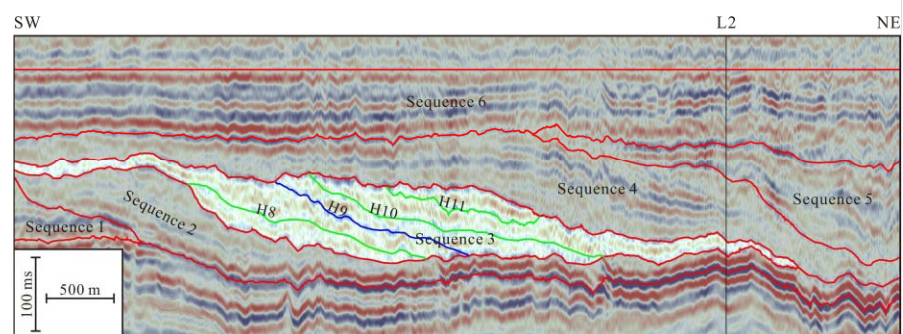
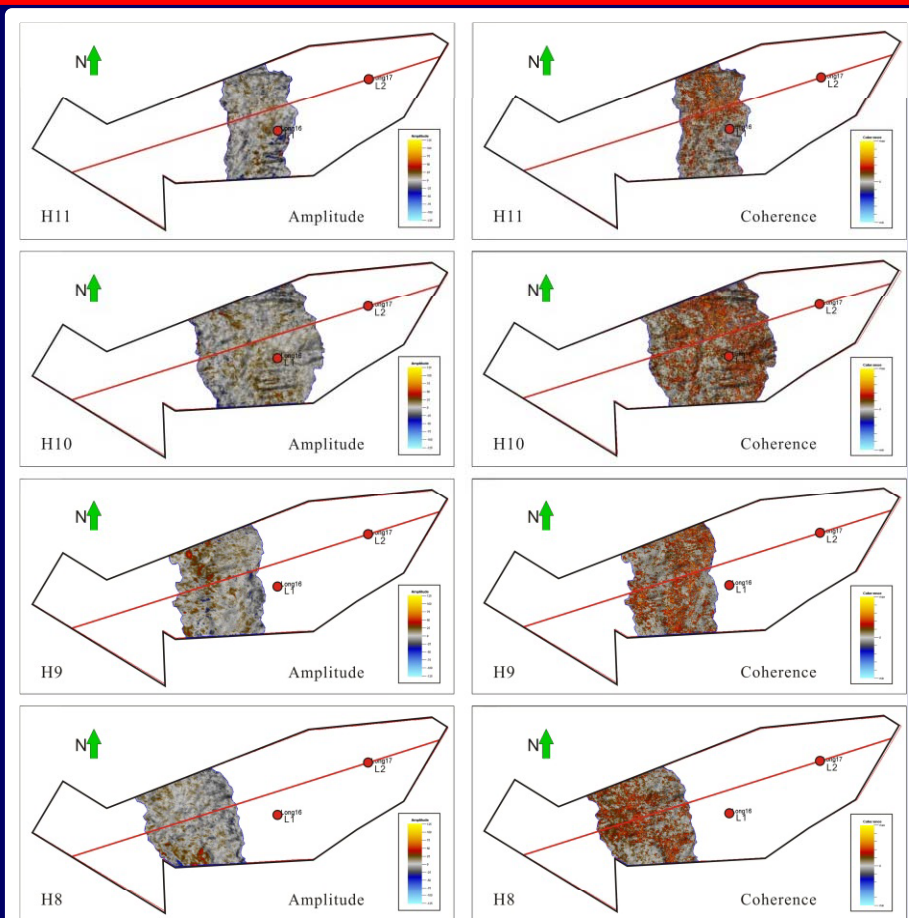


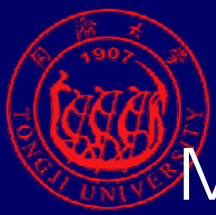
Survey L: Sequences 2-6
(Feixianguan Fm.)

Survey J: Sequence 1
(Changxing Fm.)



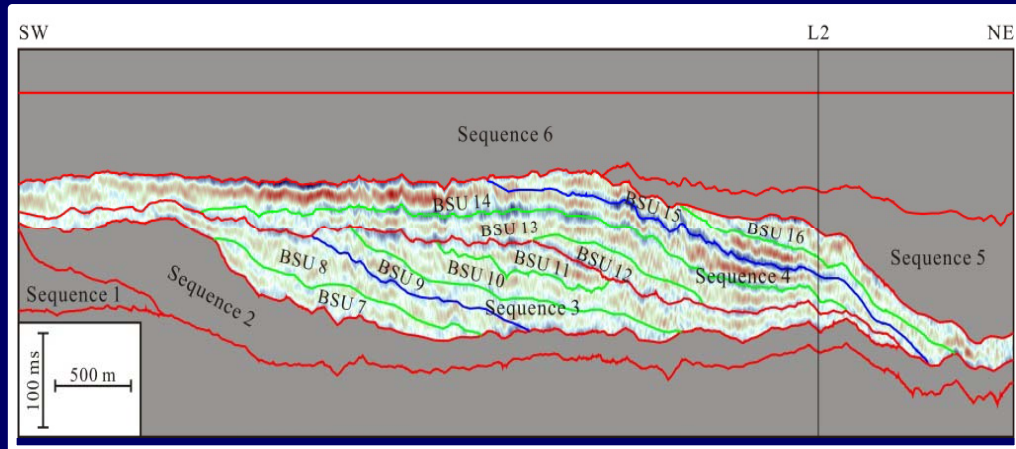
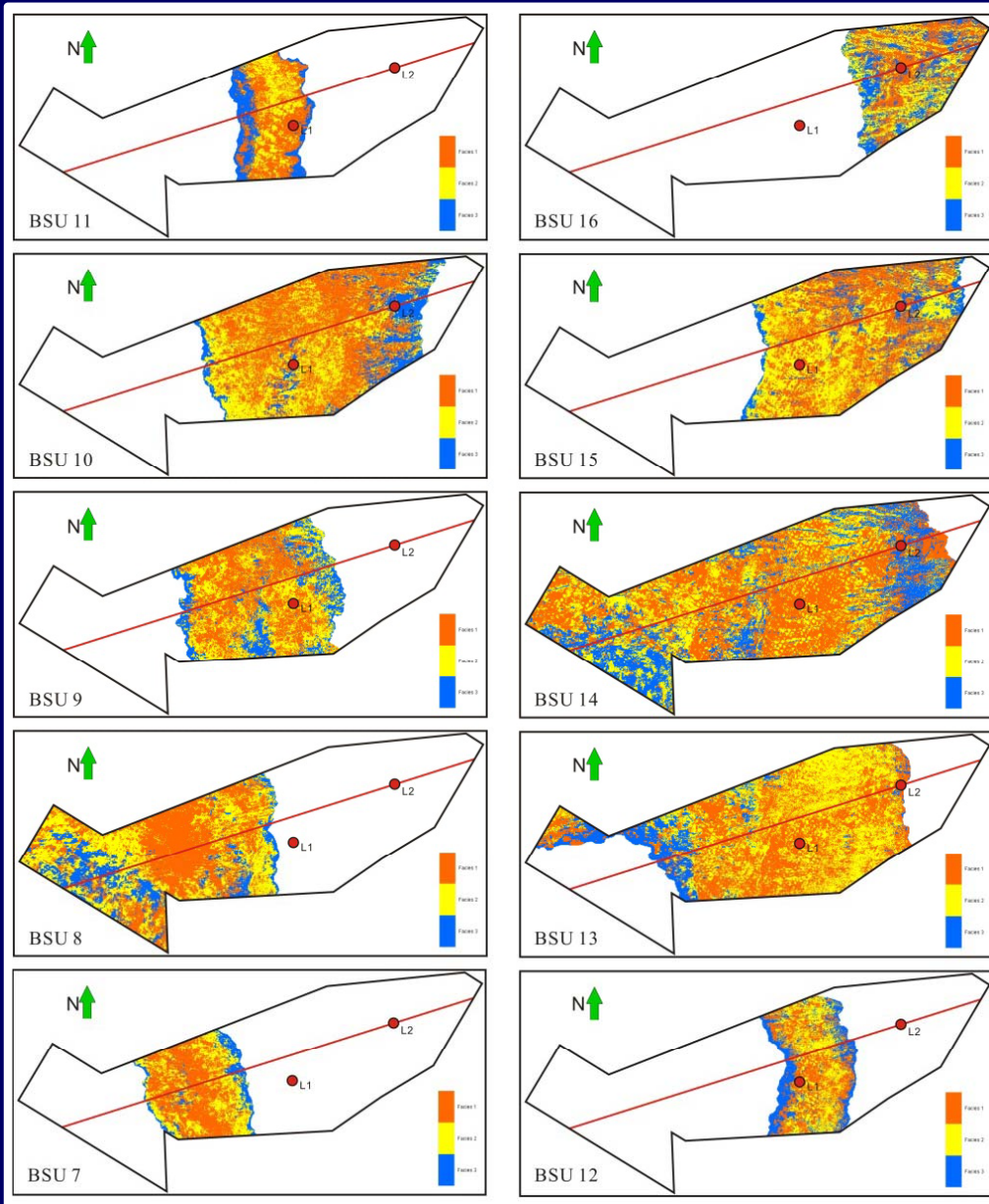
Seismic Geomorphology: Method 2 - Horizon slicing



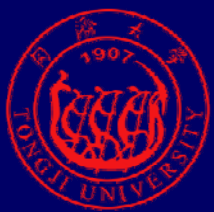


Seismic Geomorphology:

Method 3 - Analysis of 'Basic Seismic Units'



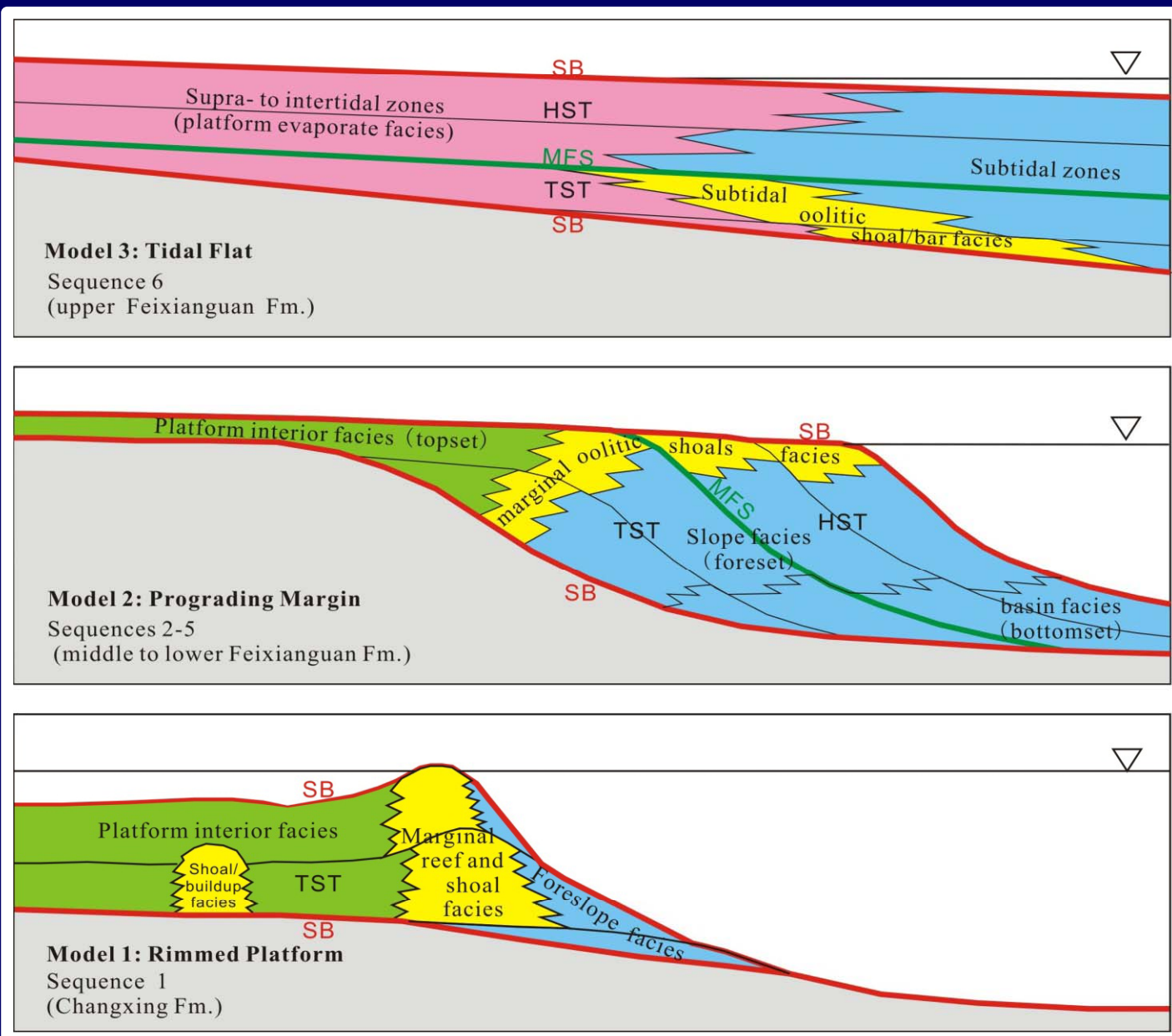
- Seismic facies maps of 10 BSUs in Sequences 3 and 4

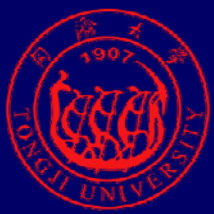


Integration:

Geological models for reservoir prediction

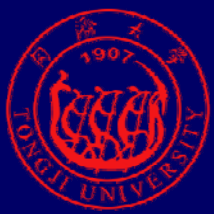
- Transgressive marginal reef facies in sequence 1 and oolitic shoal facies in the prograding packages of sequences 2 to 5 constitute the potential reservoirs.





Summary

- An integrated seismic stratigraphic and seismic geomorphological interpretation method is presented. It is based on the careful horizon picking by using our 'all-reflector tracking' method (Zhong et al., 2010).
- Application to the upper Permian to lower Triassic carbonate reservoirs in northern Sichuan Basin, 6 seismic sequences, 10 system tracts, 24 BSUs were defined; and the characteristics and the temporal and spatial evolution of the sequence, facies and geomorphology were reconstructed.
- Three types of reservoir geologic models were constructed. Transgressive marginal reef facies in sequence 1 and the oolitic shoal facies in the prograding packages of sequences 2 to 5 were suggested as the potential reservoirs.



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Thanks for your
attention !

QUESTIONS?