

# **Characteristics and Resource Potential of Lacustrine Shale Oil and Gas in China\***

**Jin Zhijun<sup>1</sup>, Gao Bo<sup>2</sup>, and Wu Xiaoling<sup>2</sup>**

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## **Abstract**

Chinese petroliferous basins contain several organic rich lacustrine shales, including the Upper Cretaceous Qingshankou Formation in the Songliao Basin, Paleogene Shahejie Formation in the Bohai Bay Basin, Triassic Yanchang Formation in the Erdos Basin, Triassic-Jurassic strata in the Sichuan Basin, and Permian and Jurassic in the Zhungeer Basin. In comparison with the marine shales in the USA, lacustrine shales in China are characterized by young geologic age, limited areal extent, large facies variation, variable organic input, low thermal maturity, less brittle mineral, high clay content, and poor diagenesis. Since 2008, China has been actively engaged in lacustrine shale oil and gas exploration. Major breakthroughs have been achieved, successively in the lacustrine shale gas exploration from the Lower Jurassic Ziliujing Formation in the Sichuan Basin and the Triassic Yanchang Formation from the Erdos Basin. Significant progress has been made in the shale oil exploration from the Paleogene in several rift basins in eastern China. This presentation will utilize Sinopec's extensive core data, to address the key geological factors that make the Paleogene shale oil resource in eastern China extremely attractive, and the main technological challenges that impede the large-scale economic exploitation of this resource. Several case studies from the Ordos, Sichuan, and Zhungeer basins will be used to demonstrate the shale gas resource potential and commercial feasibility in the Upper Paleozoic and Mesozoic lacustrine sequences in China.

## **References Cited**

Jishun, R., 1999, Tectonic map of China and adjacent regions: 1<sup>st</sup> edition and 1<sup>st</sup> impression, Geological Publication House, Beijing, China, 1 map.

Schenk, C.J., and R.M. Pollastro, 2001, Natural gas production in the United States: U.S. Geological Survey Fact Sheet FS-113-01.

Skelton, P.W., 2003, The Cretaceous World: Cambridge University Press, Cambridge, UK., 360 p.



# **Characteristics and Resource Potential of Lacustrine Shale Oil and Gas in China**

**Jin Zhijun , Gao Bo, Wu Xiaoling**

**SINOPEC Research Institute of Exploration & Production**

**May, 2013**



**Will China enter a shale gas boom after the US?**

**What has been and is being done in China?**

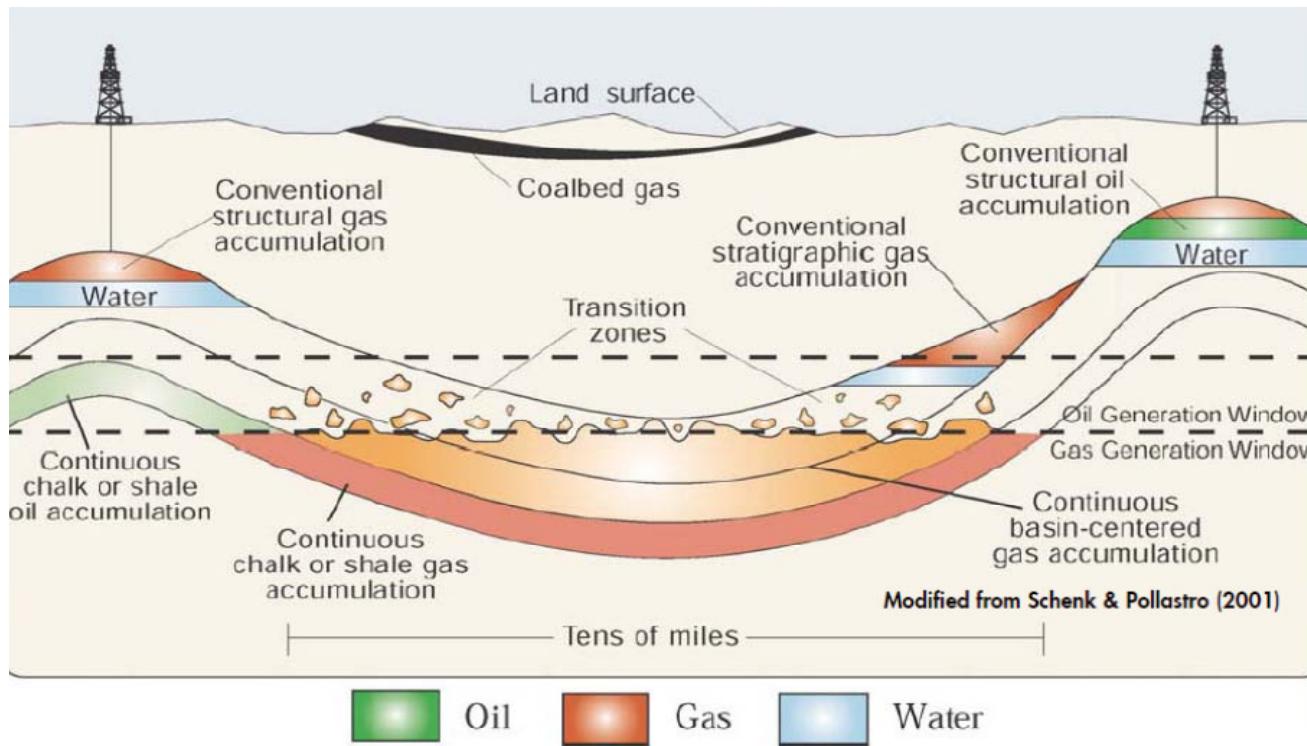
**What are the main challenges ahead?**



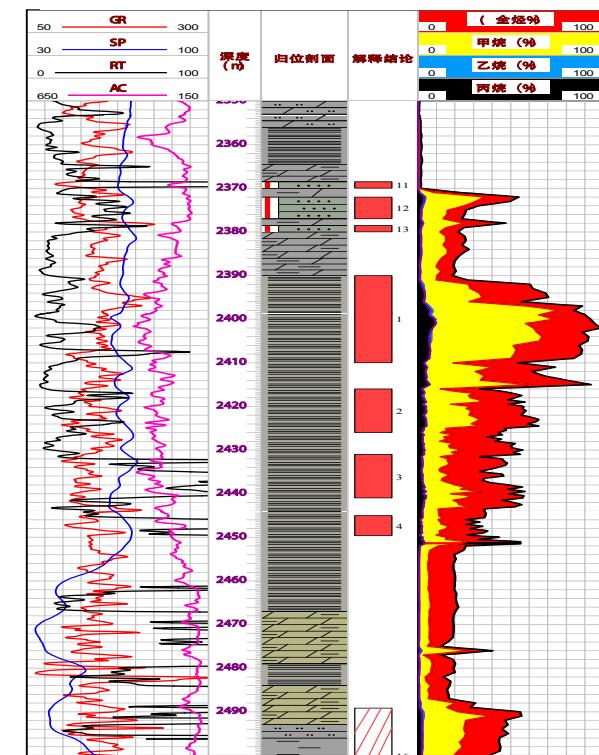
# Outline

- Introduction**
- Lacustrine Shale Gas**
- Lacustrine Shale Oil**
- Conclusions**

# Definition of shale oil



Drilling map of BY HF-1 well

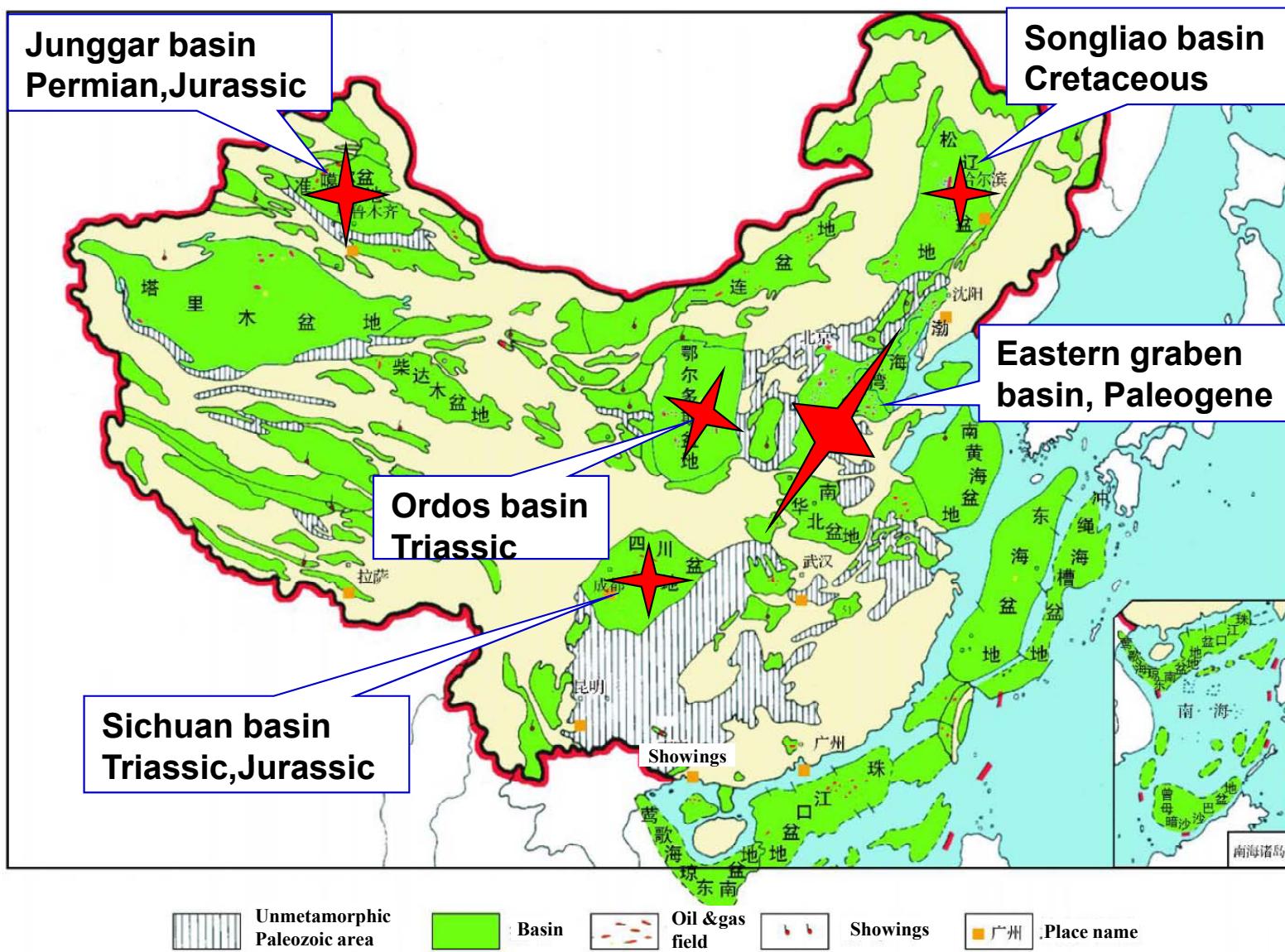


**Shale oil :** Indigenous hydrocarbons remaining in thermally mature source rocks and associated non-source interbeds after limited migration.



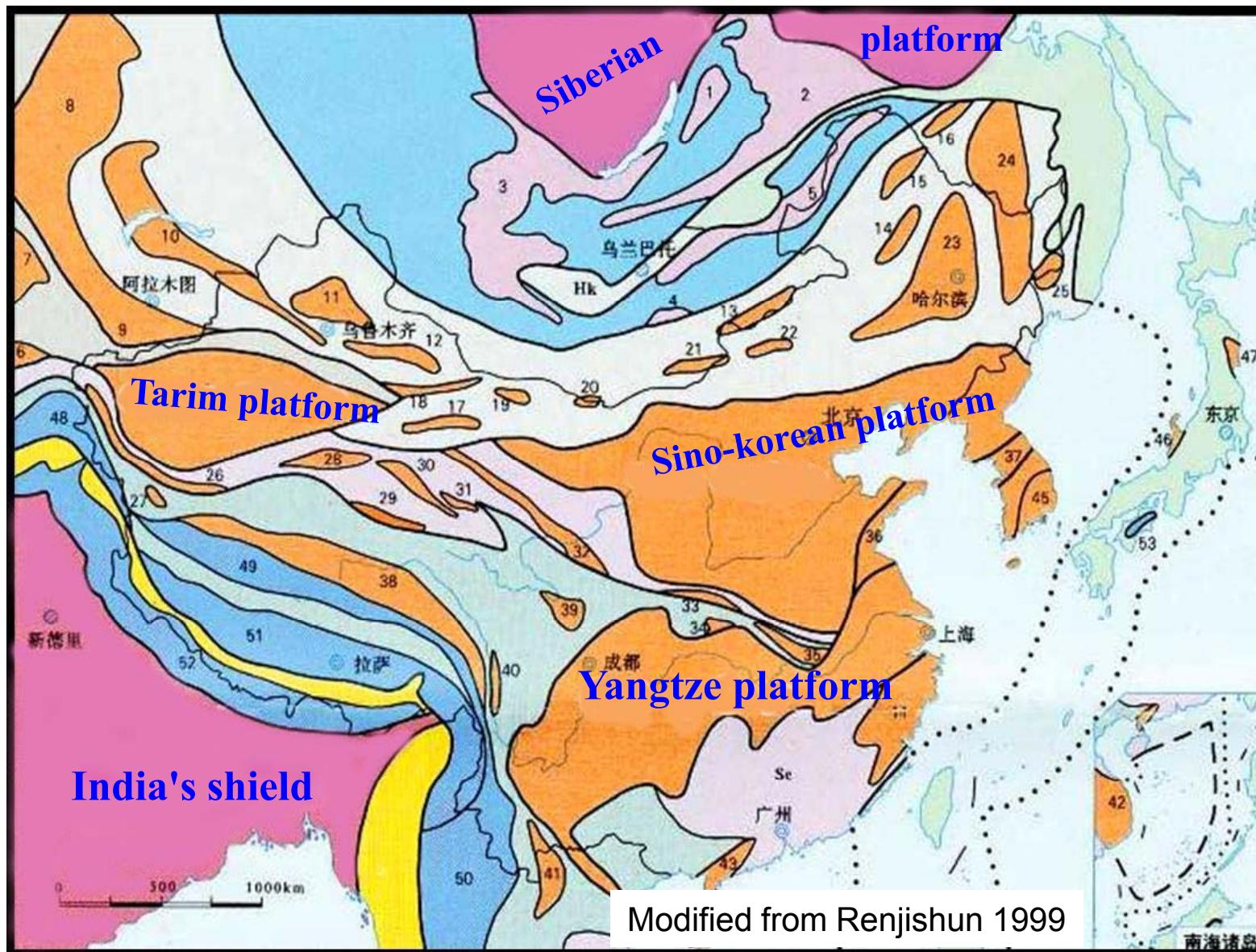


# Distribution of OM-rich lacustrine shale in China



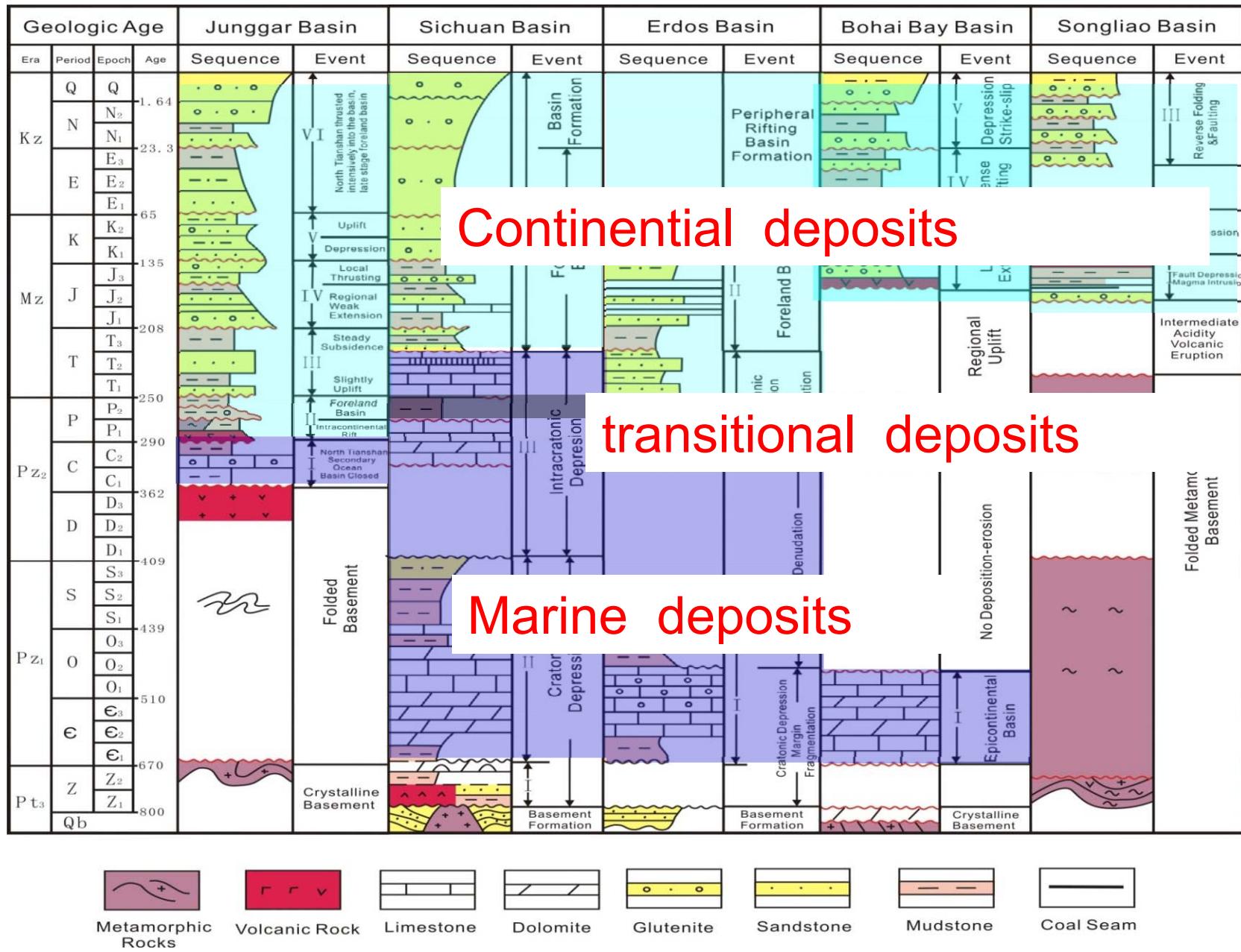


# Basic tectonic characteristics of China

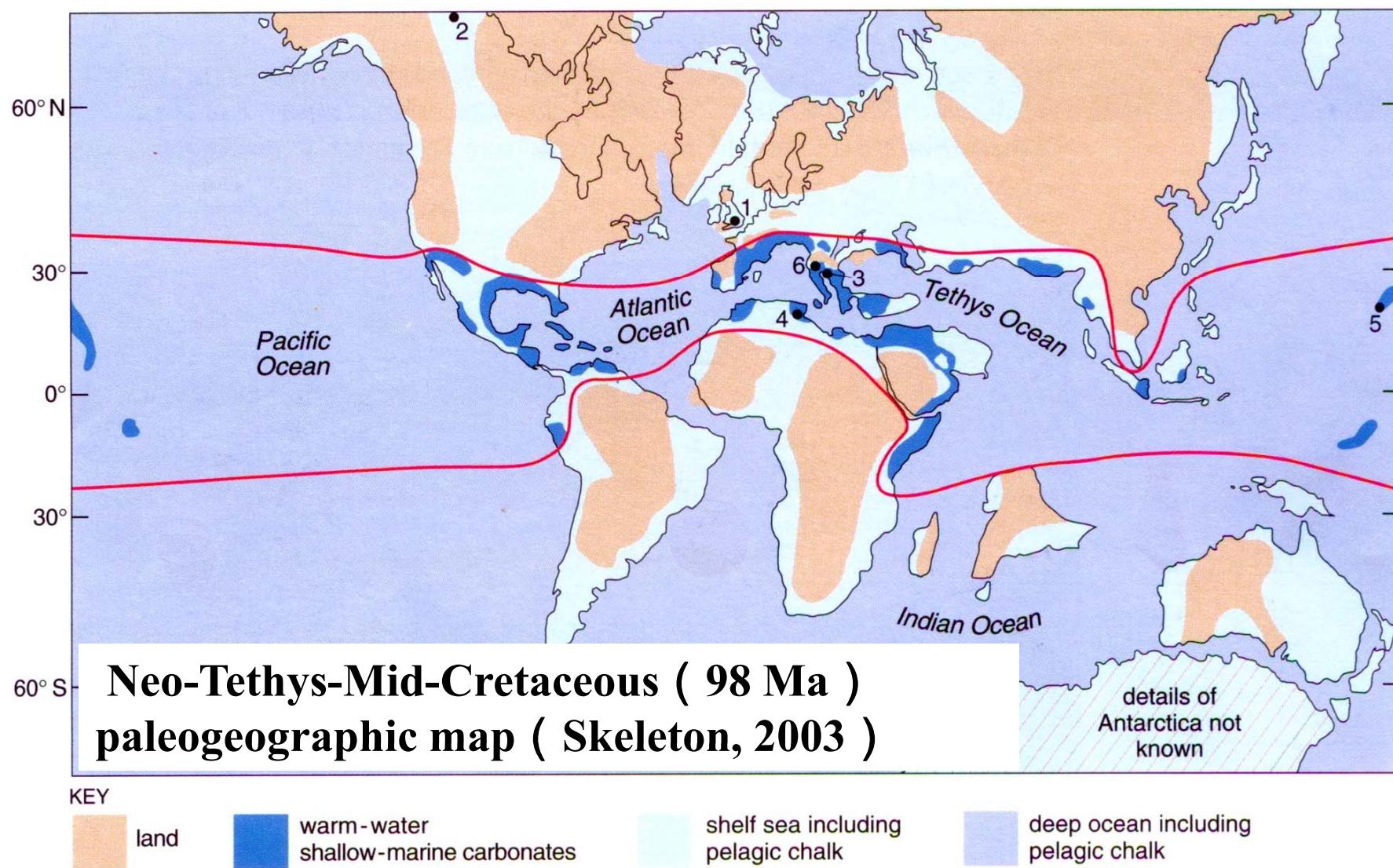


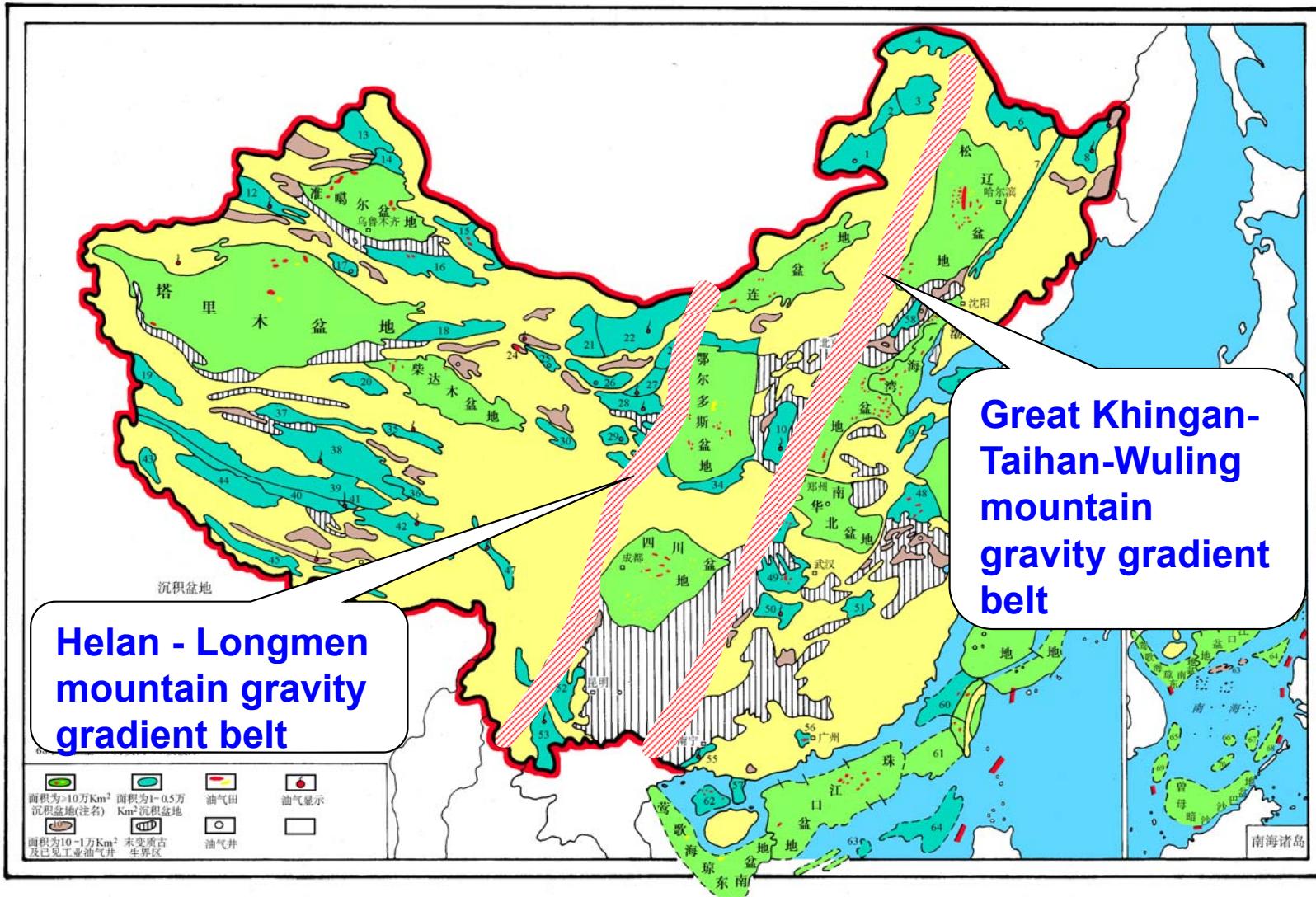
**Small craton with extensive orogenic activities**

# Multicyclic tectonic & sedimentary evolution leading to accumulation of marine, continental and transitional shales



The Mesozoic in China is dominated by non-marine deposits, with marine deposits occurring in neo-Tethys domain

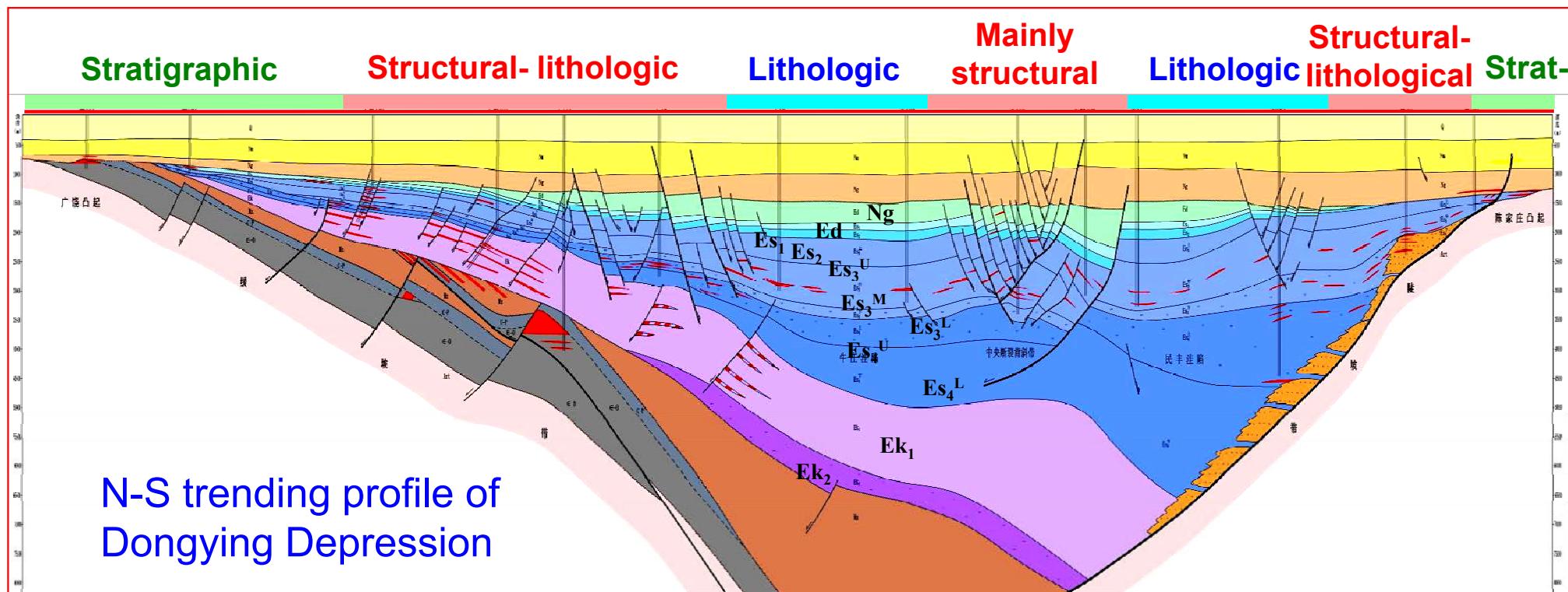




Major differences are observed in tectonic style, diageneses and petroleum potential between the two tectonic domains

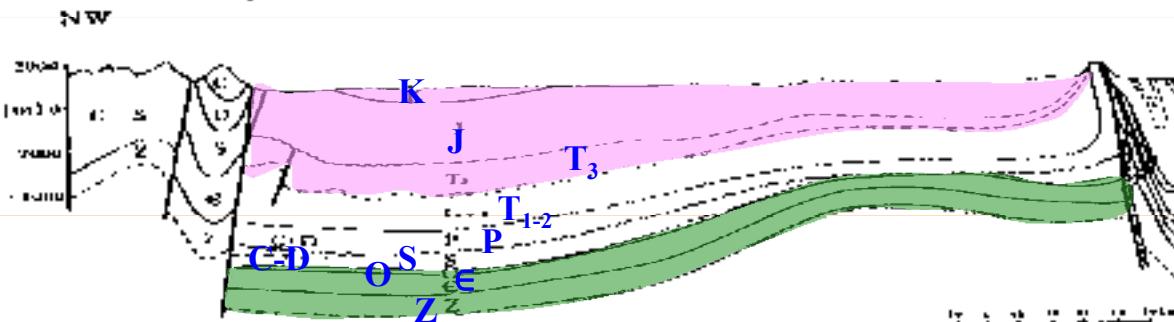


# Tectonic profile, Dongying Depression, Bohai Bay Basin





Fold and thrust belts of Longmen Mountain

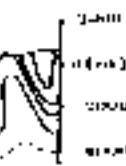


## Sichuan Basin

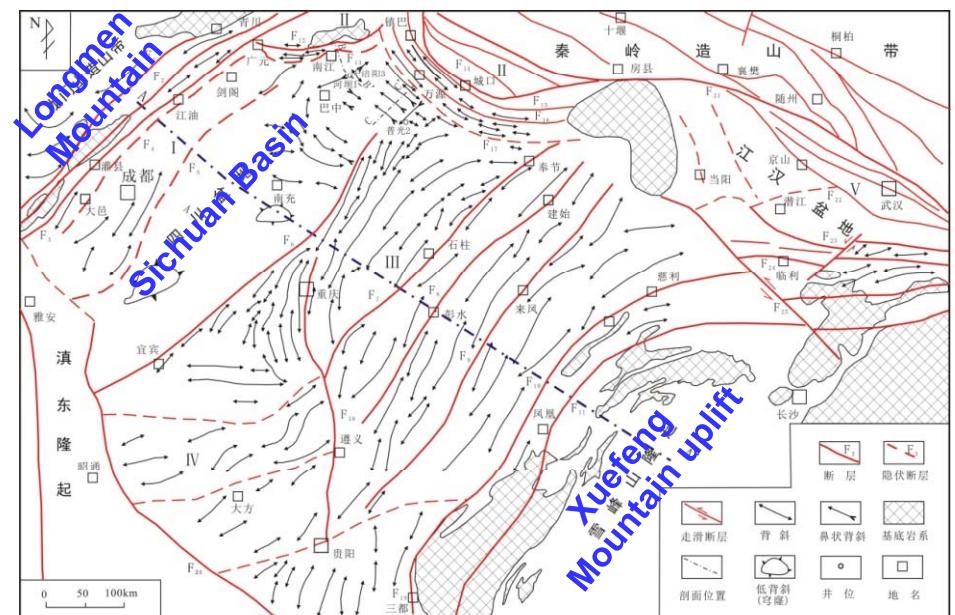
Fold and thrust belts of west Hunan-north Guizhou



SE



## Tectonic profile of Sichuan Basin





# Outline

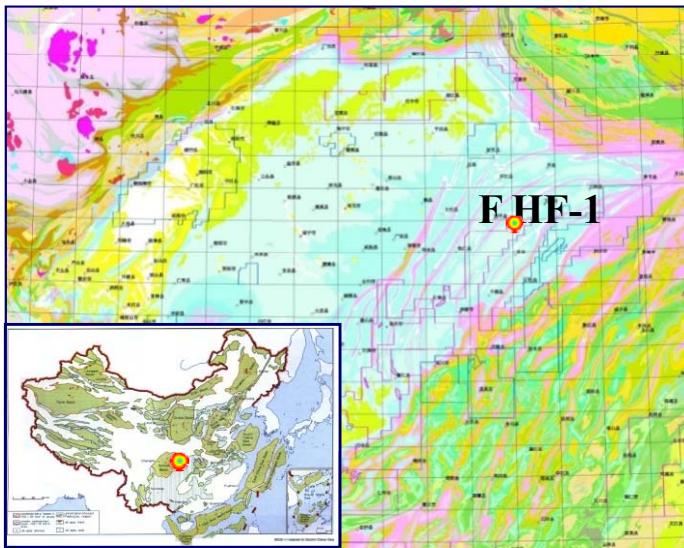
- Introduction
- Lacustrine Shale Gas
- Lacustrine Shale Oil
- Conclusions



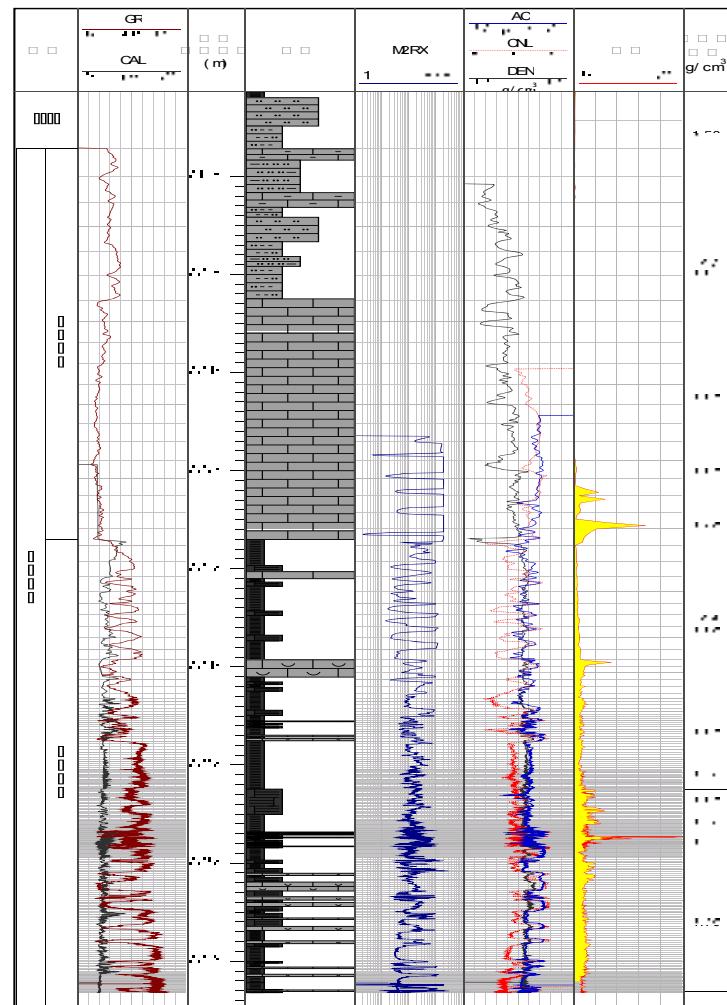
## 2.1 Progress in shale gas exploration, Sichuan Basin

( 1 ) Daily gas flow of **17317m<sup>3</sup>** obtained from F HF-1 Well, after acid fracturing of J<sub>1</sub>Z<sup>4(2)</sup>, Fuling region

- Horizontal payzone : J<sub>1</sub>Z<sup>4(2)</sup>
- Vertical length: **3570 m** , horizontal length : **1136.75 m**
- March 14, 10-stage fracking, test **1107m<sup>3</sup>/d**
- May 26, gained gas **17317 m<sup>3</sup>/d** after diversion acidification treatment in 4 segments



J<sub>1</sub>Z<sup>4</sup> composite stratigraphic column of FY1 Well

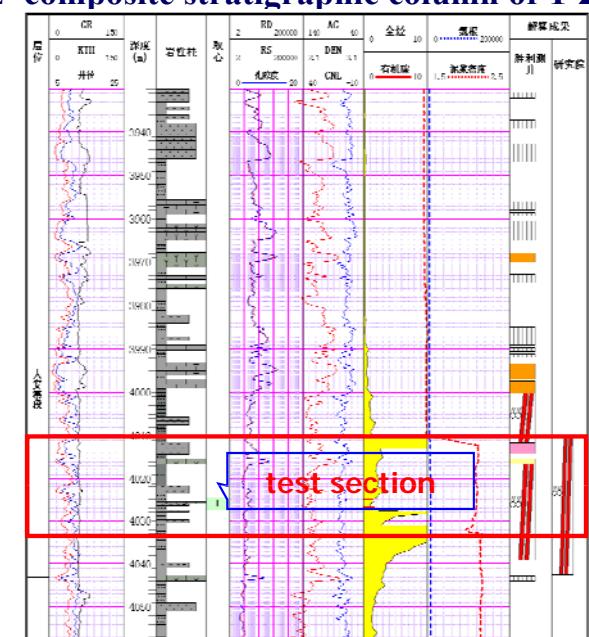
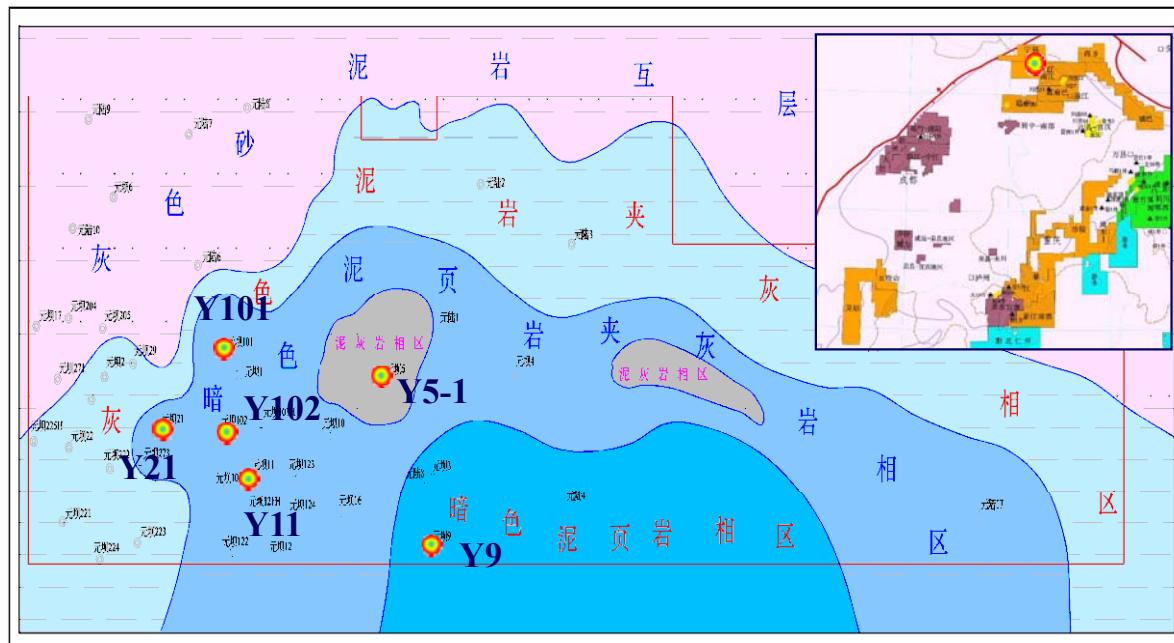


## 2.1 Progress in shale gas exploration, Sichuan Basin

( 2 ) High gas flow from J<sub>1</sub>Z<sup>4(2)</sup> (Daanzhai) obtained from several wells ,Yuanba area

Well	Target	Perforation interval (m)	Initial daily output(10 <sup>3</sup> m <sup>3</sup> )
Y5-1	J <sub>1</sub> Z <sup>4(2)</sup>		42.3
Y21	J <sub>1</sub> Z <sup>4(2)</sup>	4035-4110	507
Y11	J <sub>1</sub> Z <sup>4(2)</sup>	3880-3940	144.4
Y101	J <sub>1</sub> Z <sup>4(2)</sup>	4207-4238	139.7
Y102	J <sub>1</sub> Z <sup>4(2)</sup>	3912-3935	237.8
Y9	J <sub>1</sub> Z <sup>4(2)</sup>	3838-3878	2.6
	J <sub>1</sub> Z <sup>2</sup>	4035-4110	11.5

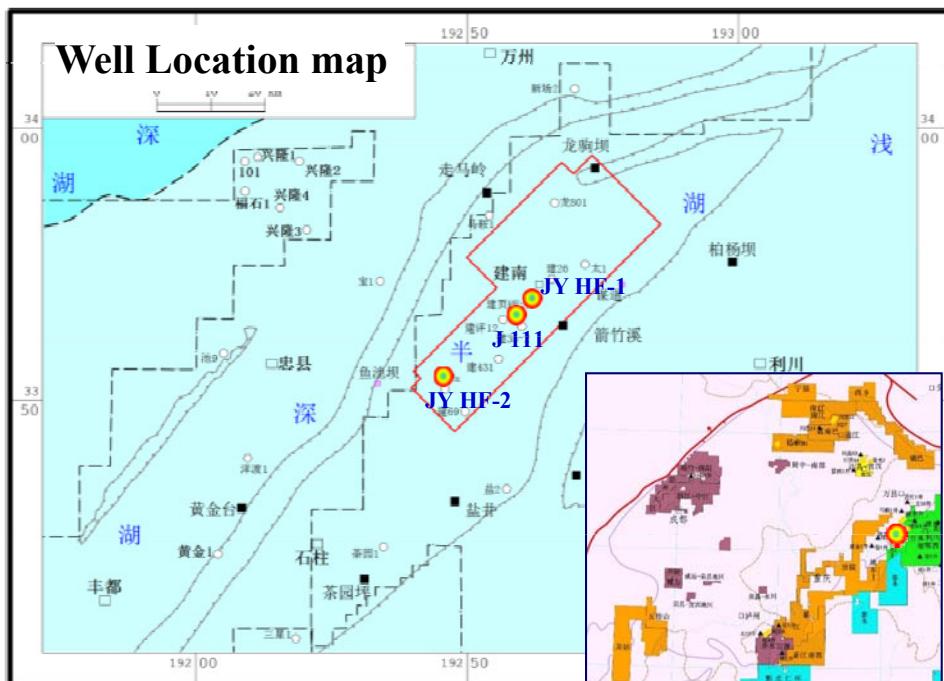
J<sub>1</sub>Z<sup>4</sup> composite stratigraphic column of Y 21 Well



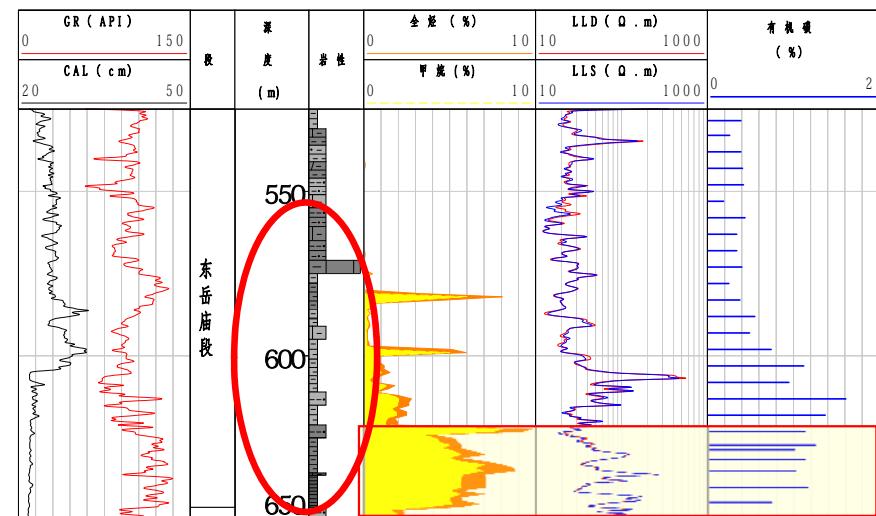
## 2.1 Progress in shale gas exploration, Sichuan Basin

### ( 3 ) Gas flow from J<sub>1</sub>z<sup>2</sup>(Dongyuemiao) in several wells in Jiannan region

Well	Target	Well type	Total Depth (m)	Horizontal length(m)	Stages of fracturing	Initial output (10 <sup>3</sup> m <sup>3</sup> /d)	Present output (10 <sup>3</sup> m <sup>3</sup> /d)
JY 111	J <sub>1</sub> z <sup>2</sup>	vertical	634			3.9	2.0-3.0
JY HF-1	J <sub>1</sub> z <sup>2</sup>	horizontal	1778	1020	7	12.3	2.9
JY HF-2	J <sub>1</sub> z <sup>2</sup>	horizontal	2888	1000	10		flowback



**J<sub>1</sub>z<sup>2</sup> composite stratigraphic column of Jian 111 Well**

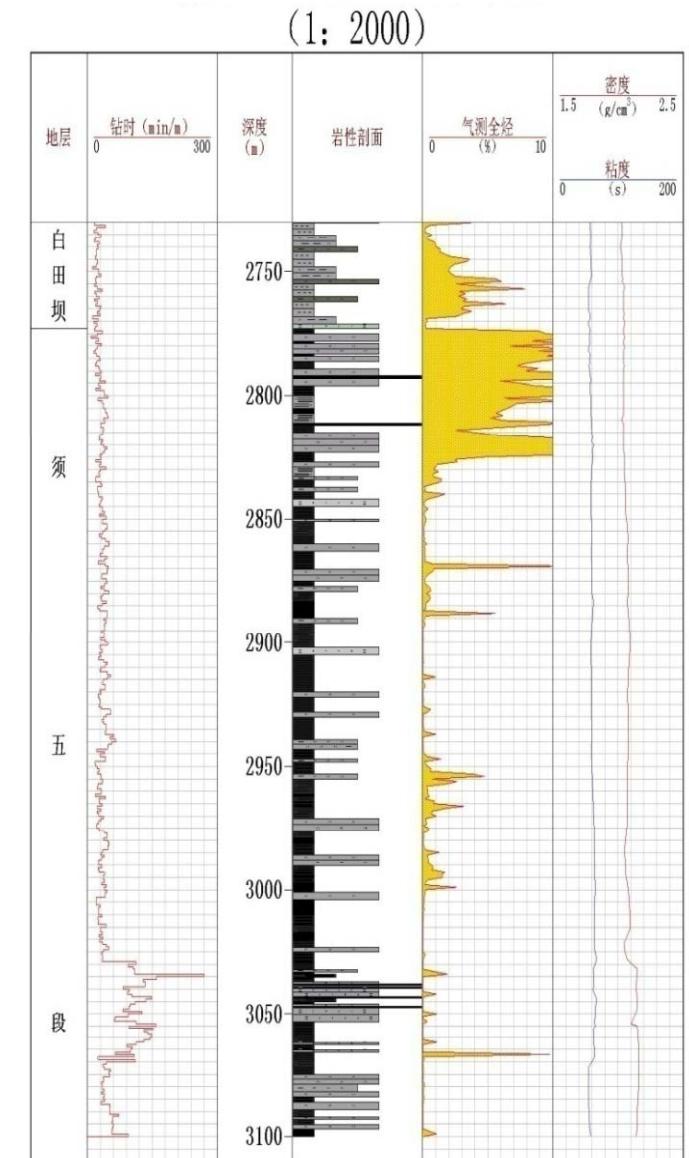
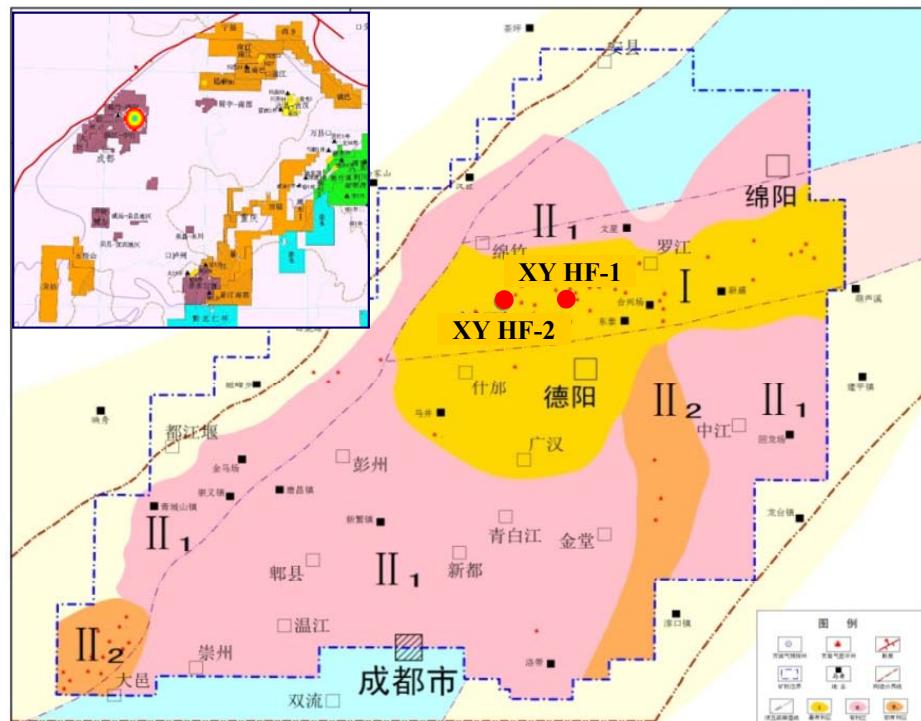


## 2.1 Progress in shale gas exploration, Sichuan Basin

### ( 4 ) Shale gas obtained from T<sub>3</sub>x<sup>5</sup>, Chuanxi depression

Composite stratigraphic column of XY HF-1 Well

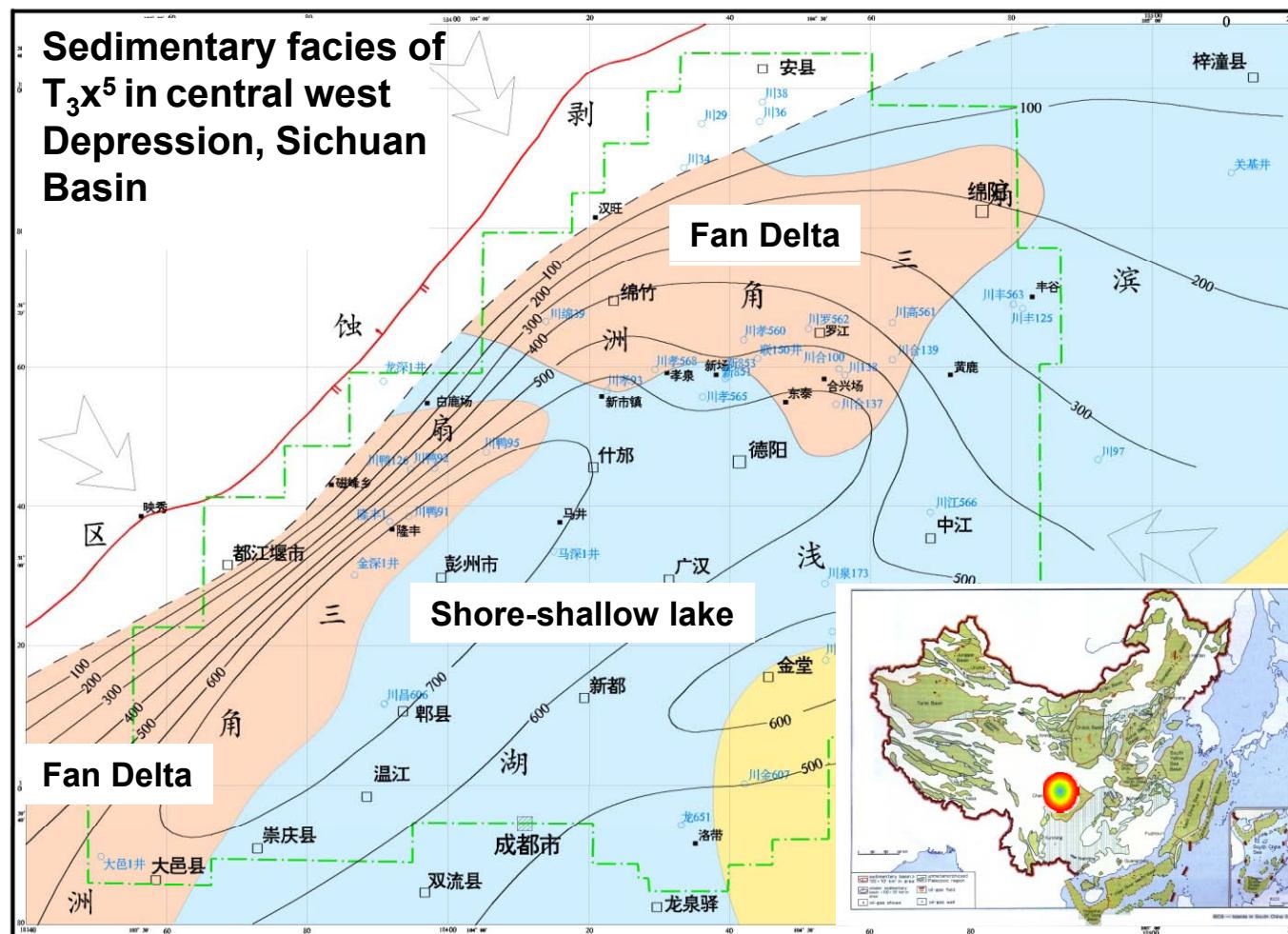
Well	Target Strata	Well type	Total Depth (m)	Horizontal length(m)	Stages of fracturing	Initial output (10 <sup>3</sup> m <sup>3</sup> /d)	Present output (10 <sup>3</sup> m <sup>3</sup> /d)
XY HF-1	T <sub>3</sub> x <sup>5</sup>	horizontal	4077	793	7	Flowbacking,2000m <sup>3</sup> /d	
XY HF-2	T <sub>3</sub> x <sup>5</sup>	horizontal	4102	815	10	45	21



## 2.2 Characteristics of Mesozoic shale, Sichuan Basin

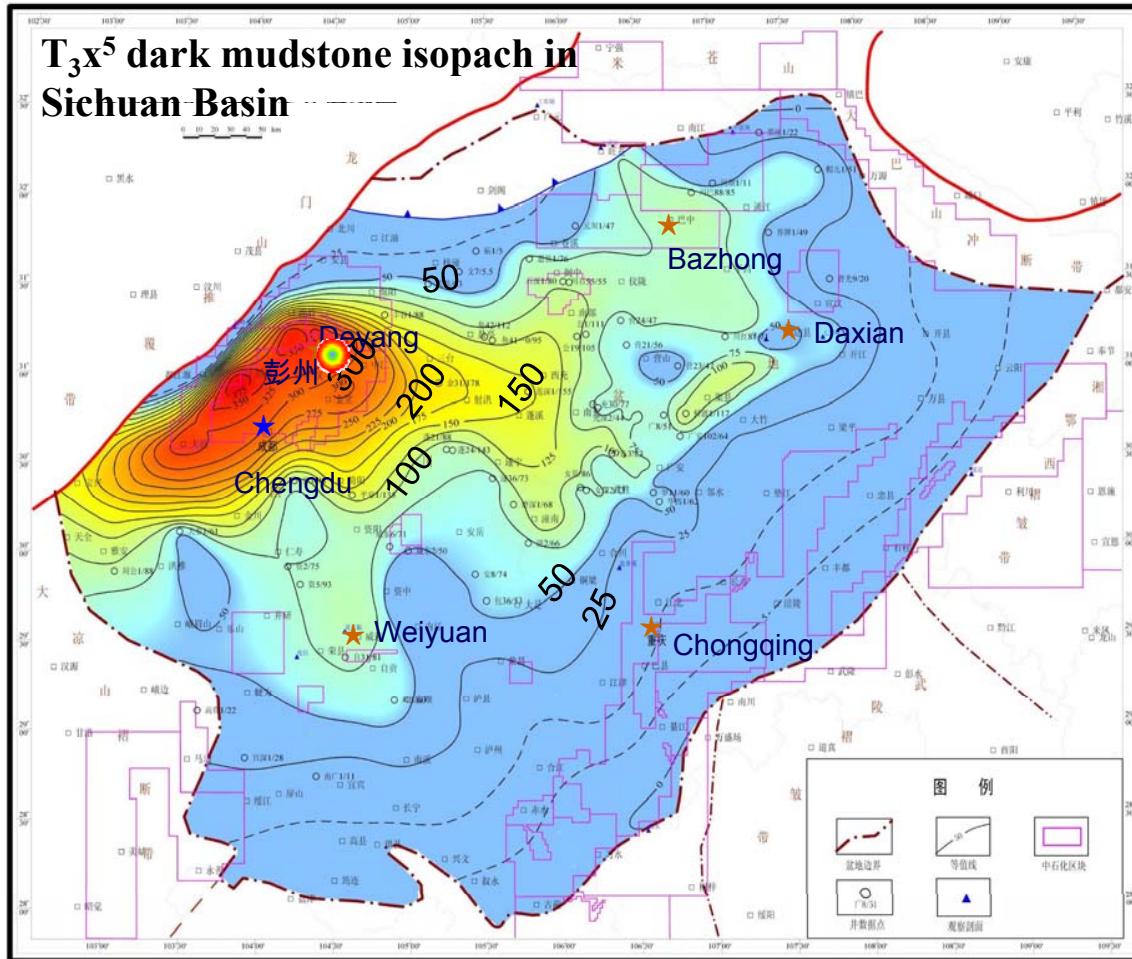
Two organic-rich shales occur in the Sichuan Basin

- Upper Triassic coal-bearing swampy-lacustrine shales
- Middle-Lower Jurassic semi-deep to deep lacustrine shales

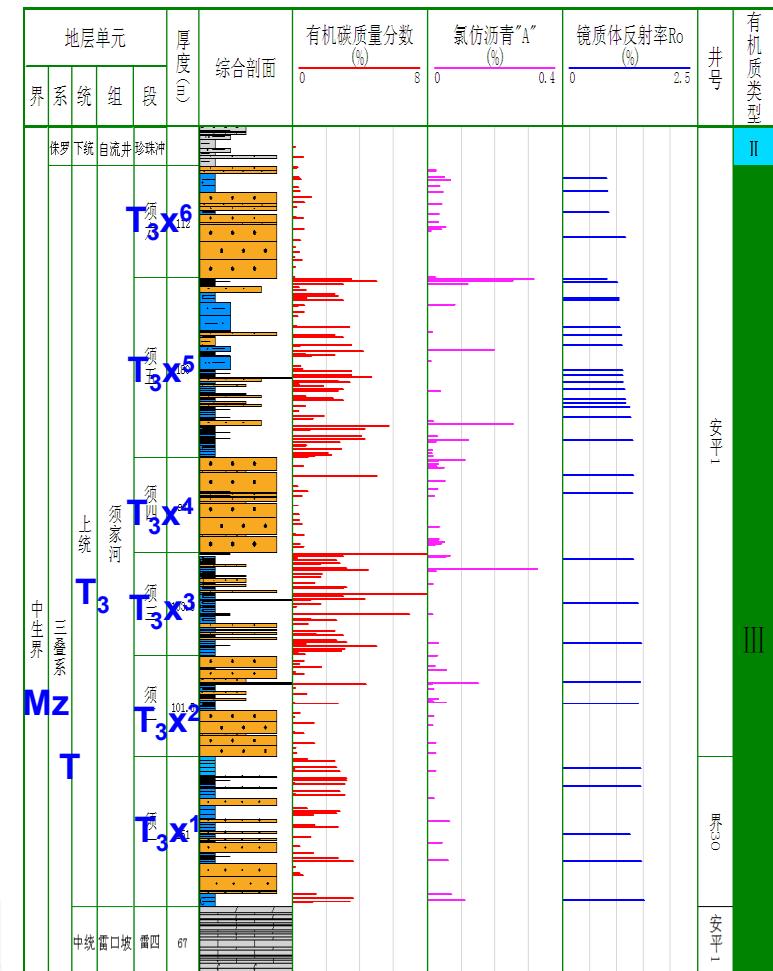


## 2.2.1 The Triassic shale of Sichuan Basin

### ■ Thick mudstones with high TOC



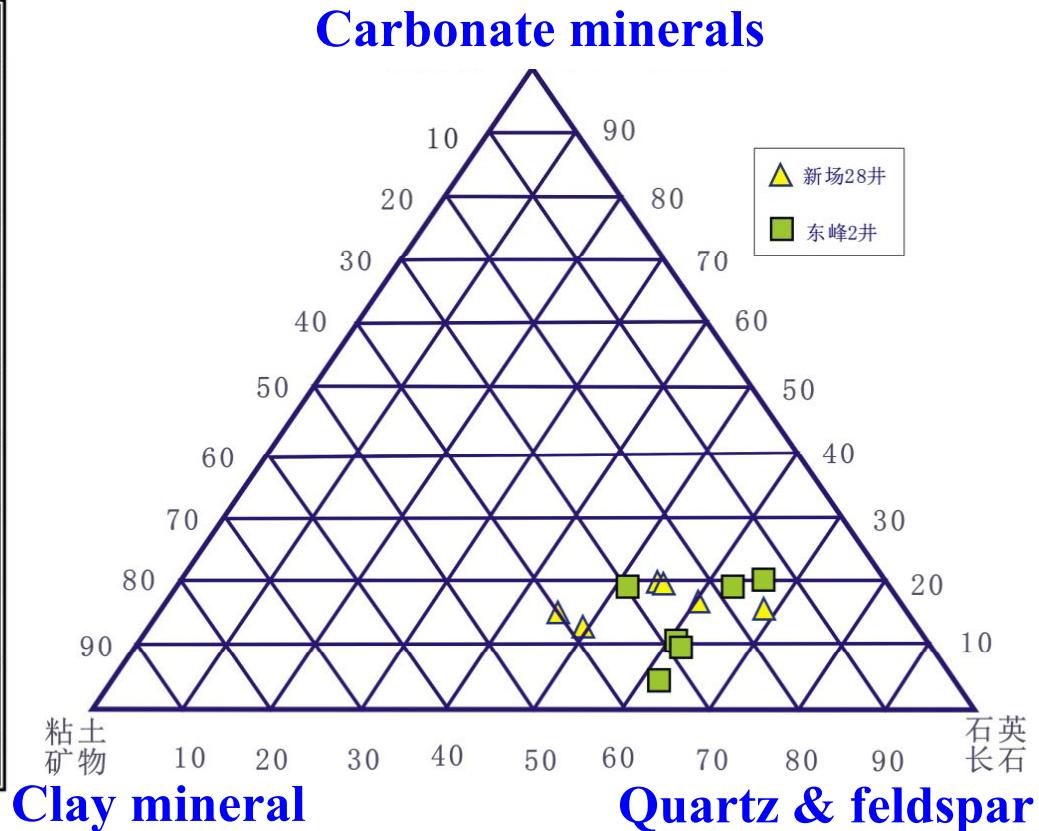
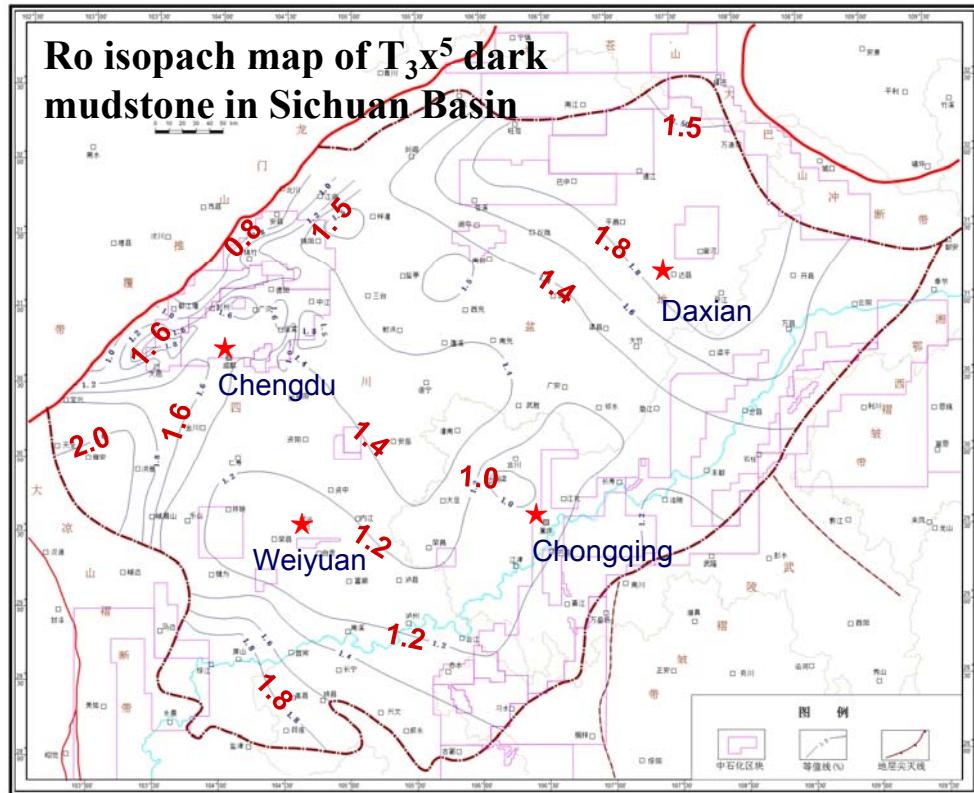
T<sub>3</sub>x composite histogram of Sichuan Basin



- Sedimentary center is located in West Sichuan Depression
- Total thickness is 100-300 m
- TOC: 1-4%

## 2.2.1 The Triassic shale of Sichuan Basin

### ■ Type III kerogen with moderate Ro and high brittleness



□ Ro 1.0~1.8%

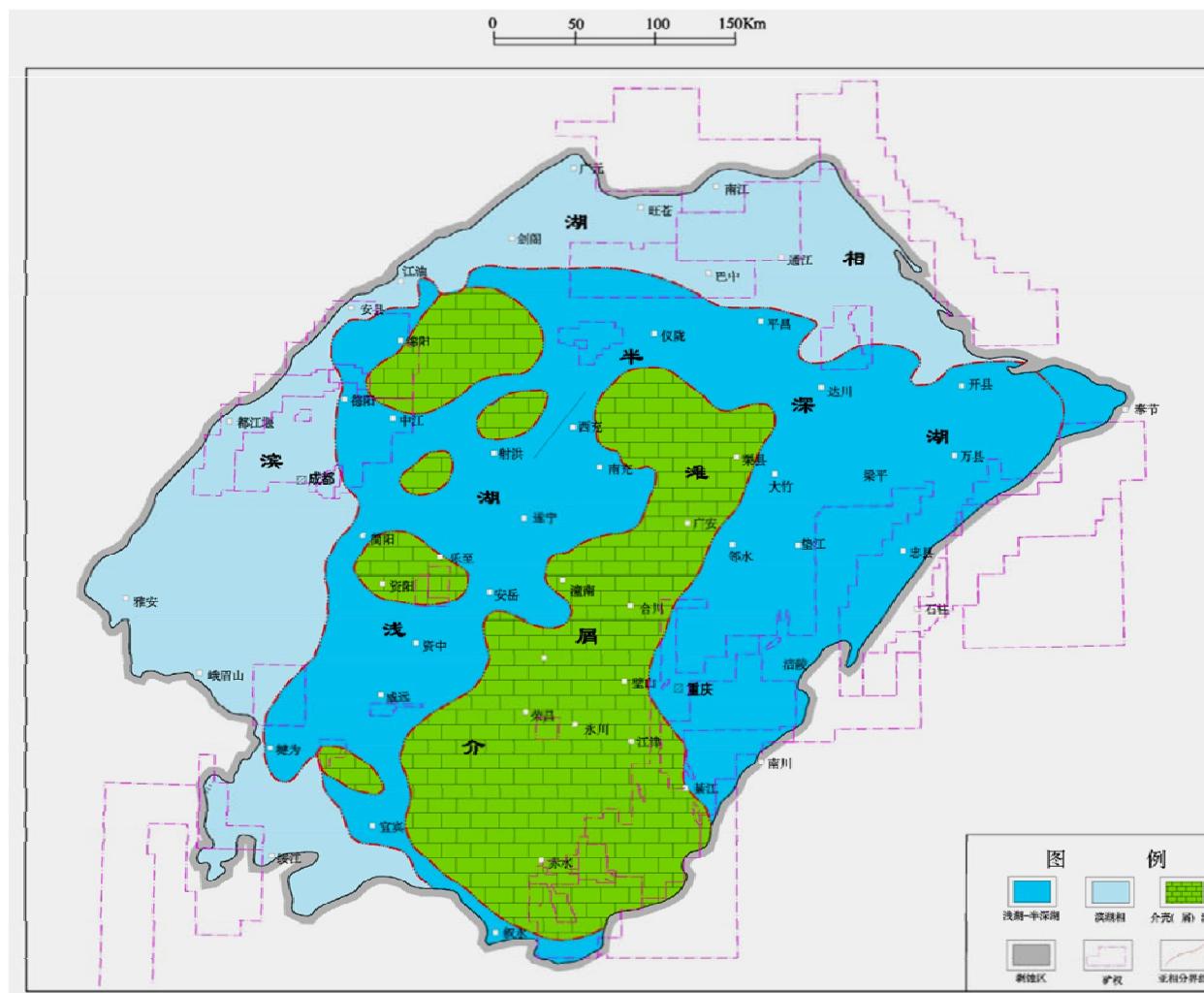
□ Low clay content, generally <40%

□ Quartz content generally >40%

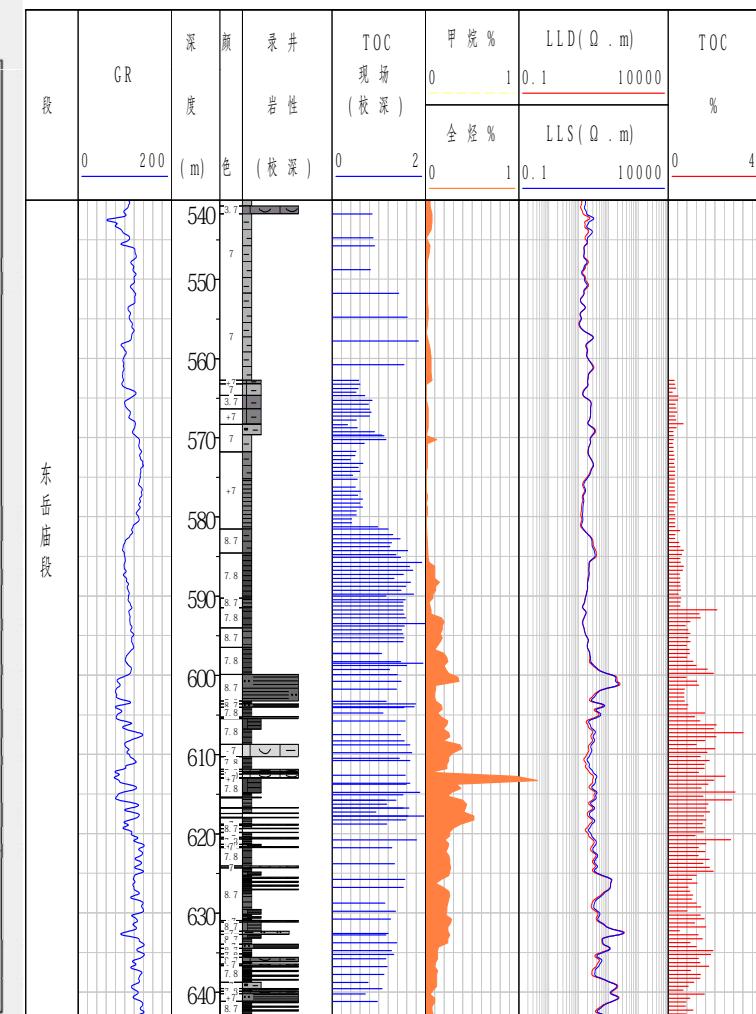


### **2.2.2 The Jurassic shale of Sichuan Basin**

# Sedimentary facies map of J<sub>1</sub>z<sup>2</sup> in Sichuan Basin



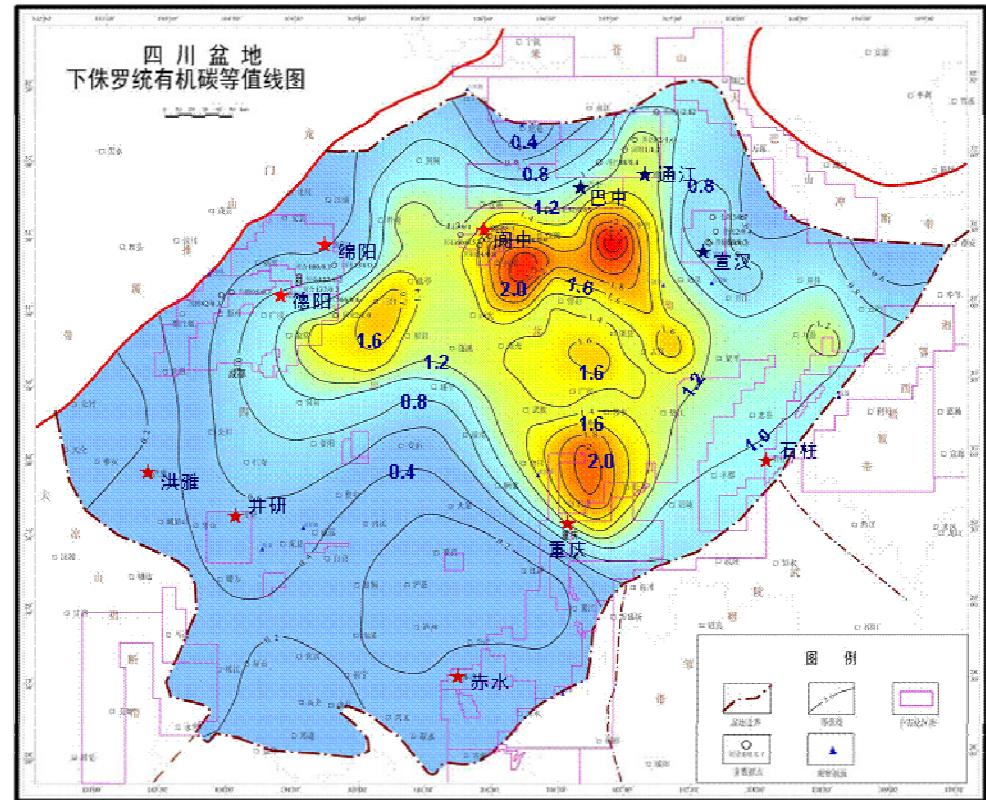
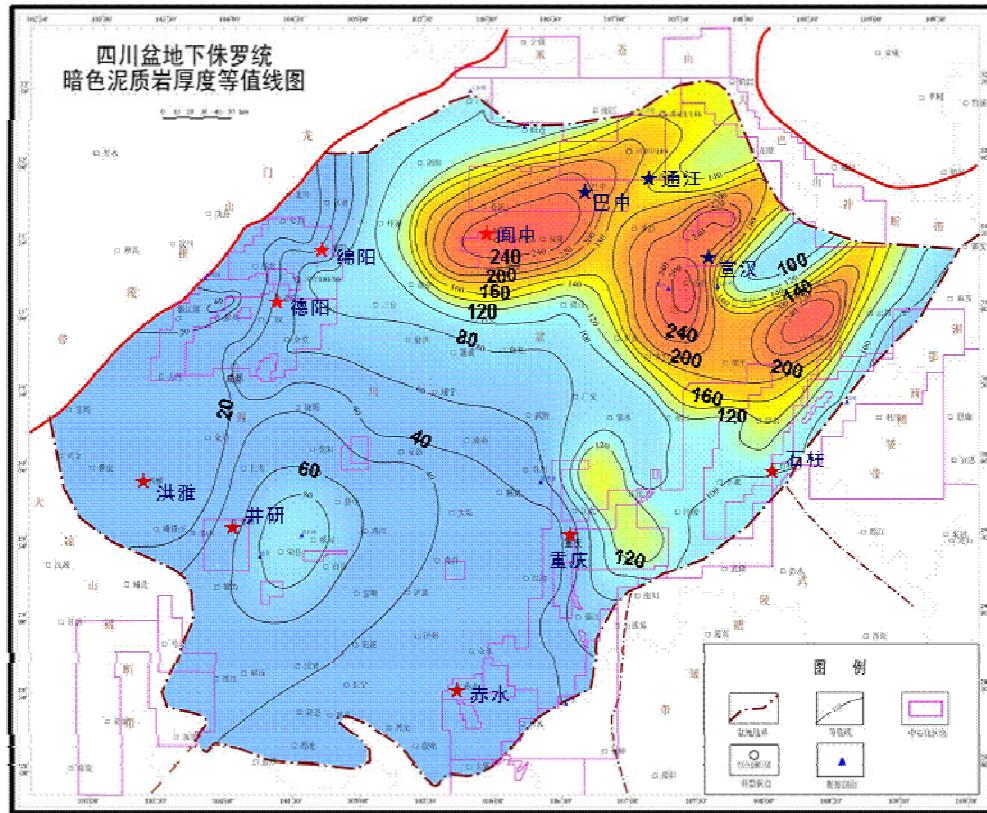
## J<sub>1</sub>z<sup>2</sup> composite histogram of Well J1HF



- ❑ Organic-rich shale deposited in semi-deep to deep lake facies
  - ❑ Organic shale is frequently interbedded by shell limestone
  - ❑ Hydrocarbon content correlate positively with TOC

## 2.2.2 The Jurassic shale of Sichuan Basin

### ◆ Lower Jurassic shale isopach and TOC distribution, Sichuan Basin



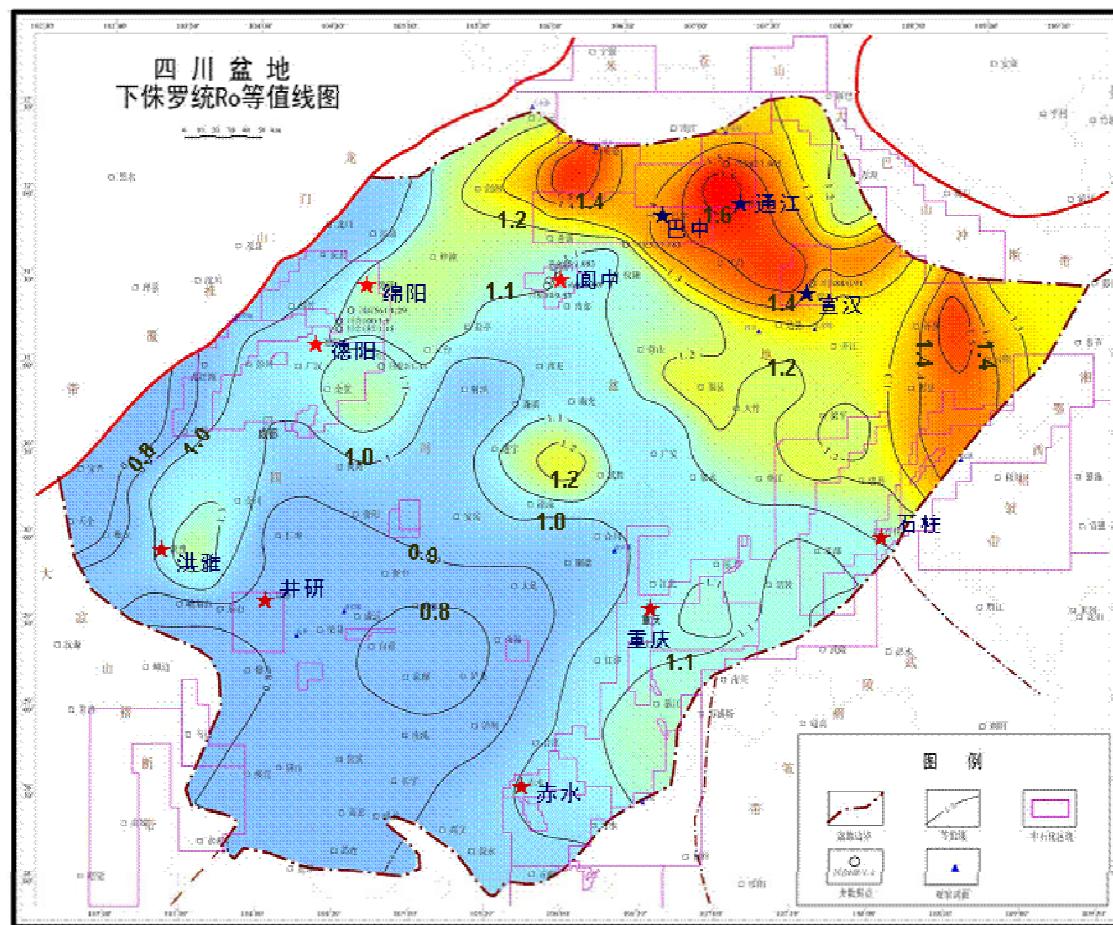
- Sedimentation center is located in NE Sichuan Basin
- Dark shale thickness is 120-240m

- TOC: 1.2-2.0%
- High quality source rocks distributed mainly in central Sichuan



### **2.2.2 The Jurassic shale of Sichuan Basin**

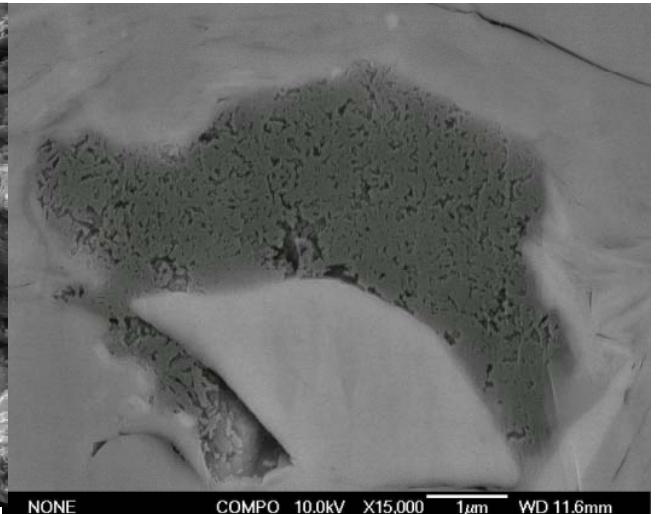
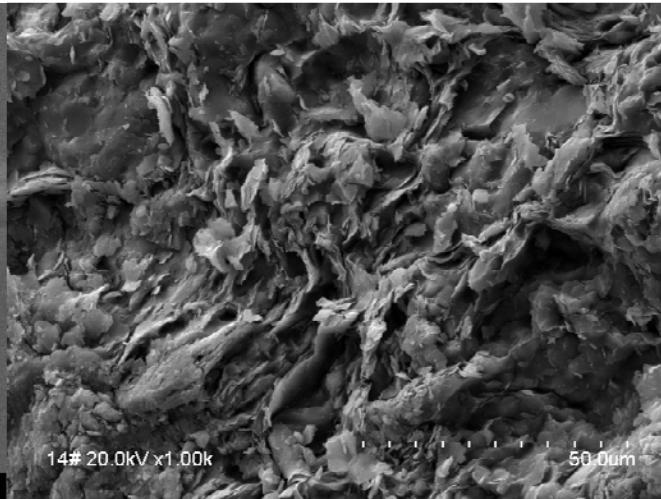
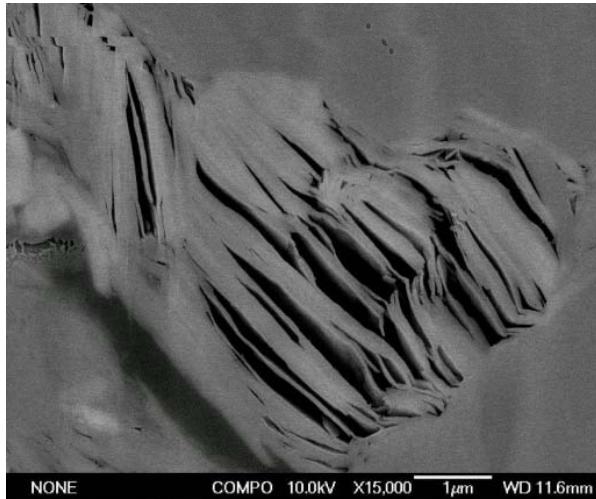
## ◆ Organic type and thermal maturation



- ◆ Type II karogen dominant
  - ◆ Maturity level : 0.8-1.6% Ro

## 2.2.2 The Jurassic shale of Sichuan Basin

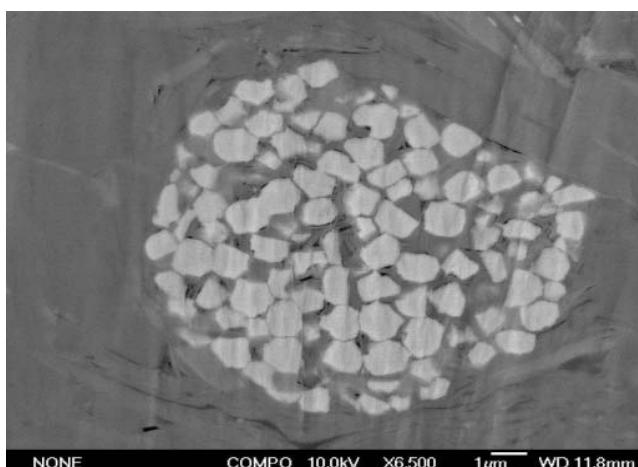
Reservoir storage space ranges from micropores, nanopores, to microfractures



YI4Daanzhi.3789.24m mudstone

YB9.Dongyuemiao 4058m mudstone-shale

YL4.Qian2 3647.18m shale



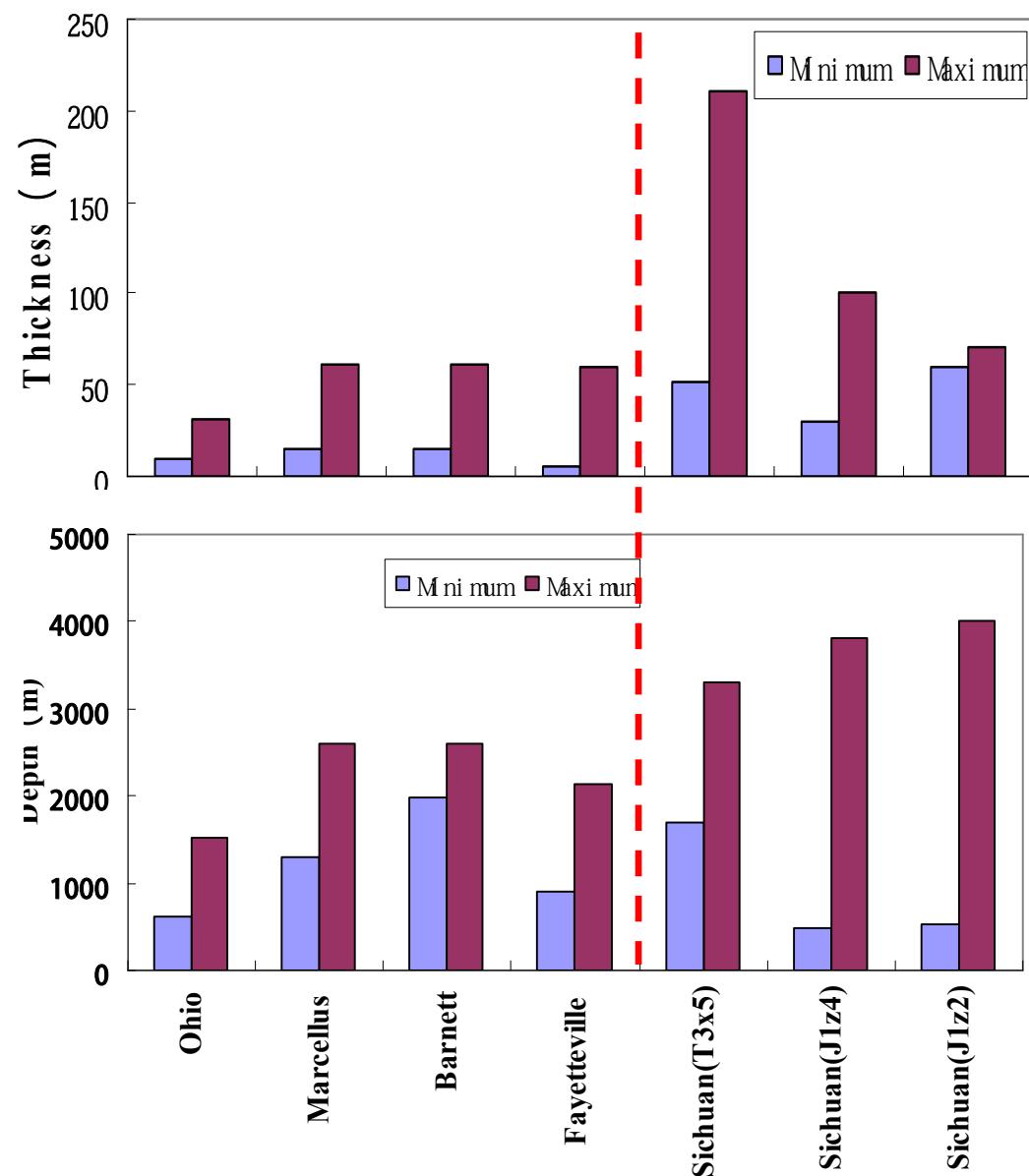
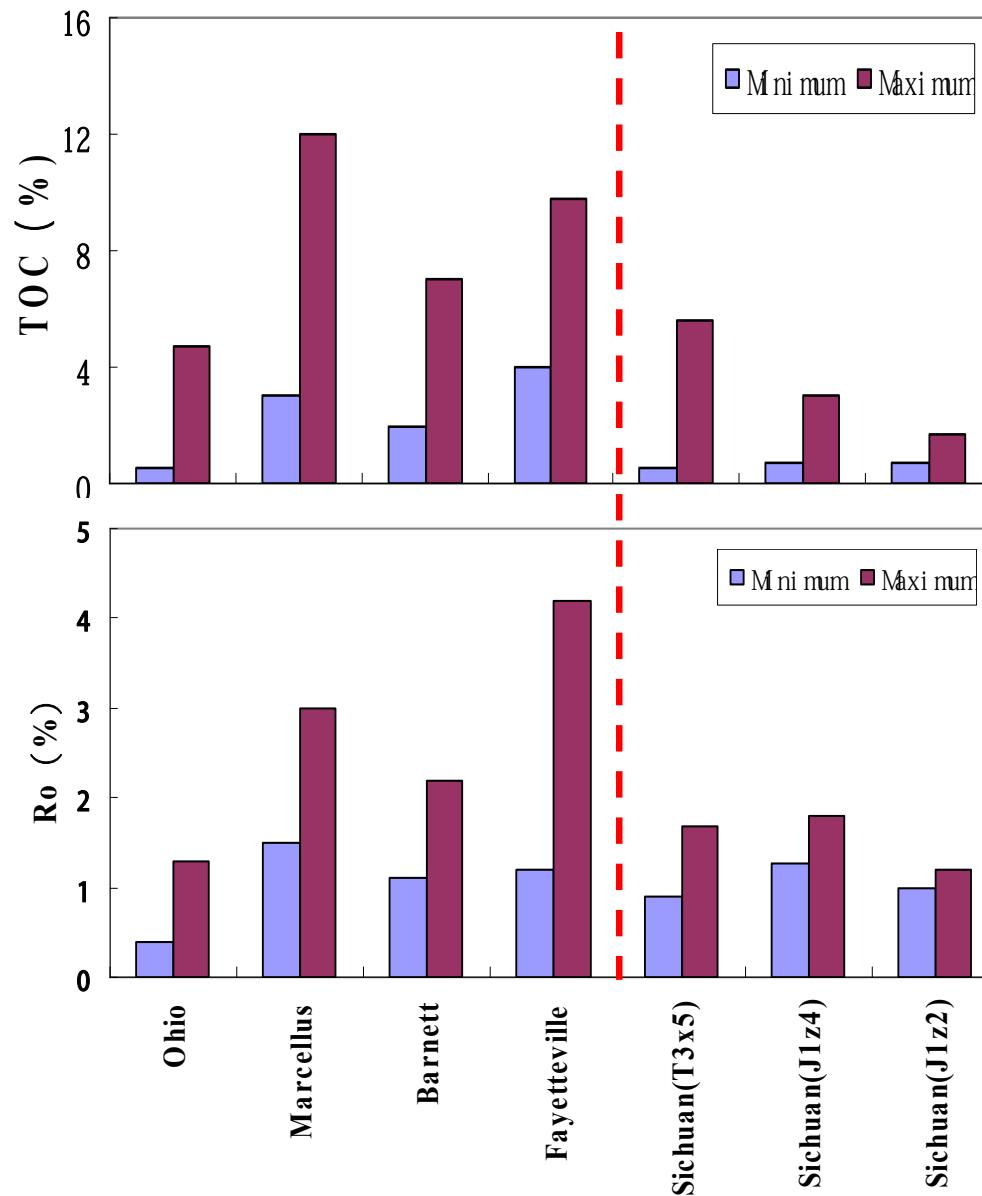
YL4.Qian2 3647.14m shale

XL101. Dongyuemiao Horizontal fractures

XL101 , 2154.76m , Daanzhai , Two groups fracture



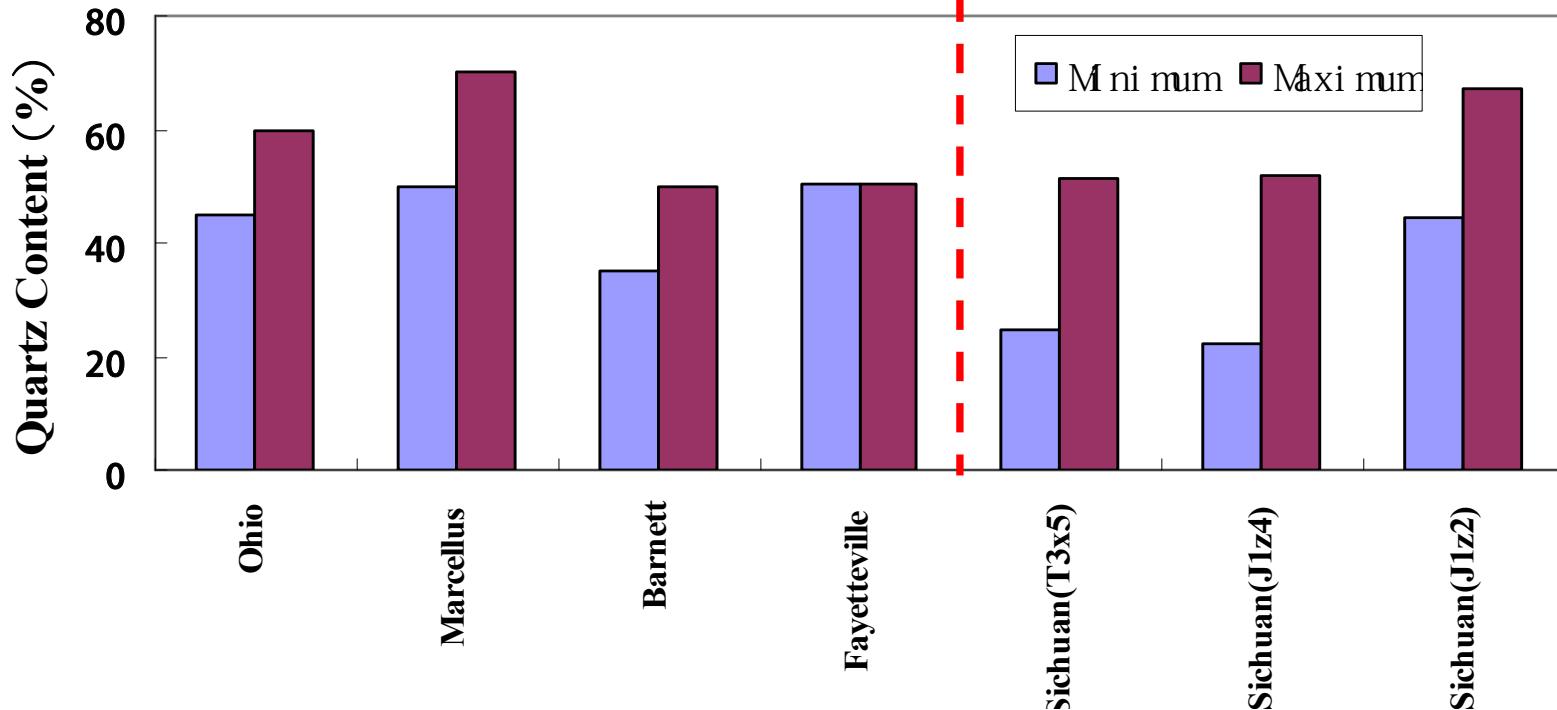
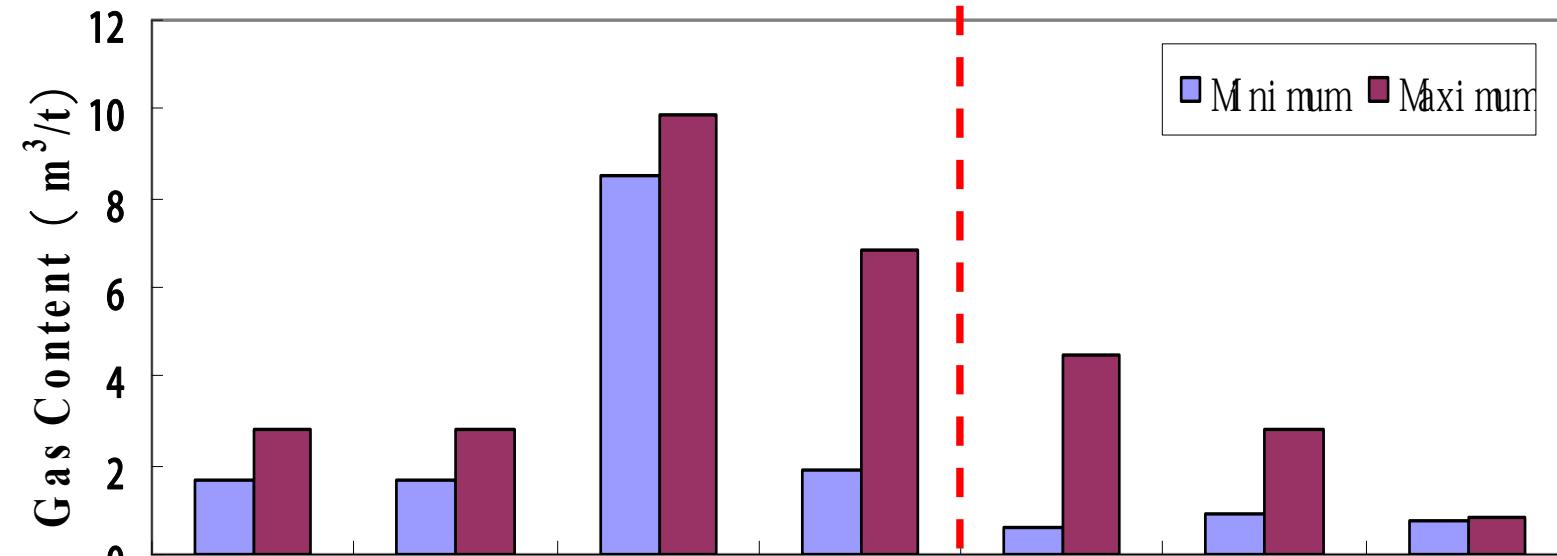
# Characteristics of Mesozoic shales in Sichuan Basin



Relatively organic-lean with variable organic types, large cumulative shale thickness, and wide range of burial depth

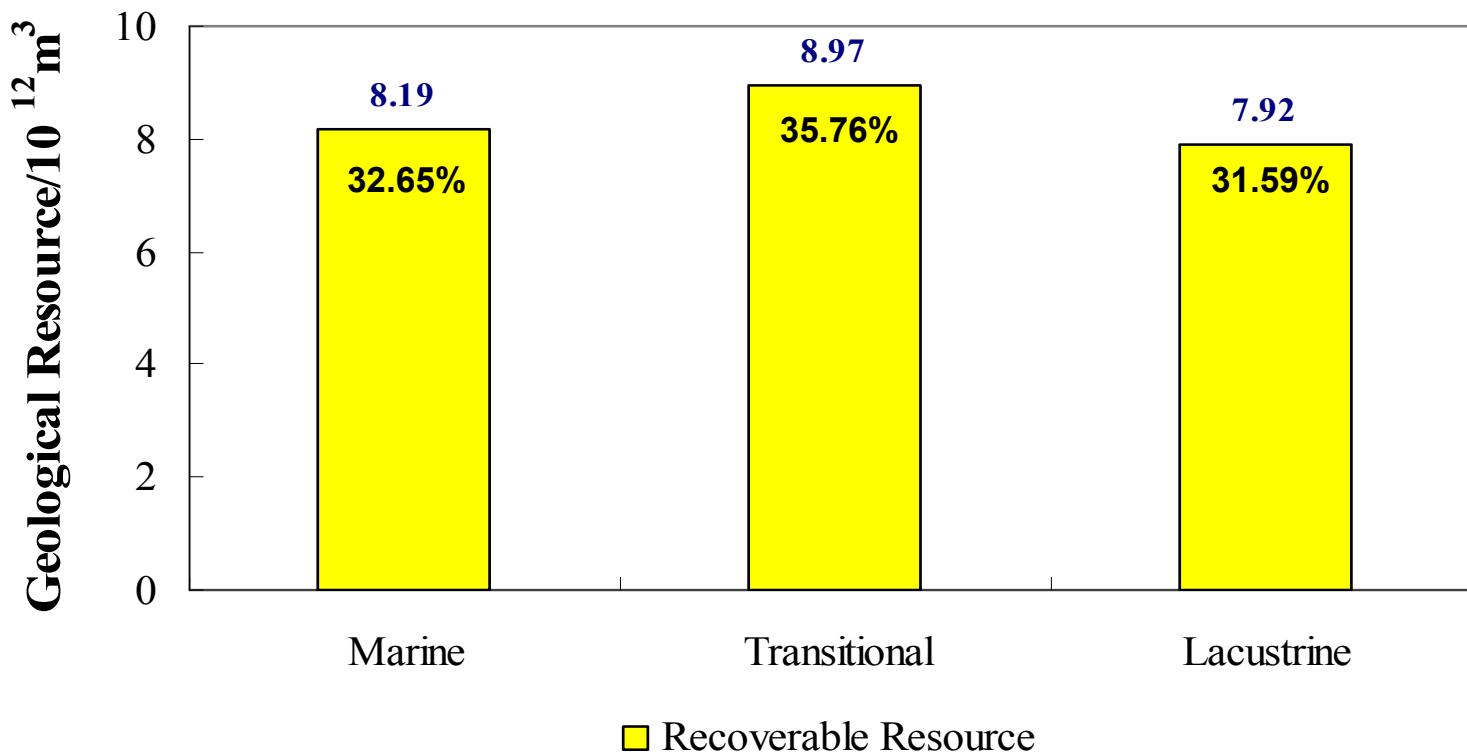


# Characteristics of Mesozoic shales in Sichuan Basin



Relatively low in gas and silicate contents

## 2.3 Lacustrine shale gas resource in China



According to Ministry of Land and Resources of PRC (2012):

□ Shale gas recoverable resource : **25.08 TCM**

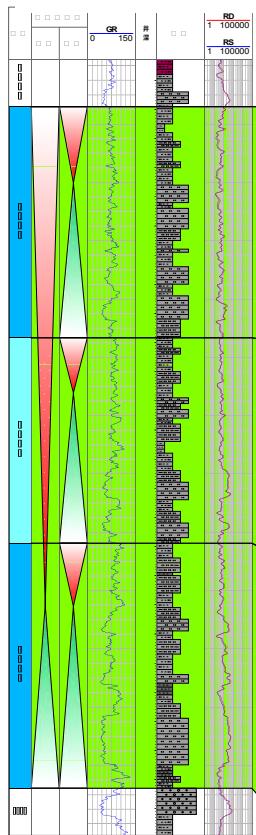
□ Lacustrine shale gas recoverable resource: **7.92 TCM, 31.59%**



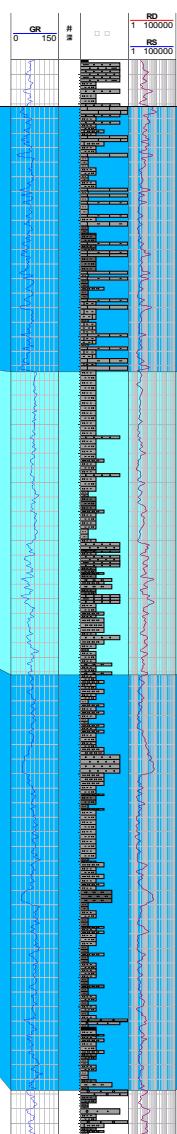
# Summary: Lacustrine shale gas systems in Sichuan Basin

Forland basin setting, rapid facies variation, organic-lean, multiple types of storage space, and strong heterogeneity

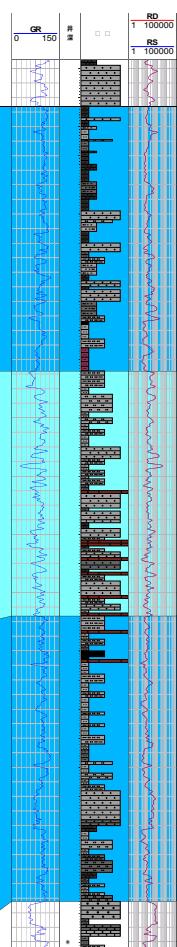
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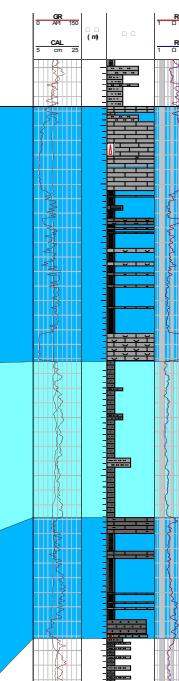
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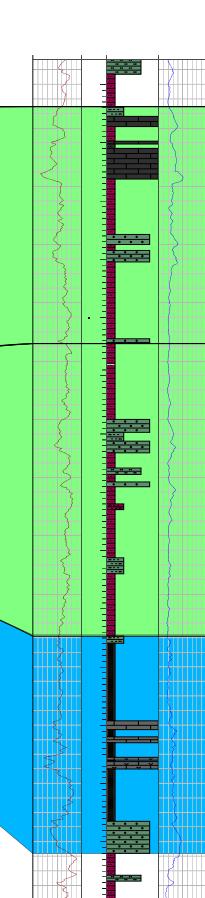
普光6井



兴隆101井



苟西1井





# Outline

- Introduction
- Lacustrine Shale Gas
- Lacustrine Shale Oil
- Conclusions



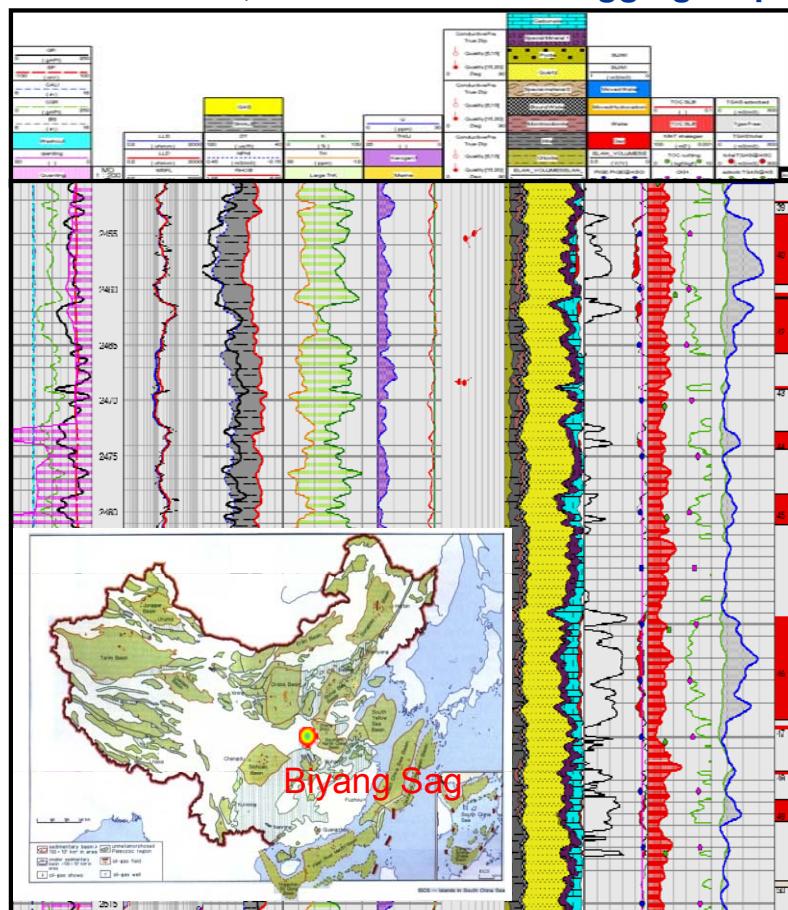
### 3.1 Progress in shale oil exploration in eastern China

#### 1<sup>st</sup> shale oil well in China: Biyang sag, Nanxiang basin

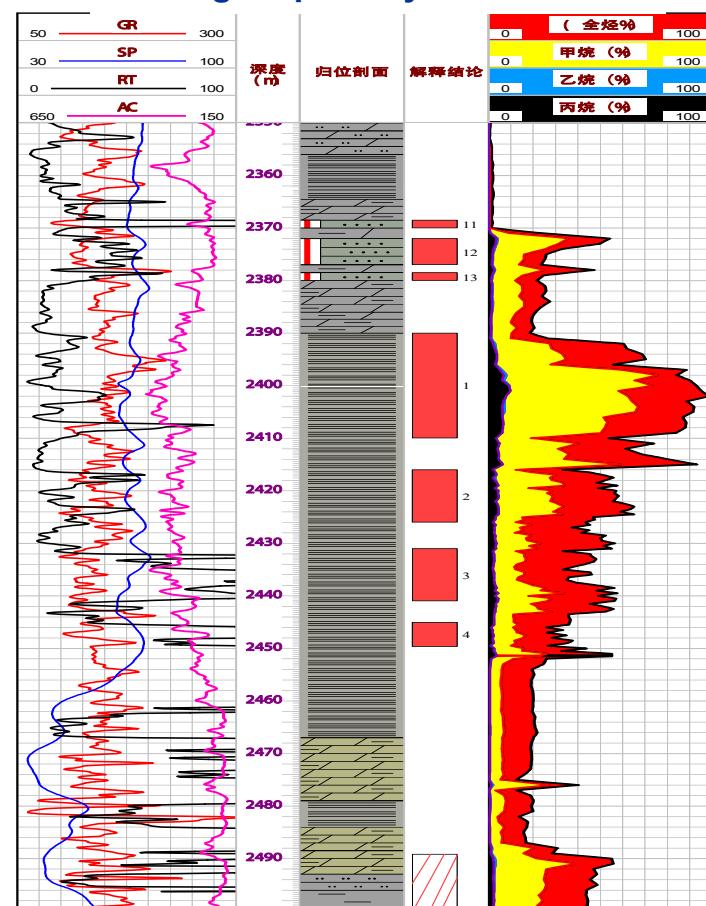
★Well. A1 : Vertical well , 1/23, 2011,  
2450-2510m shale section flow 4.68m<sup>3</sup>/d oil  
after fracturing.

★B HF-1 : 12, 2011-1, 2012, E<sub>3</sub>H<sup>3</sup> , 15  
Stages fracturing , 8mm glib , oil 22.5m<sup>3</sup>/d ,  
gas 1072m<sup>3</sup>/d

Anshen 1 well, 2450-2510m multi logging map

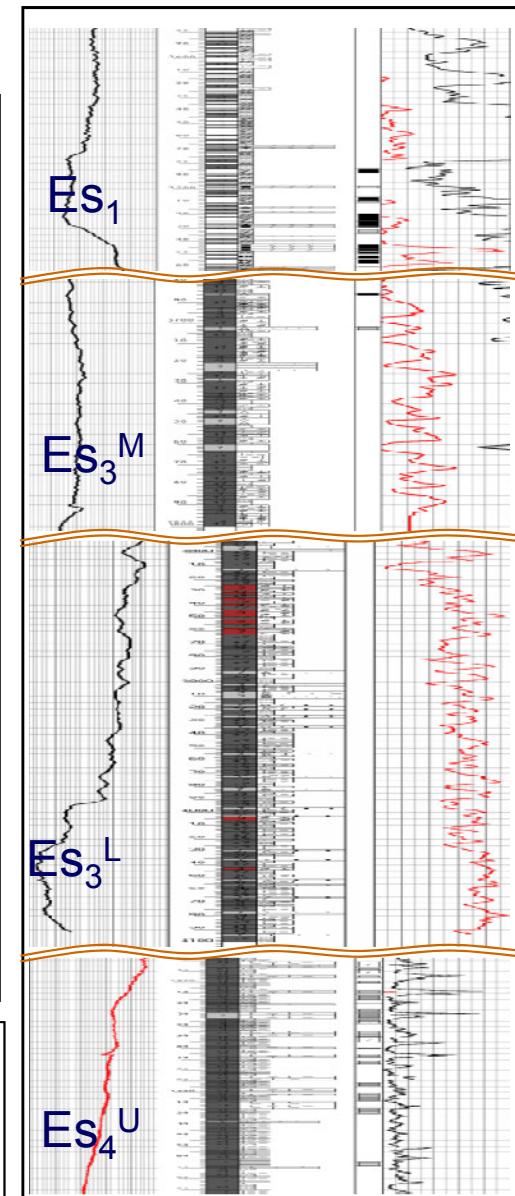
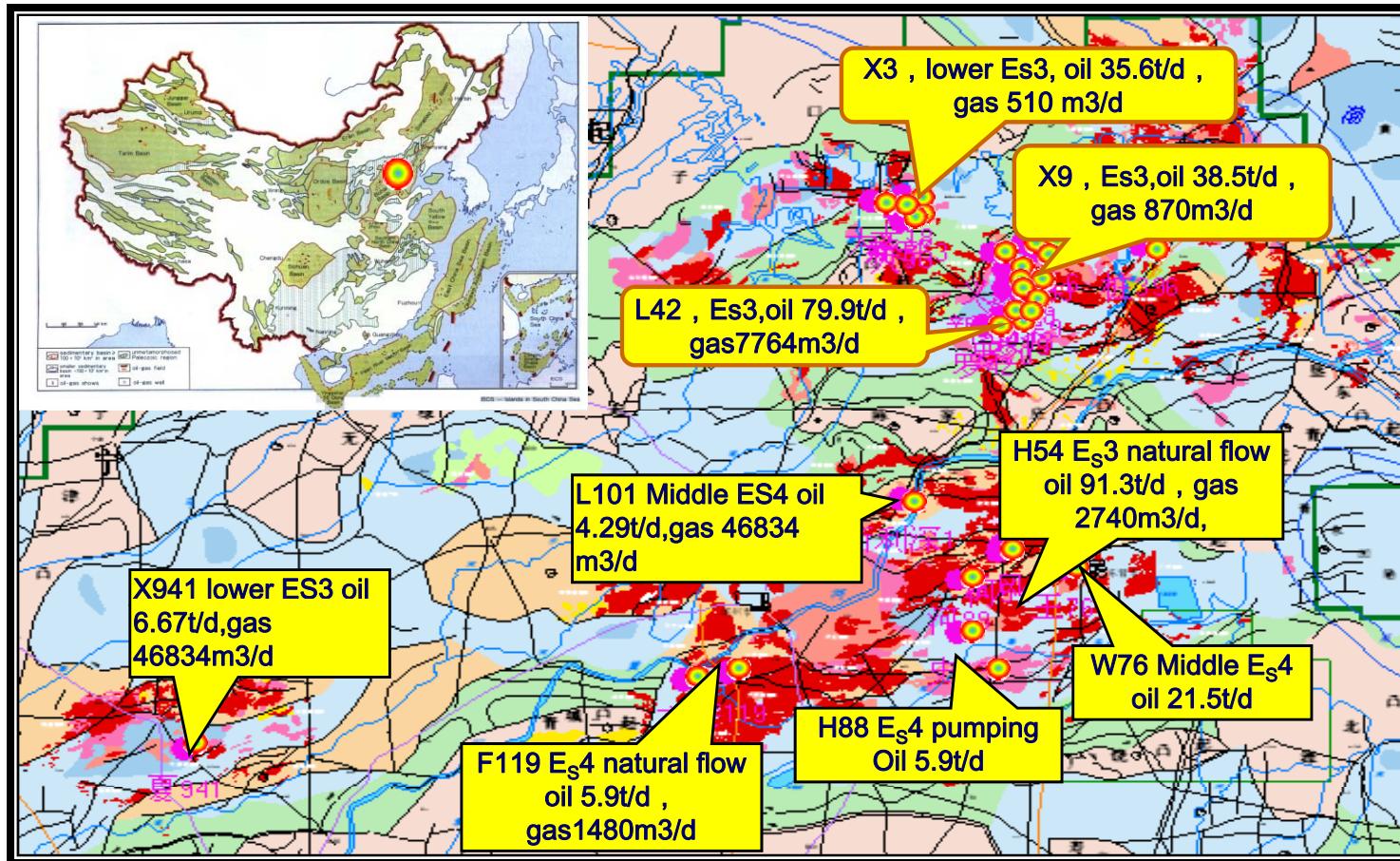


Drilling map of Biye HF-1 well



### 3.1 Progress in shale oil exploration in eastern China

#### Jiyang Depression, Bohai Bay basin

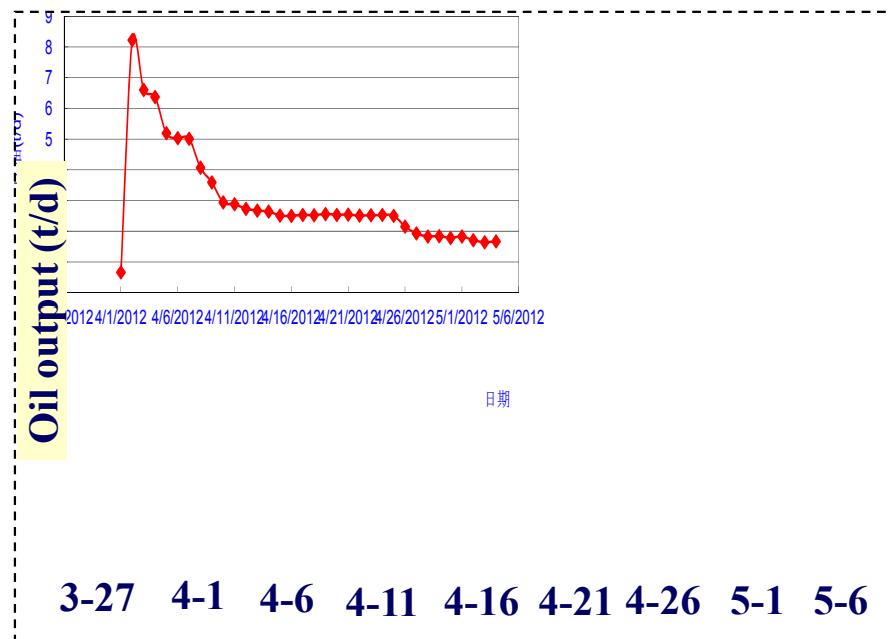
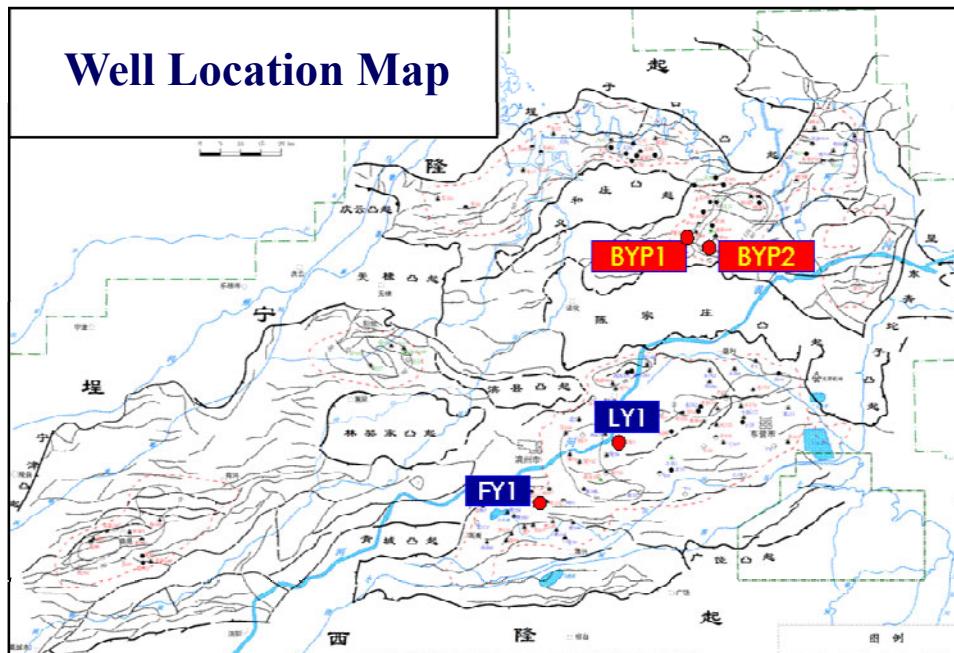


- Strong oil/gas shows encountered in the shale intervals from **320** exploration wells by the end of 2012
- **35** of which produce oil in commercial quantity



# Jiyang depression of Bohai Bay basin

Well	Location	Target Stratum	Well-type	Total Depth(m )	Horizontal Length(m)	Fracturing Stage	Initial oil output (t)
BYP1	Zhanhua	E <sub>2</sub> S <sup>3</sup>	horizontal	4335	1176	9	8.22
BYP2	Zhanhua	E <sub>2</sub> S <sup>3(L)</sup>	horizontal	3645	882	5	8
LY1	Dongying	E <sub>2</sub> S <sup>3(L)</sup>	vertical	3924			5.1
FY1	Dongying	E <sub>2</sub> S <sup>3(L)</sup>	vertical	3622			8.93

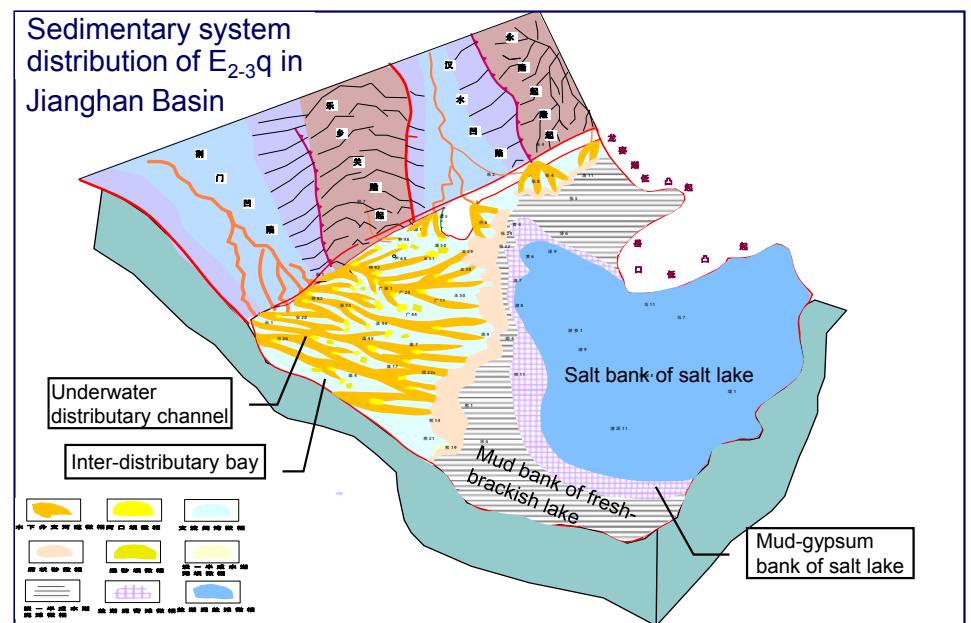
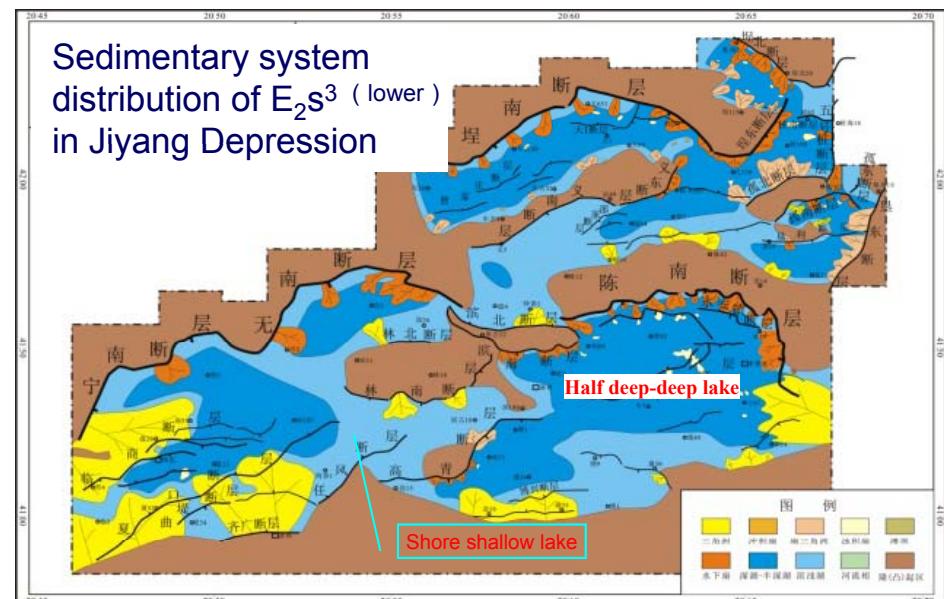


BYP1 well's production after 2<sup>nd</sup> section was fractured



## 3.2 Characteristics of Paleogene shale

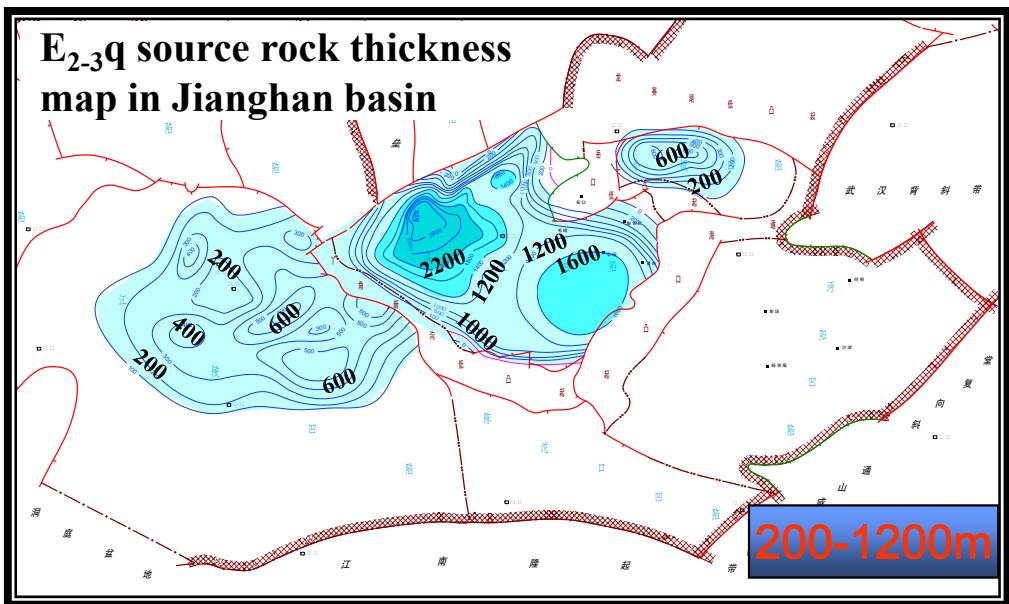
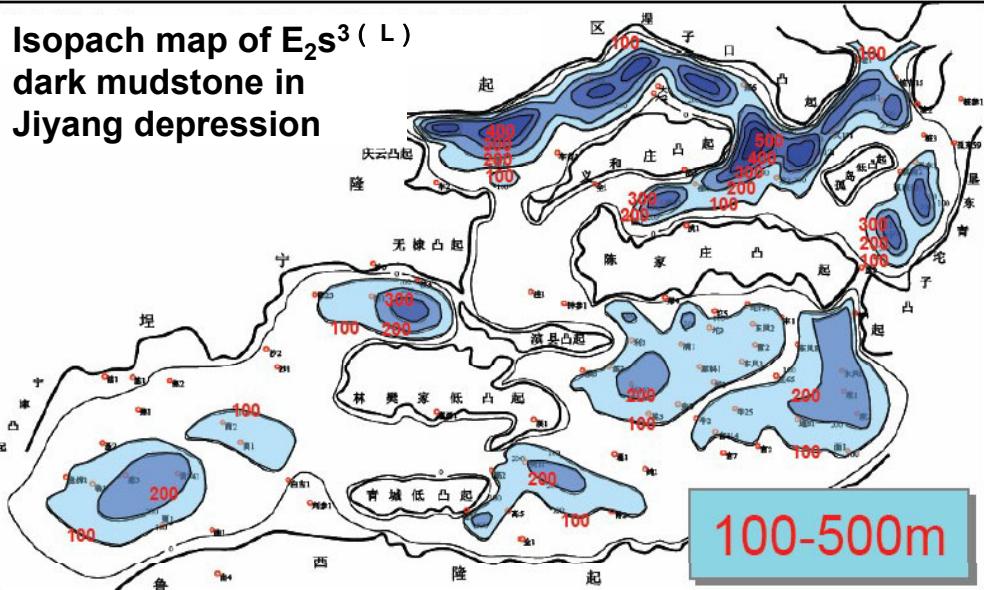
Depositional environment:  
mainly deep to semi-deep  
lacustrine, with rapid facies  
variation



### 3.2.1 Paleogene source rock characteristics

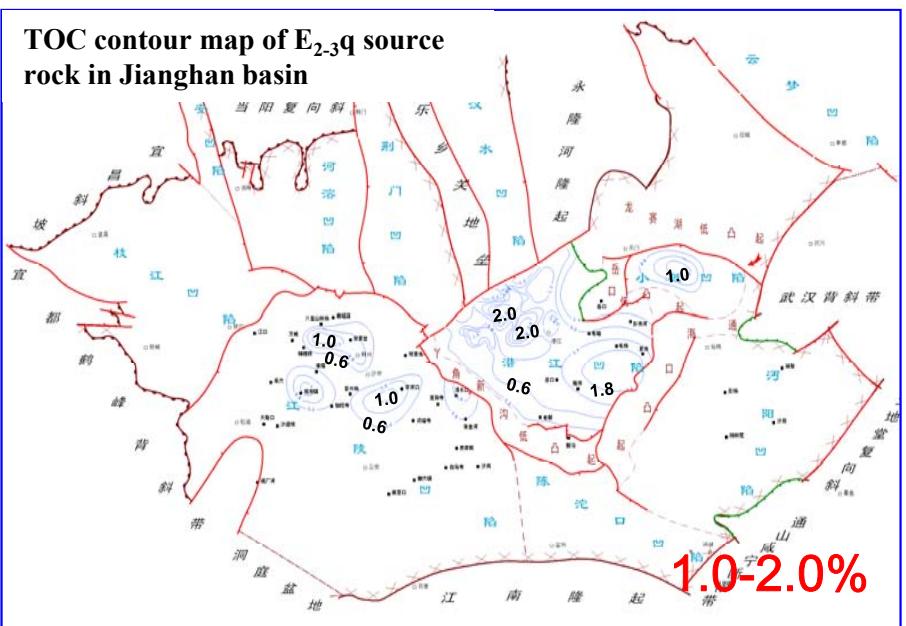
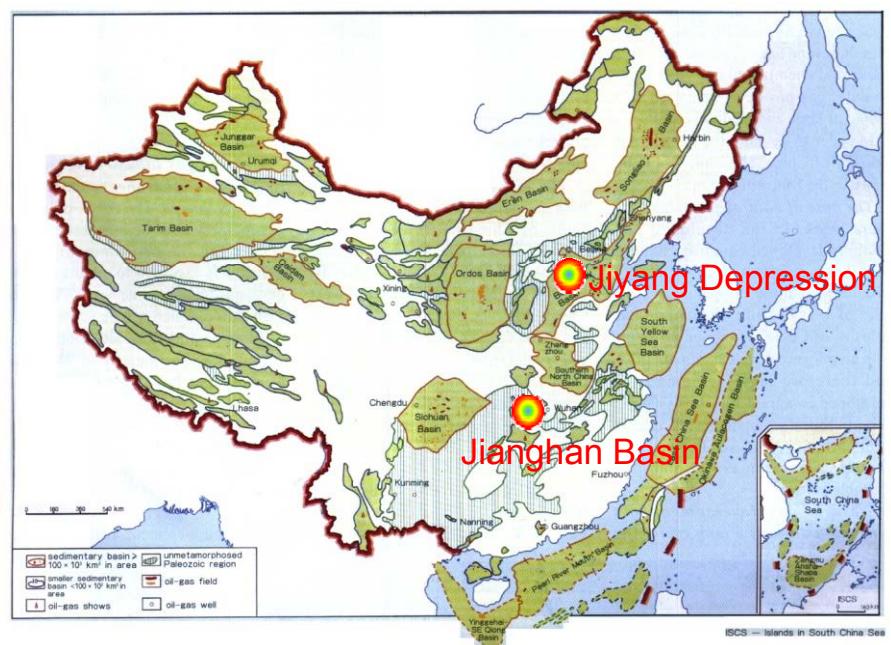
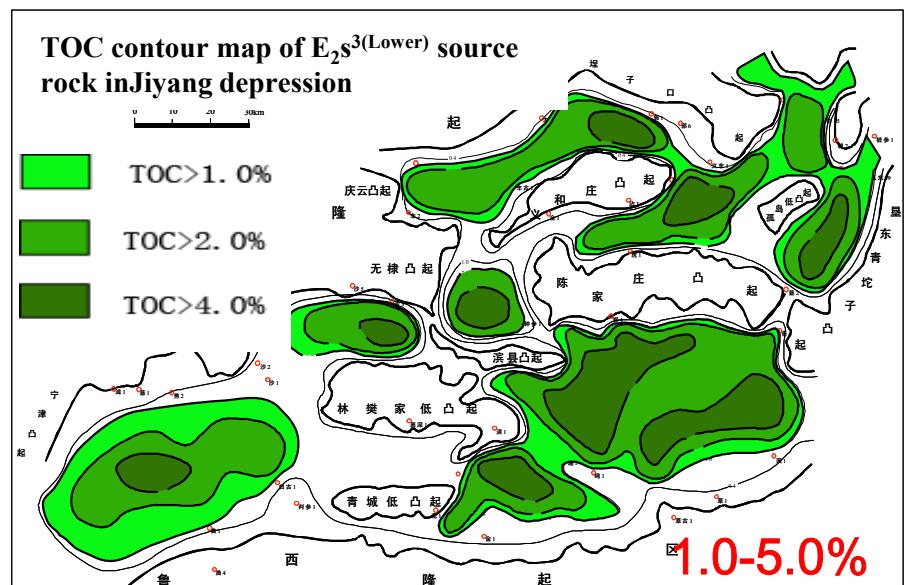
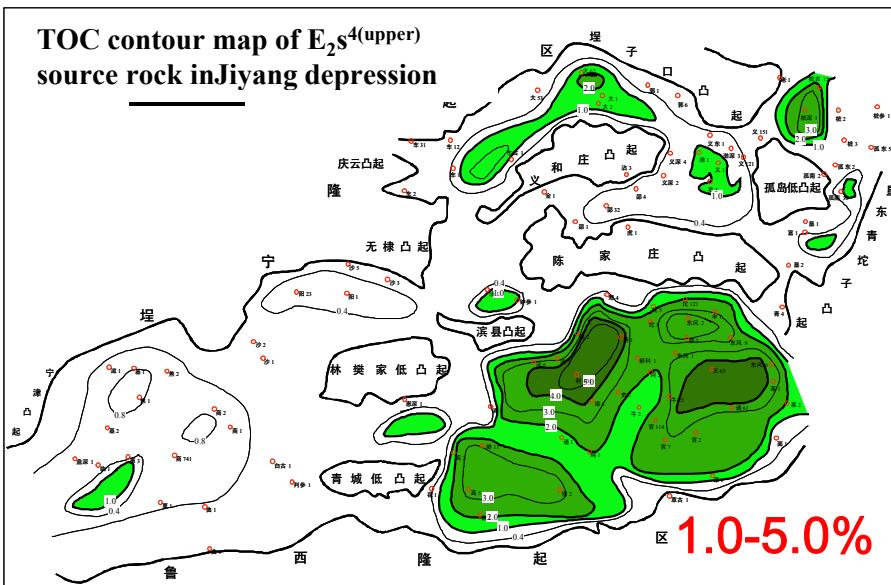
(1) Generally in large thickness but quite variable, depending on sedimentary facies

■ Black shale thickness > 100m,  
locally > 300m



## 3.2.1 Paleogene source rock characteristics

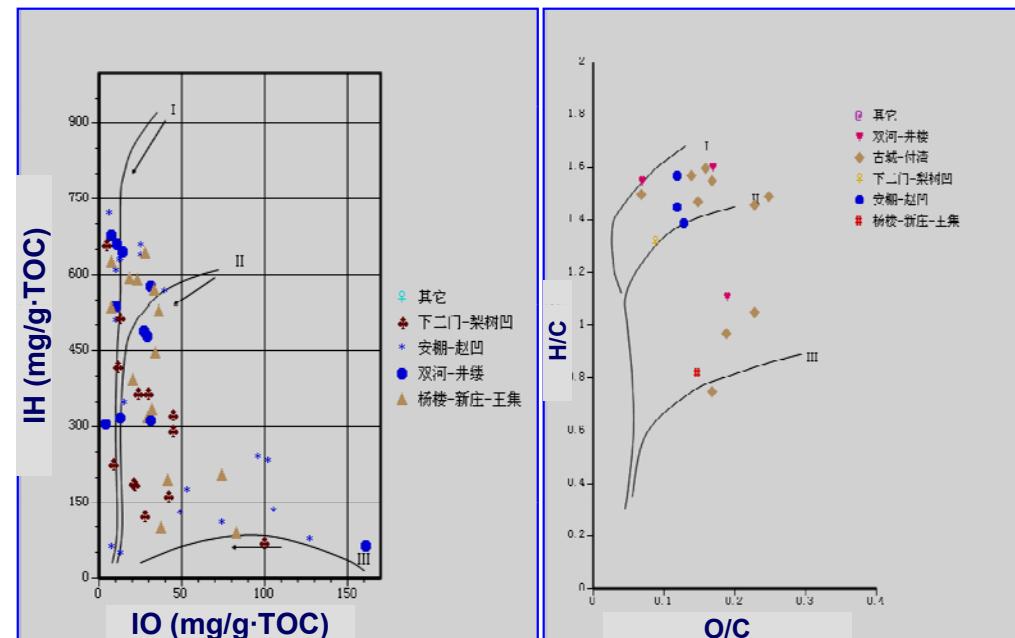
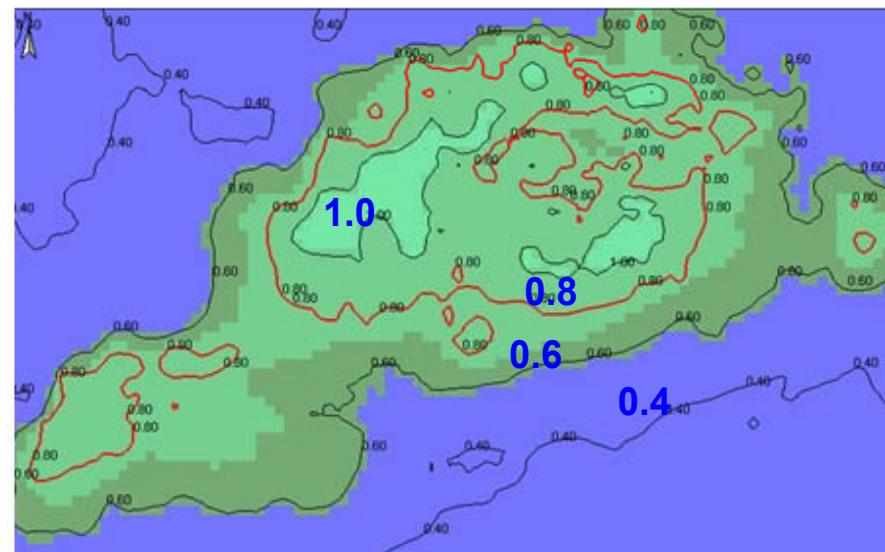
### (3) Relatively high organic richness



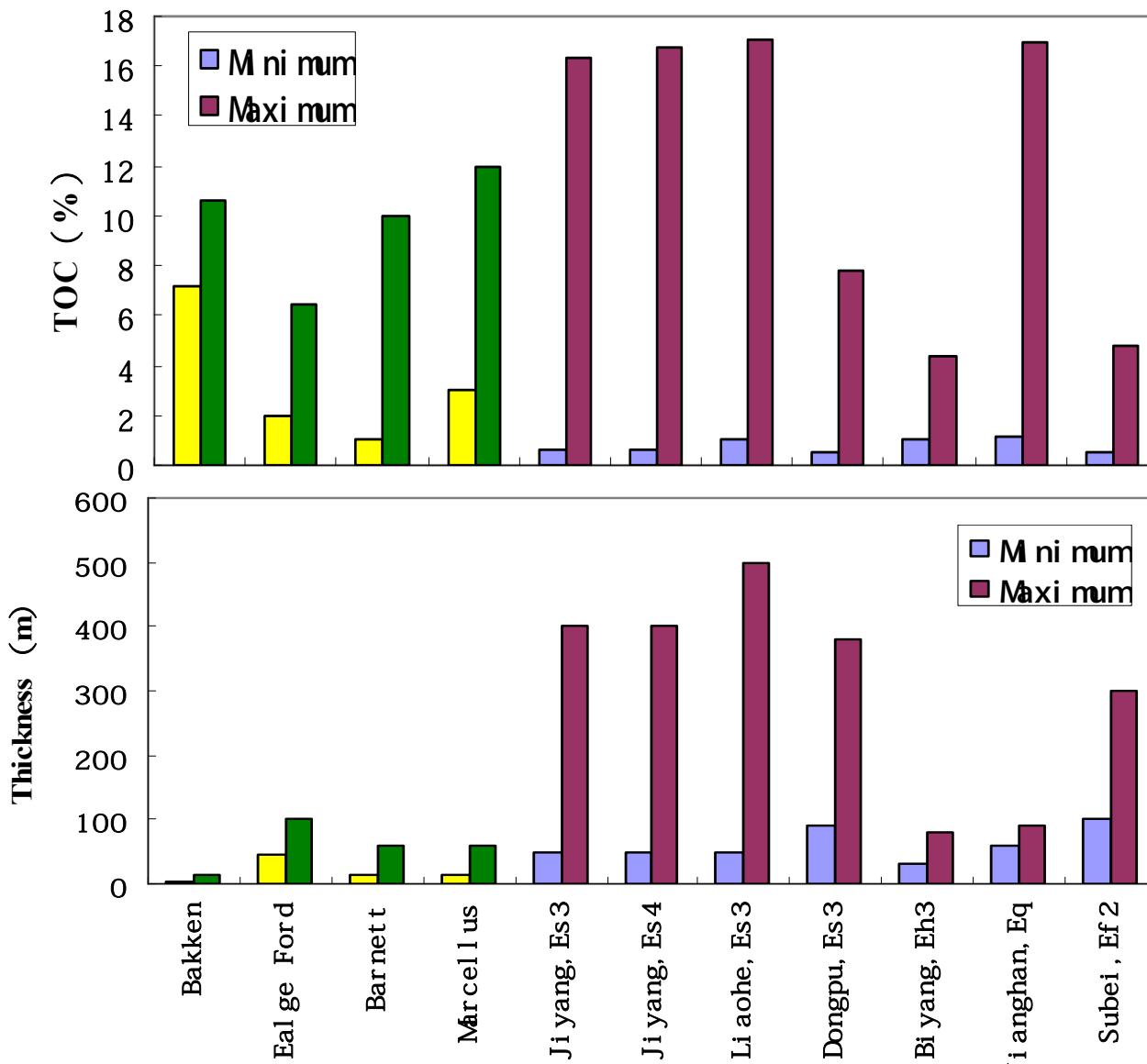
### 3.2.1 Paleogene source rock characteristics

(4) Organic matter dominated by type I and II kerogens, with thermal maturity  $< 1.3\% \text{Ro}$ , mainly in peak oil generation

Ro distribution of  $E_2 S^3$ (Lower) in Dongying Sag

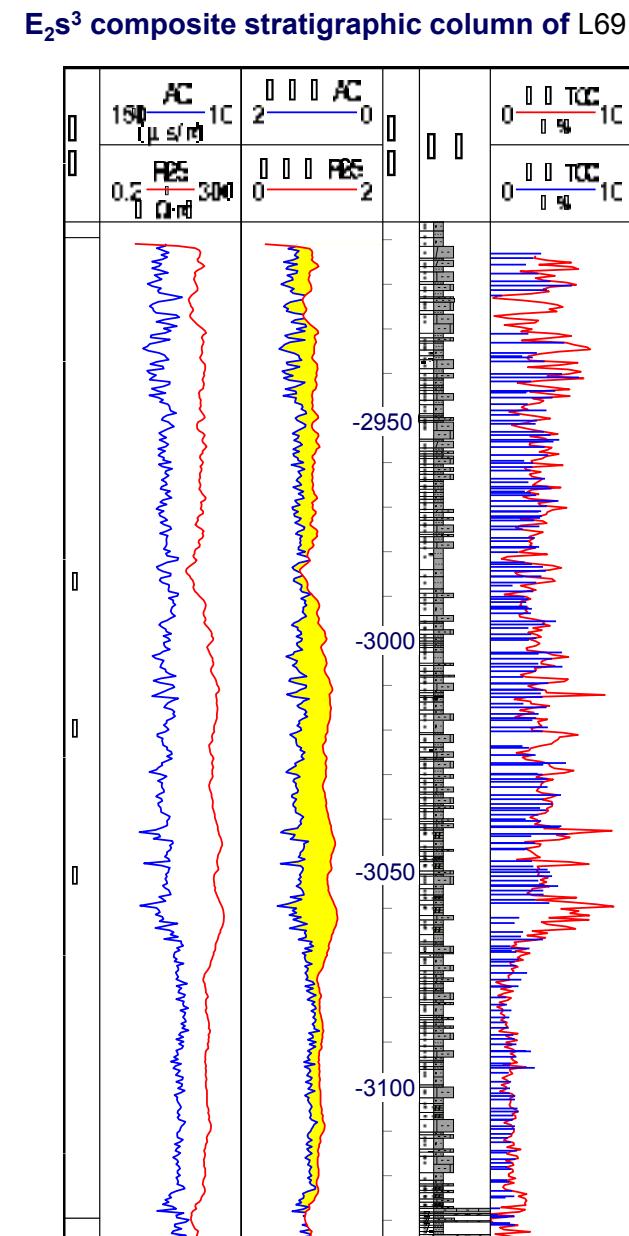


### 3.2.1 Paleogene source rock characteristics

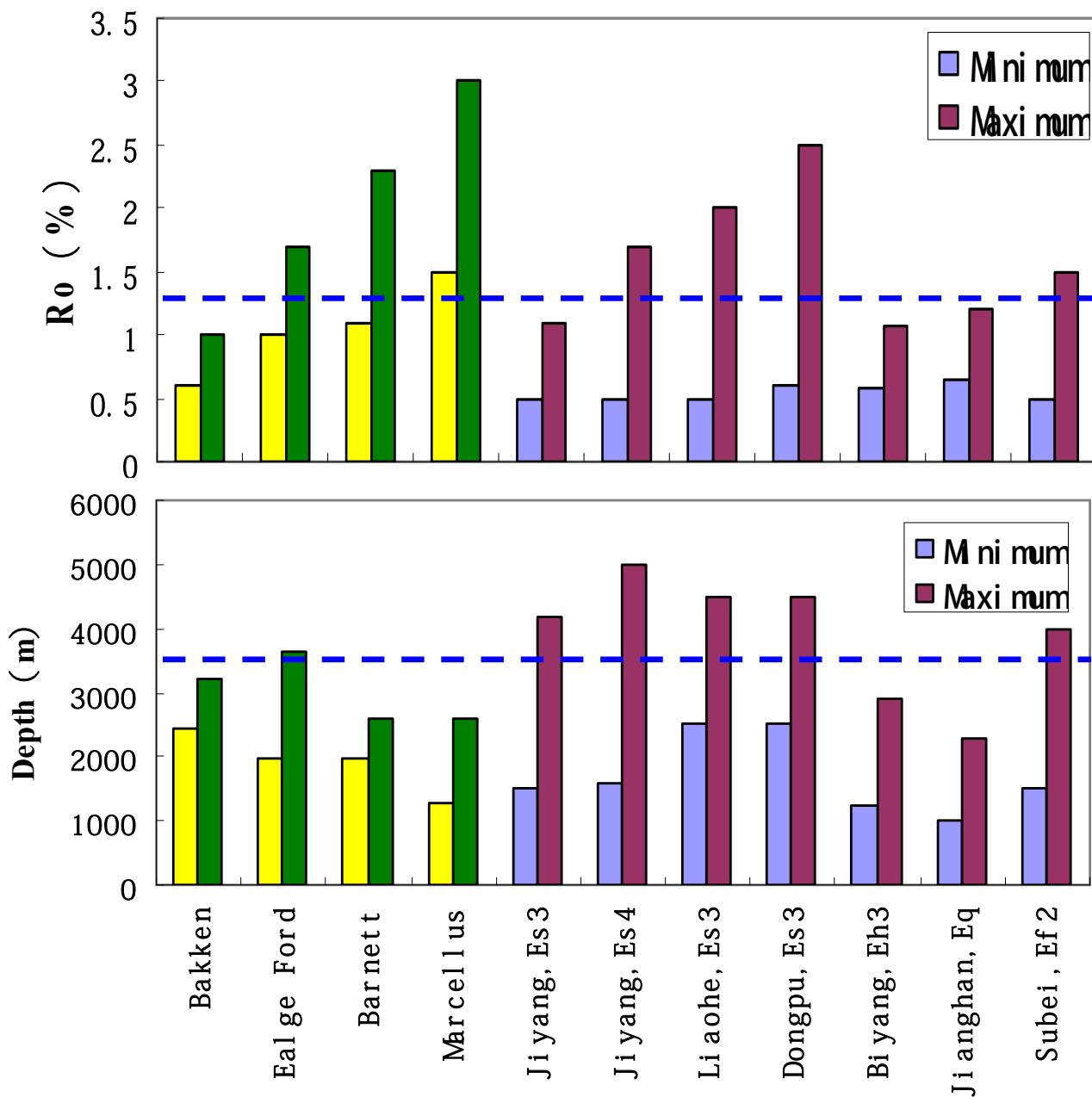


□ Average TOC 1-4%

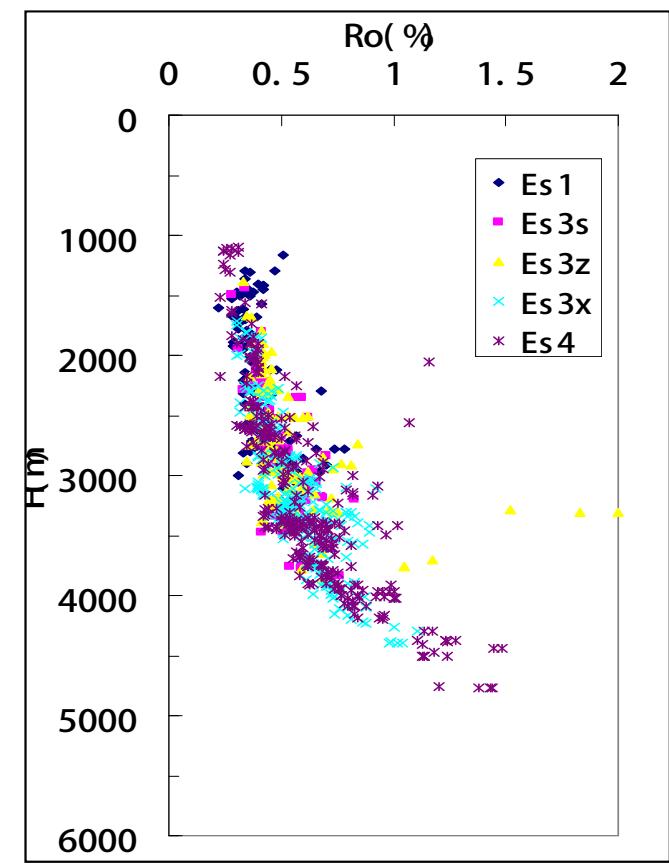
□ Large thickness, over 300 m in places



### 3.2.1 Paleogene source rock characteristics



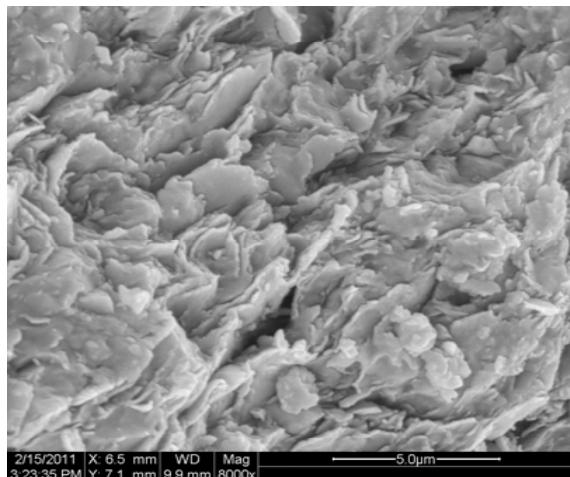
Ro- buried depth correlation in Jiyang



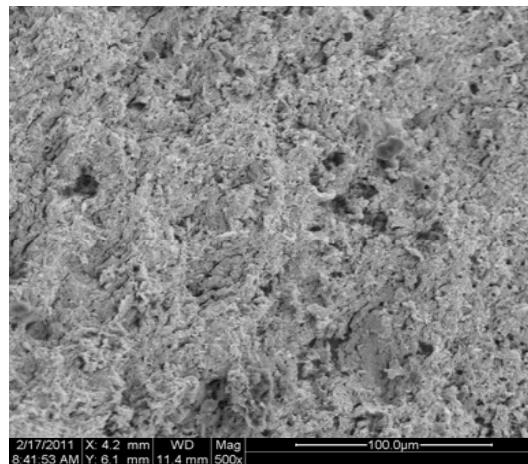
□ **Ro:** generally  $<1.3\%$ , can attain to  $2\%$  in the deep sag  
□ **Depth:** commonly  $<3500\text{m}$  ,  $>3500\text{m}$  in deep sag

## 3.2.2 Paleogene shale reservoir characteristics

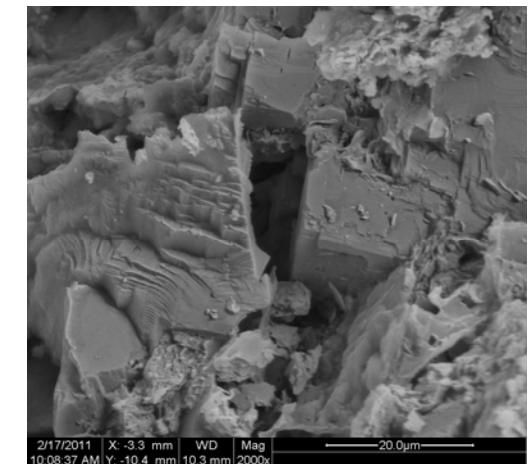
### (1) Reservoir storage space including micropores, nanopores and microfractures



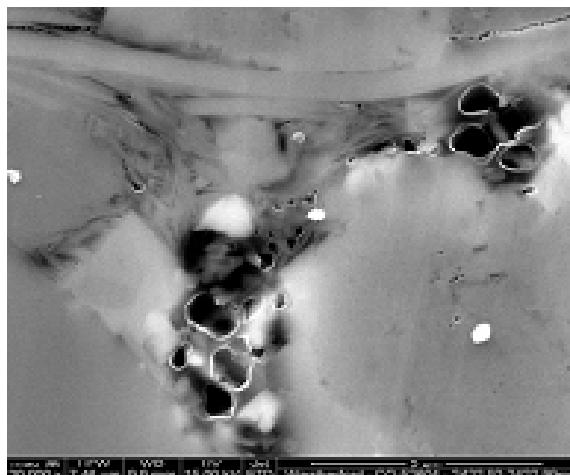
F1 Well , Upper E<sub>2</sub>s<sup>4</sup>  
mircopore of I/S mixed layer



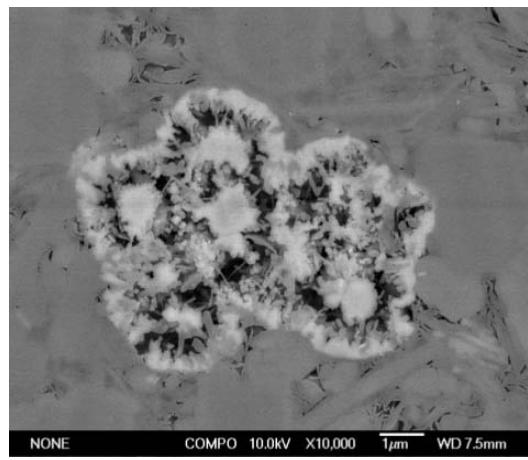
L64, Upper E<sub>2</sub>s<sup>4</sup>,  
micropore of clay mineral



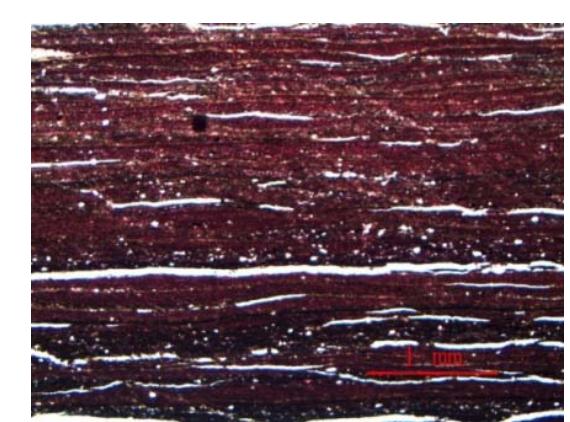
L90 , Upper E<sub>2</sub>s<sup>4</sup> ,  
sandy interparticle micropore



BY HF-1 , E<sub>3</sub>h<sup>3</sup>, Organic nanopore ( X18000 )



P18, Upper E<sub>2</sub>s<sup>3</sup>,  
Intracrystal dissolved hole of calcite

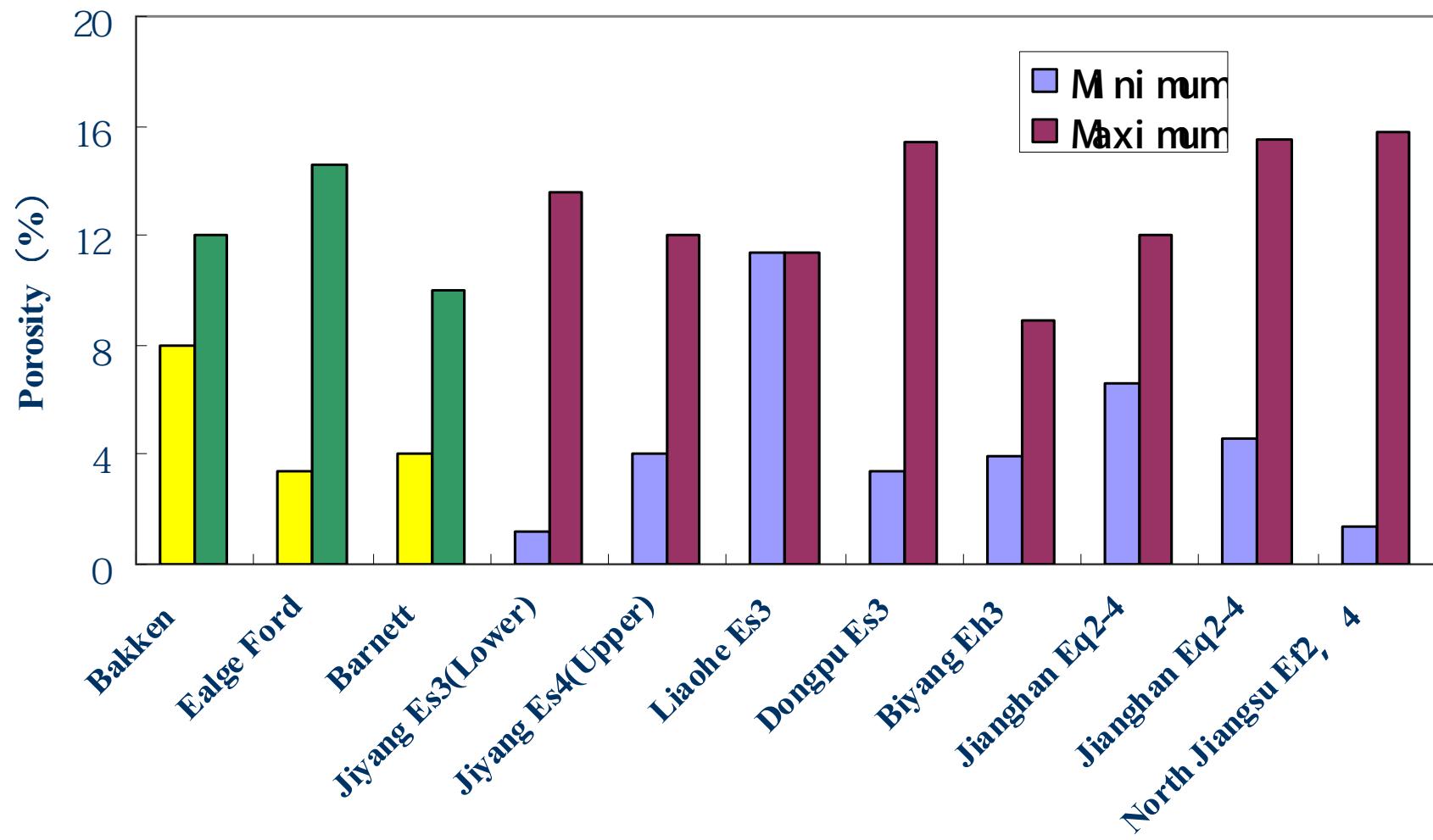


W31 , Upper E<sub>2</sub>s<sup>4</sup>,  
dry shrinkage fractures

Abundant microfractures, including shringkage fracture, interlaminar seam



### 3.2.2 Paleogene Shale Reservoir Characteristics



Porosity comparison with other shale oil systems

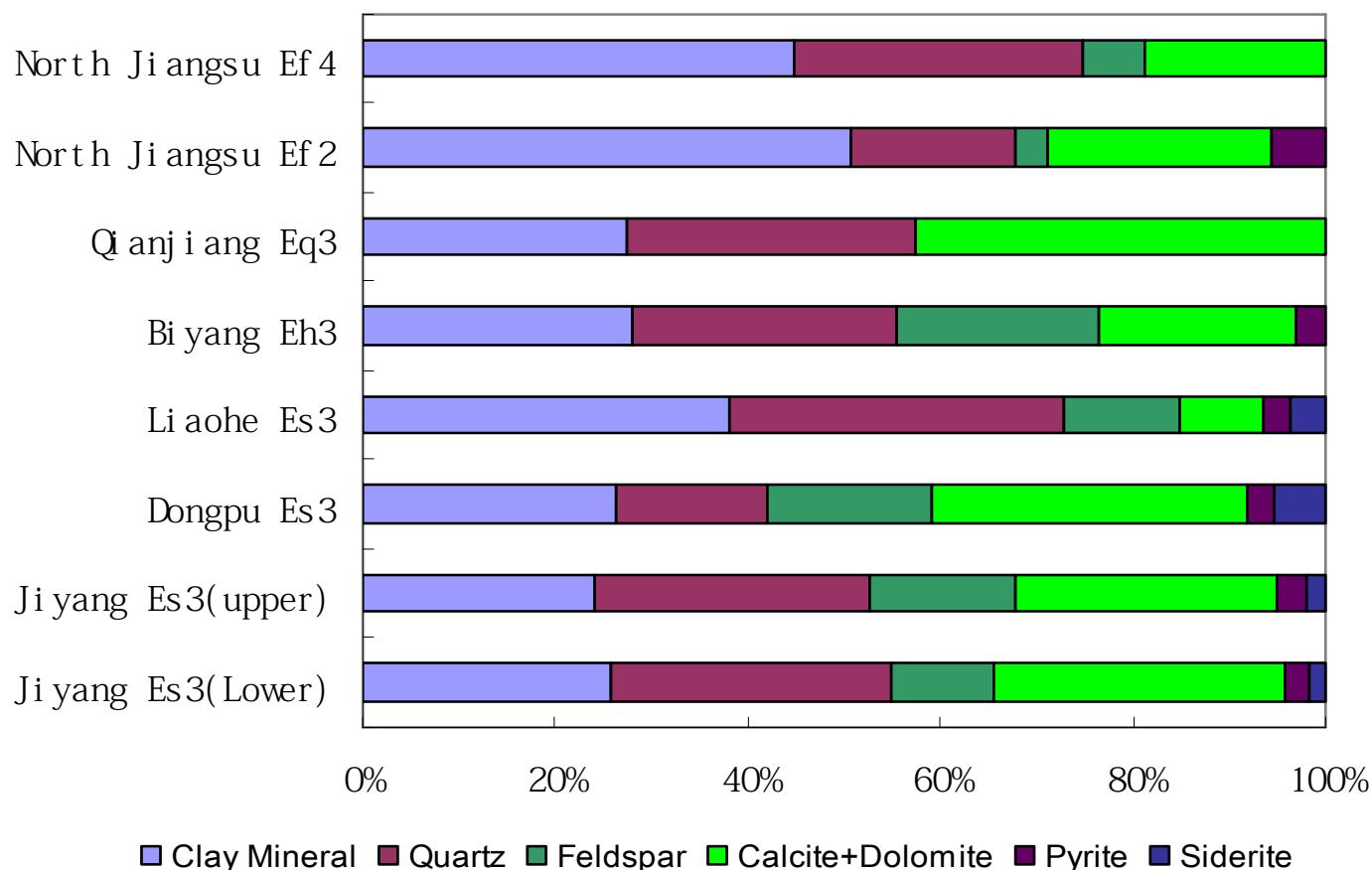


## 3.2.2 Paleogene Shale Reservoirs Characteristics

(2) Generally enriched in brittle minerals, mainly quartz and carbonate, with clay content < 50%

Jiyang Depression  
( E<sub>2</sub>S<sup>3-4</sup> ) :

- Clay : 10-40%
- Quartz: 20-30%
- Carbonate: 20-60%





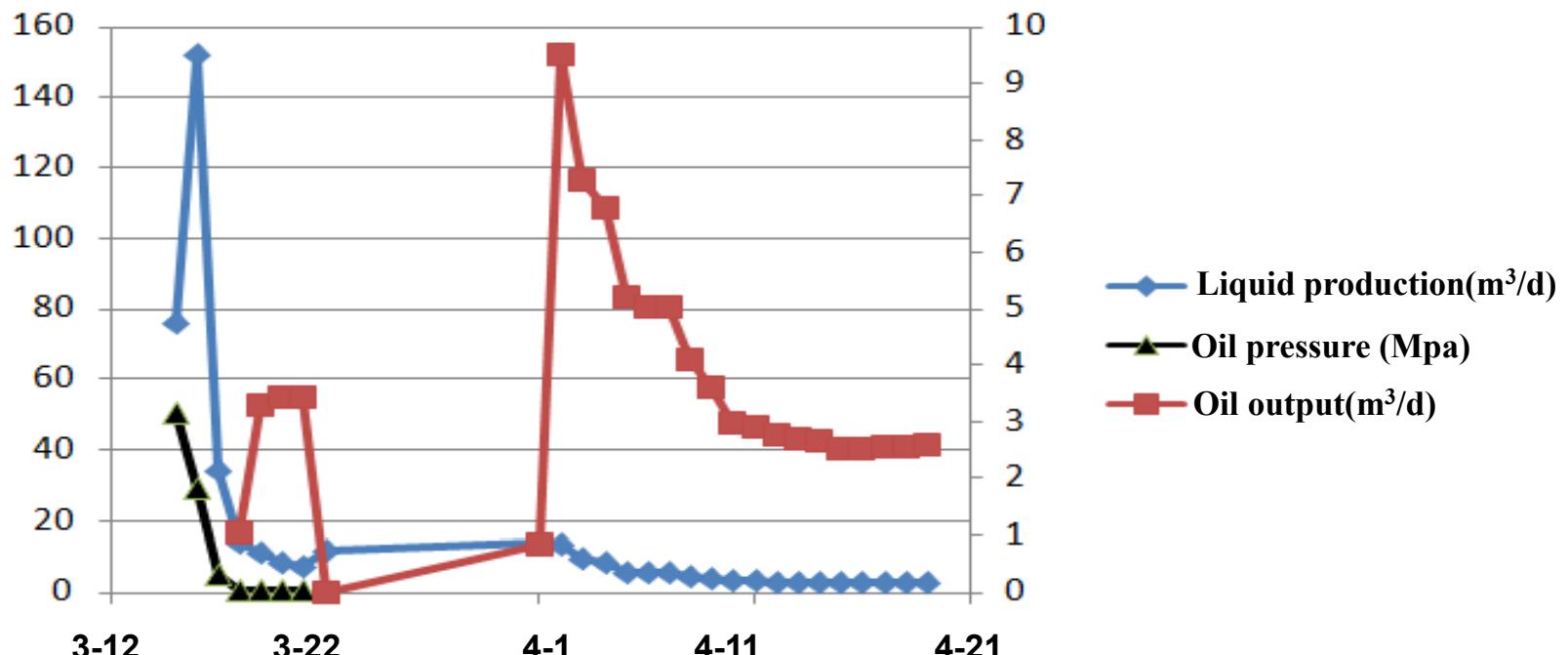
### 3.3 Paleogene Shale Oil Resources Potential

Basin	Area ( ×10 <sup>3</sup> km <sup>2</sup> )	Strata	Oil generated (10 <sup>9</sup> t)	Oil expulsed (10 <sup>9</sup> t)	Residual oil (10 <sup>9</sup> t)	Conventional Resource volume (10 <sup>9</sup> t)	Estimated shale oil resources (10 <sup>9</sup> t)	
							2%	5%
Bohai Bay	195	E <sub>2</sub> s	144.68	50.55	94.137	14.893	1.883	4.707
Nanxiang	17	E <sub>3</sub> h	2.786	1.052	1.734	0.365	0.035	0.087
Subei	21.4	E <sub>1</sub> f	15.556	3.973	11.583	0.427	0.232	0.579
Jianhang	36.4	E <sub>2-3</sub>	9.078	1.174	7.904	0.472	0.158	0.395
Songliao	260	K <sub>2</sub>	150.607	67.246	83.361	11.307	1.667	4.168
Total	529.8		322.707	123.995	198.719	27.464	3.974	9.936

According to the 3rd round petroleum resources evaluation of China, the total oil generated in Eastern China amounts to about 323 billion tons, while the residual quantity amounts to about 199 billion tons.

# Challenges

## □ Rapid production decline after fracking



Production curve of BYP1 Well after fracturing

The Initial production of horizontal well is lager than the vertical well, however, the production of the former declines faster than the latter generally.



## Characteristics of lacustrine shale oil system in eastern China

- Rift basin setting
- Young geologic age with low thermal maturity
- High oil viscosity with low mobility
- Relatively poor frackability
- Consequence low initial production rate, rapid production decline



# Physical property of Paleogene shale oil

Region	Well	API	Freezing point	Wax	Polar	Pressure	GOR	Viscosity (mPa.s)			
		(ρ420)	(°C)	(%)	(%)	Coefficient		50°C	70°C	80°C	90°C
Biyang Depression	AS1	30	39	34.21	18.8	0.95		33.52	15.72	12.06	9.56
		33	38	31.02	20.41		121	24.04	12.16	8.91	6.78
		31	39	31.44	21.83			22.7	9.13	7.26	6.3
	HF-1	31	39	34.21	21.83	1.05	127				
Zhanhua Depression	BYP1	22	31	21.54		1.5		69			
	L42	26	31	17.24	34.75	1.7		28.4			
	L 19	22	21	12.95	36.61			38.2			
USA	Bakken	41				1.1-1.4	80-250				
	Eagle Ford	45				1-1.5	513-5041				



# Outline

- Introduction
- Lacustrine Shale Gas
- Lacustrine Shale Oil
- Conclusions



## Conclusions

- ◆ Lacustrine shales in China have large gross thickness, high TOC, different types of reservoirs pore spaces and abundant hydrocarbon shows, so that they have a great shale oil & gas potential.
- ◆ Drawing on the successful experience of US shale oil and gas, China has made significant progresses in exploration for lacustrine shale oil & gas in the past 3 years.
- ◆ China is facing great challenges in exploration for lacustrine shale oil & gas, such as prediction of favorable play fairways, shale wellbore stability problems, rapid production decline after fracking.



# Acknowledgment

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and permission to release this work**