

Accumulation Conditions for Ordovician Gas Enrichment in the West Margin of Ordos Basin, China*

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Abstract

The Ordos Basin, which is situated in the north part of China, is one of the largest basins in terms of natural gas resources in China. Most oil and gas fields were found in clastic rock of Carboniferous, Permian, and Triassic horizons. It was demonstrated that gas found in the top of Ordovician carbonate weathering crust in mid-east Ordos Basin was from the overlying coal-bearing strata. However, natural gas accumulation from marine source rocks in Ordovician was found recently in the west margin of the Ordos Basin. The purpose of this paper is to describe the geological conditions of gas accumulation in the Ordovician in the west margin of the Ordos Basin and the identification of the Petroleum System.

The marine source rocks occurred in the Kelimoli and Wulalike formations of the Ordovician which consist of shale, mudstone, and marlstone, and are mainly distributed in the west margin of the Ordos Basin where sedimentary environments are deep ramp faces. The thickness of strata ranges from 20 m to 200 m, the thickest deposition occurred in the west part and the thinnest in the east. Deposited in marine ramp settings, the shales are rich in organic matter and the TOC ranges from 0.19% to 4.55%. The kerogens are dominated by type I or II and the biological type is mainly the original marine invertebrates and algae. Thermal maturity is mostly in the range of 1.4 to 2.8% Ro.

Limestone bedding karst cavity reservoir in the Kelimoli Formation and beach face dolomite reservoir in the Zhuozishan Formation constituted the main space for the gas accumulation. The bedding karst cavity reservoir, with the average porosity between 4% to 6% and the permeability between $0.1 \times 10^{-3} \mu\text{m}^2$ and $2.0 \times 10^{-3} \mu\text{m}^2$, is the main gas reservoir while the dolomite reservoir mainly produces water. The limestone bedding karst cavity reservoir is mainly distributed in the west with the thickness between 60 m and 170 m and is interbedded with the source rock while the dolomite reservoir is mainly distributed in the east.

The overlying coal-bearing strata, which are continuous and widely distributed, prepared the high quality, good cap rock. The vitrinite reflectance values and the homogenization temperature of fluid inclusions suggest that the onset of the oil generation started in the late Jurassic and gas in the early Cretaceous. There is a good exploration potential in the future.



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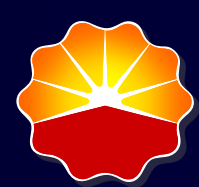
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-  1. Geologic Background
-  2. Source Rock Terms
-  3. Reservoir Conditions
-  4. Petroleum System
-  5. Conclusions



1. Geologic Background

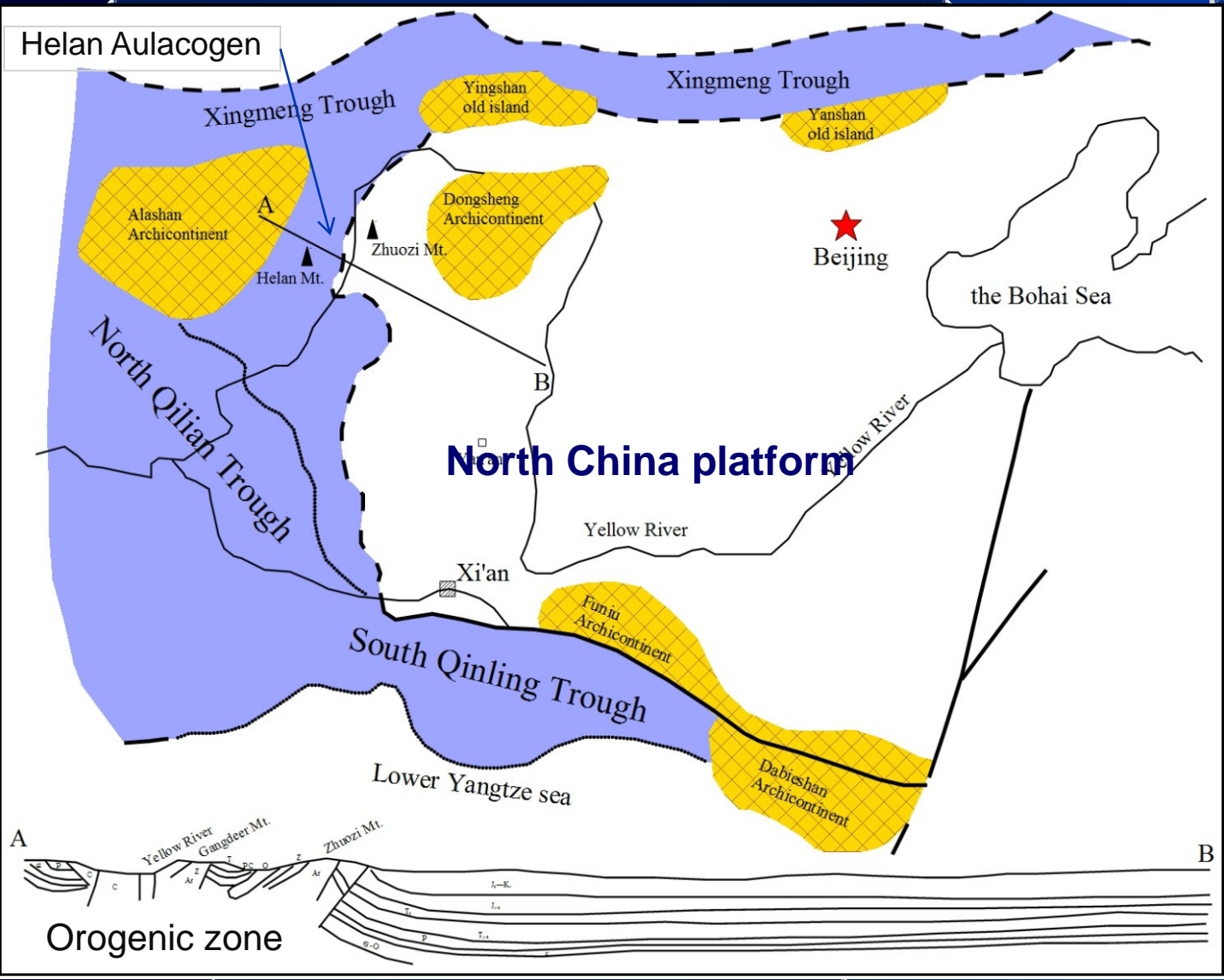


Era		Period	
Mesozoic		Cretaceous	Clastic Rock
		Jurassic	
		Triassic	
Palaeozoic	Pz ₂	Permian	120Ma
		Carboniferous	
		Devonian	
	Pz ₁	Silurian	Carbonate
		Ordovician	
		Cambrian	

The Ordos basin located near the western margin of North China platform in central China.

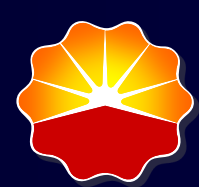


1. Geologic Background



After Wang
Hongzhen 1984

Paleogeographic map of North China platform in early-paleozoic



1. Geologic Background



- The Upper Ordovician sequence is absent over the east part of the basin except on the western and southern margin of the Ordos area.
- For the western margin of the basin, the Ordovician sequence consists of seven Formations.
- The Zhuozishan Formation and Kelimoli Formation are the main reservoir.

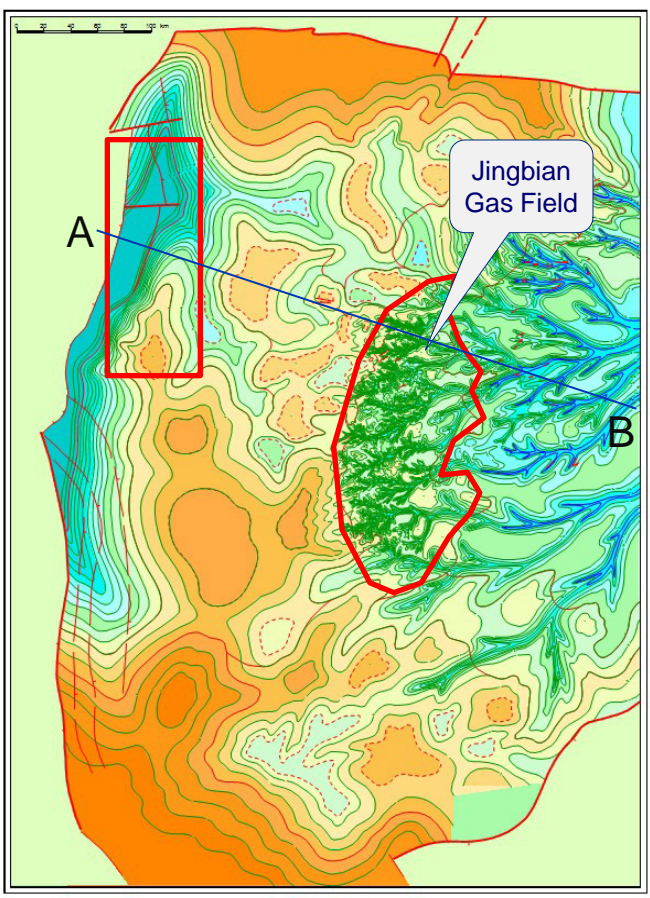
Age Ma	International Stratigraphic Chart			GSSP	Ordos Basin Stratigraphic Chart		
	PERIOD	EPOCH	AGE		West	South	East
443.7	Ordovician	Late	Hirnantian	🔑			
445.6			Katian	🔑		Dongzhuang FM.	
						Beiguoshan FM.	
455.8			Sandbian	🔑	Sheshan FM.		
					Gongwusu FM.		
					Lashizhong FM.	Pingliang FM.	
460.9		Middle	Darriwilian	🔑	Wulalike FM.		
					Kelimoli FM.	Sandaogou FM.	Majiagou FM. Ma6 MEM.
468.1			Dapingian	🔑	Zhuozishan FM.		Ma5 MEM.
471.8					Sandaokan FM.	Shuiquanling FM.	Ma4 MEM.
	Early	Early	Floian	🔑			Ma1~Ma3 MEM.
478.6			Trema-Docian	🔑			Liangjiashan FM.
488.3						Machuan FM.	Yeli FM.



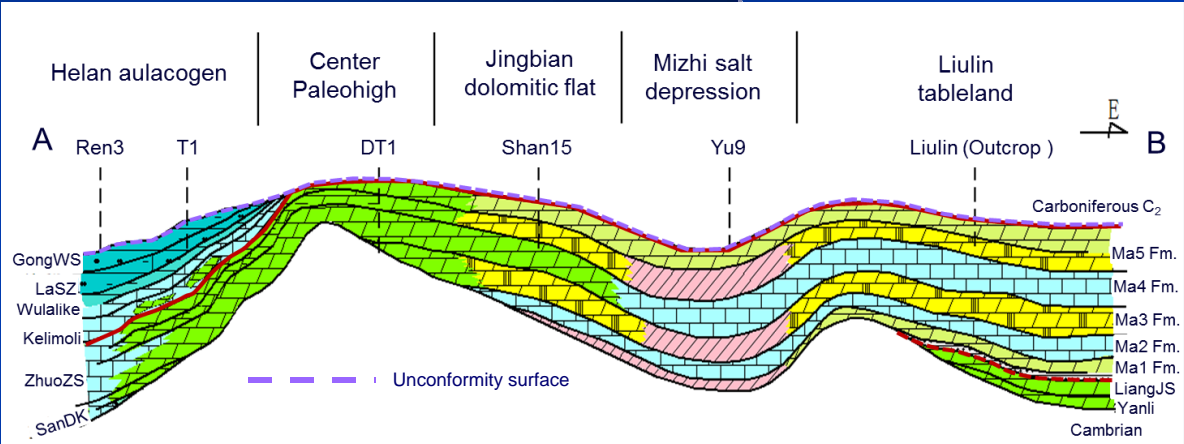
1. Geologic Background



Paleo-geomorphic map before Carboniferous



stratigraphic correlation diagram



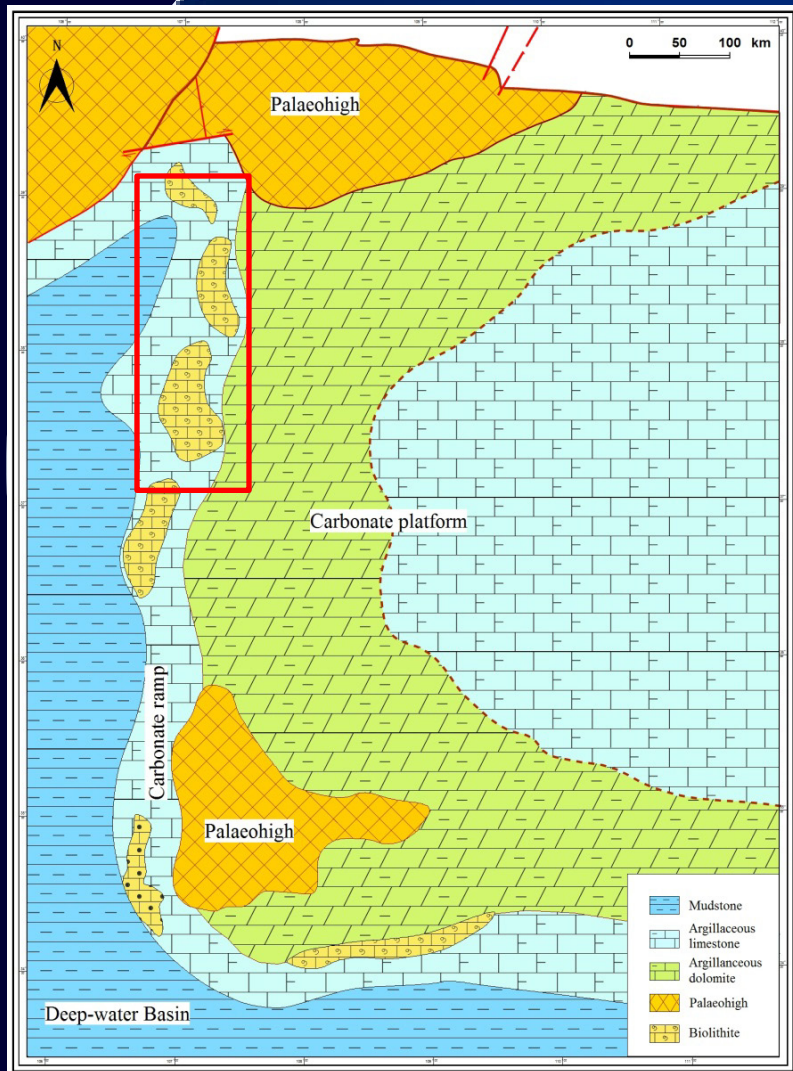
- After the Jingbian Gas Field was found, other new fields need to be explored. WHERE?



1. Geologic Background



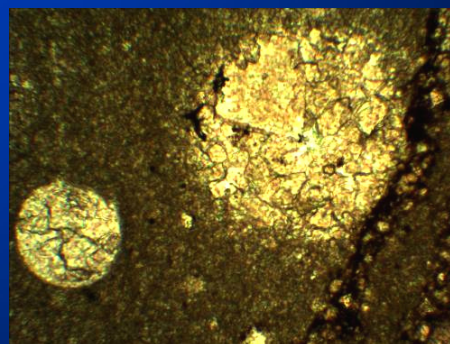
Lithofacies Paleogeographic Map of Ordovician



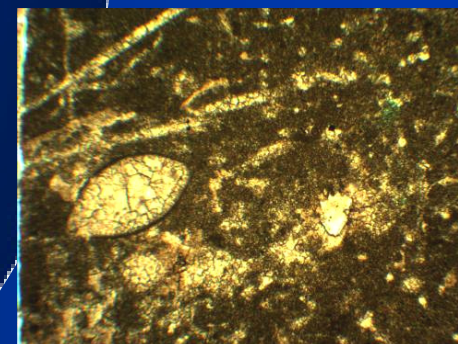
Well Yu2 Kelimoli FM. 3998.1m ,
Bioclastic limestone



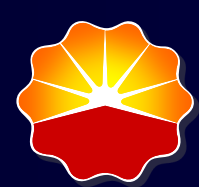
Well Na1 Kelimoli FM. 3917.21m ,
Sandy biosparite



Well T2 Kelimoli FM. 4039.3m ,
micritic dolomite



Well T1 Kelimoli FM. 3973.8m ,
bioclast micritic dolomite



2. Source Rock Terms



Statistics of organic carbon content in the Wulalike

Well or Area	Thickness (m)	Mudstone (WT. %)		marlite		limestone		Remarks
		Range	Avg. (Num.)	Range	Avg. (Num.)	Range	Avg. (Num.)	
Pingliang	41.3	0.07-1.08	0.56 (21)	0.24-0.44	0.35 (6)	0.03-0.33	0.19 (13)	data from Chen. etc.
Shibangou	26.4	0.09-0.82	0.31 (10)					
Ren 3	104	0.15-1.20	0.67 (6)		0.31 (1)	0.08-0.15	0.11 (3)	
Zhuozishan	78.1	0.88-1.22	1.09 (3)			0.11-0.69	0.26 (14)	
Na 1		0.19-4.55	1.46 (37)					
Yu 1				0.30-1.16	0.51 (19)			
E 19		2.39-2.42	2.41 (2)			0.22-1.80	0.57 (6)	
Bu 1						0.10-0.32	0.15 (14)	

- ◆ MudStone is the main marine source rocks.
- ◆ The TOC ranges from 0.19% to 4.55%.

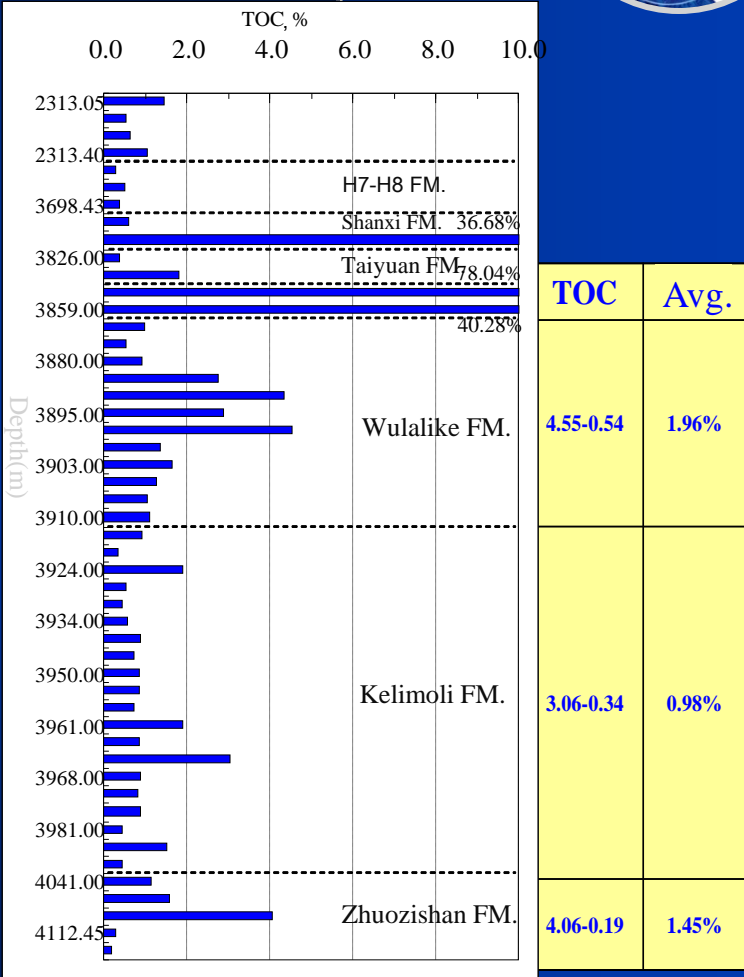


2. Source Rock Terms



- ◆ The marine source rock occurred in the Kelimoli and Wulalike formations
- ◆ Mainly consists of mudstone, marlite and limestone
- ◆ mainly distributed in the west margin of Ordos basin where sedimentary environments are deep ramp faces.
- ◆ The thickness of Wulalike source rock ranges from 20 to 100m.

TOC of Well Na1



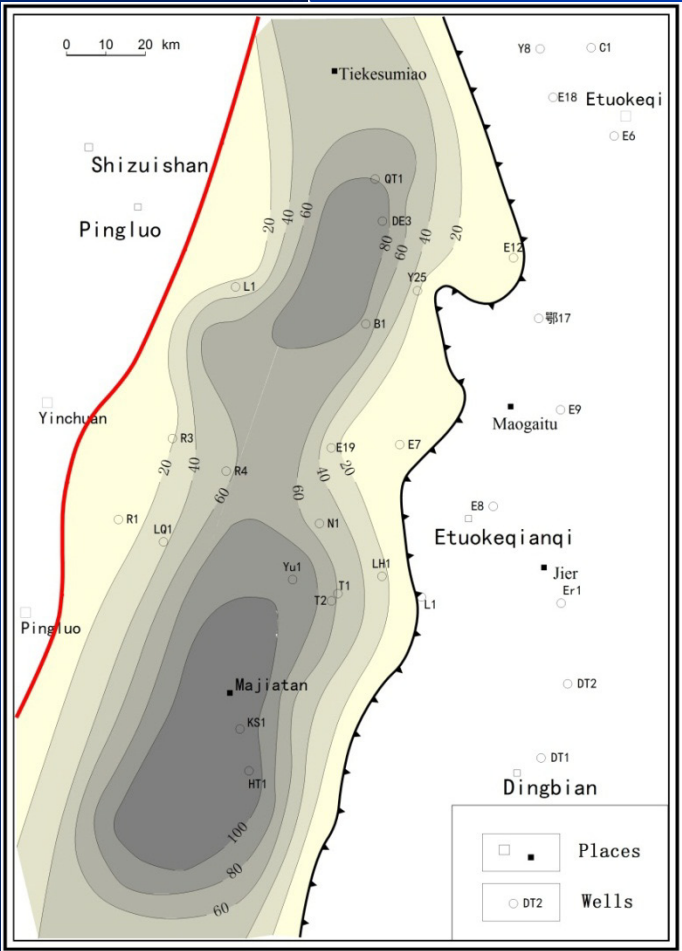


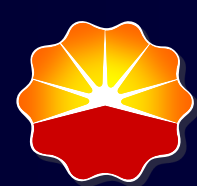
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The Thickness Map of Wulalike Source Rock





2. Source Rock Terms



The data of carbon isotope value

Well	Depth (m)	FM.	$\delta^{13}\text{C}$ (PDB , ‰)				
			C1	C2	C3	iC4	nC4
Yu1	4083.0-4085.0	Kelimoli	-38.92	-27.17	-25		
LT1	2832.0-2837.0	Ma5_7	-39.26	-23.78	-19.72	-19.72	-20.45
T1	3934.0-3940.0	Kelimoli	-34.26	-25.71	-20.45		
Su360	3981.0-3989.0	Kelimoli	-33.29	-21.43	-24.51		
Su357	3958.0-3961.0	Kelimoli	-33.32	-24.53	-22.94		
S255	3443.5-3456.5	Ma5_1	-33.73	-26.35	-25.81	-20.61	-22.07
S277	3070.0-3072.0	Ma5_3	-32.74	-25.26	-24.52	-21.05	-21.84
Su203	3919.0-3926.0	Ma5_5	-33.56	-26.46			
Su361	3692.0-3710.0	Shanxi_1	-33.71	-24.48	-24.26	-21.39	-21.61
Tie1	4157.0-4161.0	Benxi	-30.10	-24.91			

- ◆ The gas founded in Kelimoli FM. is from Ordovician itself.
- ◆ The gas is not from the overlying coal-bearing strata
- ◆ The carbon isotope value of methane from the overlying coal-bearing strata ranges from -34.84‰ to -31.85‰ at large.
- ◆ The carbon isotope value of methane from Kelimoli formation in well Yu1 is -38.92‰



3. Reservoir Condition



Reservoir characteristics of Kelimoli FM.

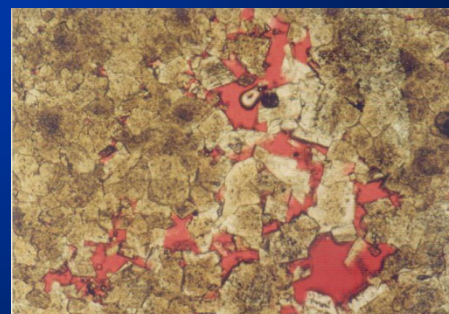
Rock type	<ul style="list-style-type: none"> • bioclastic limestones • Brecciola, • algal limestone, • Dissolve freckle dolomite
Area	About 6500Km ²
Thickness	60-180m
Karstification	<ul style="list-style-type: none"> • Bedding atmospheric corrosion • Burial dissolution modification
Pore type	<ul style="list-style-type: none"> • Karst cave • dissolved pore • Intergranular dissolved pore
Average porosity	4 ~ 6%
Permeability	0.1 ~ 2.0×10 ⁻³ μm ²



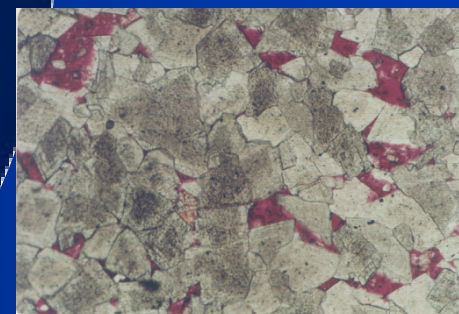
Well T2 grain limestone
Dissolved pore cave developed.



Well E6, ×40 times
Fine-grained dolomite
Dissolved pore cave developed



Well E7 ×50 times
Grain dolostone
Intergranular pore



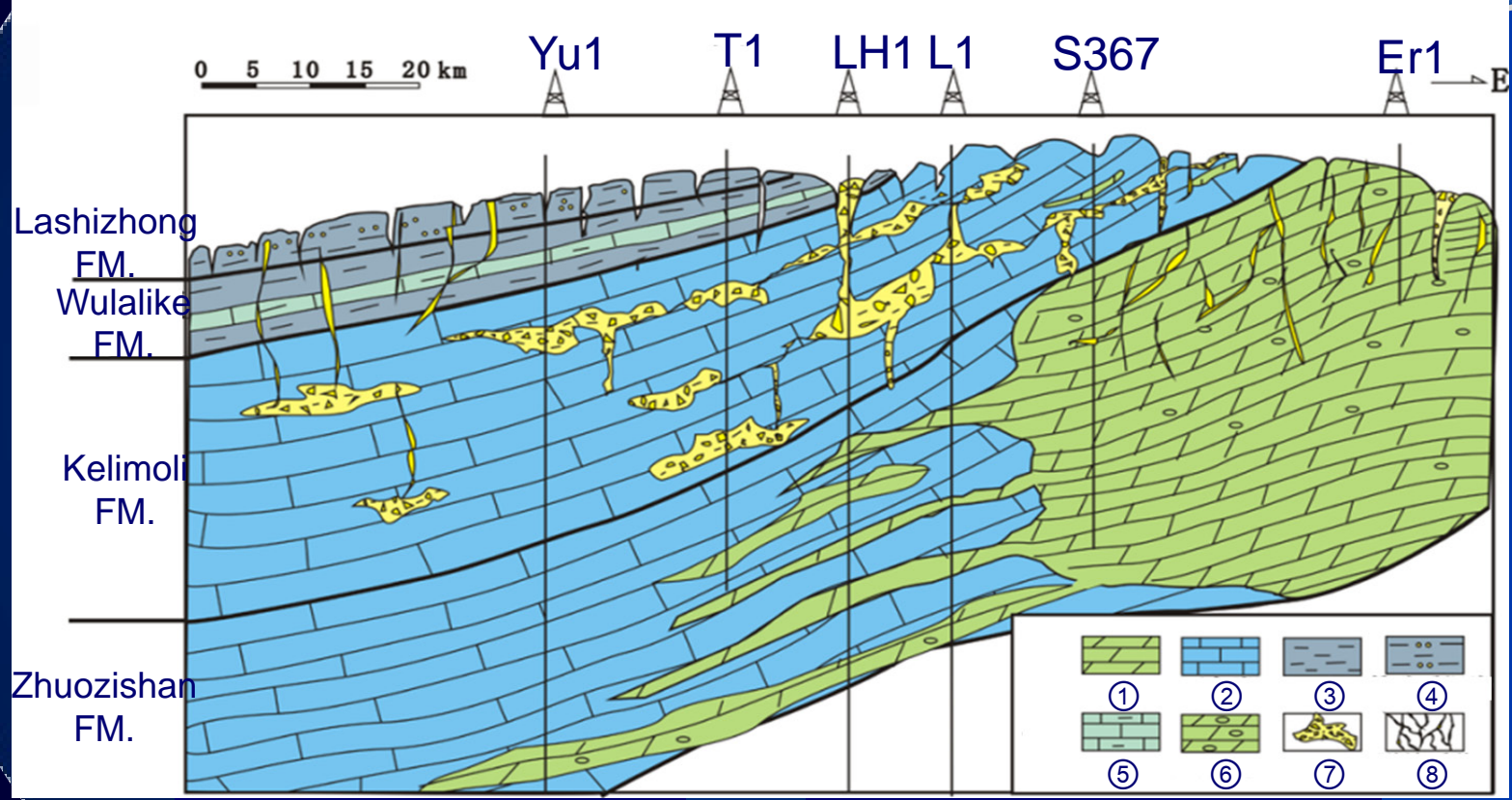
Well T2 ×75 times ,
finely crystalline dolomite
Intergranular pore



3. Reservoir Condition

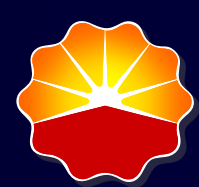


Karst Evolution Model



- ① Dolomite
- ② Limestone
- ③ Mud shale
- ④ Silty mudstone

- ⑤ Micrite
- ⑥ Pore-cave dolomite
- ⑦ Karst cave
- ⑧ Fracture system



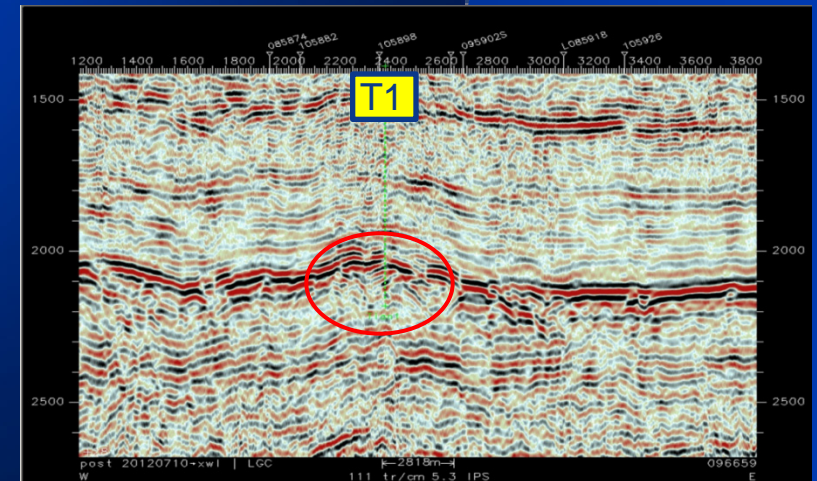
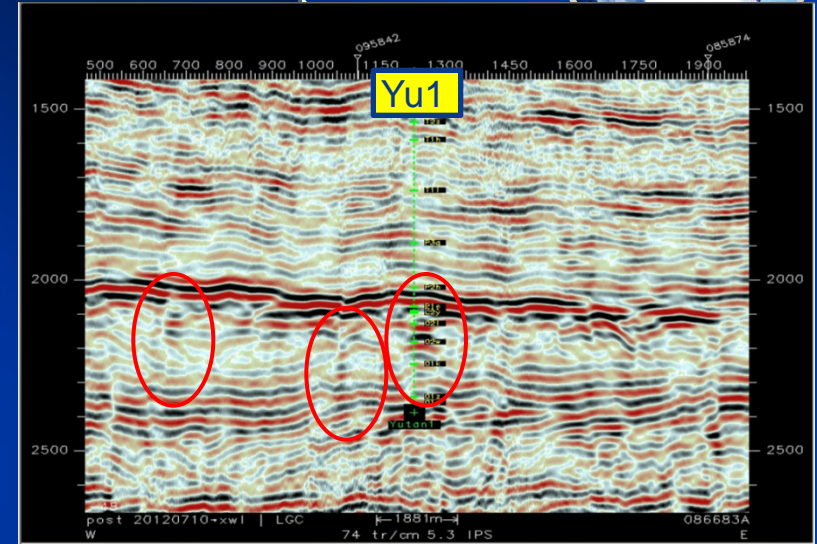
3. Reservoir Condition



◆ Different seismic responses for two kinds of karst caves

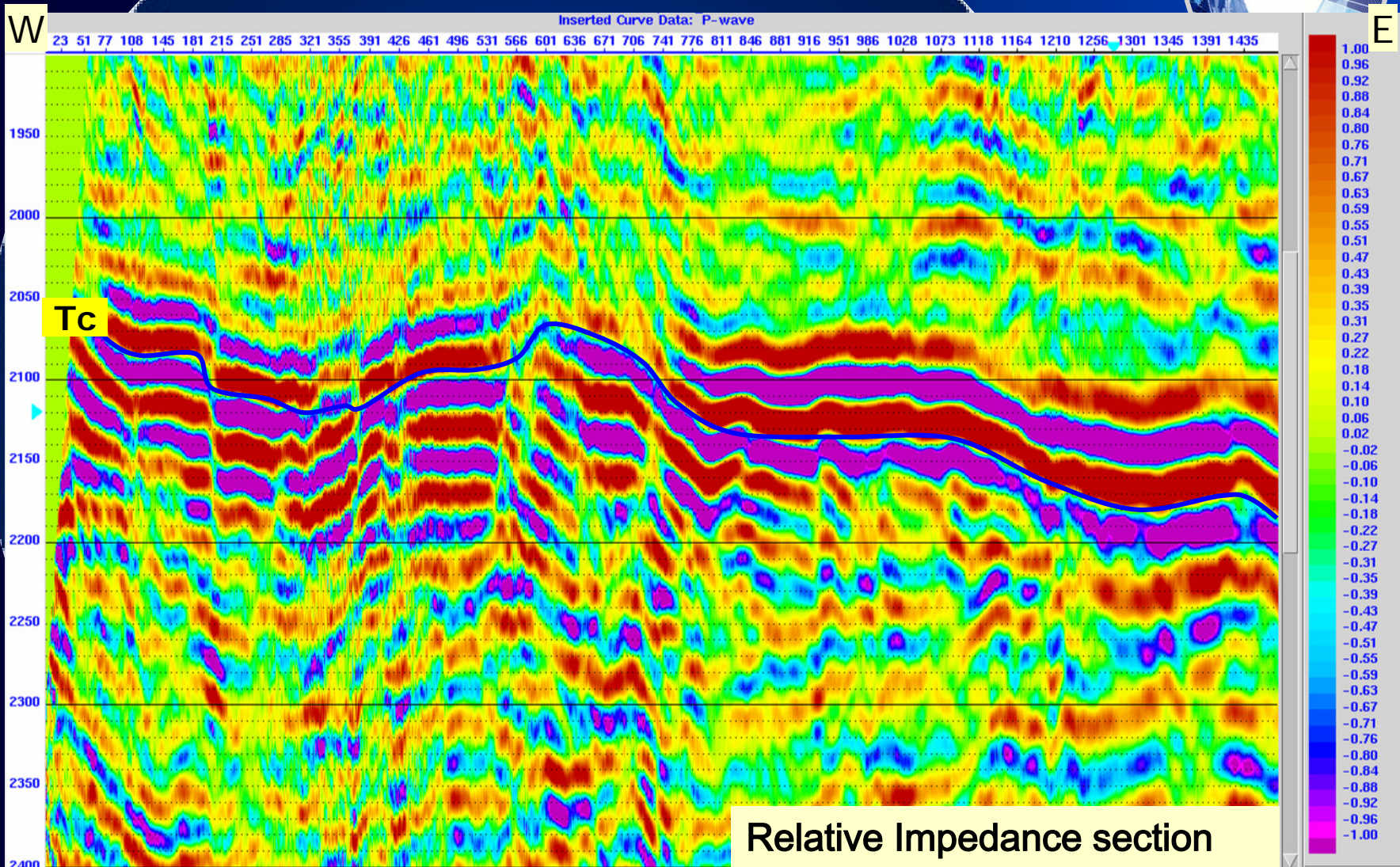
The seismic response of **small and medium-sized karst caves** is that the seismic amplitude enhance. Small fractures and tiny cracks developed in the top of the caves. With good cap layer of overlying rock, those fractures developed good reservoir strata.

The seismic response of **large karst caves** is that the seismic events mix and disorderly array. Large fractures and faults developed around the caves. The caves were filled by collapse breccia and argillaceous rock of the mixed deposits.





3. Reservoir Condition



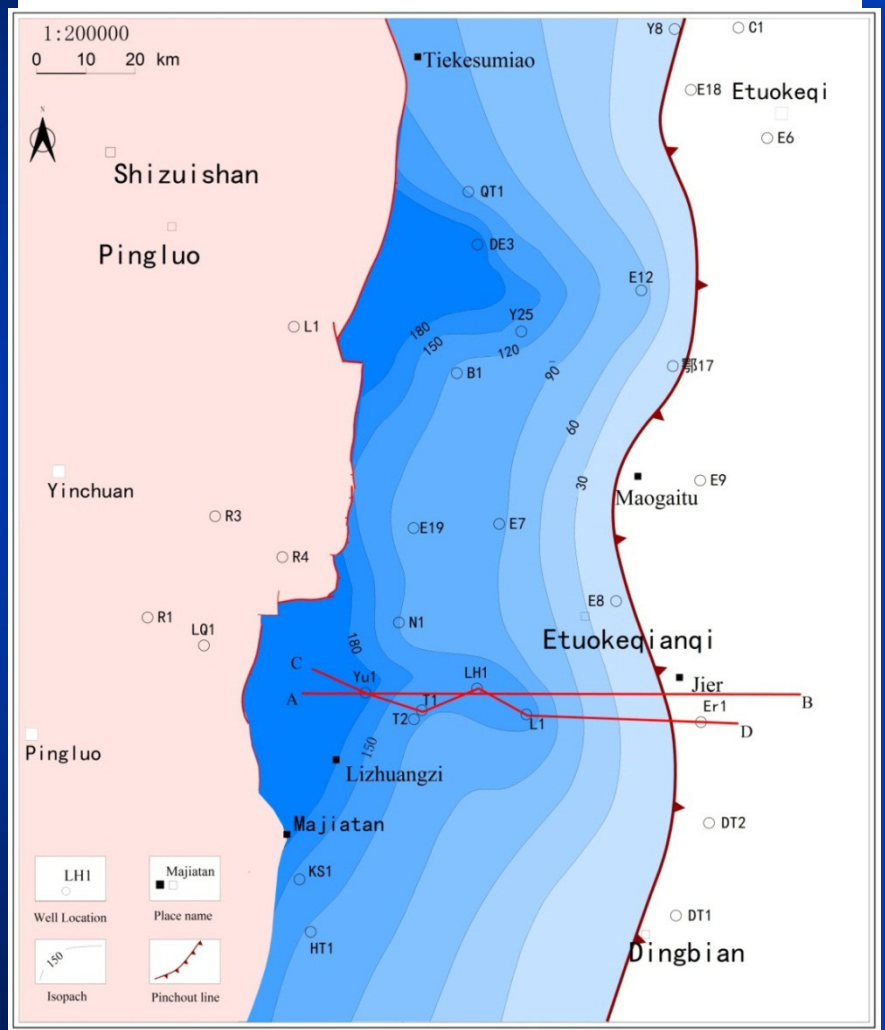


3. Reservoir Condition



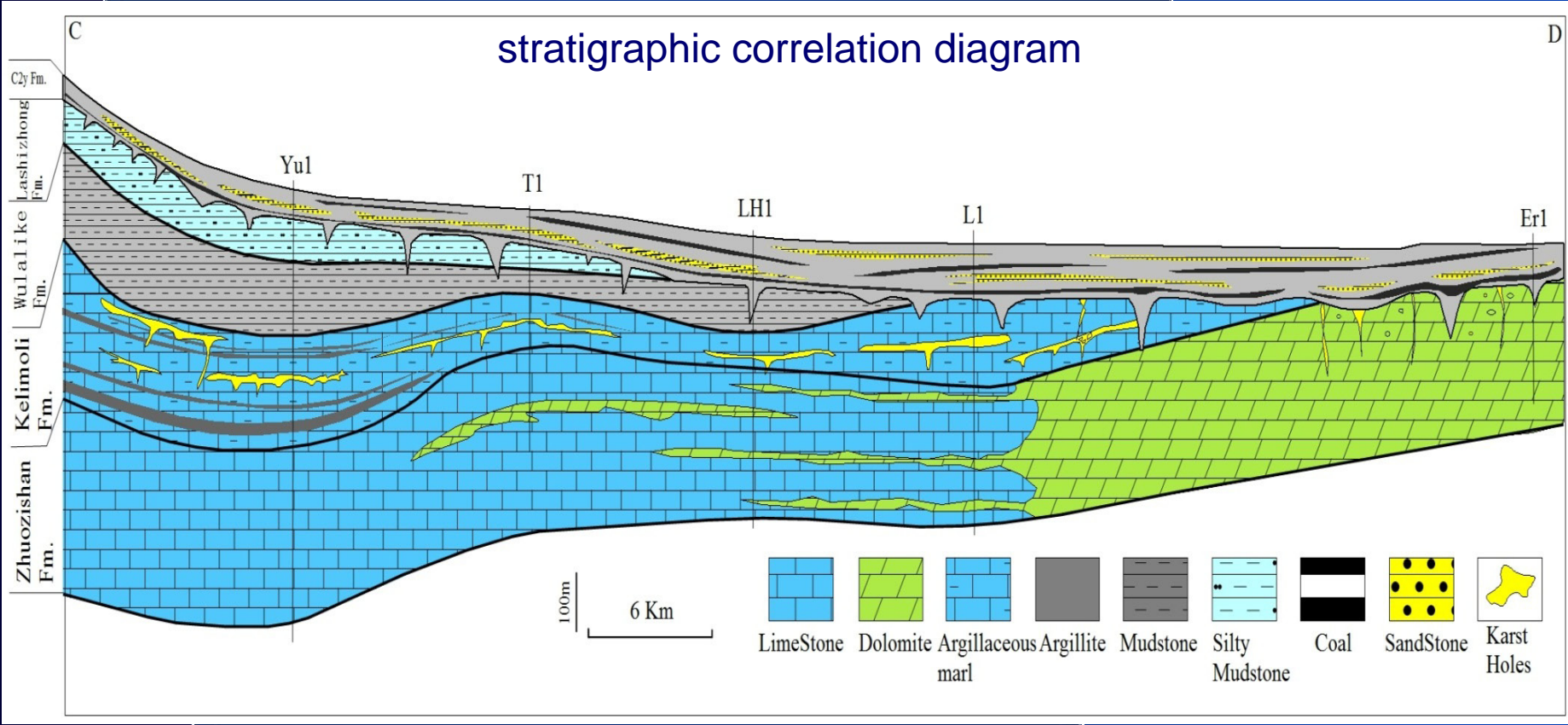
- ◆ The Thickness Map of Kelimoli Fm.
- ◆ the thickest deposition occurred in the west part and the thinnest in the east .
- ◆ The formation wedges out to the east.
- ◆ The thickness of Kelimoli FM. ranges from 20m to 200m.

The Thickness Map of Kelimoli FM.





3. Reservoir Condition





Contents



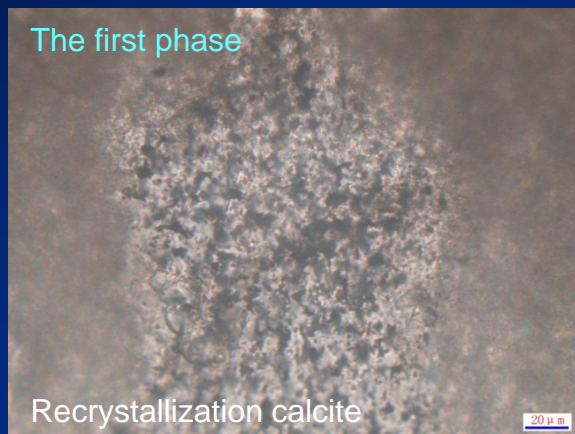
1. Geologic Background
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5. Conclusions



(1) Fluid inclusions of two stages developed



The distribution
of dark brown
liquid
hydrocarbon
inclusions



Well QT1 Kelimoli FM. Micrite

The distribution
of gray gas
hydrocarbon
inclusions



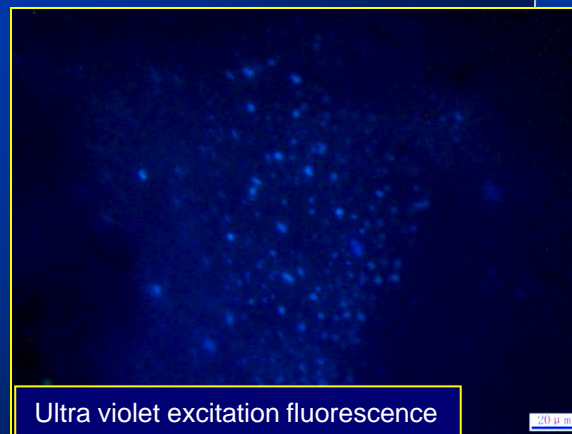
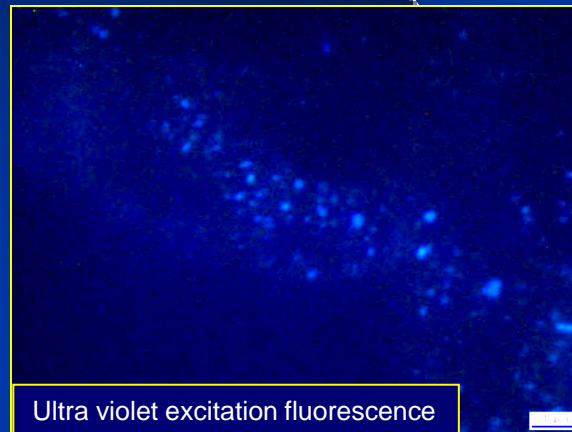
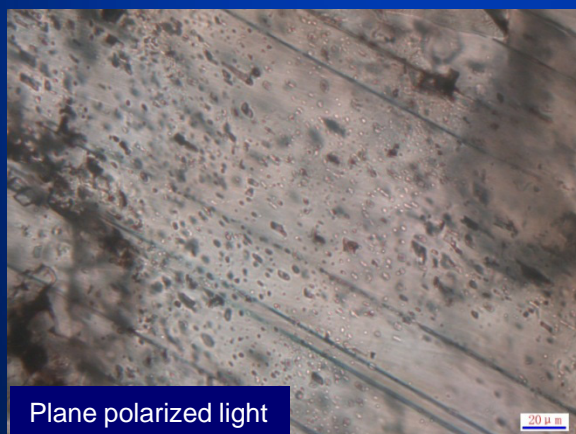
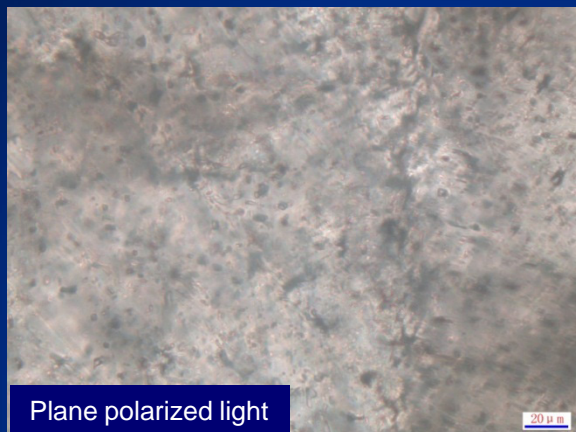
Well Yu1 Kelimoli FM. Granular limestone



(1) Fluid inclusions of two stages developed



- ◆ Hydrocarbon inclusions develop in secondary diagenetic mineral.
- ◆ Existing the process of oil and gas migration.



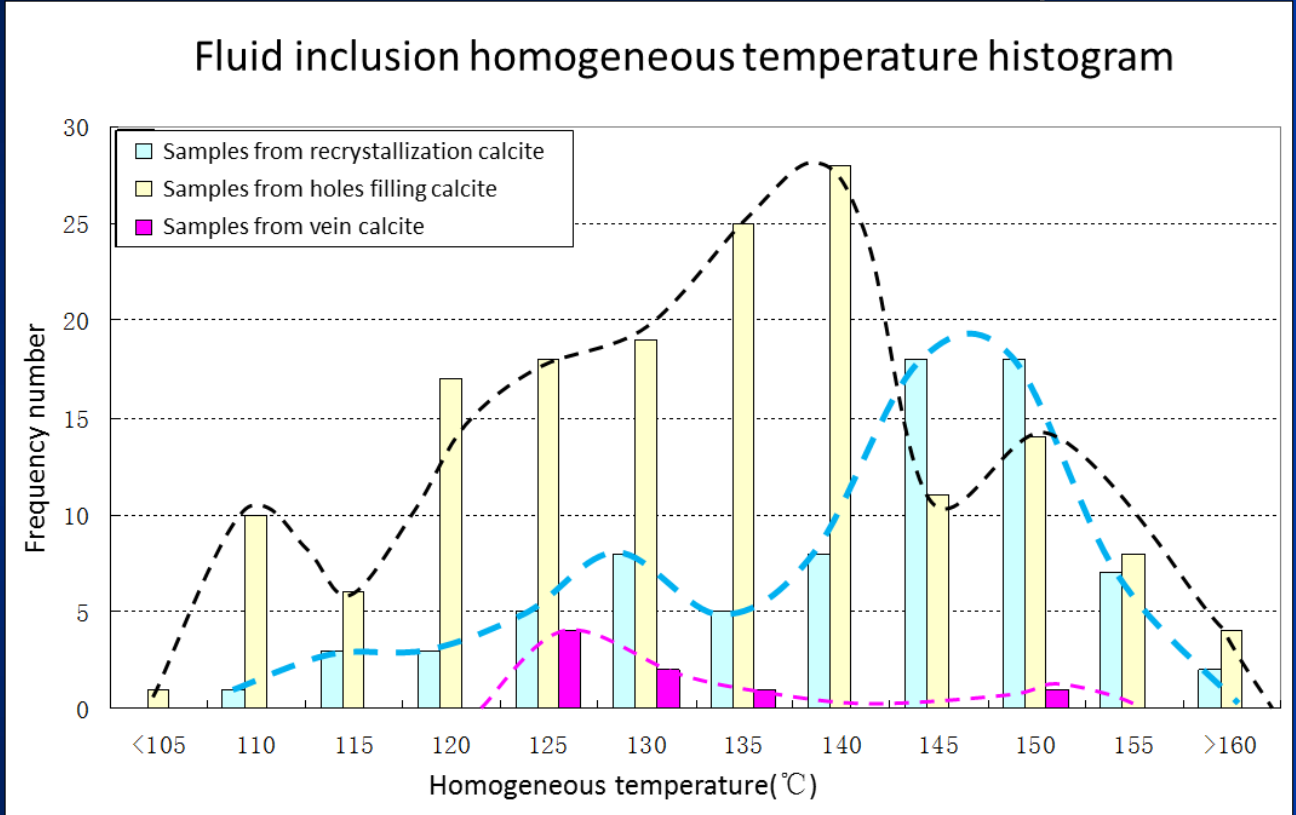
QT1 well Kelimoli FM.

Gas and liquid hydrocarbon inclusion
developed in vein calcite

Light blue fluorescence



(2) Main temperature is between 115-145°C



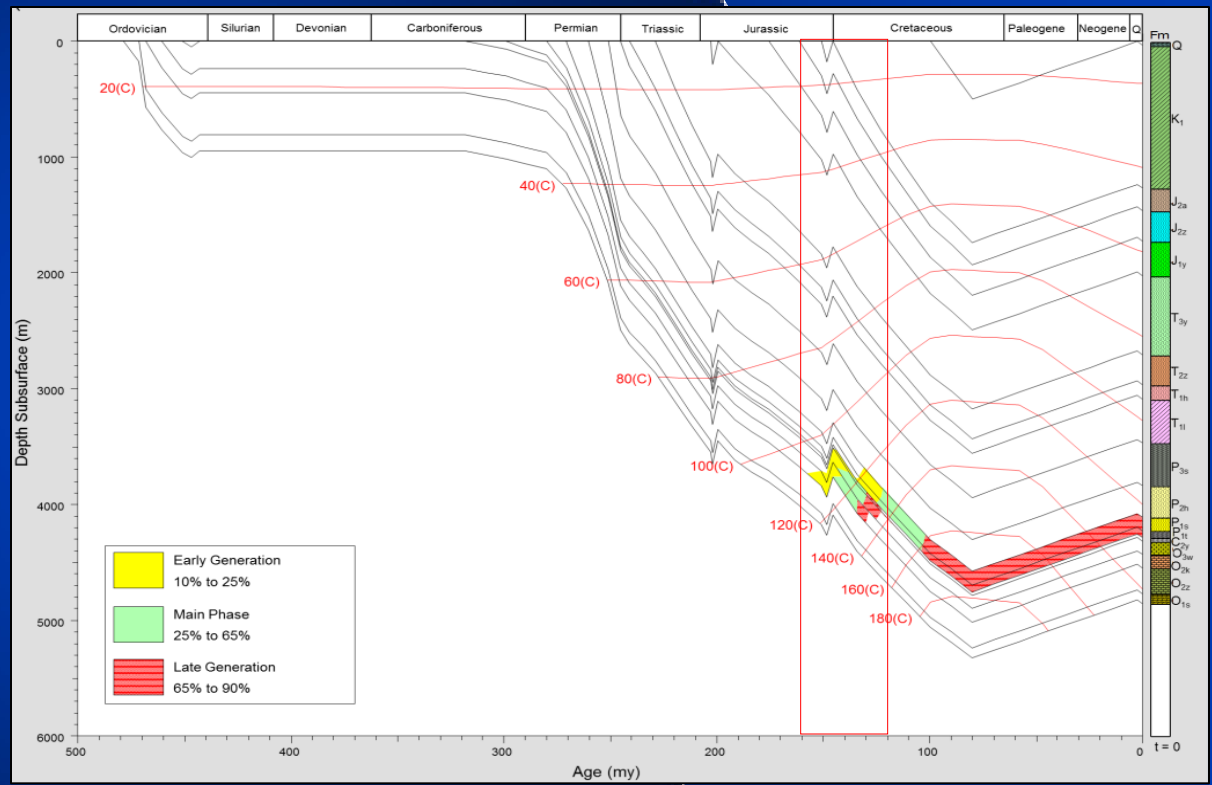
Fluid inclusion homogeneous temperature histogram indicates that the main temperature is between 115-145°C Celsius degree.



(3) There were three periods of charge and accumulation of hydrocarbon in Kelimoli FM.



- ◆ The stage of late Jurassic
- ◆ The early stage of the early Cretaceous(Main accumulation stage)
- ◆ The middle-late stage of the early Cretaceous



● The hydrocarbon charging ages range 160Ma-120Ma at large.



(4) The essential elements and processes of the Wulalike-Kelimoli(.) petroleum system



- ◆ The Wulalike mudstone is not only the source rock but also good local cap rock.
- ◆ The Kelimoli limestone is the main reservoir rock.
- ◆ The overlying coal-bearing strata widely distributed prepared the good regional cap rock with high quality.
- ◆ The overburden rock layers include the late Carboniferous, Permian and all the Mesozoic and Cenozoic.

The events chart for the speculative Wulalike-Kelimoli(.) petroleum system

O			C	P			T	J	K	E	N	Q	Epoch
O _{1S}	O _{2Z-K}	O _{3W-L}	C _{2Y}	P _{1T-S}	P _{2H}	P _{3S}							Events
													Source Rock
													Reservoir Rock
													Seal Rock
													Overburden Rock
													Trap Formation
													Generation-Migration-Accumulation
													Preservation Time
													Critical Moment

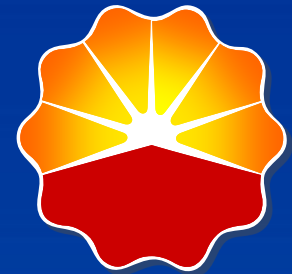
- No definitive gas-source rock correlation has been performed.
- Lithology lateral change in Kelimoli FM. is the main factor to control the traps.
- Structure movement is the minor factor for traps.
- The preservation condition is good.



Conclusions



- **The Wulalike mudstone is the main source rock.**
- **The Kelimoli limestone with karst caves is the main reservoir rock.**
The permeable-storage space mainly consists of breccia filling in the bedding karst cavity or fractures beside the karst caves.
- **The Wulalike mudstone and the overlying coal-bearing strata widely distributed prepared the local and regional cap rock separately.**
- **The critical moment for hydrocarbon charging ranges 160Ma-120Ma at large.**



Thank You !

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奉献能源

创造和谐