2011 GSA Northeastern/North-Central Joint Section Meeting

Evaluation of CO_2 Geological Storage Capacity in the Paleozoic Formations of the Ordos Basin, China

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Outline

- Motivations
- The Ordos Basin Geologic Background
- 3D Geologic Modeling
- Potential Reservoirs-Caprock Assemblages
- CGS Capability and CO_2 Leakage Risk
- Conclusions
- Acknowledgements

Motivations

The Shenhua Group, China's biggest coal producer, is planning to launch the CCS project for its modern DCL plant which produces CO_2 3.67Mt/yr.

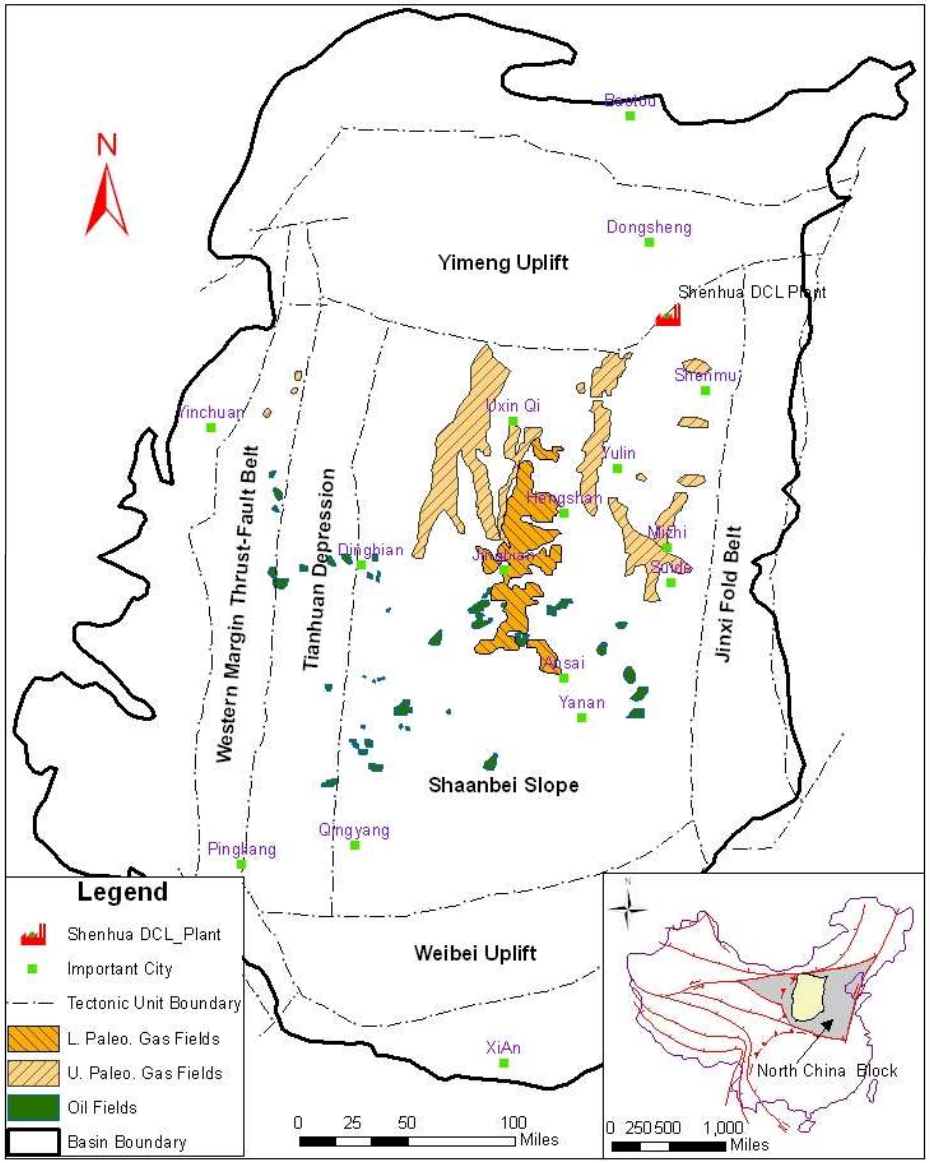
Shenhua DCL Plant in Inner Mongolia, China

Motivations

- In 2004, about 100Mt CO_2 emission in the Ordos Basin

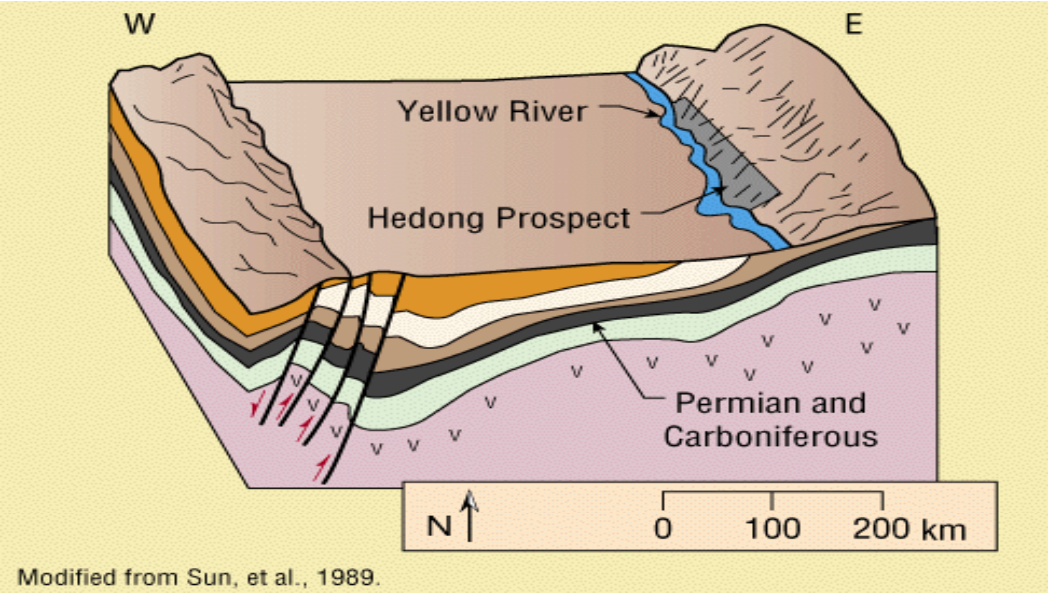
- In the future, more CO_2 emission in the Ordos Basin due to Coal-To-Liquid development in the Ordos Basin

Geologic Background



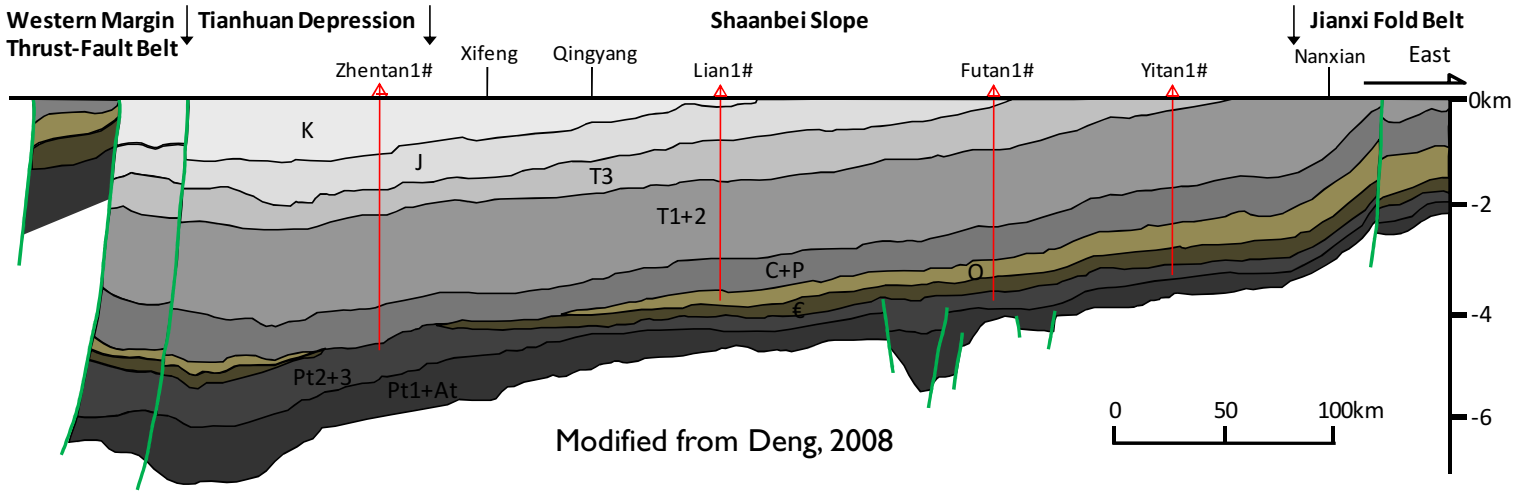
- In North China Block
- Area: 370,000 km^2 (140,000mi^2), as big as half Texas
- Thickness: 2,000~10,000m
- Proven oil reserves: 10*10^{8}metric tons
- Proven gas reserves: 1.54*10^{12}m^3
- Abundant of coal mining
- Six tectonic units

Geologic Background



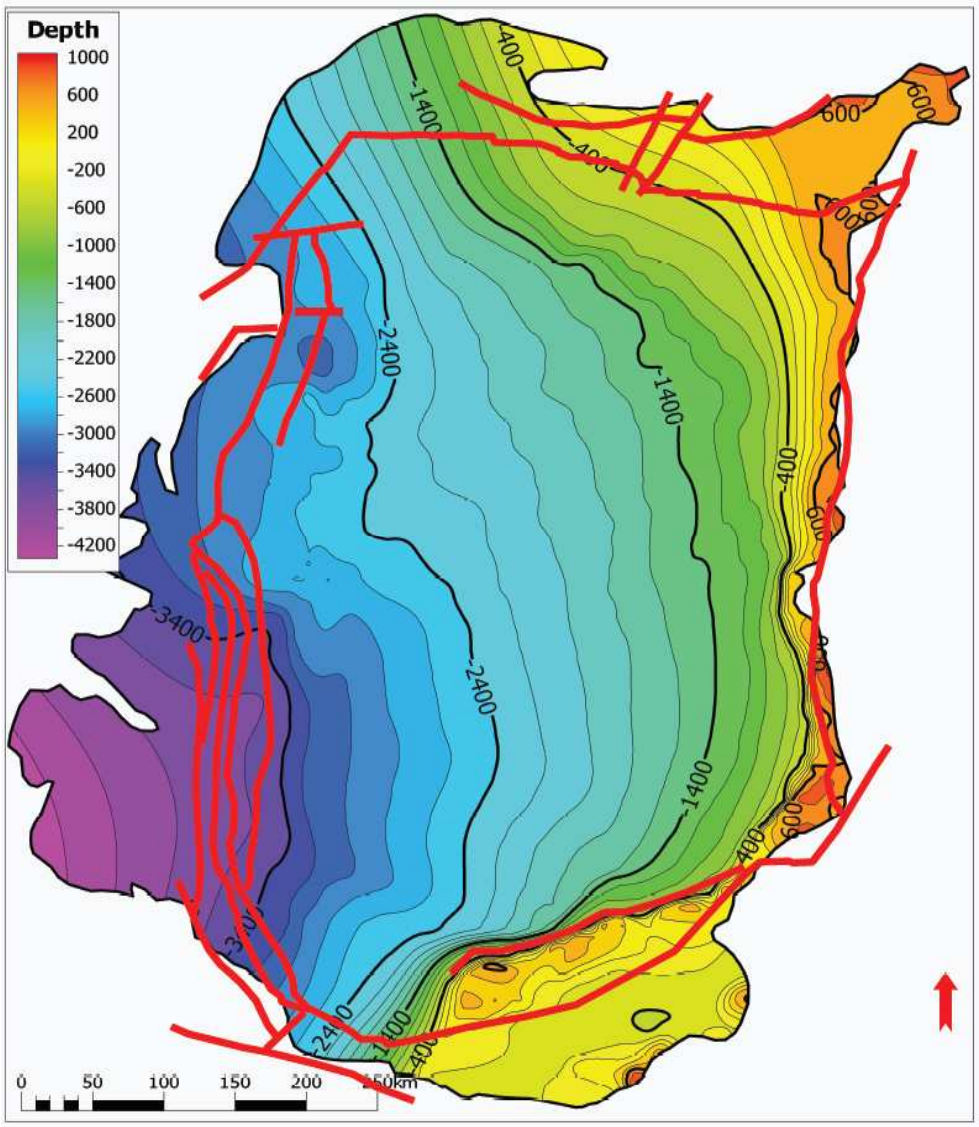
Modified from Sun, et al., 1989.

- A huge monocline in Tianhuan Depression and Shaanbei Slop
- Most of the faults in Western Margin Thrust-Fault Belt and Jinxi Belt
- Dip angle less than 1°
- Deeping to west



Modified from Deng, 2008

Geologic Background



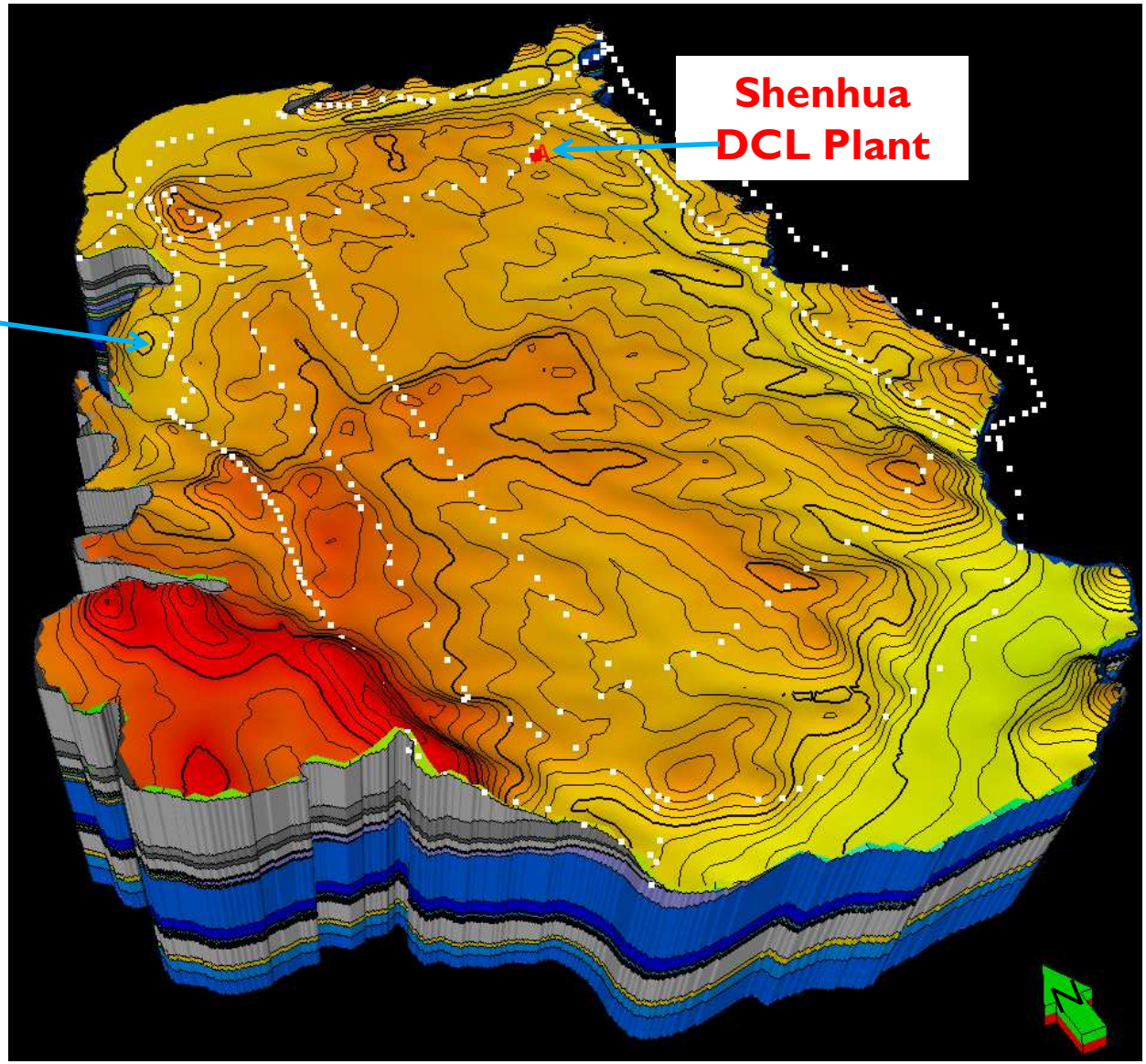
Carboniferous Top Structure Map with Major Faults

Geologic Background

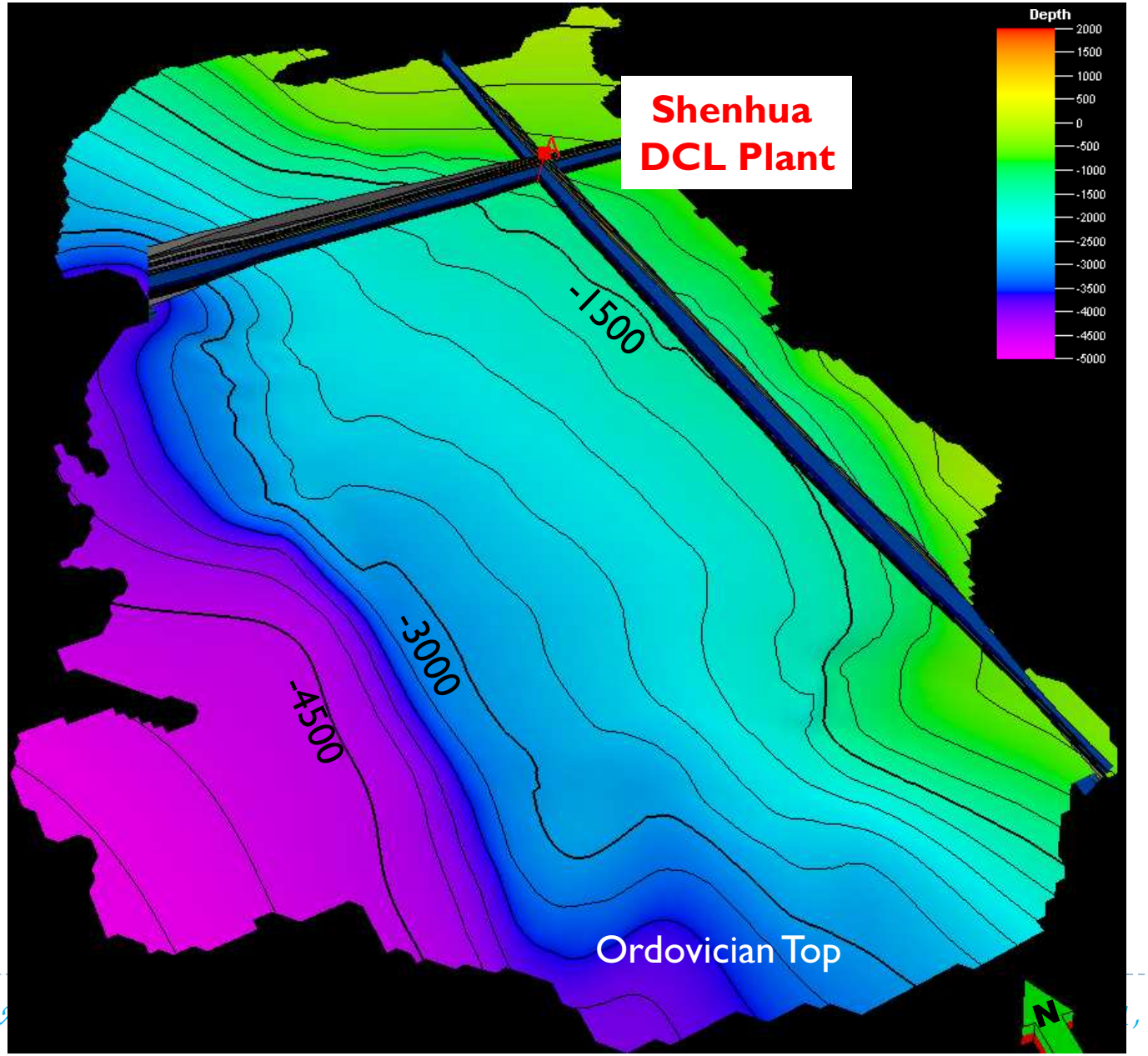
Geologic Time			Group	Thickness (m)	Lithology
Era	Period	Epoch			
Cenozoic	Neogene			10-200	
	Paleogene			0-10	
Mesozoic	Cretaceous	Lower	Luohe	0-770	
			Yijun		
	Jurassic	Middle	Anding	100-400	
			Zhiluo	100-450	
		Lower	Yanan	250-350	
		Lower	Fuxin	0-120	
	Triassic	Upper	Yanchang	400-1200	
		Middle	Zhifang	150-850	
		Lower	Heshanggou	40-100	
			Liujiagou	100-820	
Paleozoic Upper	Permian	Upper	Shiqianfeng	250-280	
			Shangshihezi	140-160	
		Lower	Xiashizhezi	120-215	
			Shanxi	80-110	
	Carboniferous	Upper	Taiyuan	25-45	
		Middle	Benxi	30-65	
Paleozoic Lower	Ordovician	Lower	Majiagou	0-1000	
			Liangjiashan	17-150	
			Yeli	13-150	
	Cambrian	Upper	Feng-Chang-Gu	34-330	
		Middle	Zhang-Xu-Mao	55-1000	
		Lower	Mantou	19-62	
Proterozoic-Archean					

Ordos Basin Hydrodynamic Systems	Lithology of Reservoir--Caprock
Mesozoic Oil System	Sandstone--Shale
Upper Paleozoic Gas System	Sandstone/Coal--Shale
Lower Paleozoic Gas System	Carbonate--Evaporate/Bauxite

3D Geologic Model

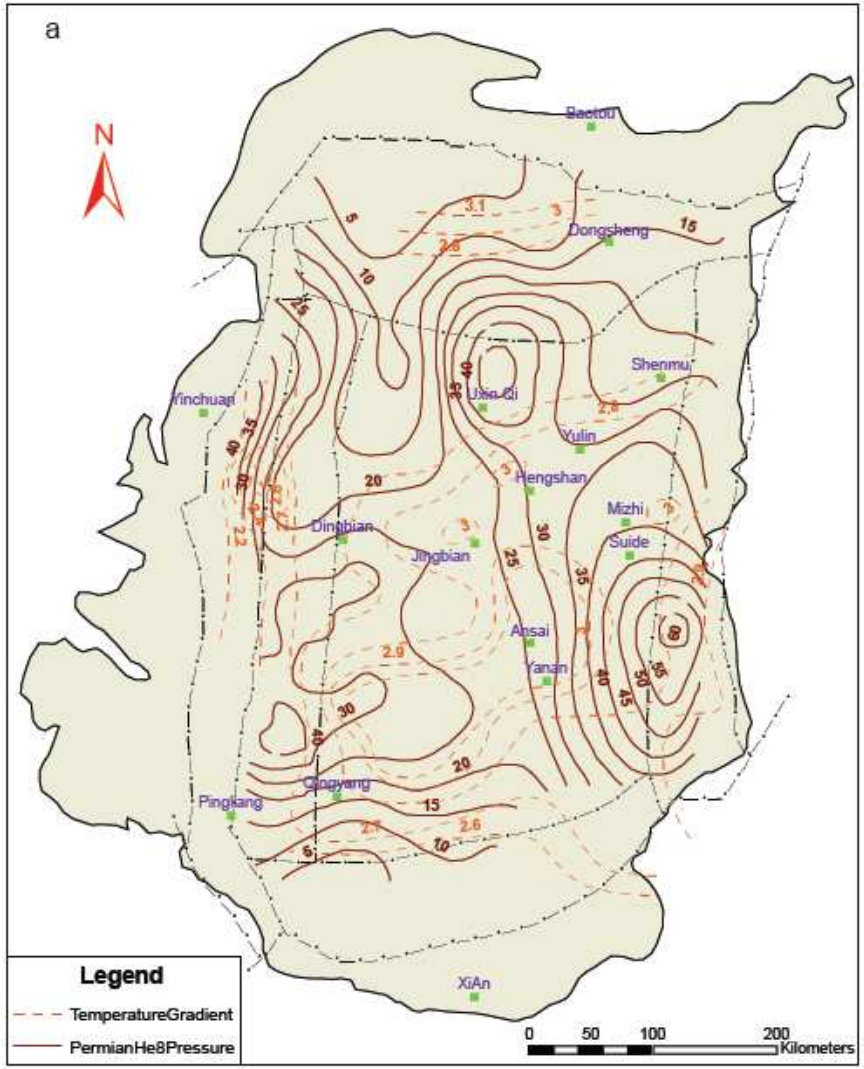


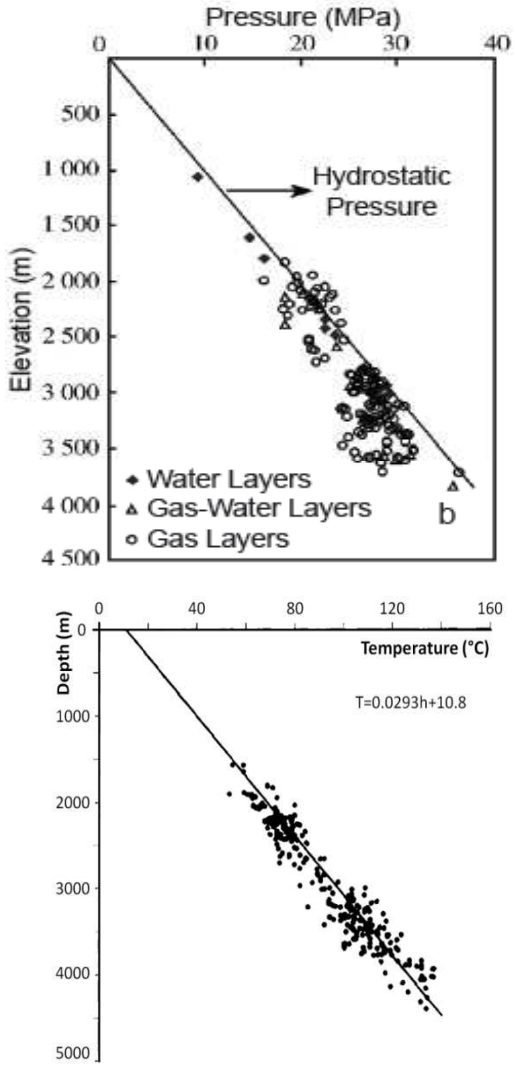
3D Geologic Model



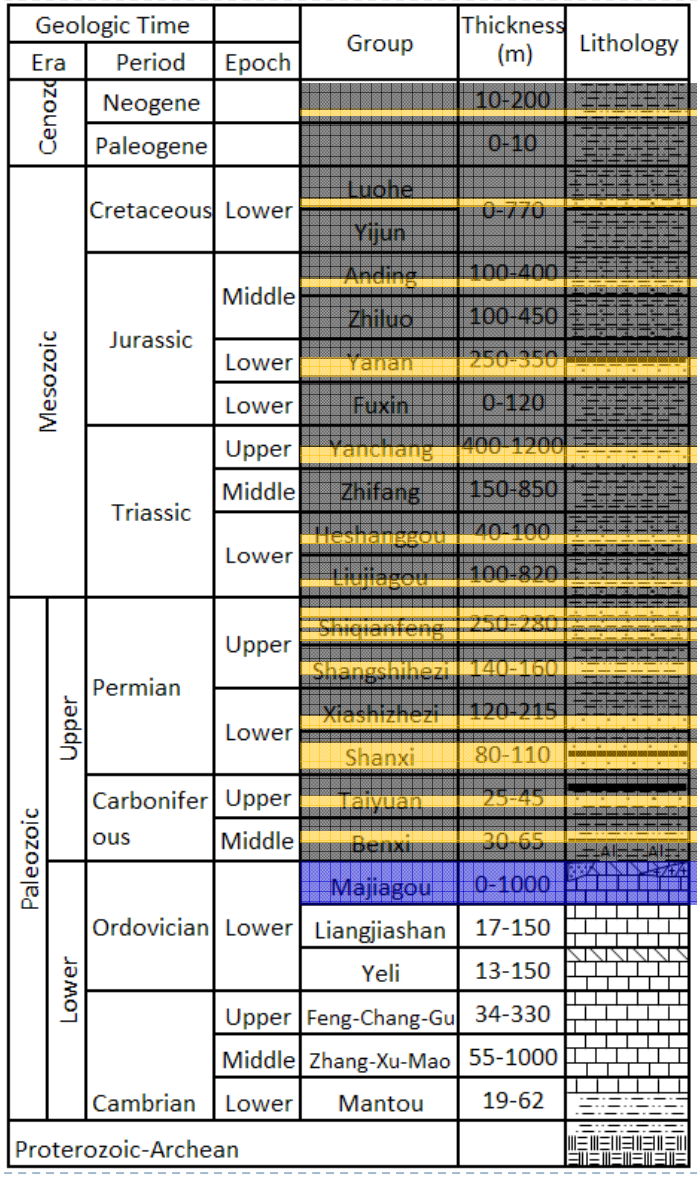
Potential Reservoirs

Geothermal Gradient and Pressure Gradient **~850m**





Potential Reservoir-Caprock System



Reservoir-Caprock Assemblages

Height of rectangle does **NOT** mean thickness

Caprock: Shale, Evaporate or Coal

Reservoir: Sandstone or Coal

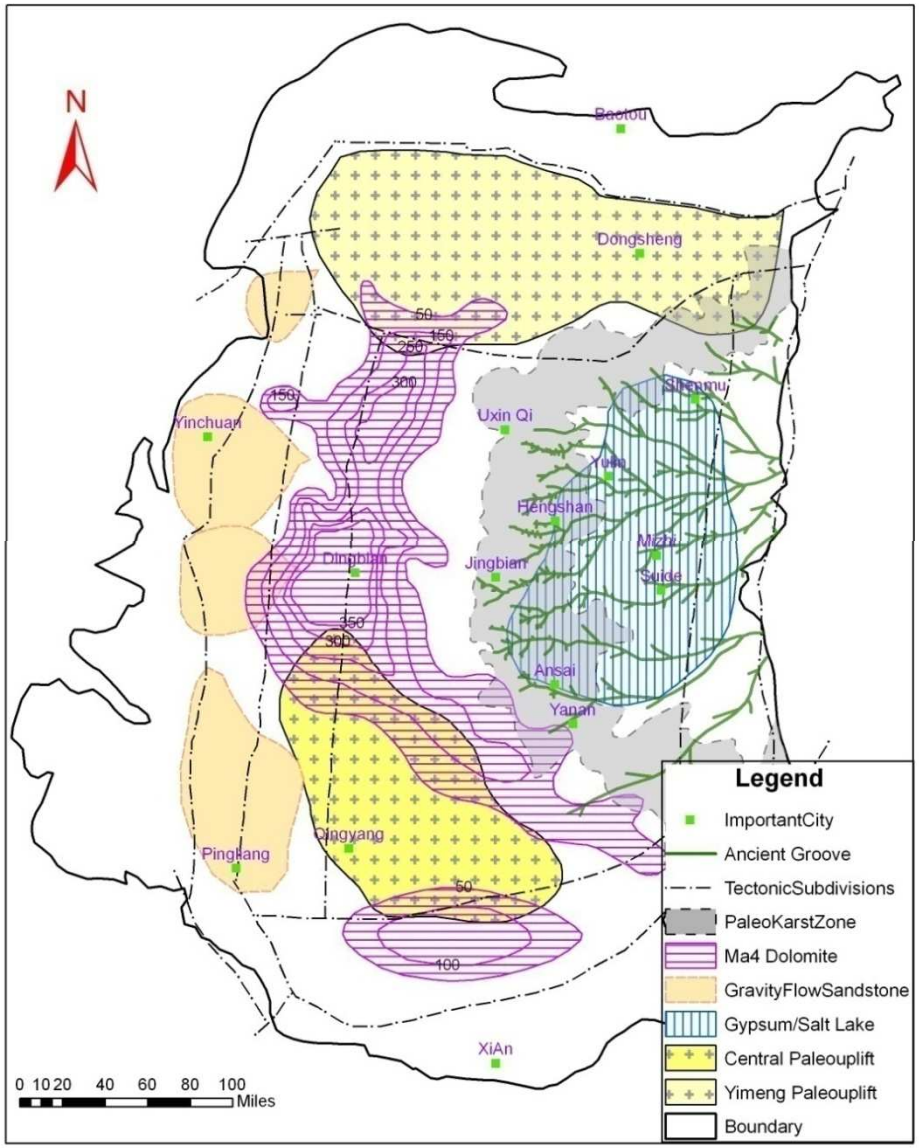
Reservoir: Limestone or Dolomite

Potential Reservoirs

Period	Formation		Thickness (m)	Lithology	Porosity (%) [2]	Permeability (mD) [2]	Reservoir Type
	Group	Member					
Jurassic	Yan'an	Yan1	----	Shaly sandstone	1-20	30-120	Oil Fields & Saline Aquifers
		Yan2					
		Yan3					
		Yan4					
Triassic	Yanchang	Ch2	----	Shaly sandstone	1-17	5-100	Oil Fields & Saline Aquifers
		Ch3					
		Ch5					
		Ch10					
Permian	Shiqianfeng	Qian1	0-39	Sandstone	5-16.7 12.5	2-411 31.37	Saline Aquifer
		Qian2	0-44				
		Qian3	0-43				
		Qian4	0-42				
		Qian5	0-36				Shenmu Gas Field & Saline Aquifer
	Xiashihezi	He5	0-5	Sandstone	5.1-14.1 10.1	0.37-5.13 0.59	Saline Aquifer
		He6	0-10		3.5-16.4 11.7	0.08-20.61 1.6	
		He7	0-10		2-18.9 7.3	0.01-15.85 0.69	
		He8	0-87		1.0-13.4 8.5	0.01-16.29 3.45	Sulige, Daniudi, Yulin, Mizhi, Zizhou, Wushen Gas Fields & Saline Aquifer
	Shanxi	Shan1	0-76	Sandstone	1.1-12.4 6.4	0.01-22.71 0.88	
		Shan2	0-48		0.9-14.5 7.4	0.01-12.27 2.55	
		---	0-20	Coal	---	---	Coal Seams
Carboniferous	Taiyuan	Tai1	0-15	Sandstone	2.7-12.3 7.9	0.01-3.1 1.50	Daniudi Gas Field & Saline Aquifer
		Tai2	0-10		0.8-11.4 8.0	0.01-2.8 0.74	
		---	0-8	Coal	---	---	Coal Seams
	Benxi	---	0-5	Coal	---	---	
Ordovician	Majiagou	Ma5	45-72	Dolomite	1-19 6.2	1-300 5	Jingbian Gas Field & Saline Aquifer
		Ma4	32-432		2-13 3.7	0.01-192 7.8	Saline Aquifer

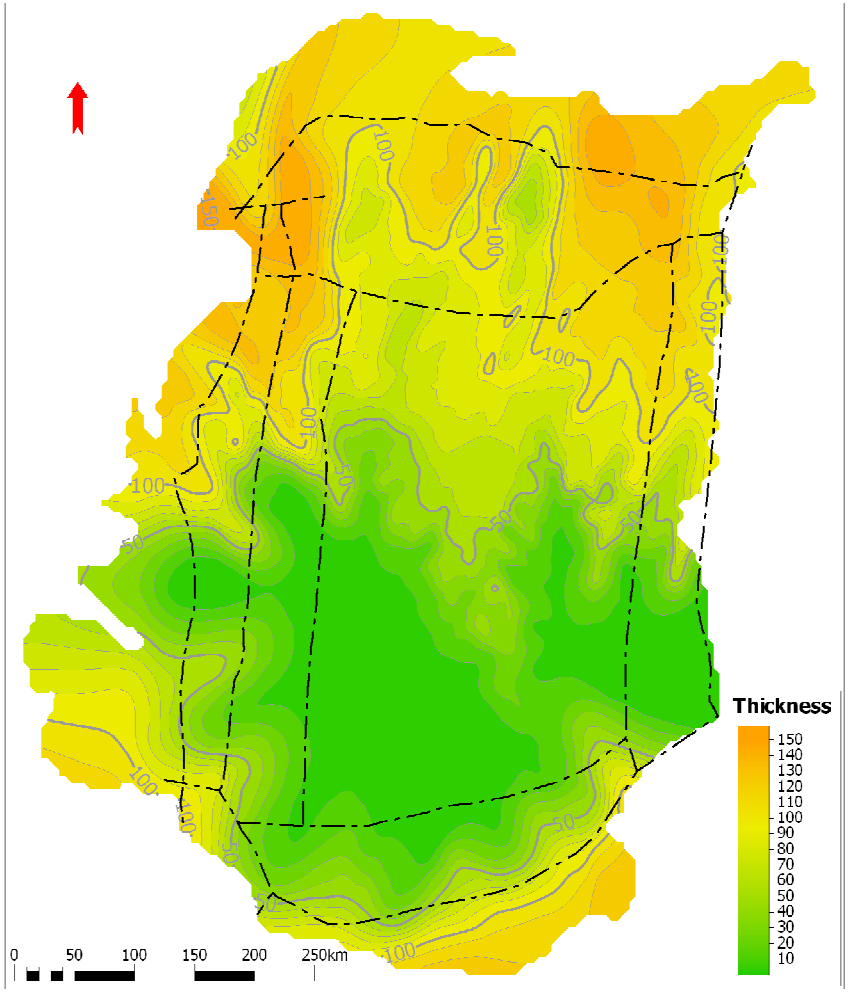
- **Widely Distributed Reservoirs**
- **Thick Sandstone and Carbonate**
- **Low Porosity**
- **Low Permeability**
- **High Heterogeneity**

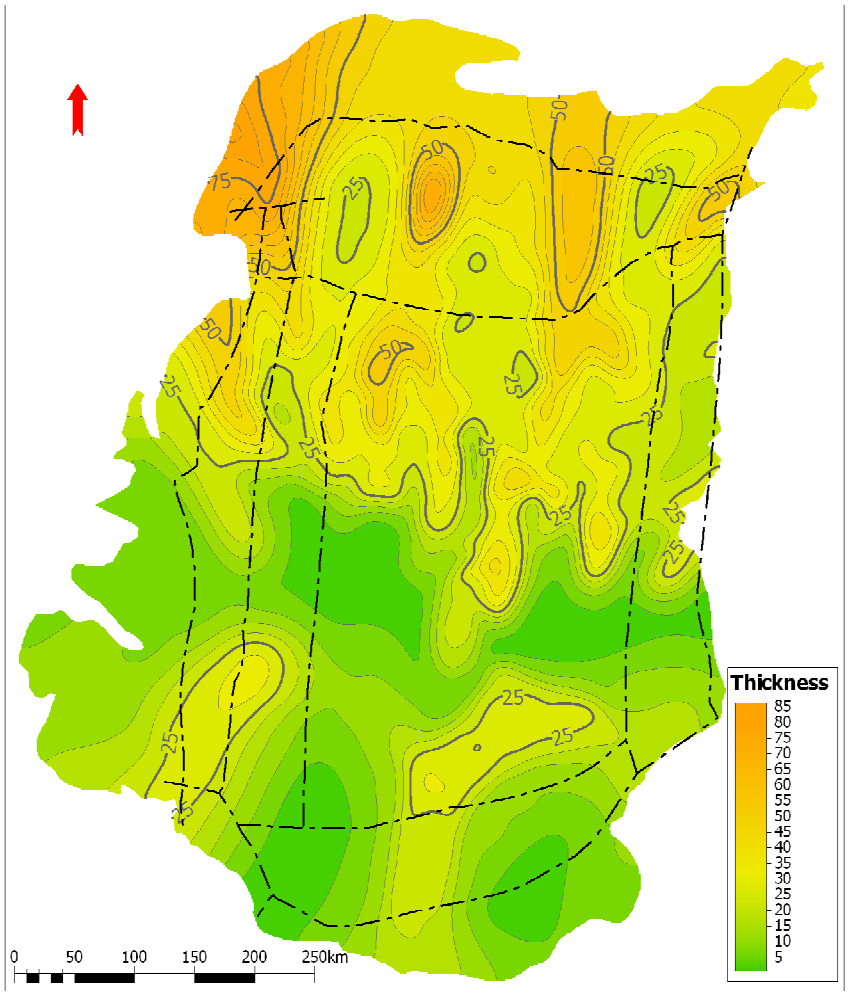
Potential Reservoirs



- **Potential Reservoirs in Ordovician**
  - **Karst Reservoir**
  - **Dolomite in Tianhuan Depression**
  - **Sandstone in Western Margin**

Potential Reservoirs

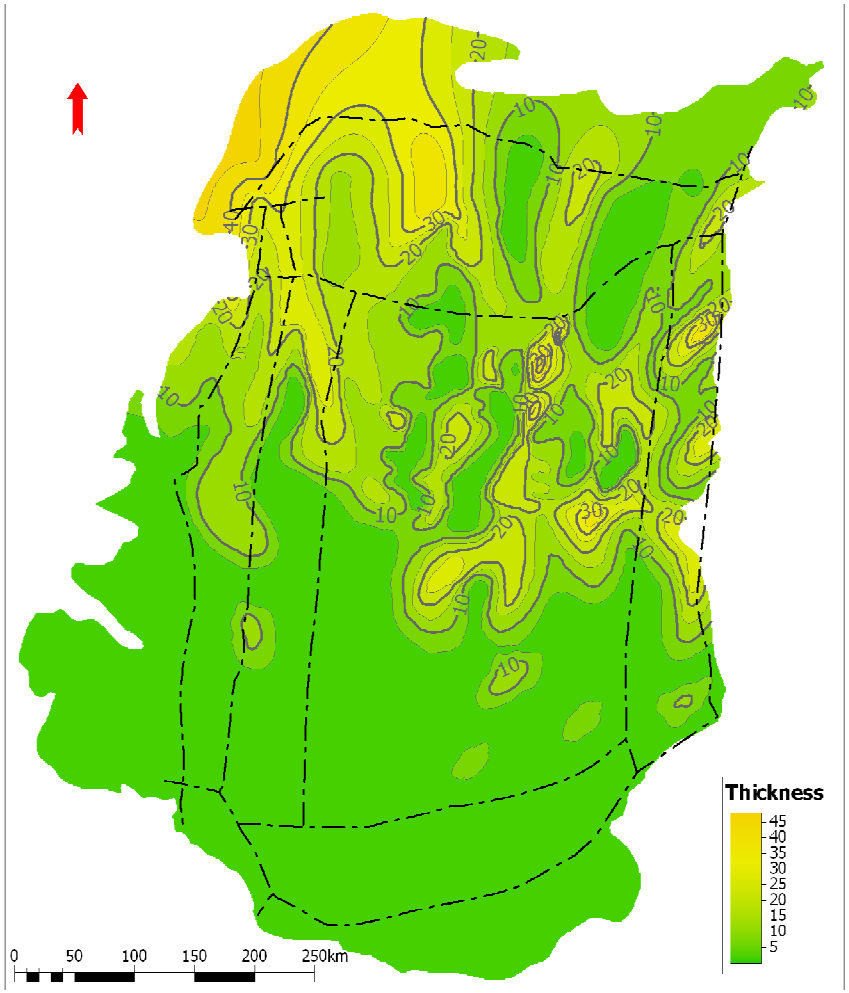




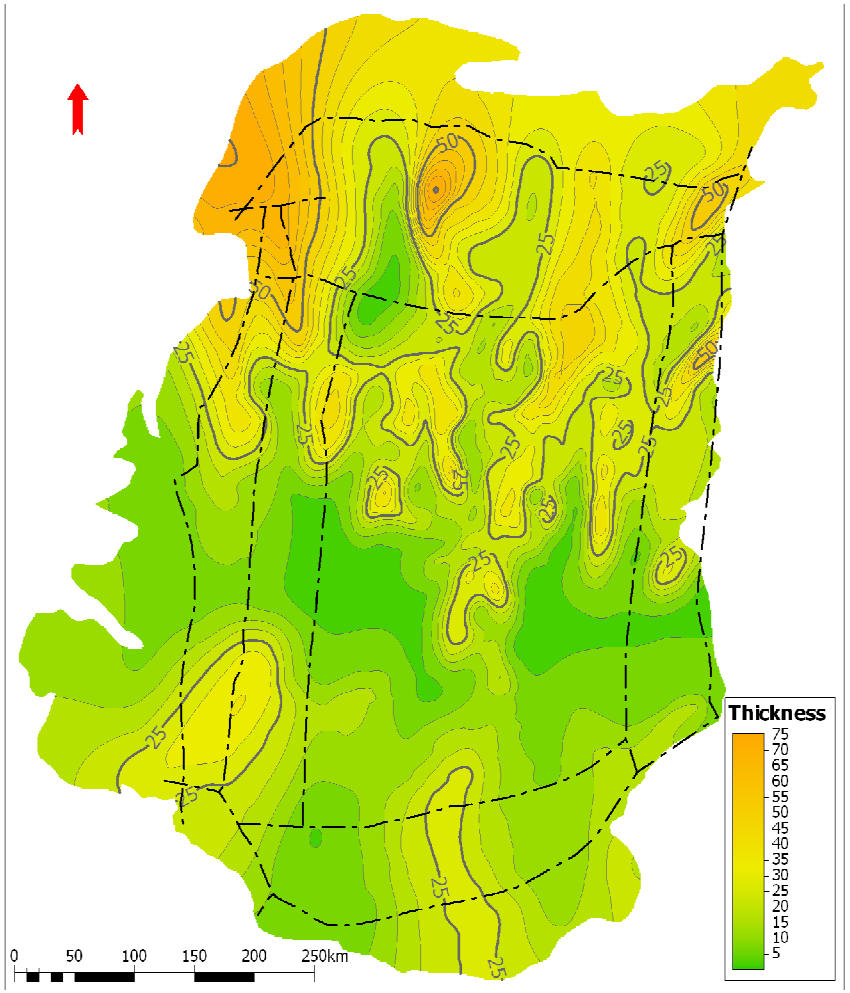
Shiqianfeng Sandstone Isopach in Permian He8 Sandstone Isopach in Permian

Unit in Meter

Potential Reservoirs



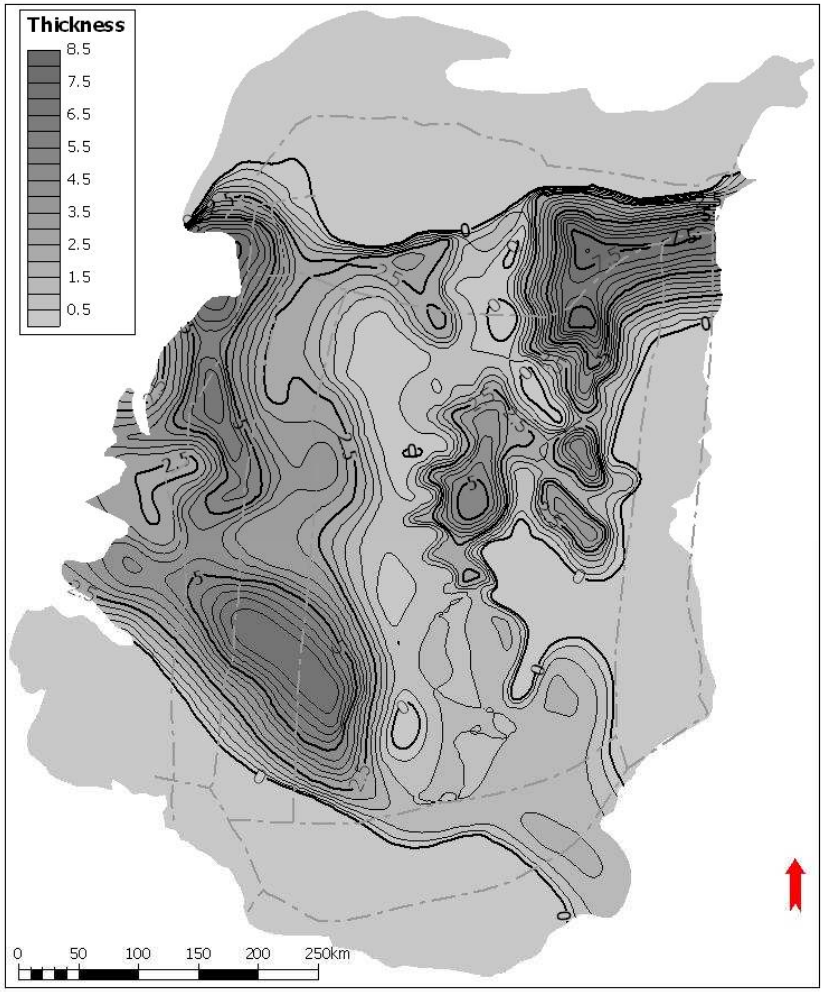
Shan1 Sandstone Isopach in Permian



Shan2 Sandstone Isopach in Permian

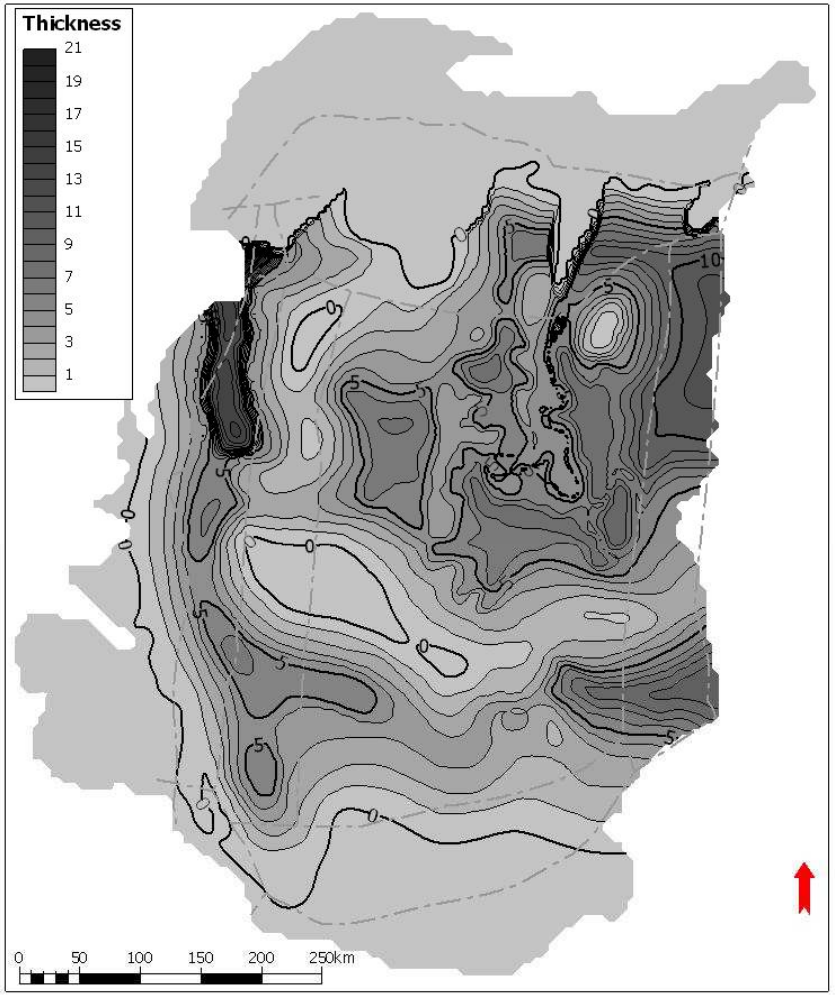
Unit in Meter

Potential Reservoirs



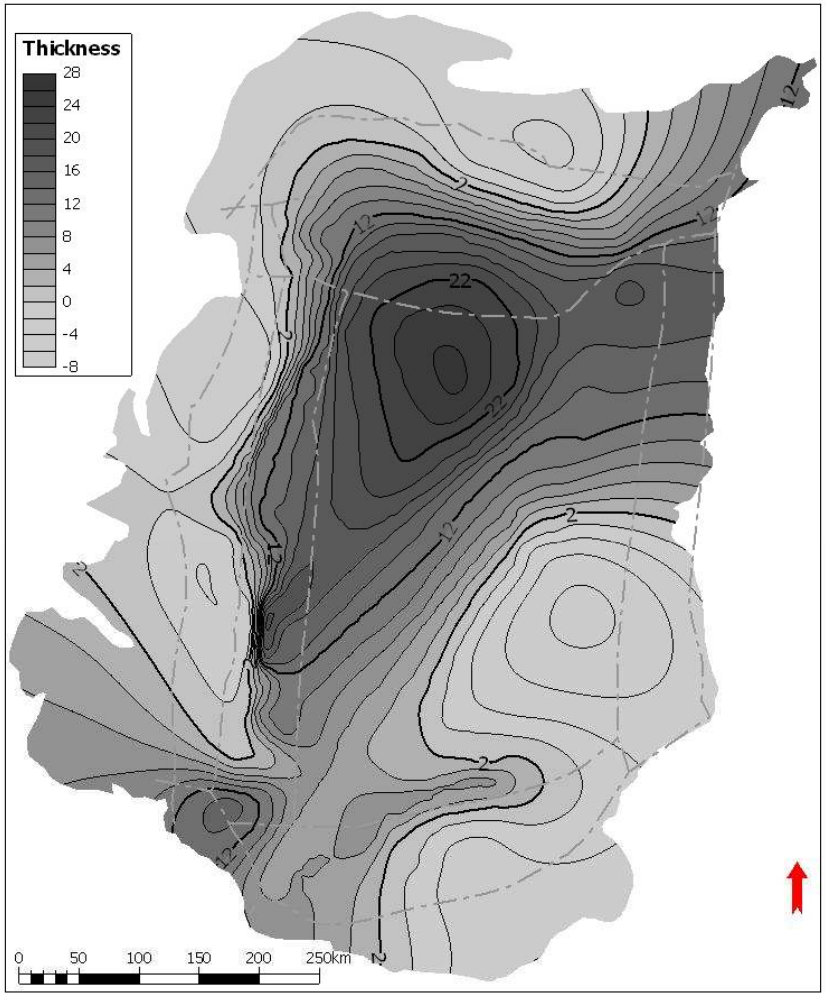
Net coal isopach for the Shanxi Group of Permian

Unit in Meter



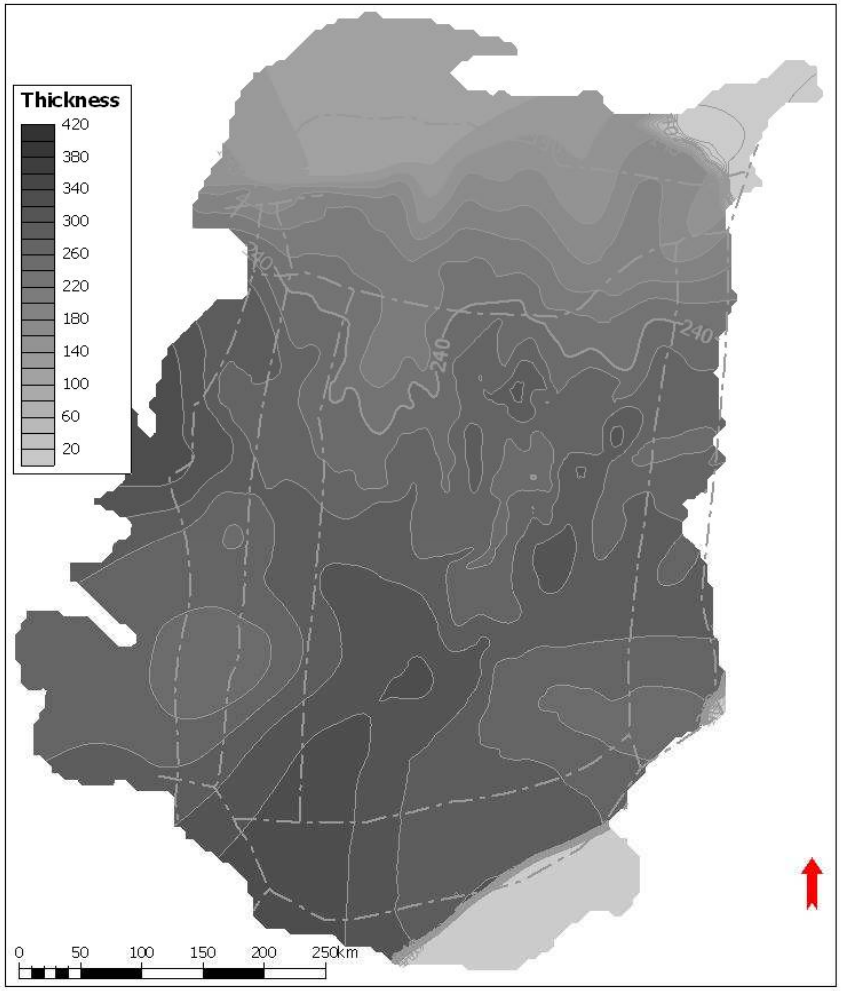
Net coal isopach for the Benxi and Taiyuan Group of Carboniferous

Potential Reservoirs

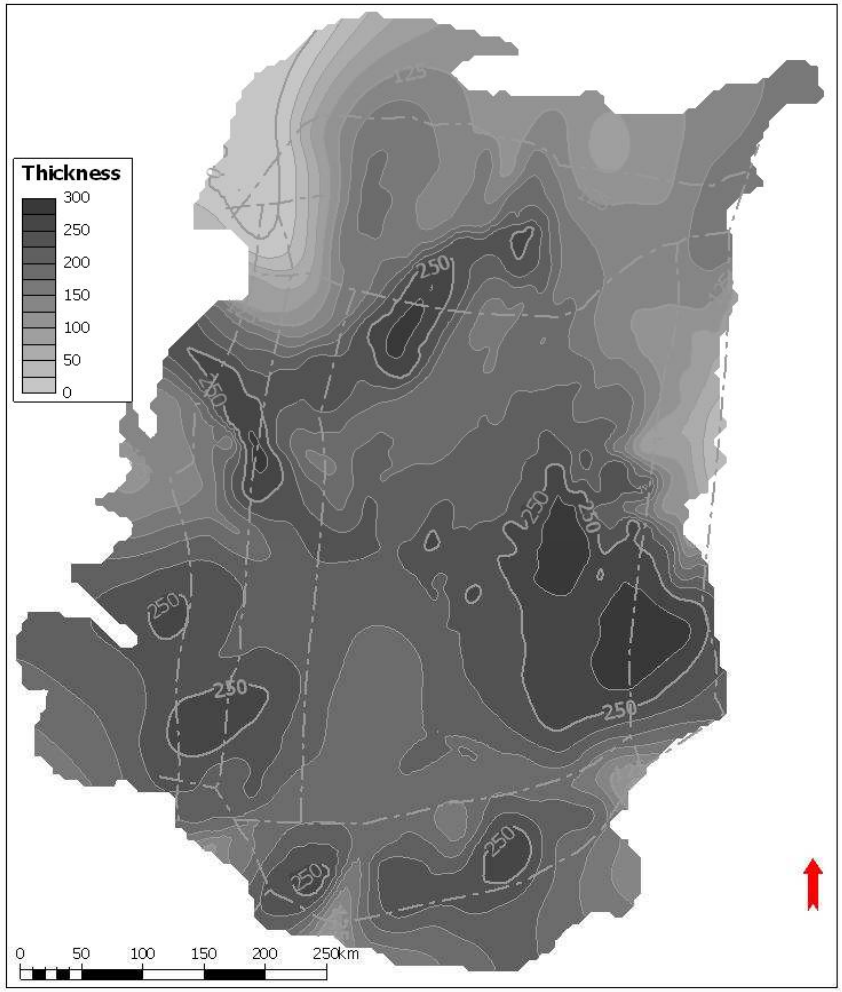


Net coal isopach for the Yan'an Group of Triassic

Potential Caprocks



Shale isopach of Shangshihezi Group of Permian



Net shale isopach of Shiqianfeng Group of Permian

Unit in Meter

CGS Capacity

Oil Fields CCS Capacity

Oil Fields		Area	Average Depth	Average Thickness	Averate Temperature	Average Pressure	Average Porosity	CO2 Density	Phase	M_{CO2}
		km^2	m	m	C	MPa	%	Kg/m^3		Gt
PetroChina Changqing	Wuqi	113.2	1415	5.8	51.0	13.9	14.65	658.5	supercritical	0.002
	Youfangzhuang	33.6	1839	5.7	63.3	18.0	17.5	662.81	supercritical	0.001
	Ansai	737.1	1179	10.8	44.2	11.6	13.3	650.8	supercritical	0.021
	Anwu	49.9	1740	5.9	60.5	17.1	16.5	663.05	supercritical	0.001
	Hujianshan	53.3	1694	5.1	59.1	16.6	16.5	661.53	supercritical	0.001
	Jingan	487.1	1445	9.2	51.9	14.2	14.5	659.02	supercritical	0.013
	Suijing	32.3	1070		41.0	10.5		644.86	supercritical	#
Yanchang	Ganguyi	170.8	477	13.9	23.8	4.7	9.51	120.15	vapor	*
	Panlong	21.4								#
	Jianyucha	51.5	600	15.0	27.4	5.9	14.9	173.52	vapor	*
	Qinghuaji	108.9	200	8.7	15.8	2.0	14	41.667	Vapor	*
	Yaodian	109.2	555	15.0	26.1	5.4	9.02	148.38	Vapor	*
	Zibei	100.5	435	6.5	22.6	4.3	9.1	105.91	Vapor	*
	Fengfuchuan	41.1	422	7.1	22.2	4.1	12.4	99.064	Vapor	*
	Zichang	118.0	375	16.8	20.9	3.7	10.49	86.607	Vapor	*
	Chuankou	146.7	573	13.6	26.6	5.6	7.1	157.91	Vapor	*
	Yanchang	215.5	490	16.6	24.2	4.8	7.6	123.78	Vapor	*
The Ordos Basin		----	----	----	----	----	----	----	----	0.038

CGS Capacity

Gas Fields CCS Capacity

Gas Fields	Sulige	Daniudi	Jingbian	Wushen	Yulin	Zizhou	Mizhi[1]	Shenmu	The Ordos Basin
OGIP ($10^8 m^3$)	5336.5	3076.9	2870.8	1451.7	1132.8	902.1	358.5	267.4	15396.7
Area (km^2)	4102.8	601.8	3665.0	689.5	1014.7	1194.7	478.30	310.2	---
Pressure (MPa)	29.0	24.2	31.0	18.2	27.3	23.7	23.2	11.1	---
Temperature (°C)	100.0	83.6	105.0	64.5	86.8	77.4	77.1	55.0	---
ρ_{CO2} (Kg/m^3)	649.2	655.4	653.4	658.0	685.2	680.1	674.3	419.7	---
Sg (%)[2]	75.0	75.0	77.0	75.0	75.0	72.7	75.0	60.0	---
Rg (%)[3]	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0	---
Rw (%)[3]	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	---
M_{CO2} (Gt)	1.02	0.68	0.52	0.41	0.23	0.21	0	0.08	3.16

Methods

$$M_{CO_2} = \rho A h_n \emptyset_e S_g \left[1 - (1 - R_g)\frac{P_i T_f Z_f}{P_f T_i Z_i} + (\frac{1}{S_g} - 1)R_w\right]$$

$$M_{CO_2} = \rho OGIP \frac{P_s T_i Z_i}{P_i T_s Z_s}\left[1 - (1 - R_g)\frac{P_i T_f Z_f}{P_f T_i Z_i} + (\frac{1}{S_g} - 1)R_w\right]$$

CGS Capacity

Saline Aquifers

- Shiqianfeng: 22.3Gt
- He8: 5.2Gt
- Shan1: 3.7Gt
- Ma4: 3.1Gt
- Shan2: 2.0Gt

$$M_{CO2}=Ah_n\phi_e\rho_{CO2}E$$

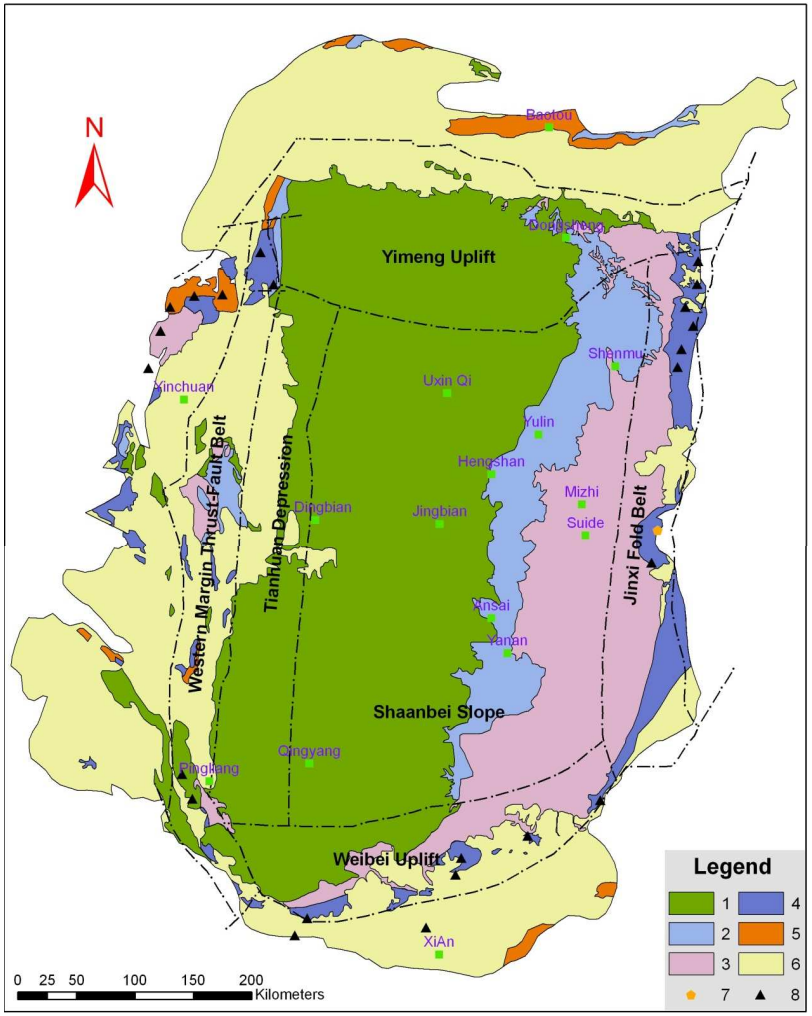
E=1%; CO2 Density=650kg/m3

Coal Beds

Totally 660Mt CO_2 with producing CBM

CO_2 Leaking Risk

- **Geologic factors**
  - Caprock sealing ability
    - Lithology
    - Thickness
    - Distribution
  - Faults
    - Open or sealed
- **Engineering factors**
  - Abundant of Oil and Gas Industry Drilling
    - Over 1,000 wells through Ordovician
    - Over 10,000 wells through Triassic
  - Wells with casing corrosion
    - 10% due to CO_2 and H_2S



1: Cretaceous; 2: Jurassic; 3: Triassic; 4: Paleozoic; 5:Proterozoic/Archaeozoic; 6: Cenozoic; 7: Permian Outcrop; 8: Shiqianfeng Outcrop

Conclusions

- **Multiple potential reservoir-caprock assemblages**
- **Huge CGS capacity in saline aquifers**
- **Large CGS capacity in gas fields, but not available now for CGS**
- **Oil fields are possible to launch CO_2-EOR, but not good for CGS**
- **Low porosity and permeability, low injection rate unless stimulation or horizontal well**
- **Casing corrosion wells as CO_2 leaking pathway**

Acknowledgements

US-CHINA energy center 中美能源中心

NETL NATIONAL ENERGY TECHNOLOGY LABORATORY

神华煤制油化工公司 CHINA SHENHUA COAL TO LIQUID AND CHEMICAL CO., LTD.

中国地质大学 China University of Geosciences

WestVirginiaUniversity.

Thanks!
Any question?

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