中国地质调查局
CHINA GEOLOGICAL SURVEY

CAGS CCS School: Geological Storage Potential Assessment and Site Selection Methods

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China Australia Geological Storage of CO_2
中澳二氧化碳地质封存

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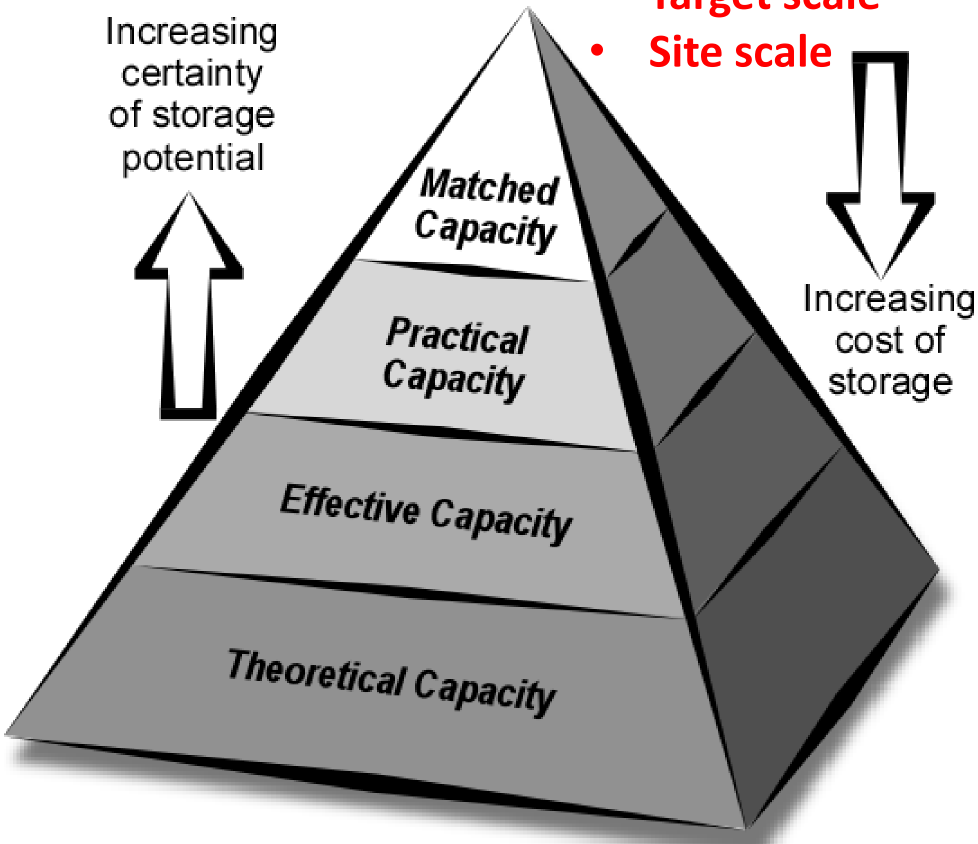
1.1 Definition of CSLF and USDOE

DOE, 2010

CSLF, 2007

- National scale
- Basin scale
- Regional scale
- Target scale
- Site scale

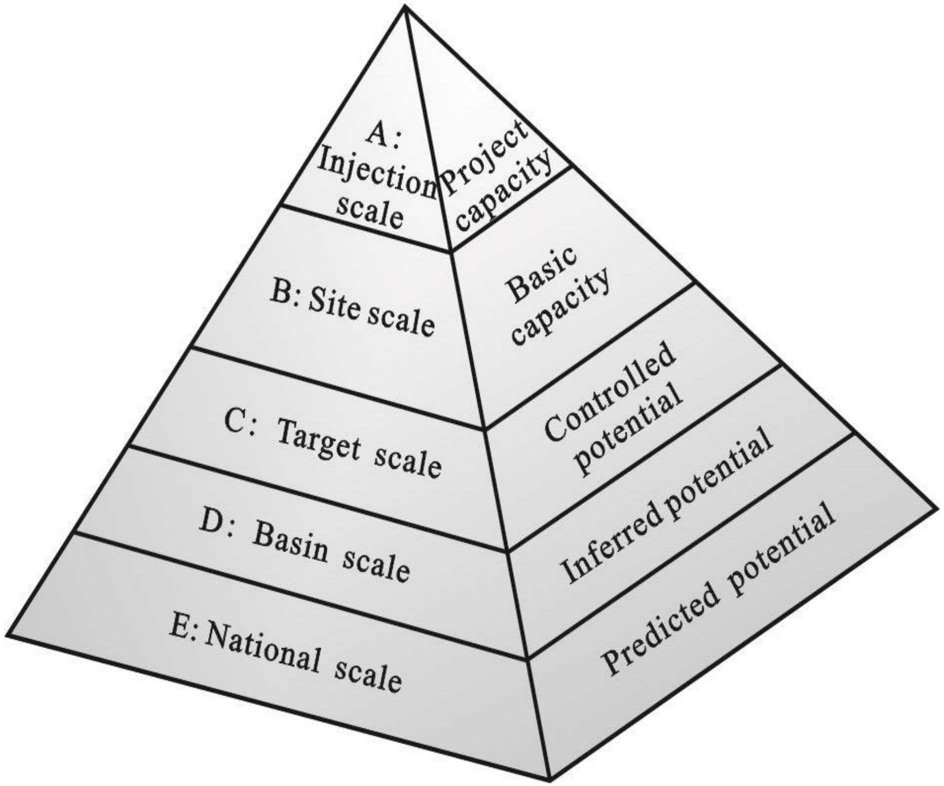


Petroleum Industry		CO_2 Geological Storage
Reserves	Implementation	**Capacity**
On Production	Implementation	Active Injection
Approved for Development	Implementation	Approved for Development
Justified for Development	Implementation	Justified for Development
Contingent Resources	Site Characterization	**Contingent Storage Resources**
Development Pending	Site Characterization	Development Pending
Development Unclarified or On Hold	Site Characterization	Development Unclarified or On Hold
Development Not Viable	Site Characterization	Development Not Viable
Prospective Resources	Exploration	**Prospective Storage Resources**
Prospect	Exploration	Qualified Site(s)
Lead	Exploration	Selected Areas
Play	Exploration	Potential Sub-Regions

	Prospective Storage Resources	
	Project Sub-class	**Evaluation Process**
Exploration	Qualified Site(s)	Initial Characterization
Exploration	Selected Areas	Site Selection
Exploration	Potential Sub-Regions	Site Screening

1.2 Definition of CGS

- 区域级预测潜力评价
  National scale – Predicted potential
- 盆地级推定潜力评价
  Basin scale – Inferred potential
- 目标区级控制潜力评价
  Target scale – Controlled potential
- 场地级基础储存量评价
  Site scale – Basic capacity
- 灌注级工程储存量评价
  Injection scale – Project capacity



CGS, 2012

1.3 Differences and similarities

- **Evaluated scale of USDOE, CSLF and CGS**
  - USDOE and CSLF method: the scales are not matched with capacity levels, for one object or scales, evaluated method is effected by technical and economic conditions;
  - CGS method: matched, for many objects in national, basin and regional scales, evaluated method is effected by geological survey or research degree. But it is unreasonable of the method of target scale potential assessment.
- **The underlying problem of potential assessment for China**
  - Large number of basins, with different tectonic background and sedimentary environment, even different formations
  - Large area, e.g. Ordos basin covers more than 250,000 km2
  - Different levels of geological survey and research, including vertical formations.

1.4 New definition

– **Mesoscale for target selection次盆地尺度（宏观尺度）**

- Suitable for potential assessment of one basin or the inner regional areas.
- Between basin and site scales which needs more geological survey for CCUS demonstration or industrialization in the short term, generally before 2030 according to carbon reduction target of China.
- Because of the large coverage and complicated geology different from abroad, the methodologies and parameters should be more suitable for geology.
- Without considering the technical and economic conditions.

CONTENTS

2.1 Potential assessment method of USDOE

CSLF-T-2008-04

Comparison between Methodologies Recommend
Storage Capacity in Geological
by
the CSLF Task Force on CO_2 Storage Ca
and
the USDOE Capacity and Fairways S
Regional Carbon Sequestration Partne

- Phase III Report -

Methodology for Development of Geologic Storage Estimates for Carbon Dioxide

APPENDIX B

Prepared for

U.S. Department of Energy
National Energy Technology Laboratory
Carbon Sequestration Program

Prepared by

Capacity and Fairways Subgroup of the Geologic Working Group
of the DOE Regional Carbon Sequestration Partnerships

August 2008

2.1 Potential assessment method of USDOE

$$G_{CO_2} = A \cdot h \cdot \varphi_e \cdot \rho_{CO_2} \cdot E_{saline}$$

A —reservoir distribution area

h —reservoir thickness

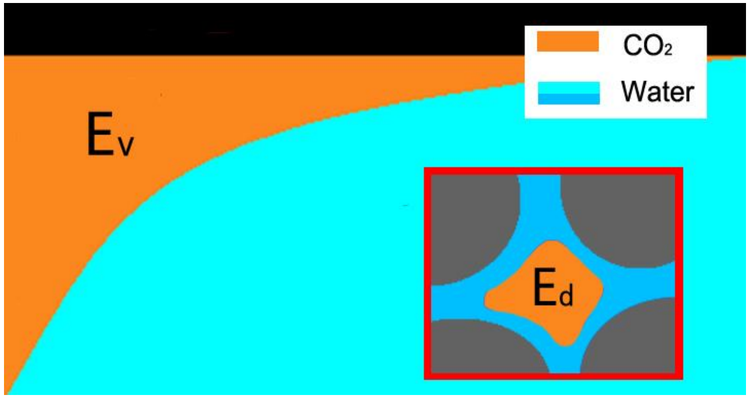
φ_e —saline aquifer average effective porosity

ρ_{CO_2} —CO2 density at reservoir temperature and pressure conditions

E_{saline} —storage efficiency (effective coefficient)

Berndt Wischnewski formula for evluation of CO2 density
http://www.peacesoftware.de/einigewerte/co2_e.html

2.1 Potential assessment method of USDOE



$$V_E = A \cdot h \cdot \phi \cdot E$$

$$E_{saline} = E_{An/At} E_{hn/hg} E_{\phi e/\phi tot} E_A E_L E_g E_d$$

$$E = E_{Geol} \cdot E_v \cdot E_d$$

- E_{Geol}为地层形貌系数，E_{Geol}=1 if homogeneous reservoir
- E_v为体积驱替系数，the volume where CO2 is distributed accounts for the total volume of the studied core or reservoir
- E_d为孔内驱替系数，the volume of injected CO2 accounts for the total porosity in one pore

2.1 Potential assessment method of USDOE

Parameters for saline formation efficiency.

Term	Symbol	P_{10}/P_{90} values by lithology			Description
		Clastics	Dolomite	Limestone	
Geologic terms used to define the entire basin or region pore volume					
Net-to-Total Area	$E_{An/At}$	0.2/0.8	0.2/0.8	0.2/0.8	Fraction of total basin or region area with a suitable formation.
Net-to-Gross Thickness	$E_{hn/hg}$	0.21/0.76[a]	0.17/0.68[a]	0.13/0.62[a]	Fraction of total geologic unit that meets minimum porosity and permeability requirements for injection.
Effective-to-Total Porosity	$E_{\phi e/\phi tot}$	0.64/0.77[a]	0.53/0.71[a]	0.64/0.75[a]	Fraction of total porosity that is effective, i.e., interconnected.
Displacement terms used to define the pore volume immediately surrounding a single well CO_2 injector.					
Volumetric displacement efficiency	E_V	0.16/0.39[a]	0.26/0.43[a]	0.33/0.57[a]	Combined fraction of immediate volume surrounding an injection well that can be contacted by CO_2 and fraction of net thickness that is contacted by CO_2 as a consequence of the density difference between CO_2 and *in situ* water.
Microscopic displacement efficiency	E_d	0.35/0.76[a]	0.57/0.64[a]	0.27/0.42[a]	Fraction of pore space unavailable due to immobile *in situ* fluids.

[a] Values from IEA GHG (2009).

Saline formation efficiency factors for geologic and displacement terms.

$$E_{saline} = E_{An/At}\, E_{hn/hg}\, E_{\phi e/\phi tot}\, E_V\, E_d$$

Lithology	P_{10}	P_{50}	P_{90}
Clastics	0.51%	2.0%	5.4%
Dolomite	0.64%	2.2%	5.5%
Limestone	0.40%	1.5%	4.1%

USDOE

2.1 Potential assessment method of USDOE

- The US-DOE methodology is based on volumetric methods for estimating subsurface volumes, in situ fluid distributions, and **fluid displacement** processes.
- The US-DOE methodology could be suitable for potential evaluation of CO2-EWR
- Subsurface storage volume estimates depend on **geologic properties** (area, thickness, and porosity of formations) and the **efficiency of storage** (the fraction of the accessible pore volume that will be occupied by the injected CO2). Storage efficiency was determined using Monte Carlo sampling, which includes efficiency terms to define the pore volume that is amenable to geologic storage and displacement terms.

CO_2 Geological Utilization and Storage (CGUS) technologies

CO2地质利用与封存技术

CGUS	Purpose	Technologies
CO_2 Geological Utilization 地质利用	Energy Production 能源增采	Enhanced Oil Recovery, CO_2-EOR 驱油
		Enhanced Coal Bed Methane, CO_2-ECBM 驱煤层气
		Enhanced Gas Recovery, CO_2-EGR 驱天然气
		Enhanced Shale Gas Recovery, CO_2-ESGR 驱页岩气
	Resources production 其它资源利用	Enhanced Geothermal Systems, CO_2-EGS 驱热
		Enhanced Uranium Leaching，CO_2-EUL 驱铀
		Enhanced Water Recovery，CO_2-EWR 驱水
CO_2 Geological Storage 地质封存	Saline Aquifers, Depleted Oil & Gas Fields, Unmineable Coal Seams 咸水层，枯竭油气田，不可采煤层	

ACCA21, 2014

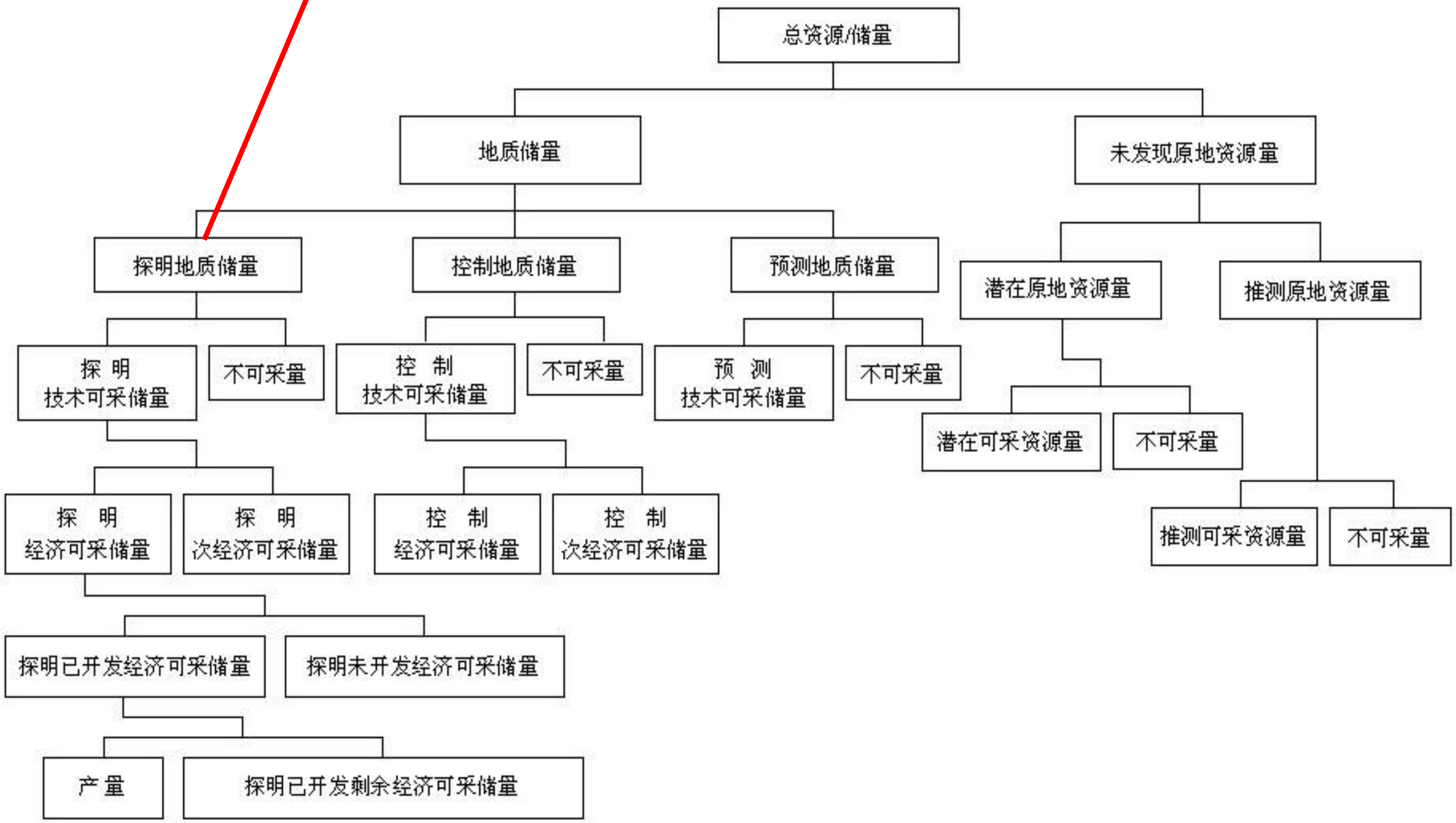
2.2 Potential assessment of depleted oil fields CO2 storage and CO2-EOR

$$G_{CO_2} = OOIP/\rho_{oil} \cdot B \cdot \rho_{CO_2} \cdot E_{oil}$$

E_{oil} → 75% (Li, 2009)

ρ_{oil} —oil density at standard atmospheric pressure

B —oil volume factor



2.2 Potential assessment of depleted oil fields CO2 storage and CO2-EOR

$$G_{CO_2-EOR} = OOIP/\rho_{oil} \cdot B \cdot E_{oil} \cdot EXTRA \cdot (P_{LCO_2} \cdot R_{LCO_2} + P_{HCO_2} \cdot R_{HCO_2})$$

$$API = (141.5 / S_g) - 131.5$$

原油重度　　原油比重

Where G_{CO_2-EOR}—storage potential of CO_2 by using CO_2-EOR technology; $EXTRA$—the proportion of extra recovery to OOIP (Table 1); P_{LCO_2}—the lowest probability of oil recovery (Table 2); P_{HCO_2}—the highest probability of oil recovery (Table 2); R_{LCO_2} =2.113 t/m^3; R_{HCO_2} =3.522 t/m^3; S_g—specific gravity; other parameters are the same as formula 2-1.

Table 1 The value of $EXTRA$ with different API gravity

$EXTRA$（%）	API
5.3	<31
1.3（API－31）+5.3	31≤API≤41
18.3	>41

Table 2 Four EOR cases with different depth/pressure and API gravity

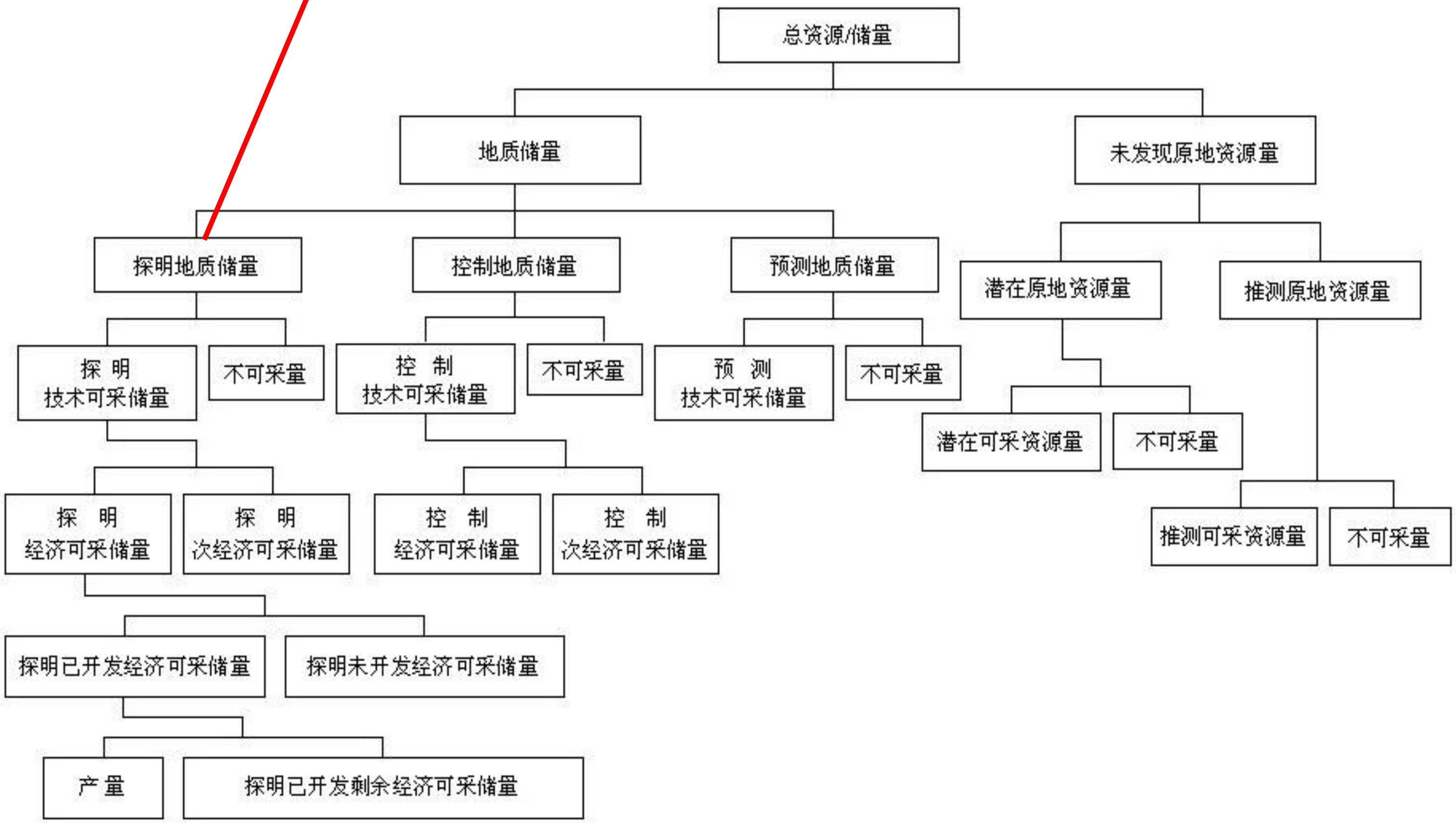
Depth	API	P_{LCO_2}（%）	P_{HCO_2}（%）
<2000	>35	100	0
	≤35	66	33
>2000	>35	33	66
	≤35	0	100

2.3 Potential assessment of depleted gas fields CO2 storage and CO2-EGR

$$G_{CO_2} = OGIP/\rho_{gasstd} \cdot B \cdot \rho_{CO_2} \cdot E_{gas}$$

→ 75% (Li, 2009)

B —gas volume factor

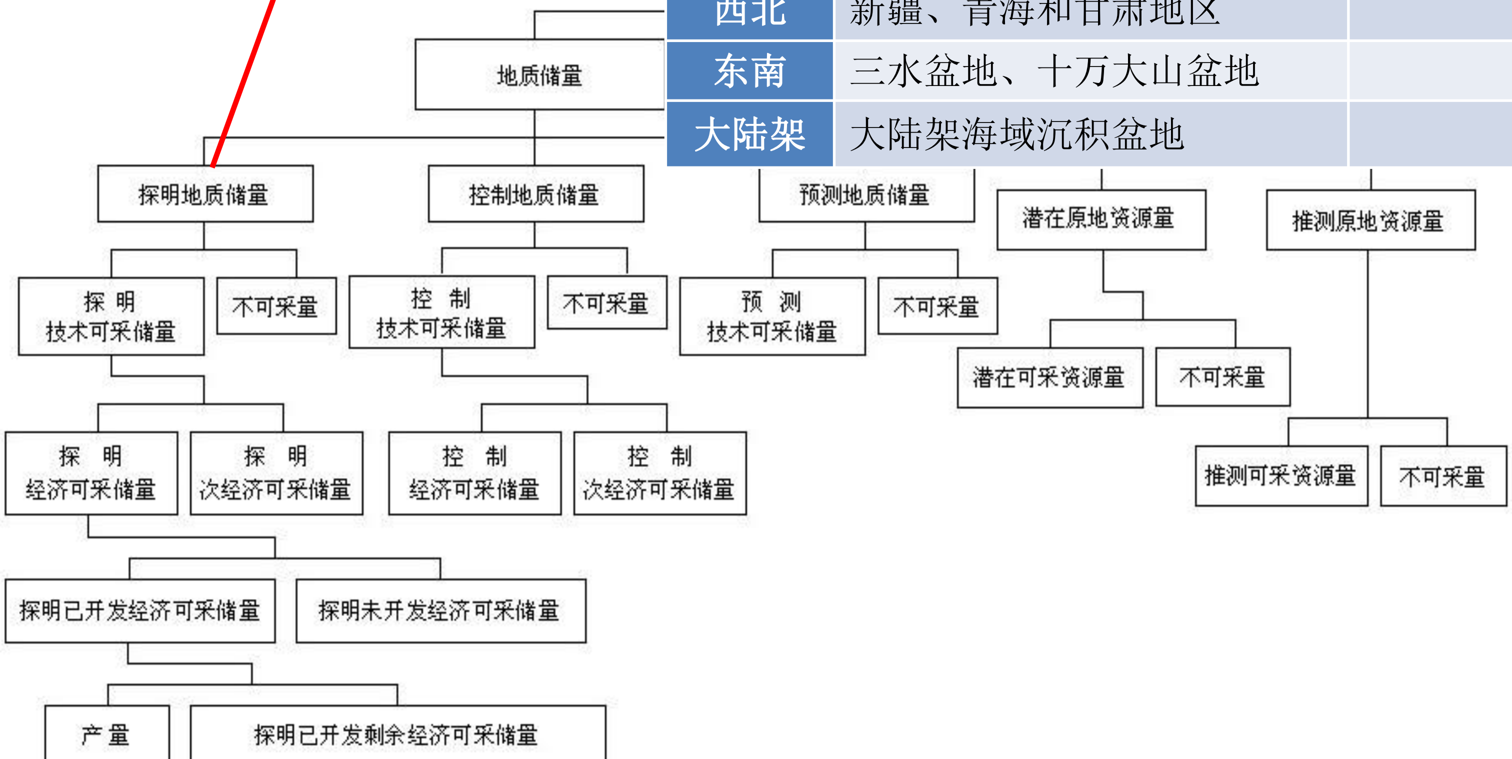


2.4 Potential assessment of depleted gas fields CO2 storage and CO2-EGR

$$G_{CO_2-EGR}=\mathrm{OGIP}/\rho_{gasstd}\cdot B\cdot \rho_{CO_2}\cdot E_{gas}\cdot C$$

75% (Li, 2009)

地区	沉积盆地	C 驱替系数
东部	东北地区、华北盆地、南襄盆地、江汉盆地、苏北盆地	0.42
中部	鄂尔多斯盆地、准噶尔盆地、楚雄盆地	0.63
西北	新疆、青海和甘肃地区	0.55
东南	三水盆地、十万大山盆地	0.66
大陆架	大陆架海域沉积盆地	0.60



2.5 Potential assessment of Unmineable coal seams CO2 storage and CO2-ECBM

$$G_{CO_2} = G_{CBM} \cdot R_{CO_2/CH_4} \cdot \rho_{CO_2 std} \cdot E_{coal}$$

Table 3 the values of R_{CO_2/CH_4} and C of different types of coal（USDOE, 2003）

Types of coal	R_{CO_2/CH_4}	C
Lignite	10	1.00
Non-caking coal	10	0.67
Weakly caking ocal	10	1.00
Long flame coal	6	1.00
Gas coal	3	0.61
Fat coal	1	0.55
Coking coal	1	0.50
Lean coal	1	0.50
Meager coal	1	0.50
Anthracite	1	0.50

Li, 2009

2.5 Potential assessment of Unmineable coal seams CO2 storage and CO2-ECBM

$$G_{\mathrm{CO_2-ECBM}} = G_{\mathrm{CBM}} \cdot R_{\mathrm{CO_2/CH_4}} \cdot \rho_{\mathrm{CO_2}std} \cdot E_{\mathrm{coal}} \cdot C$$

Table 3 the values of $R_{\mathrm{CO_2/CH_4}}$ and C of different types of coal（USDOE, 2003）

Types of coal	$R_{\mathrm{CO_2/CH_4}}$	C
Lignite	10	1.00
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Long flame coal	6	1.00
Gas coal	3	0.61
Fat coal	1	0.55
Coking coal	1	0.50
Lean coal	1	0.50
Meager coal	1	0.50
Anthracite	1	0.50

Table 4 Storage efficiency of unmineable coal seams (Goodman, 2011)

P_{10}	P_{50}	P_{90}
21%	37%	48%

2.6 Potential evaluation of CGUS

- Area: 135,000 km^2
- Length: 700 km
- Width: 340 km

2.6 Potential evaluation of CGUS

No.	Oil and Gas fields	Depth	OOIP 10^4t	OGIP 10^4t
1	独山子油田	800-1000	239	4.88
2	克拉玛依油田	200-3000	68276.07	74.06
3	百口泉油田	440-2379	11013.52	-
4	风城油田	200-3000	426	-
5	红山嘴油田	315-2045	4448	1.31
6	火烧山油田	1200-1700	5756	-
7	三台油田	1950-2800	157	27.35
8	北三台油田	2000-2600	1984	-
9	夏子街油田	1365-1860	2478	44.94
10	车排子油田	1208-3754	1093	-
11	乌尔禾油田	1110-1598	1190	-
12	彩南油田	2200-2450	5058.91	22.72
13	石西油田	3019-4372	5740	10.95
14	小拐油田	3353-3520	751	-
15	沙南油田	1770-2580	2180	-
16	石南油田	2450-2944	6386	8.24
17	呼图壁气田	3585	-	126.12
18	莫北油田	3730-4250	2032	91.73
19	陆梁油田	1100-2300	7071.36	-
20	莫索湾气田	4195	582	145.9
21	卡因迪克油田	3400-3500	188	-
22	沙北油田	1420-1520	306	-

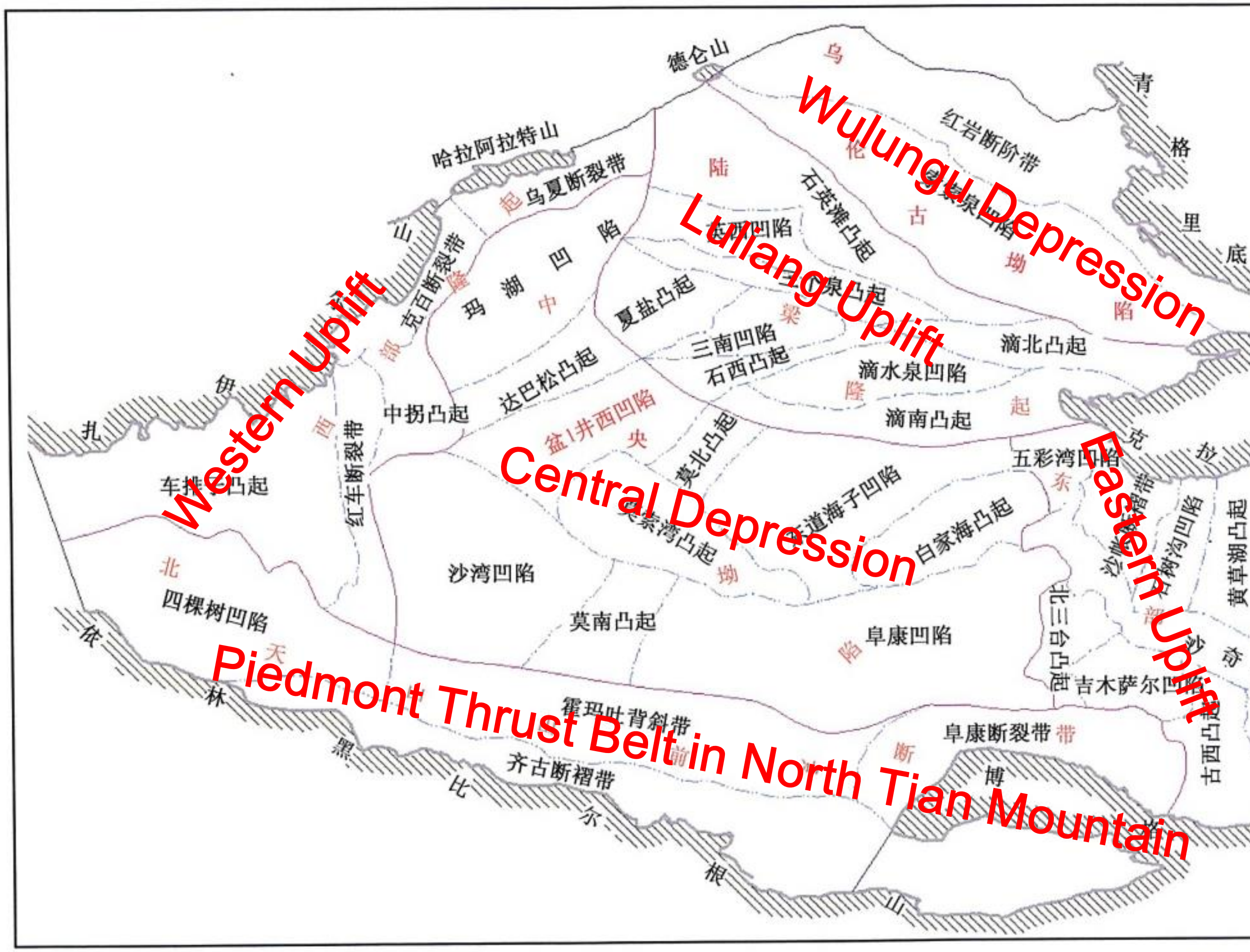
2.6 Potential evaluation of CGUS

Depth	OGIP（10^8m^3）（地质储量）	Coal
1000-1500	11614.6	Non-caking coal
1500-2000	15723.69	Non-caking coal

2.6 Potential evaluation of CGUS

First order tectonic units　一级构造单元：6

Secondary tectonic units　二级构造单元: 44

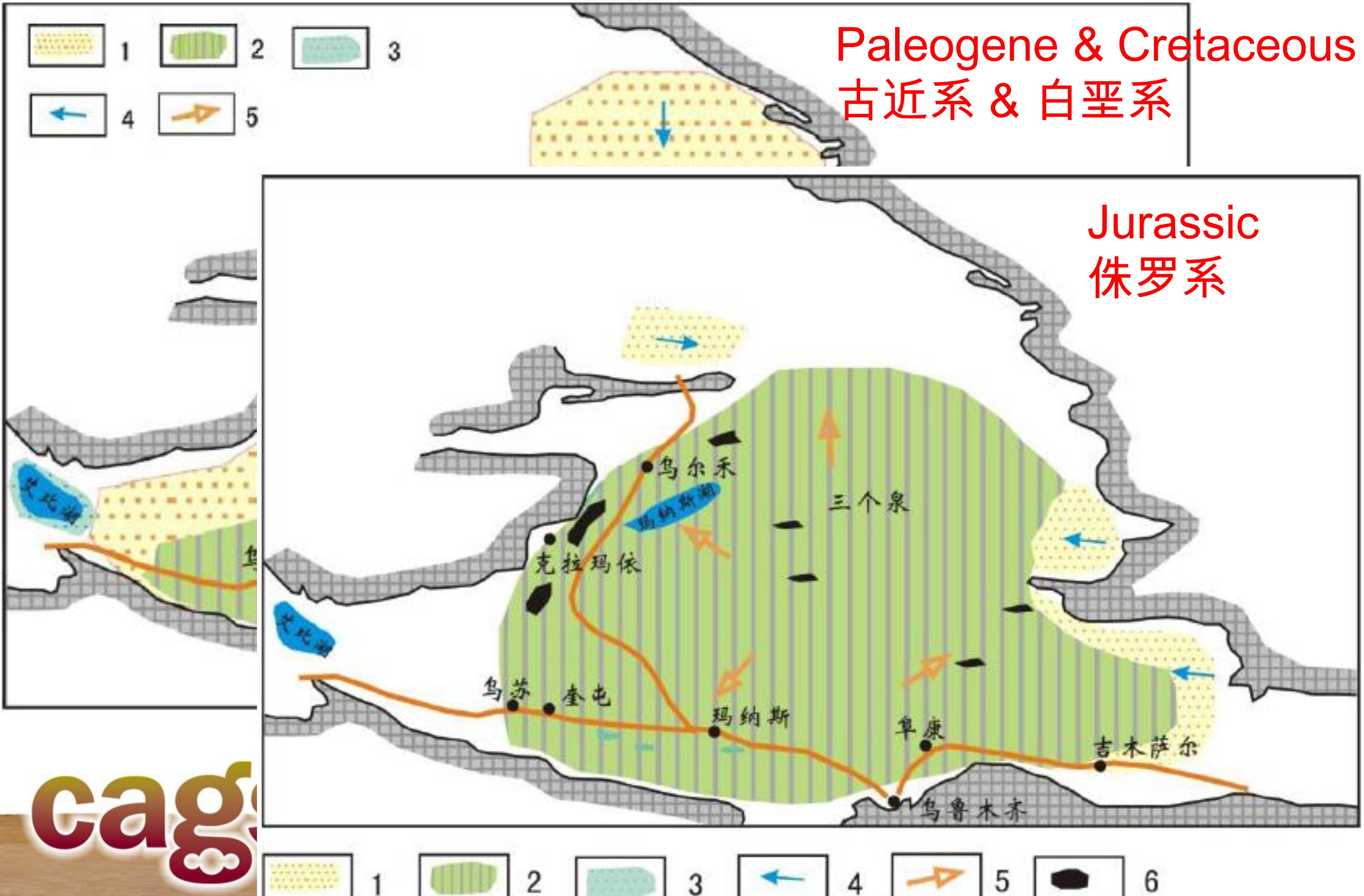


系	组	地层代号	厚度(m)	岩性剖面
Q	西域组	Q_1x	2478	
N	独山子组	N_2d	2800	
	塔西河组	N_1t		
	沙湾组	N_1s		
E	安集海河组	E_3a	1180	
	紫泥泉子组	$E_{1-2}z$		
K	东沟组	K_2d	2000	
	连木沁组	K_1l		
	胜金口组	K_1s		
	呼图壁河组	K_1h		
	清水河组	K_1q		
J	齐古组	J_3q	3600	
	头屯河组	J_2t		
	西山窑组	J_2x		
	三工河组	J_1s		
	八道湾组	J_1b		
T	白碱滩组	T_3b	1700	
	克拉玛依组	T_2k		
	百口泉组	T_1b		

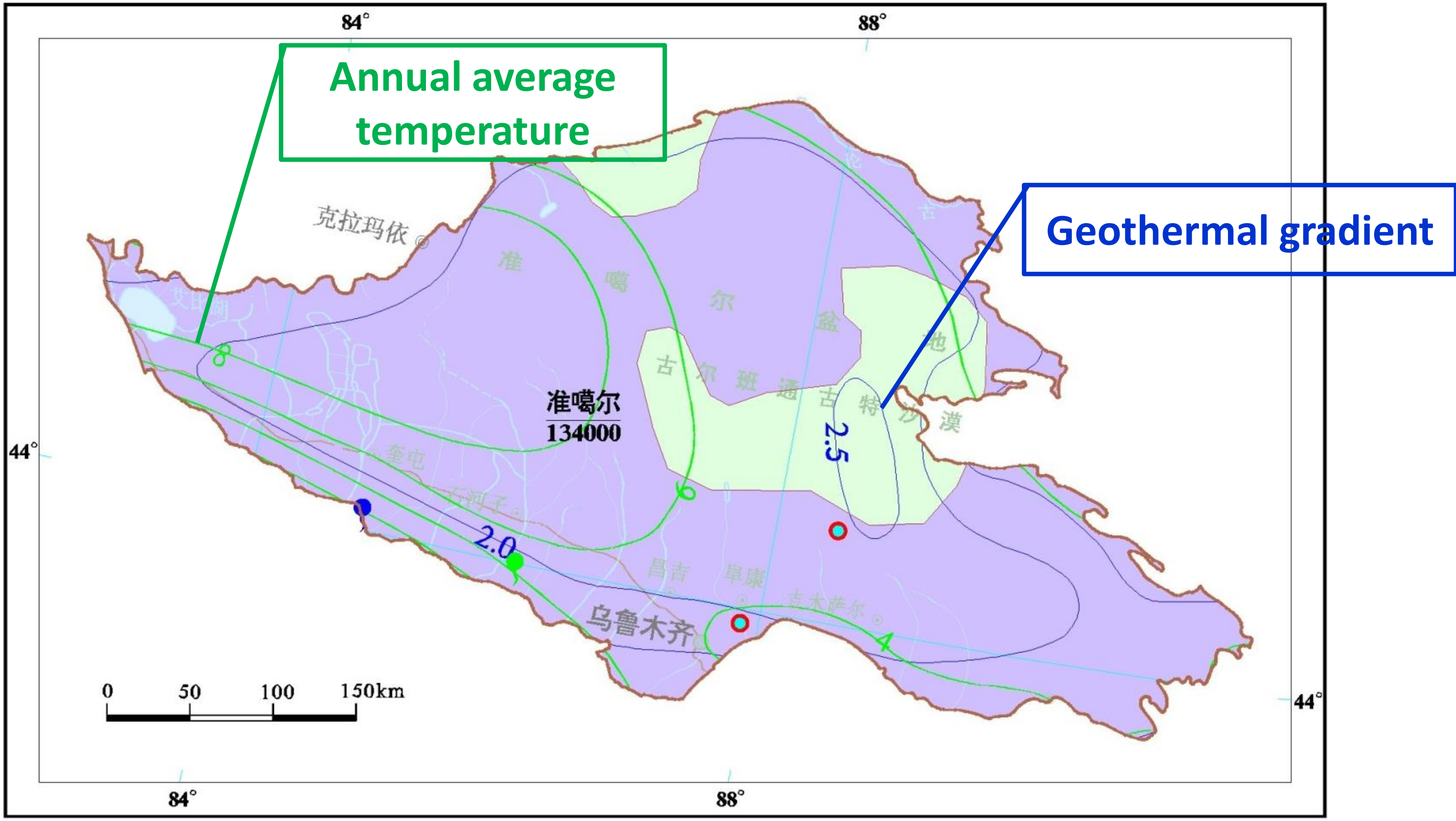
Hydrogeology 区域水文地质

Paleogene & Cretaceous
古近系 & 白垩系

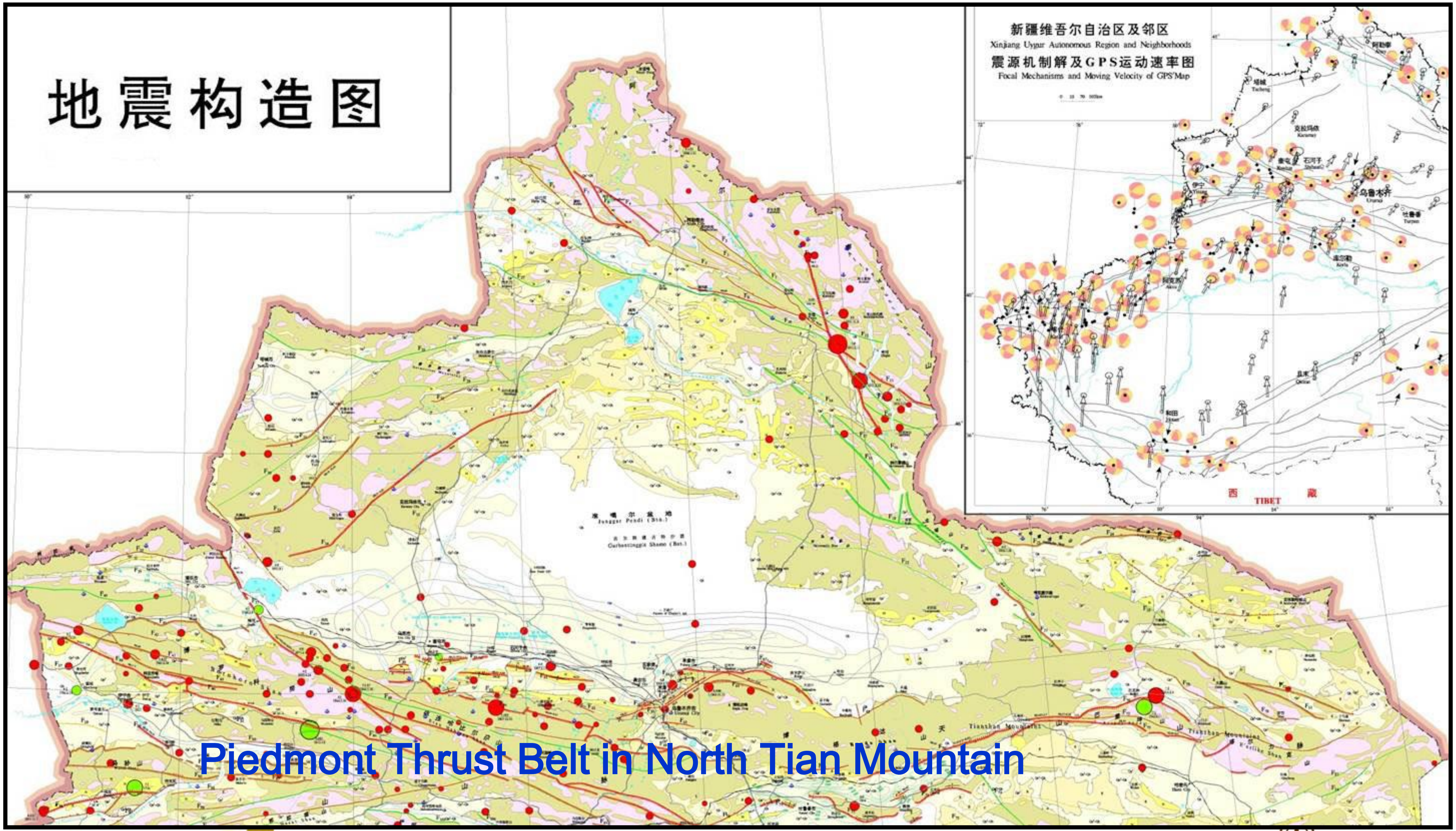
Jurassic
侏罗系



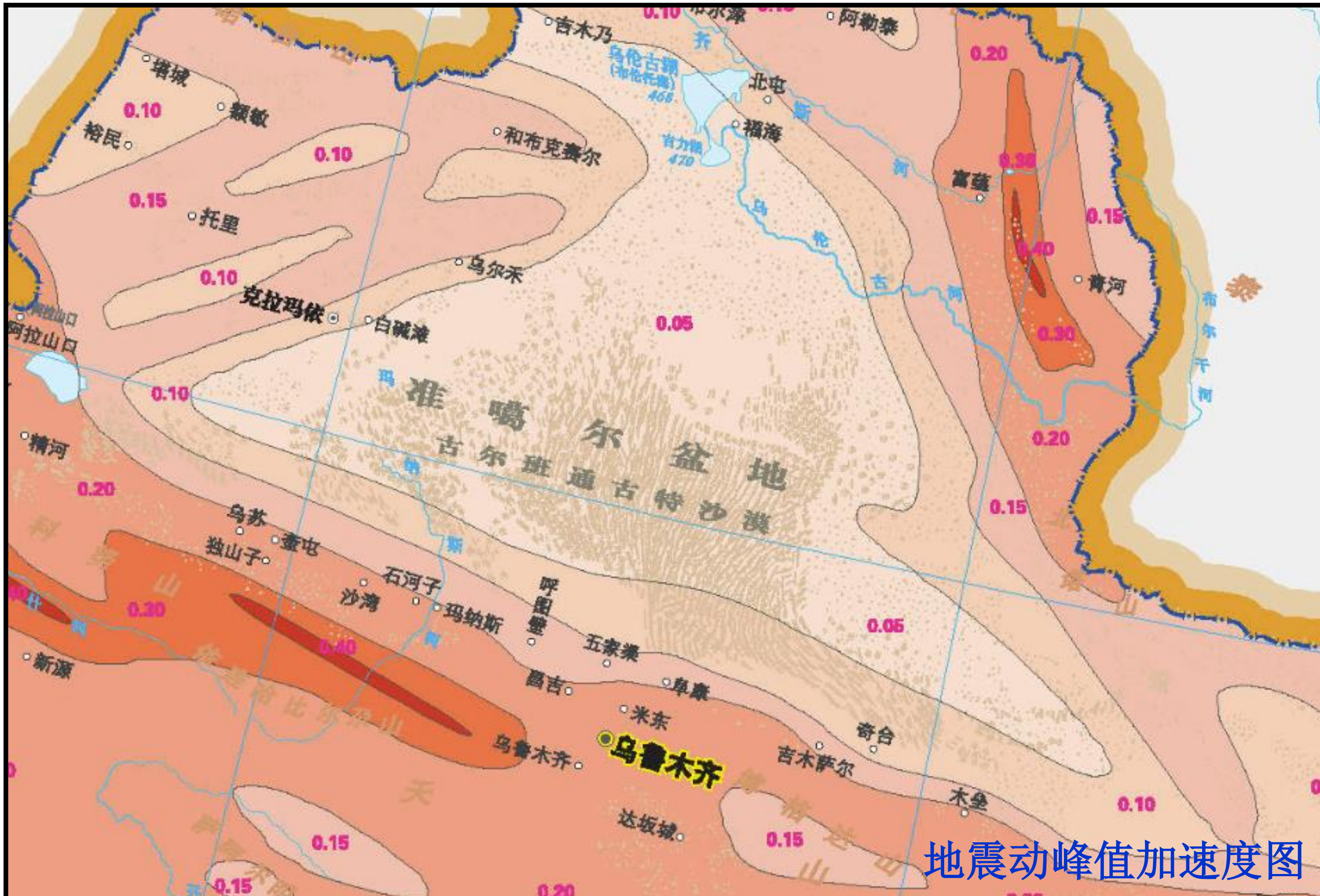
Geothermal geology 区域地温场



Seismotectonics 地震构造



Peak ground acceleration (GB 18306-2015)



2.6 Potential evaluation of CGUS

Criteria for reservoir selection basically:
储层的必须满足的基本条件：

- 深度 Depth: 800 – 3500 m
- 岩性 Lithology: clastic rocks, carbonate rocks
- 厚度 Thickness: ≥ 10 m
- 孔隙度 Porosity: ≥ 5%
- 渗透率 Permeability: ≥1 mD
- 盖层 Caprocks: regional, generally mudstone and thicker than 20 m
- 活动断裂 Distance from the nearby active faults: > 25 km
- 地震活动性 Peak ground acceleration: < 0.40 g
- 水动力条件 Hydrogeology: not open hydrodynamic area

2.6 Potential evaluation of CGUS

23 reservoirs

Section2 of Sangonghe formation

Sand-ravel rock in the bottom of Qingshuihe formation

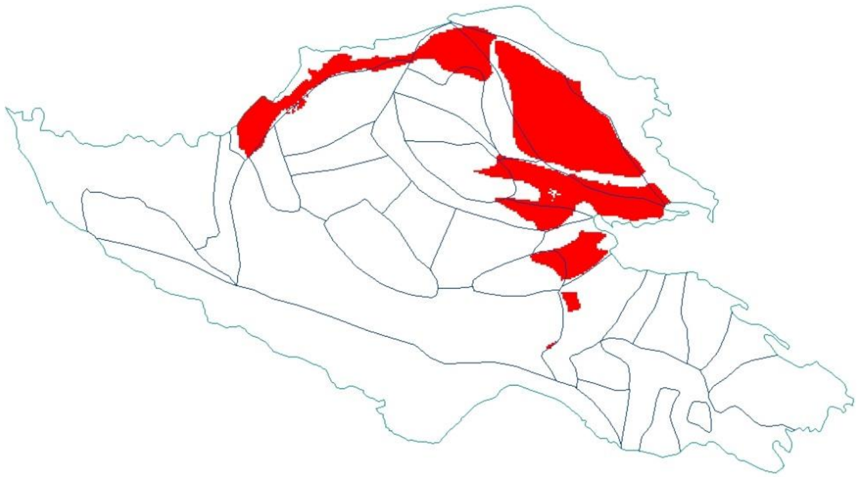
地层系统			厚度(m)	岩性剖面	储层	盖层	平均孔隙度(%)	平均渗透率($10^{-3}\mu m^2$)	储集空间	构造运动	盆地演化
系	组	地层代号									
Q	西域组	Q_1x	2478							喜马拉雅运动	准南陆内前陆盆地阶段
N	独山子组	N_2d	2800								
	塔西河组	N_1t									
	沙湾组	N_1s									
E	安集海河组	E_3a	1180								陆内统一坳陷阶段
	紫泥泉子组	$E_{1-2}z$					12.7	3.87-127	砂岩孔隙型为主		
K	东沟组	K_2d	2000				22.25	110.38		燕山运动II幕	
	连木沁组	K_1l					>20	>50			
	胜金口组	K_1s									
	呼图壁河组	K_1h					>15	9.68-607.48			
	清水河组	K_1q					16.29	1.47-369.82			
J	齐古组	J_3q	3600				>10	3.62-161.99		燕山运动I幕	压扭盆地阶段
	头屯河组	J_2t					18.35			晚印支运动	伸展盆地阶段
	西山窑组	J_2x					>10	1-225.04			
	三工河组	J_1s					>10	1-375.36			
	八道湾组	J_1b					>10	>5			
T	白碱滩组	T_3b	1700				>10	>50		早印支运动	陆内坳陷阶段
	克拉玛依组	T_2k									
	百口泉组	T_1b					13.18	16.15-77.12			

2.6 Potential evaluation of CGUS

- Triassic reservoirs

三叠系储层

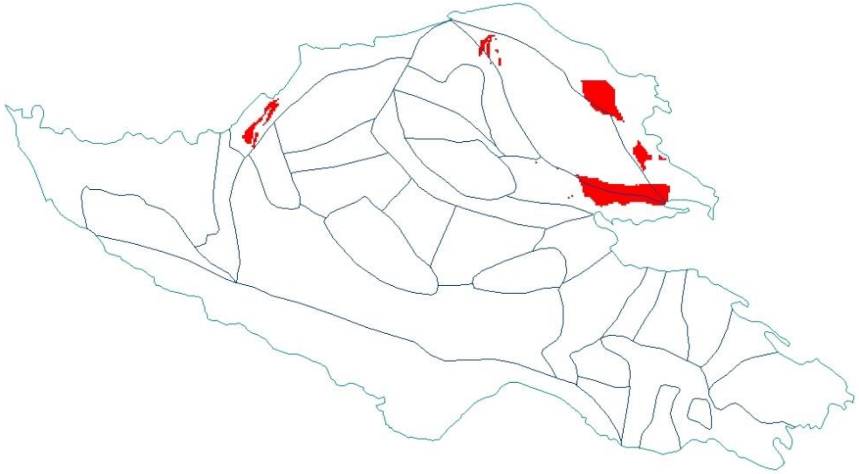
Low exploration and research degree



Baikouquan Formation

Φ: 13.18% average

K:16.55 - 77.12 mD



Baijiantan Formation

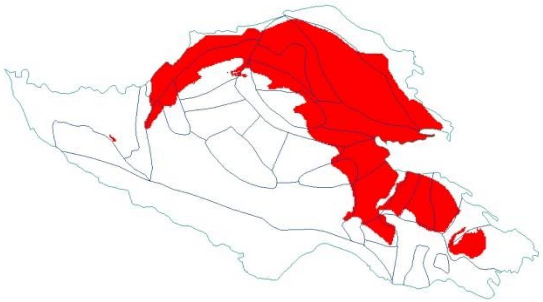
Φ: 14.1% - 19.12%

K: 20.92 ~ 57.48 mD

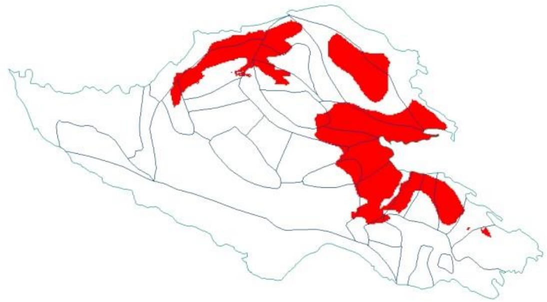
2.6 Potential evaluation of CGUS

– Jurassic reservoirs 侏罗系储层

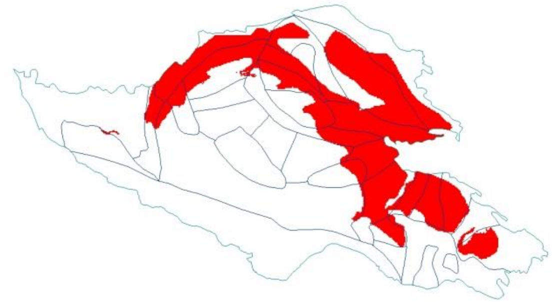
Badaowan Formation


Section1

Φ: 8.61% average
K: 2.31 mD average

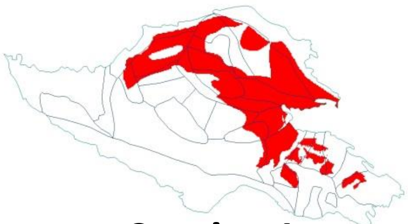

Section2

Φ: 15.29% average
K: > 10 mD


Section3

Φ: 16.14% average
K: > 10 mD

Sangonghe Formation


Section1

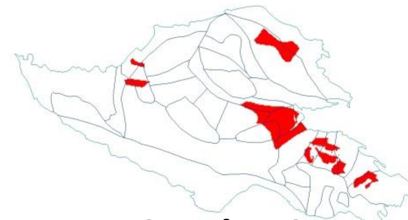
Φ: 9.64% average
K: 30.18-375.36 mD


Section2-2

Φ: 12.74% average
K: 1-190 mD


Section2-1

Φ: 11.38% average
K: 1-143 mD

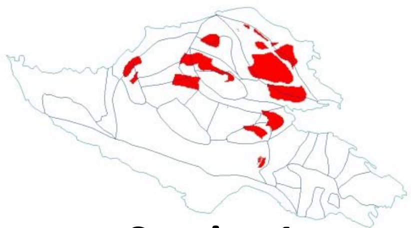

Section3

Φ: 16.54% average
K: 17.58-75.76 mD

2.6 Potential evaluation of CGUS

– Jurassic reservoirs 侏罗系储层

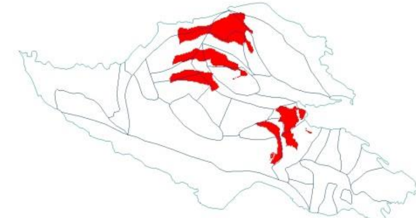
Xishanyao Formation



Section1

Section2

Section3

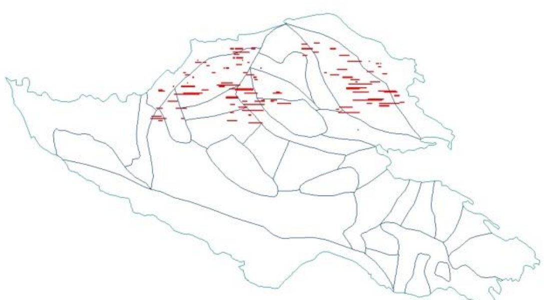


Section4

Φ: 13.1-19.7%
K: 2.7-225 mD

Φ: 19.7% average
K: 225 mD average

Φ: 13.1-19.7%
K: 2.7-225 mD



Φ: 18.35% average

Toutunhe Formation

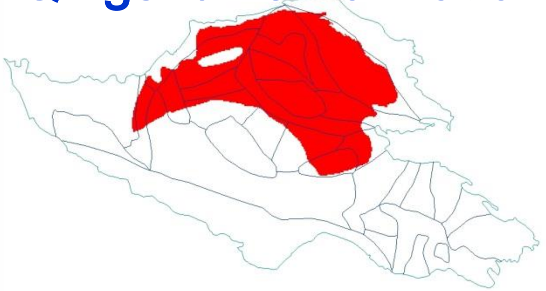
Φ: 12.5% average
K: 3.62-161.99 mD

Qigu Formation

2.6 Potential evaluation of CGUS

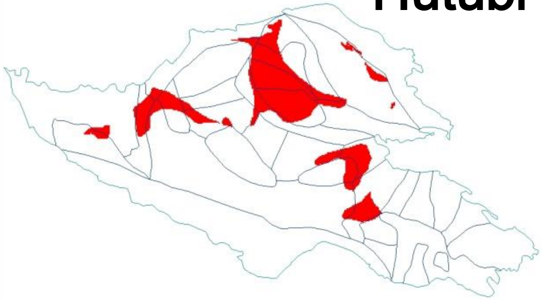
– Cretaceous reservoirs 白垩系储层

Qingshuihe Formation

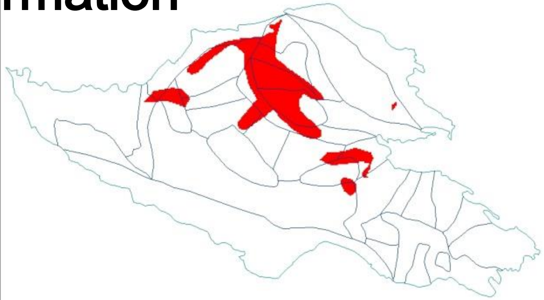


Φ: 16.29% average
K: 1.47-369.82 mD

Hutubi Formation



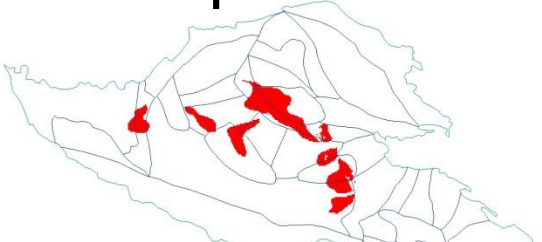
Section1



Section2

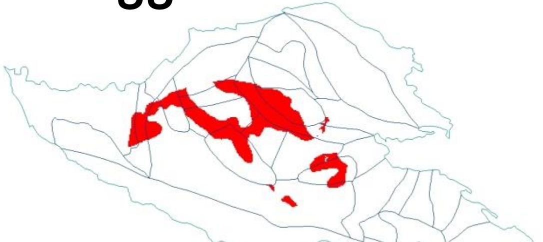
Φ: 18.27% average
K: 44.71 mD average

Lianmuqin Formation



Φ: 28.16% average
K: 166.22 -529.84 mD

Donggou Formation

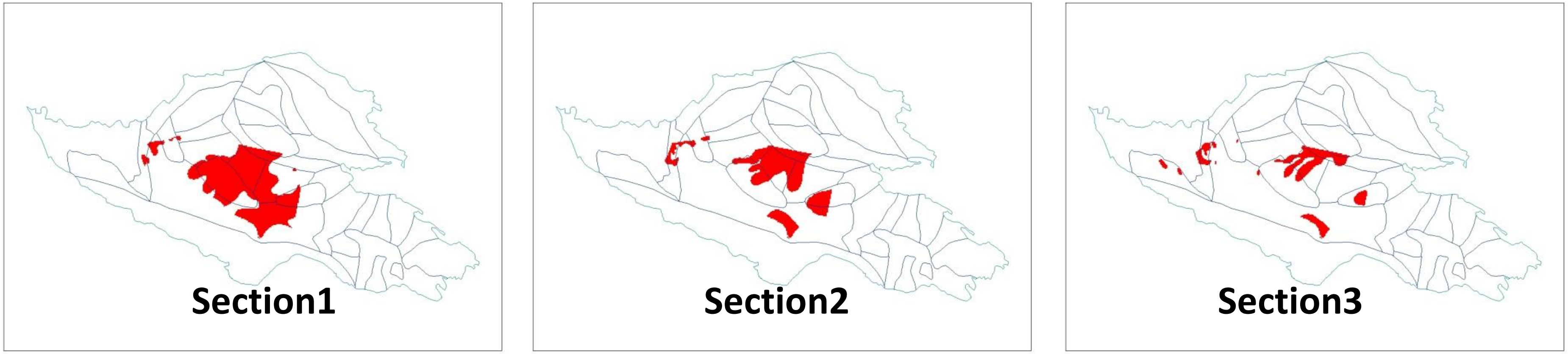


Φ: 22.25% average
K: 110.38 mD average

2.6 Potential evaluation of CGUS

– Paleogene reservoirs
古近系储层

Ziniquanzi Formation



Φ: 12.47% average
K: 3.87-127 mD

2.6 Potential evaluation of CGUS

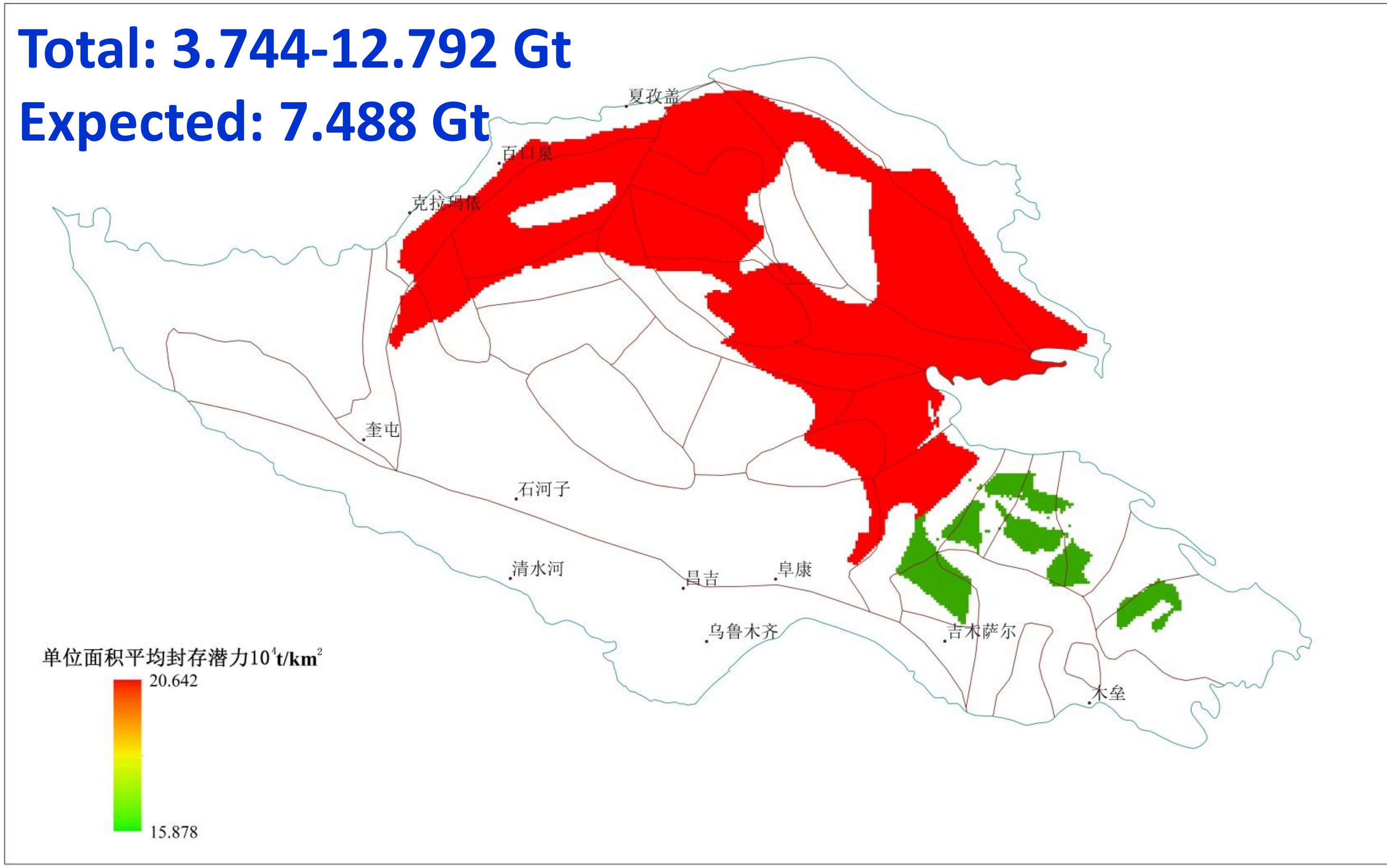
CGUS technologies	Potential (Gt)	Credibility
Enhanced oil recovery, CO_2-EOR	0.148	Effective, Credible
Depleted oil field CO_2 storage	1.345	Effective, Credible
Enhanced gas recovery, CO_2-EGR	0.009	Effective, Credible
Depleted gas field CO_2 storage	0.016	Effective, Credible
Enhanced coal bed methane, CO_2-ECBM	2.281-5.215 4.02 expected	Theoretical, Less Credible
Unmineable coal seams CO_2 storage	3.405-7.783 6 expected	Theoretical, Less Credible
CO2-EWR/deep saline aquifers	4.8027-164.093 96.055 expected	Theoretical, Less Credible

中澳二氧化碳地质封存

2.6 Potential evaluation of CGUS

Total: 3.744-12.792 Gt

Expected: 7.488 Gt



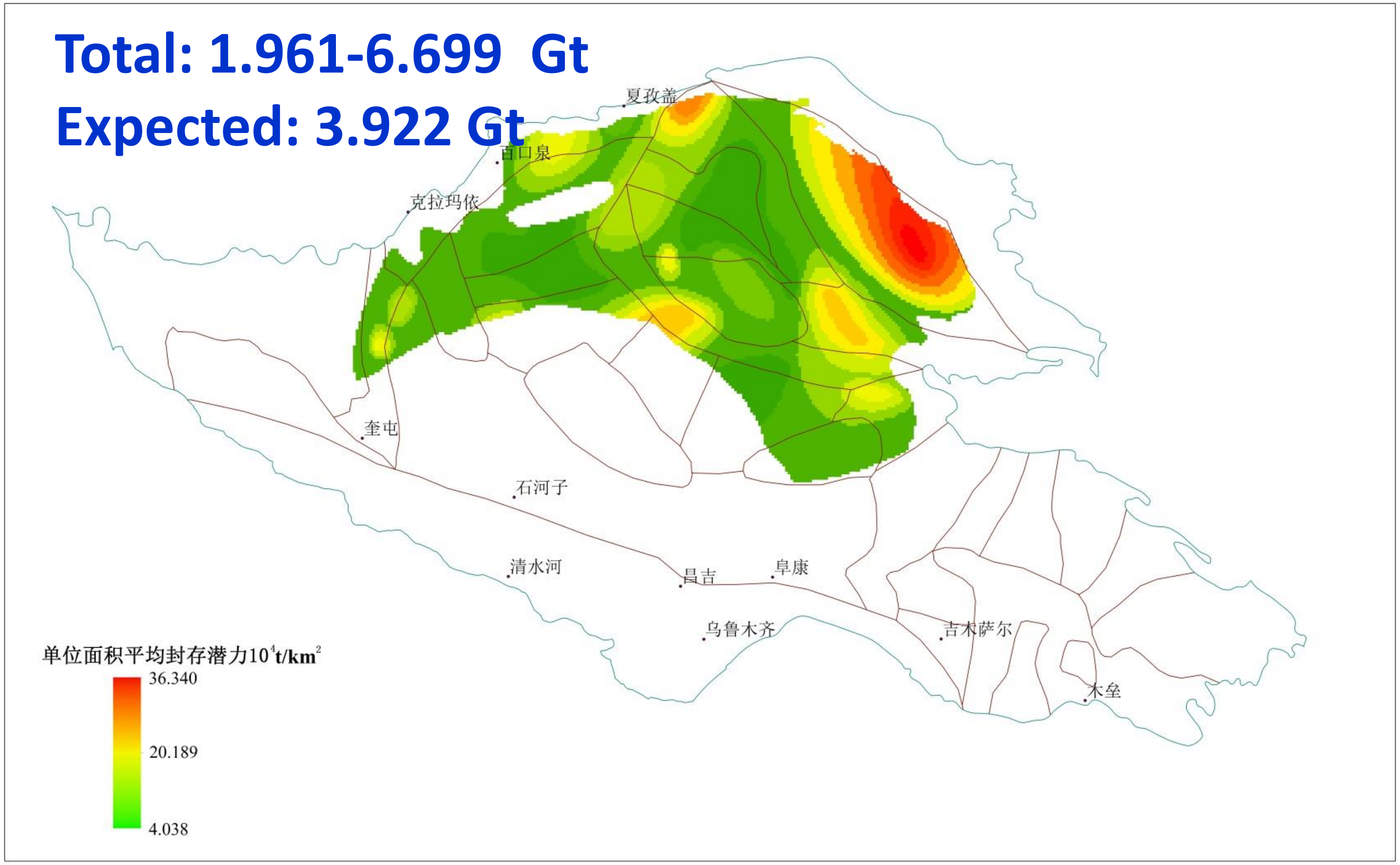
Potential of 2nd sandstone group in section 2 of Sangonghe Formation

三工河二段二砂组主力储层单位面积封存潜力

2.6 Potential evaluation of CGUS

Total: 1.961-6.699 Gt

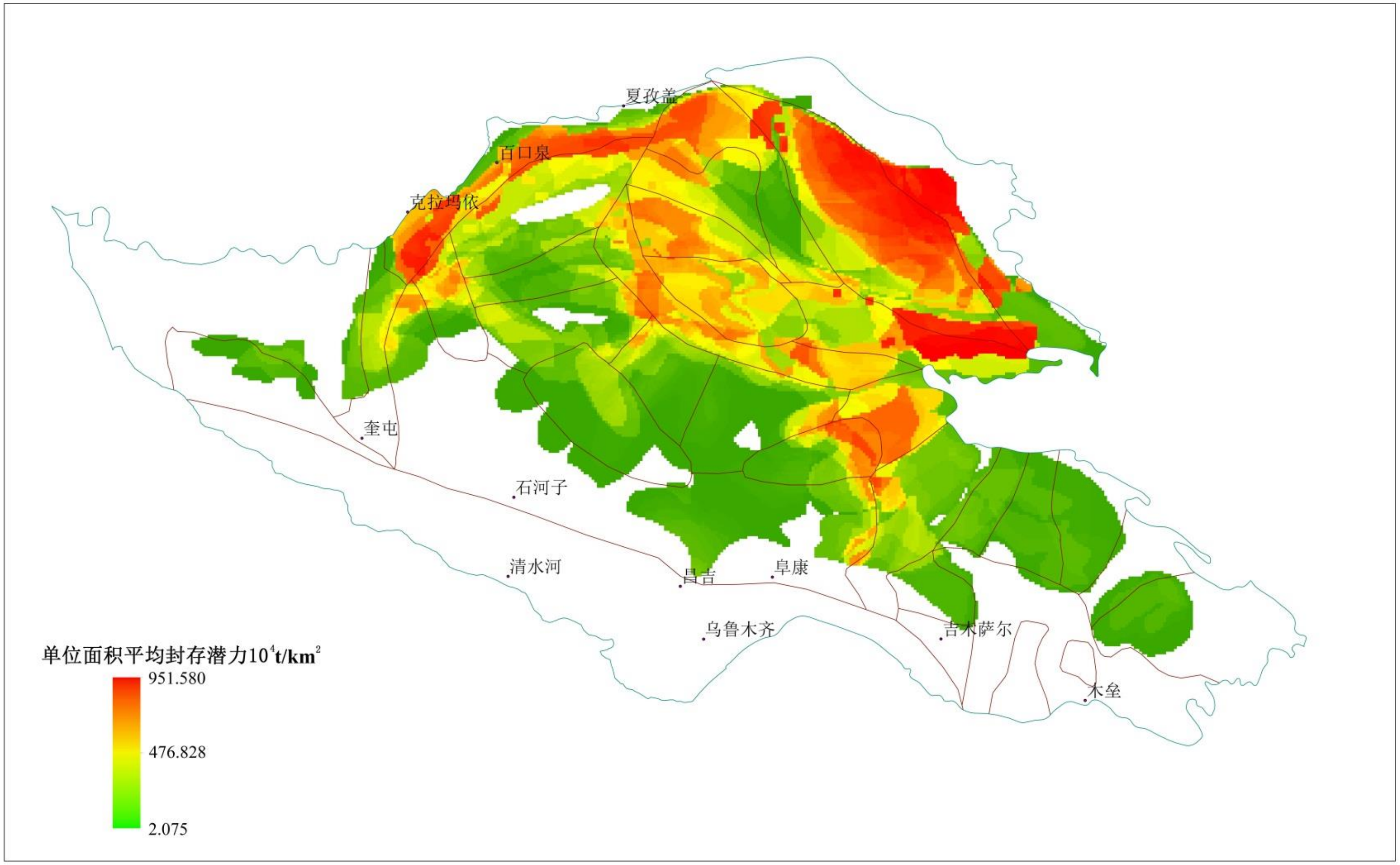
Expected: 3.922 Gt



Potential of sandstones in the bottom of Qingshuihe Formation

清水河组底部砂砾岩主力储层单位面积封存潜力

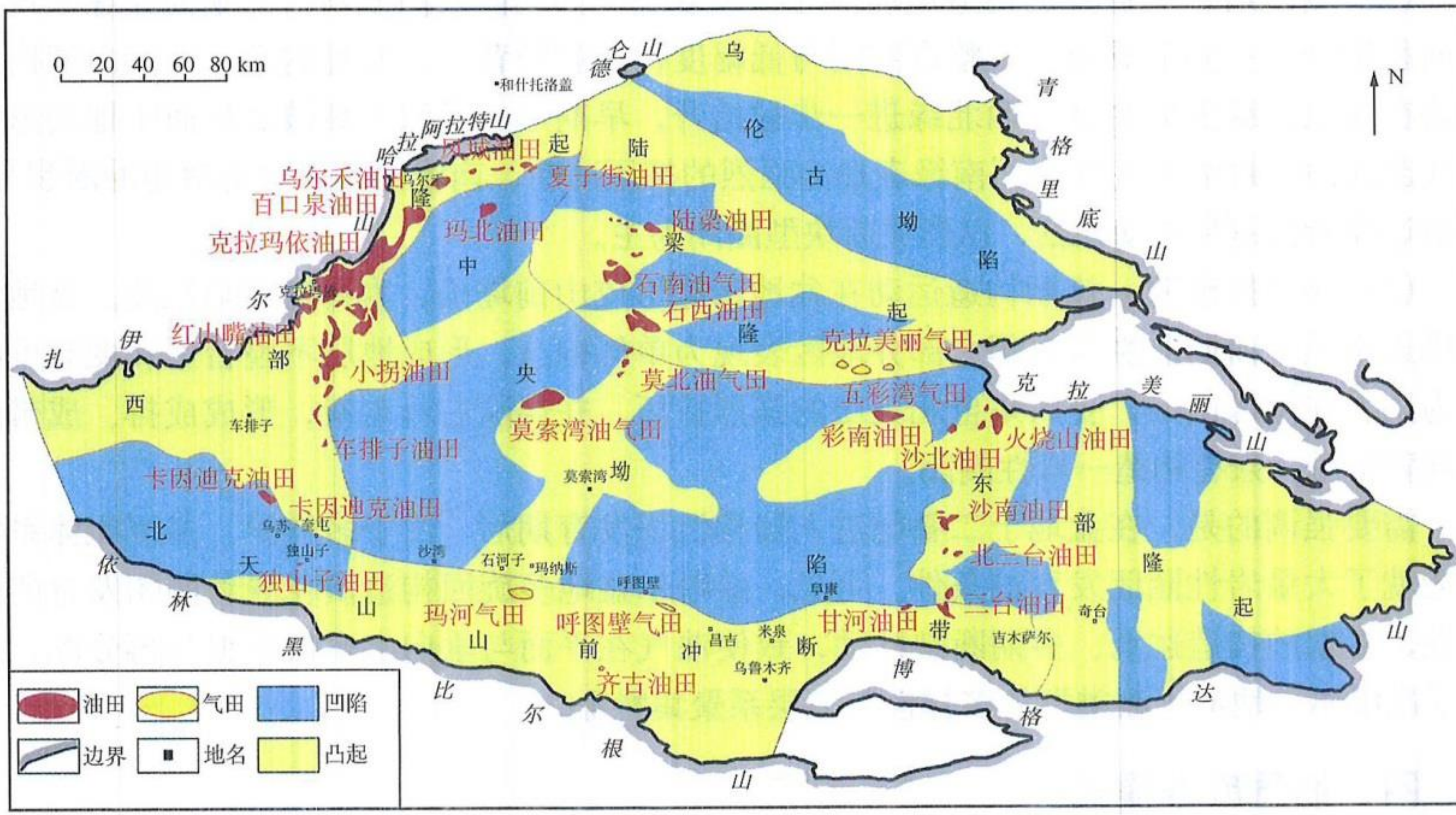
2.6 Potential evaluation of CGUS



Total potential of deep saline aquifers CO2 geological storage/EWR

CONTENTS

Targets of EOR/EGR/depleted oil & gas fields CO2 storage in mesoscale

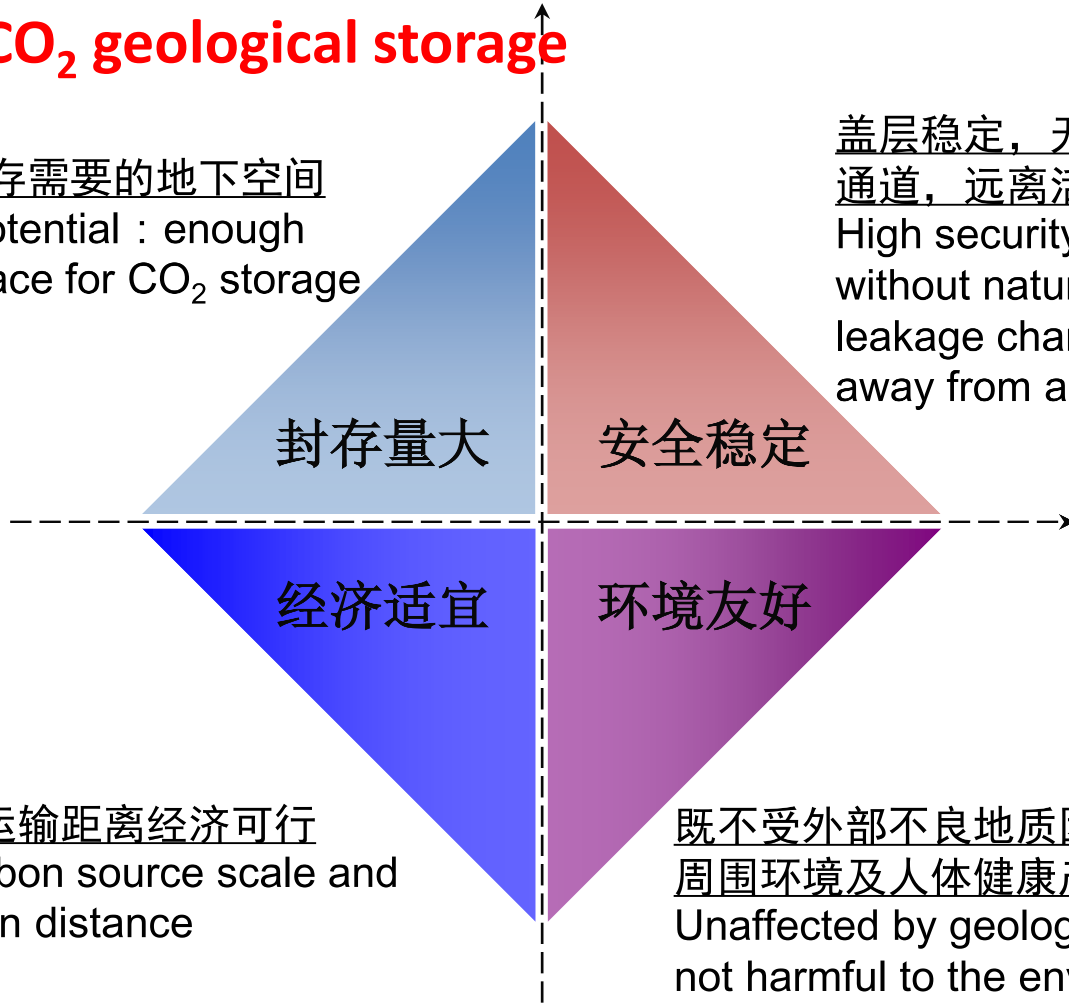


China Australia Geological Storage of CO_2

中澳二氧化碳地质封存

Geological suitability assessment for CO2-EWR target selection

Guideline for CO_2 geological storage



<u>具有能够满足封存需要的地下空间</u>
Great storage potential：enough underground space for CO_2 storage

<u>盖层稳定，无天然、人为泄漏通道，远离活动断裂</u>
High security: stable caprocks without natural or artificial leakage channels, and far away from active faults

<u>碳源规模、运输距离经济可行</u>
Feasible carbon source scale and transportation distance

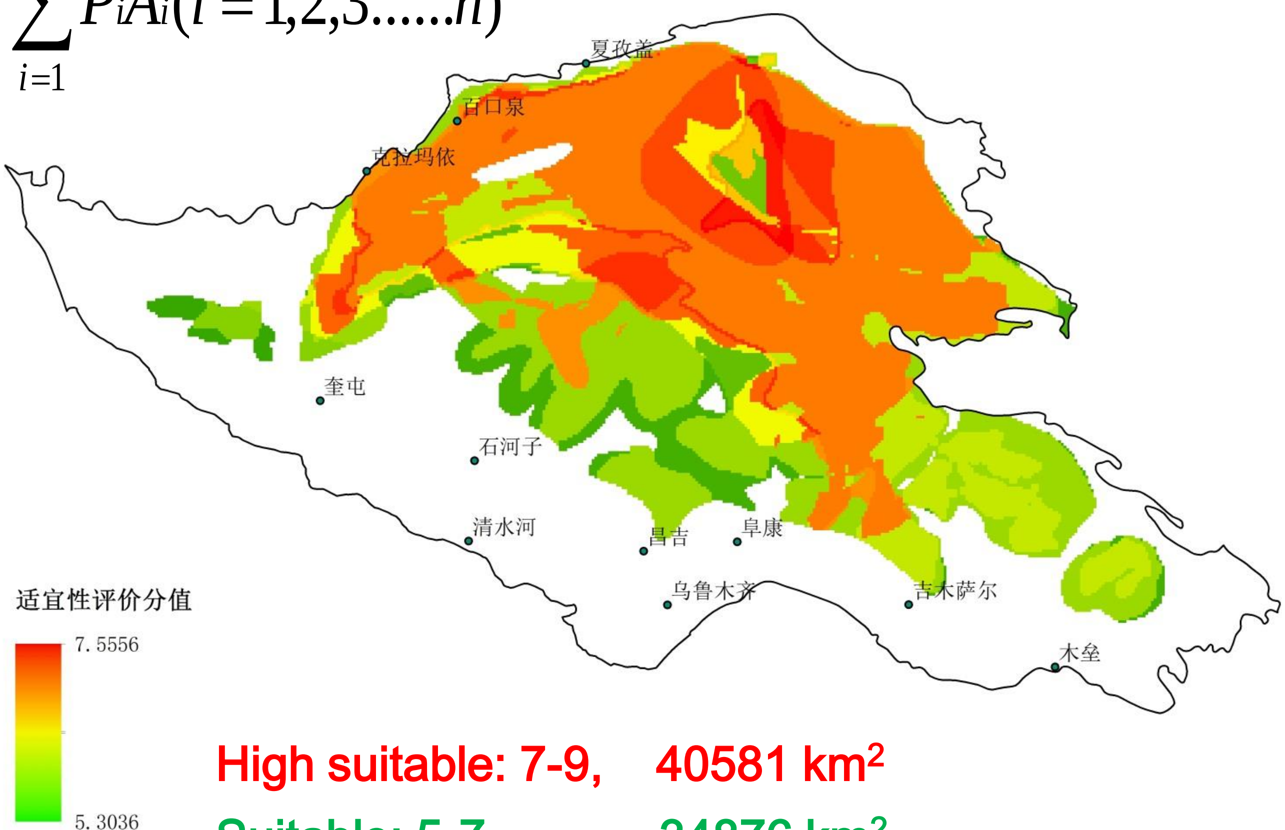
<u>既不受外部不良地质因素影响，又不会对周围环境及人体健康产生不可接受的危害</u>
Unaffected by geological hazards, and not harmful to the environment and human

Geological suitability assessment for CO2-EWR target selection

Level one index	Weight	Level two index	Weight	Level three index	Weight	Good	Normal	Poor	Key veto factor
Reservoir conditions and storage potential	0.50	Characteristic of the best reservoir	0.60	Lithology	0.07	Clastic	Mix of Clastic and Carbonate	Carbonate	
				Single layer thickness h/m	0.11	≥80	30 ≤ h < 80	10 ≤ h < 30	< 10
				Sedimentary facies	0.36	River, Delta	Turbidity, Alluvial fan	Beach bar, Reef	
				Average porosity ϕ/%	0.20	≥15	10 ≤ ϕ < 15	5 ≤ ϕ < 10	< 5
				Average permeability k/ mD	0.27	≥50	10 ≤ k < 50	1 ≤ k < 10	< 1
		Storage potential	0.40	Storage potential per unit area G (10^4 t/km^2)	1.00	≥100	10 ≤ G < 100	< 10	
Geological safety	0.50	Characteristic of the main caprock	0.62	Lithology	0.30	Evaporites	Argillite	Shale and dense limestone	
				Thickness h/m	0.53	≥100	50 ≤ h < 100	10 ≤ h < 50	< 10
				Depth D/m	0.11	<1000	1000 ≤ D ≤ 2700	>2700	
				Buffer caprock above the main caprock	0.06	Multiple sets	Single set	None	
		Hydrodynamic conditions	0.24	Hydrodynamic conditions	1.00	Groundwater high-containment area	Groundwater containment area	Groundwater semi-containment area	Groundwater open area
		Seismic activity	0.14	Peak ground acceleration	0.50	< 0.05 g	0.05 g, 0.10 g	0.15 g, 0.30 g	≥0.40 g
				Development degree of fractures	0.50	Simple	Moderate	Complex	Within 25 km of active faults

Geological suitability assessment for CO2-EWR target selection

$$P = \sum_{i=1}^{n} P_i A_i (i = 1,2,3......n)$$



High suitable: 7-9, 40581 km^2

Suitable: 5-7, 34876 km^2

CONTENTS

4.1 Guideline for CO_2 geological storage site selection

场地选址技术流程
Technological process of site selection

钻探勘查

•Drillings

地球物理勘查

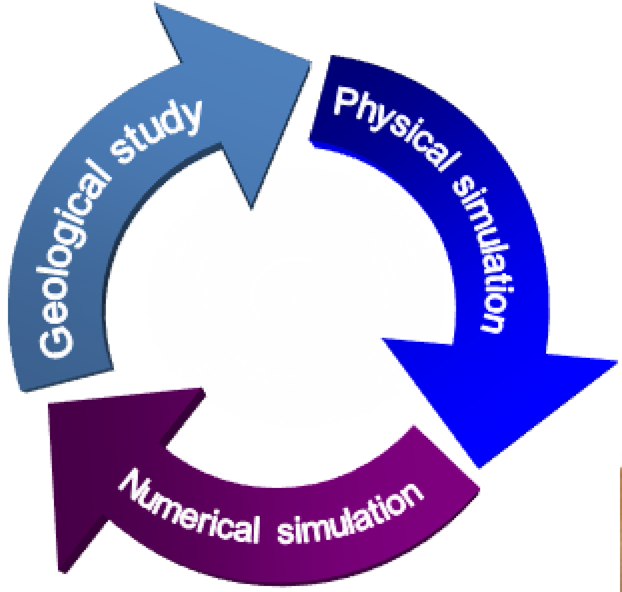
•Geophysical survey

地面调查

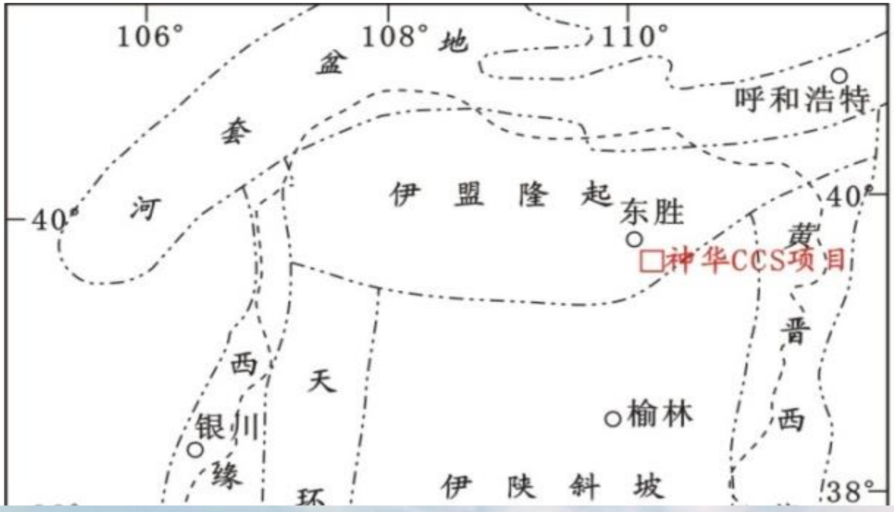
•Outcrop geological survey

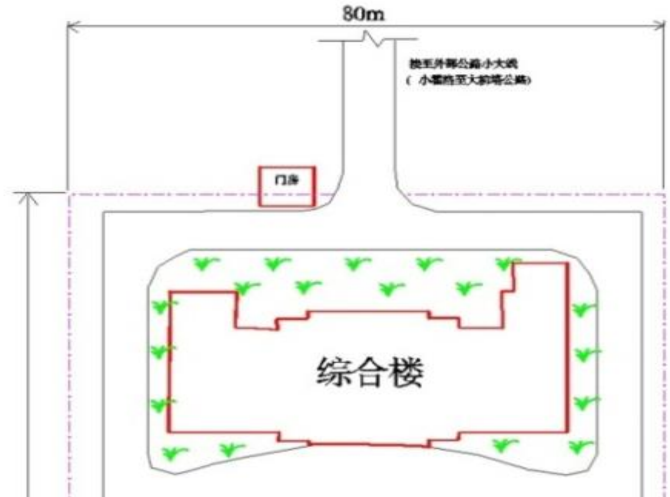
区域评估

•Feasibility study of regional geology



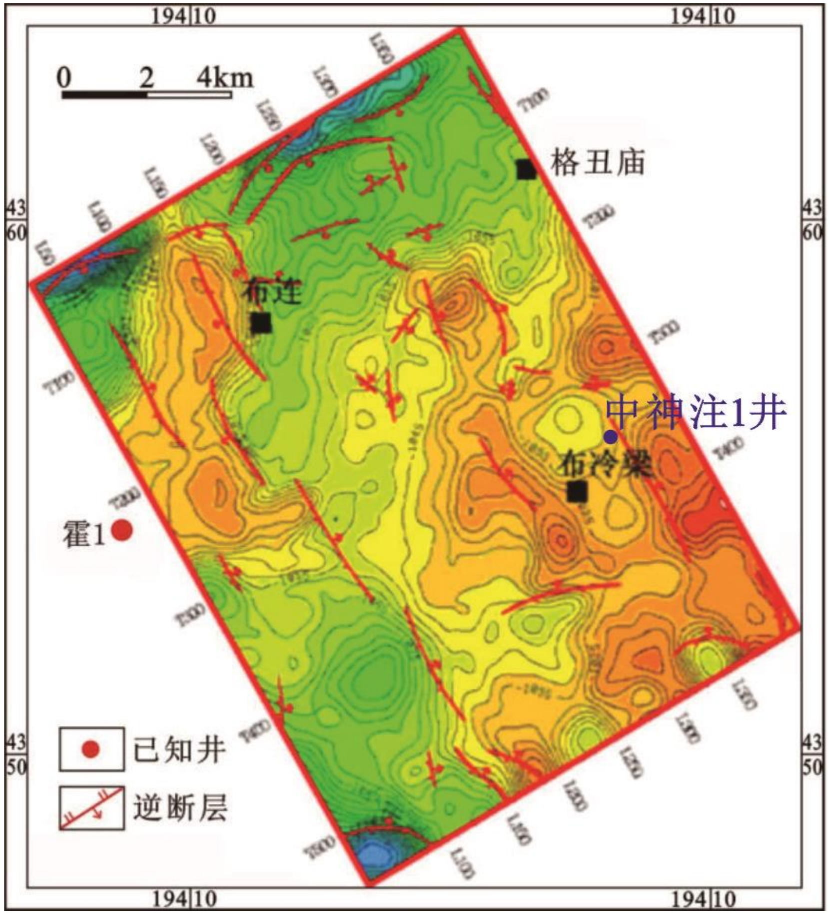
4.2 Geology


106°
108°
110°
地
盆
套
河
40°
呼和浩特
伊盟隆起
东胜
神华CCS项目
40°
黄
晋
西
西
天
银川
缘
榆林
西
伊陕斜坡
环
38°


80m
门房
综合楼

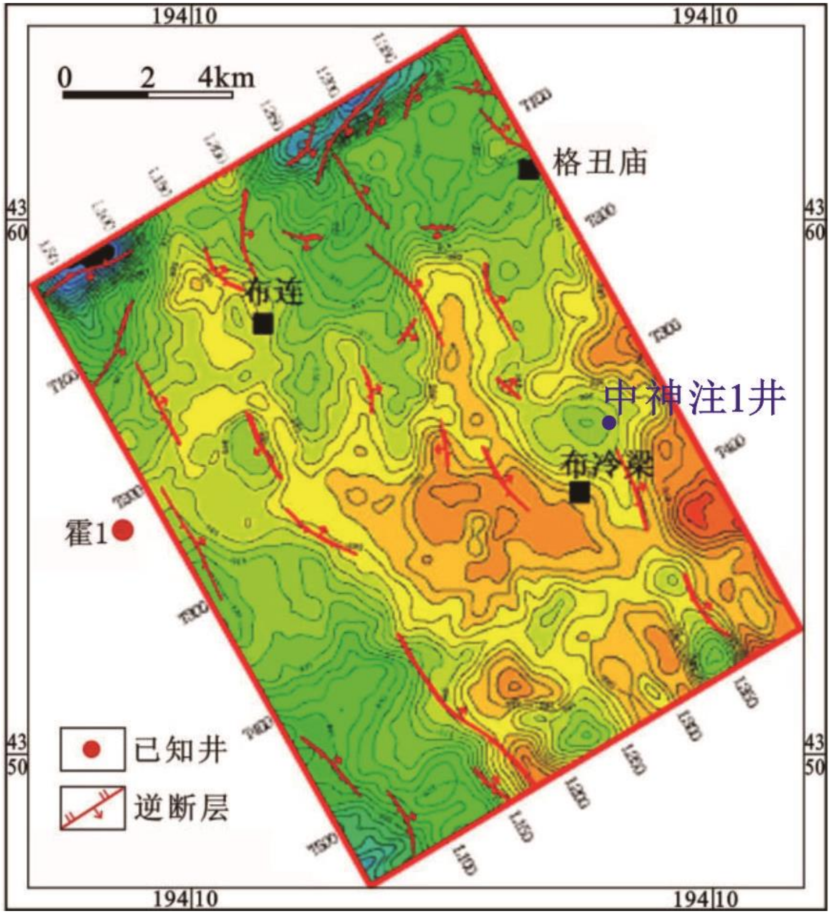

缓冲罐与
注入泵区
中神注1井
中神监2井
中神监1井
办公区

4.2 Geology



太原组底部构造

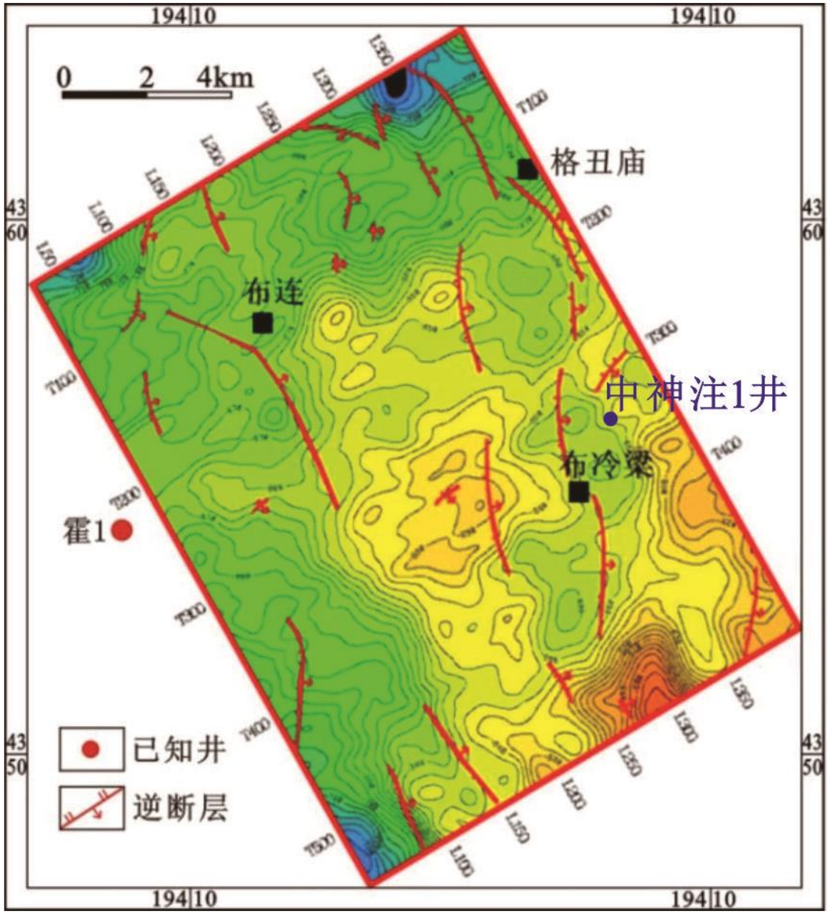
Geostructure of Taiyuan Formation



下石盒子组底部构造

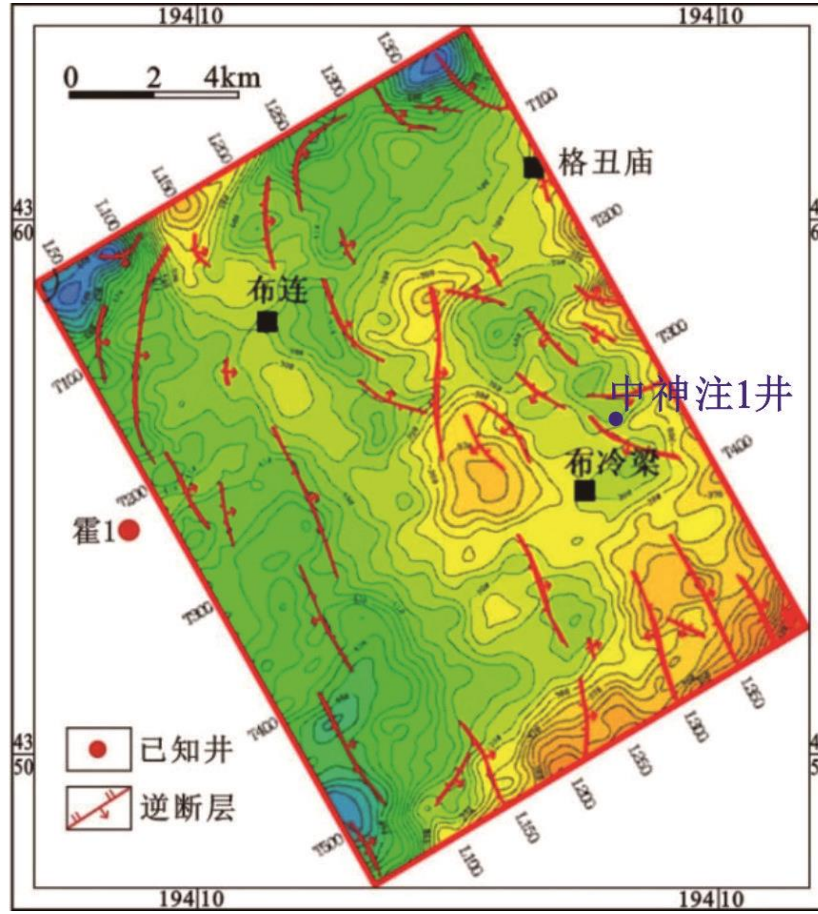
Geostructure of low Shihezi Formation

4.2 Geology



石千峰组底部构造

Geostructure of Shiqianfeng Formation



刘家沟组底部构造

Geostructure of Liujiagou Formation

地层平缓，无层间断裂，注入井周边1km范围内无解释断裂

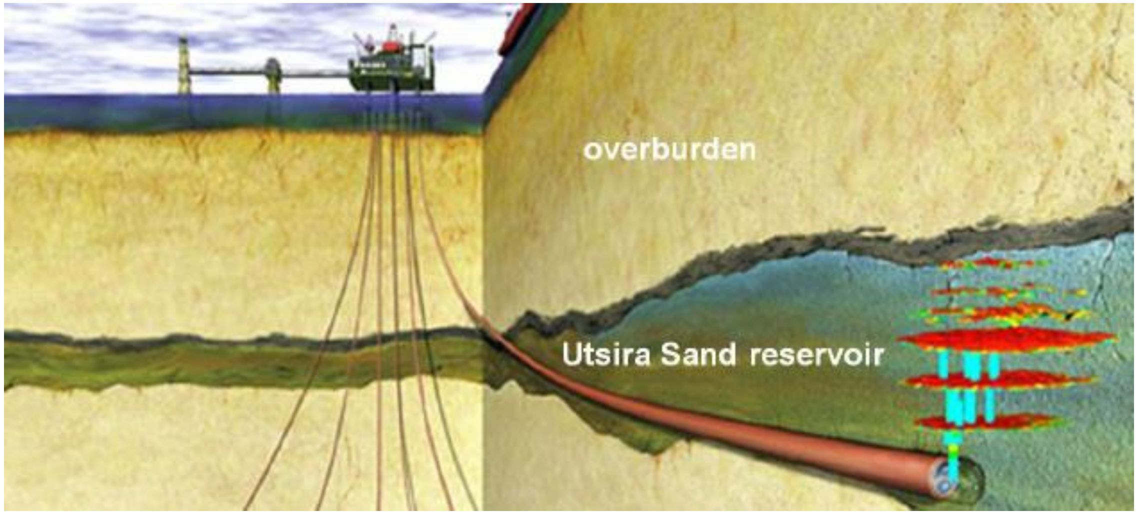
4.2 Geology

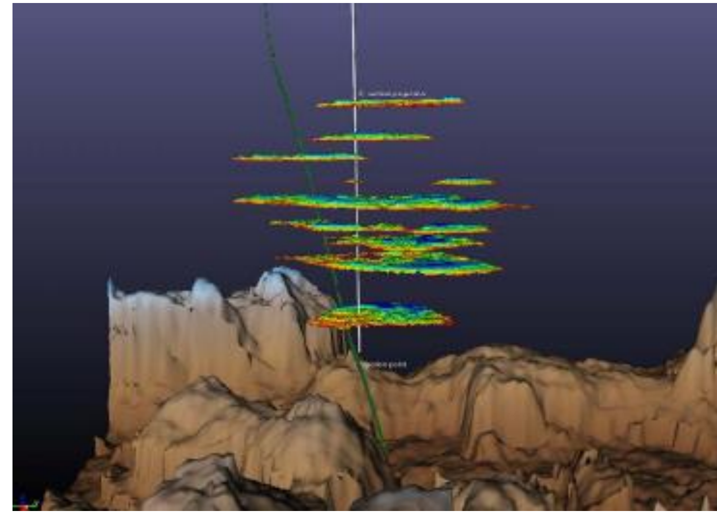
界	系	统	组	地层代号	深度(m)	柱状图	厚度(m)	岩性描述
新生界	第四系			Q	15		15	黄褐色粘土层、浅棕色砂质粘土层及砂砾石层
	白垩系		东胜—罗汉洞组	K_1^{d-l}	143		128	浅红色细砂岩与紫红色泥岩互层
中生界	侏罗系	中统	安定组	J_2a	178		35	浅灰色细砂岩为主，夹棕红色泥岩
			直罗组	J_2z	253		75	灰绿色泥岩与浅灰色中细砂岩互层
		下统	延安组	J_1y	450		197	上部以浅灰—深灰色中砂岩为主，夹深灰色泥岩及黑色煤层（8.0m）；中部深灰色泥岩与浅灰色中砂岩互层，夹黑色煤层（6.0m）及炭质泥岩；下部浅—灰白色中砂岩与深灰色泥岩互层，夹黑色煤层（4.0m）及炭质泥岩
	三叠系	上统	延长组	T_3y	958		508	上部浅灰色厚层中砂岩与深灰色中—薄层泥岩互层；中部以浅灰色细砂岩为主，夹浅灰色中砂岩与灰色泥质砂岩；下部深灰色泥岩、灰色砂质泥岩与灰白色中砂岩、含砾细砂岩、灰绿色含砾细砂岩呈互层
		中统	纸坊组	T_2z	1376		418	上部深灰—棕红色泥岩、灰色砂质泥岩与浅灰色泥质砂岩、浅灰色细砂岩、中砂岩互层；中部棕红、灰绿色泥岩、砂质泥岩与浅灰色泥质砂岩、细砂岩互层；下部棕红，浅灰色泥岩砂质泥岩与浅灰色泥质砂岩、灰绿色细砂岩互层
		下统	和尚沟组	T_1h	1574		198	上部浅灰色泥质砂岩、灰绿色细砂岩与棕红色泥岩互层；中部以浅红色细砂岩为主，夹棕红色泥岩和砂质泥岩；下部棕红色泥岩、砂质泥岩与浅红色、灰绿色细砂岩呈互层
			刘家沟组	T_1l	1695		150	上部以浅红色细砂岩为主，次为浅红色细砂岩、泥质砂岩与棕红色泥岩、砂质泥岩互层；中部浅红色细砂岩与棕红色泥岩、砂质泥岩互层；下部以浅红色细砂岩为主，夹棕红色泥岩、泥质砂岩和灰绿色细砂岩
古生界	二叠系	上统	石千峰组	P_3sh	1986		291	上部浅红色细砂岩与棕红色泥岩、浅红色砂质泥岩互层；中部浅红色细砂岩、泥质砂岩与浅红色砂质泥岩、棕红色泥岩互层；下部棕红色泥岩、砂质泥岩与浅红色细砂岩（灰黑色含砾细砂岩）互层
		中统	石盒子组	P_2sh	2233		247	上部棕红色泥岩、浅红色砂质泥岩、泥质砂岩与浅红色细砂岩互层；中部灰色砂质泥岩、深灰色泥岩与浅红色、浅灰色细砂岩互层；下部浅灰色细砂岩、灰色泥质砂岩与深灰色泥岩、灰色砂质泥岩互层
		下统	山西组	P_1s	2313		80	本组以浅灰色细砂岩为主，次为灰色泥质砂岩、砂质泥岩与深灰色泥岩、炭质泥岩互层
	石炭系	上统	太原组	C_2t	2335		26	顶部以黑色煤层、浅灰色细砂岩为主，夹深灰色泥岩
		中统	本溪组	C_2b	2363		28	灰色泥质砂岩、深灰色泥岩与黑色煤层呈互层
	奥陶系	中统	马家沟组	O_2m	2510		147	本组以褐灰色白云岩为主，夹褐灰色泥质灰岩

- 马家沟组：Cl—Na•Ca，TDS含量为7148.94 mg/L
- 石盒子组：Cl—Ca•Na，TDS含量为9510.38 mg/L
- 石千峰组：Cl—Ca•Na，TDS含量为31212.34 mg/L
- 刘家沟组：Cl—Ca•Na，TDS含量为65111.14 mg/L

均为咸水，不可直接利用

Shenhua CCS Demon-project in China VS. Sleipner Project in Norway





我国陆相沉积咸水层地质条件差：

1. 低孔低渗

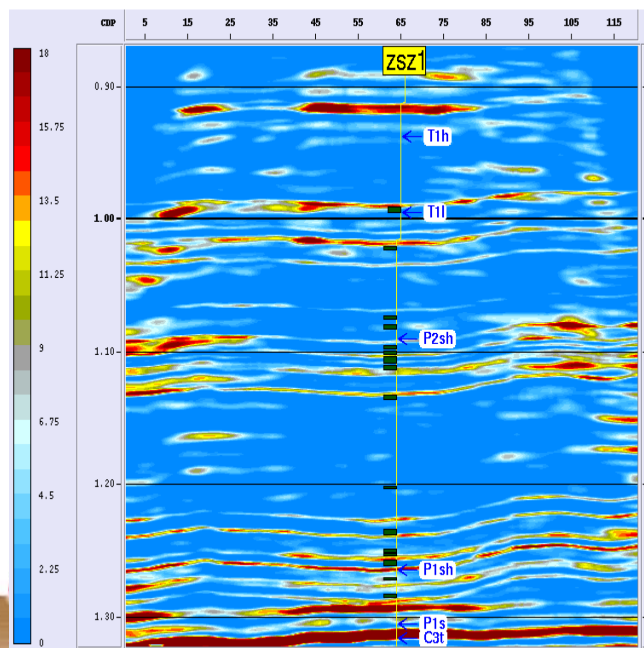
2. 层间非均质性强

3. 层内非均质性强

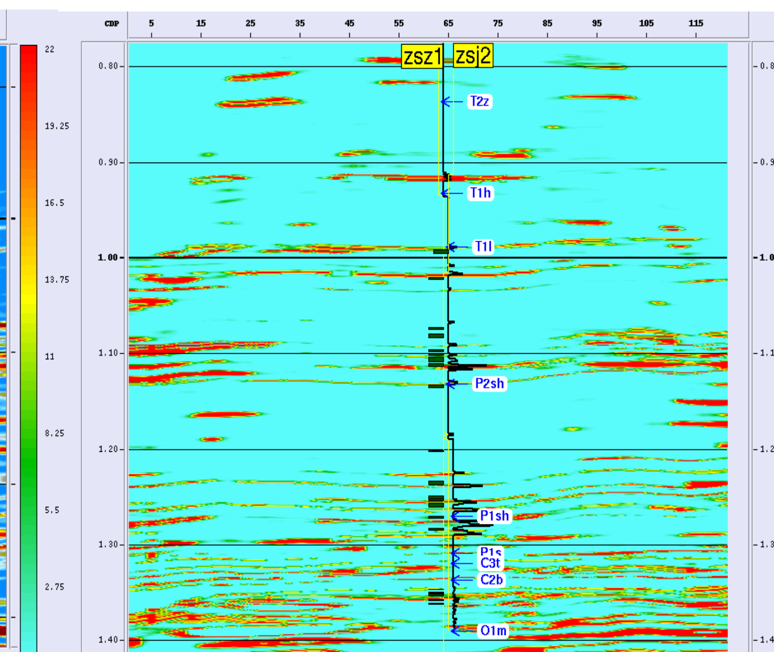
1.Low porosity & permeability

2. Fast lithological changing

3. Strong heterogeneity

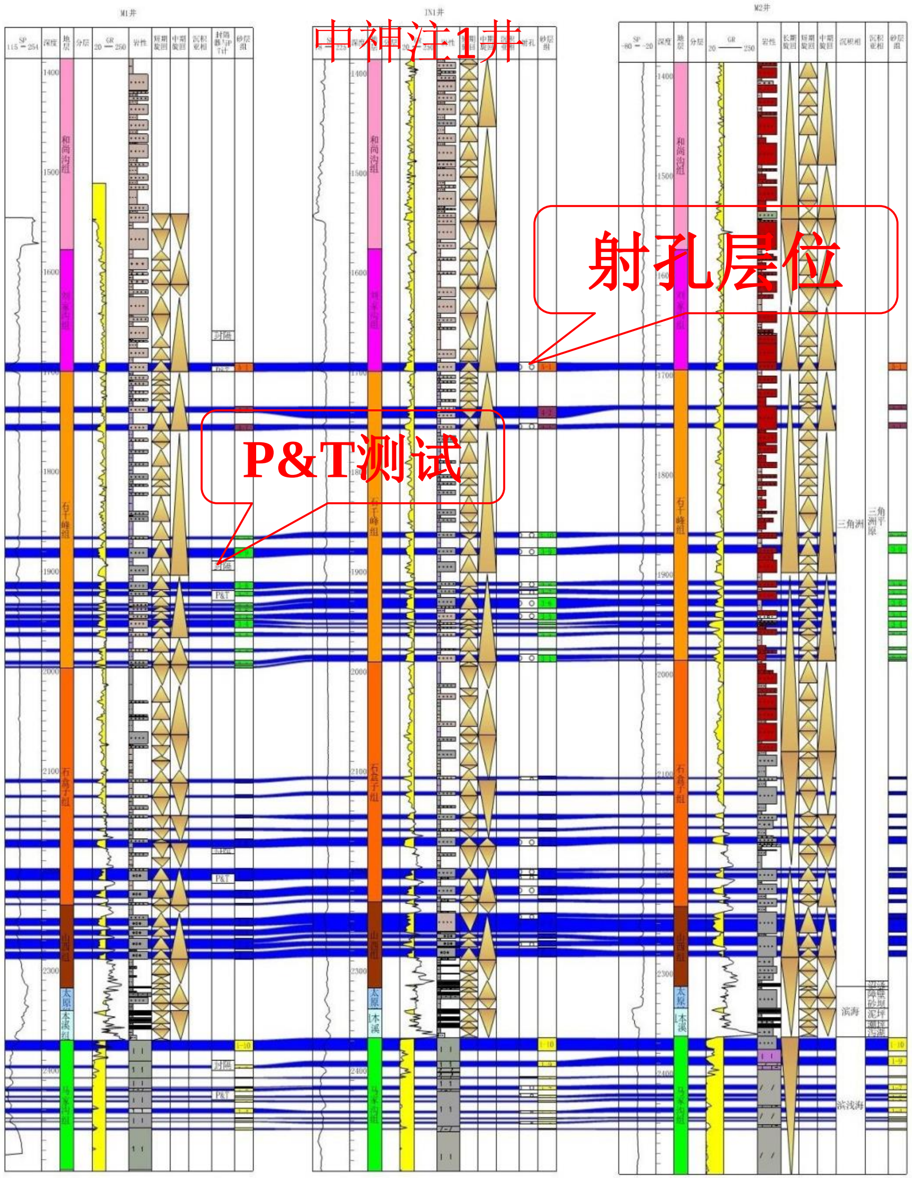


porosity



permeability

4.3 Reservoirs—High resolution sequence stratigraphic analysis



高分辨率层序地层分析

层位	序号	射孔井段（m）	厚度（m）	孔隙度（%）	渗透率 $\times10^{-3}\ \mu m^2$	解释结论	所属砂层组
刘家沟组	1	1690.0-1699.0	9	10.6	2.81	水层	5
石千峰组	1	1751.4-1756.8	5.4	12.4	5.47	水层	
	2	1860.4-1866.0	5.6	9.3	1.57	水层	4
	3	1876.0-1883.6	7.6	5	0.1	水层	
	4	1909.8-1915.2	5.4	9.6	1.77	水层	
	5	1918.4-1922.8	4.4	10.2	2.36	水层	
	6	1926.2-1936.6	10.4	6.1	0.24	干层	3
	7	1940.6-1947.8	7.2	11.2	3.52	水层	
	8	1982.8-1990.0	7.2	12.9	6.58	干层	
石盒子组	1	2105.8-2109.0	3.2	12.6	5.99	干层	
	2	2167.0-2175.6	8.6	12	4.67	水层	
	3	2197.8-2203.4	5.6	8.8	1.23	干层	
	4	2204.6-2208.2	3.6	12.2	5.03	水层	2
	5	2215.0-2223.6	8.6	8.0	0.79	干层	
山西组	1	2243.6-2247.8	4.2	12.5	5.7	水层	
	2	2271.2-2275.6	4.4	11.3	4.48	水层	
马家沟组	1	2406.2-2407.0	0.8	3.3	/	II级裂缝	
	2	2415.0-2419.0	4	5.6	/	II级裂缝	
	3	2423.4-2426.4	3	5	/	I级裂缝	1
	4	2440.0-2442.4	2.4	5.5	/	II级裂缝	
	5	2451.0-2453.0	2	5.1	/	II级裂缝	

Perforated intervals：21层，3 dry layers

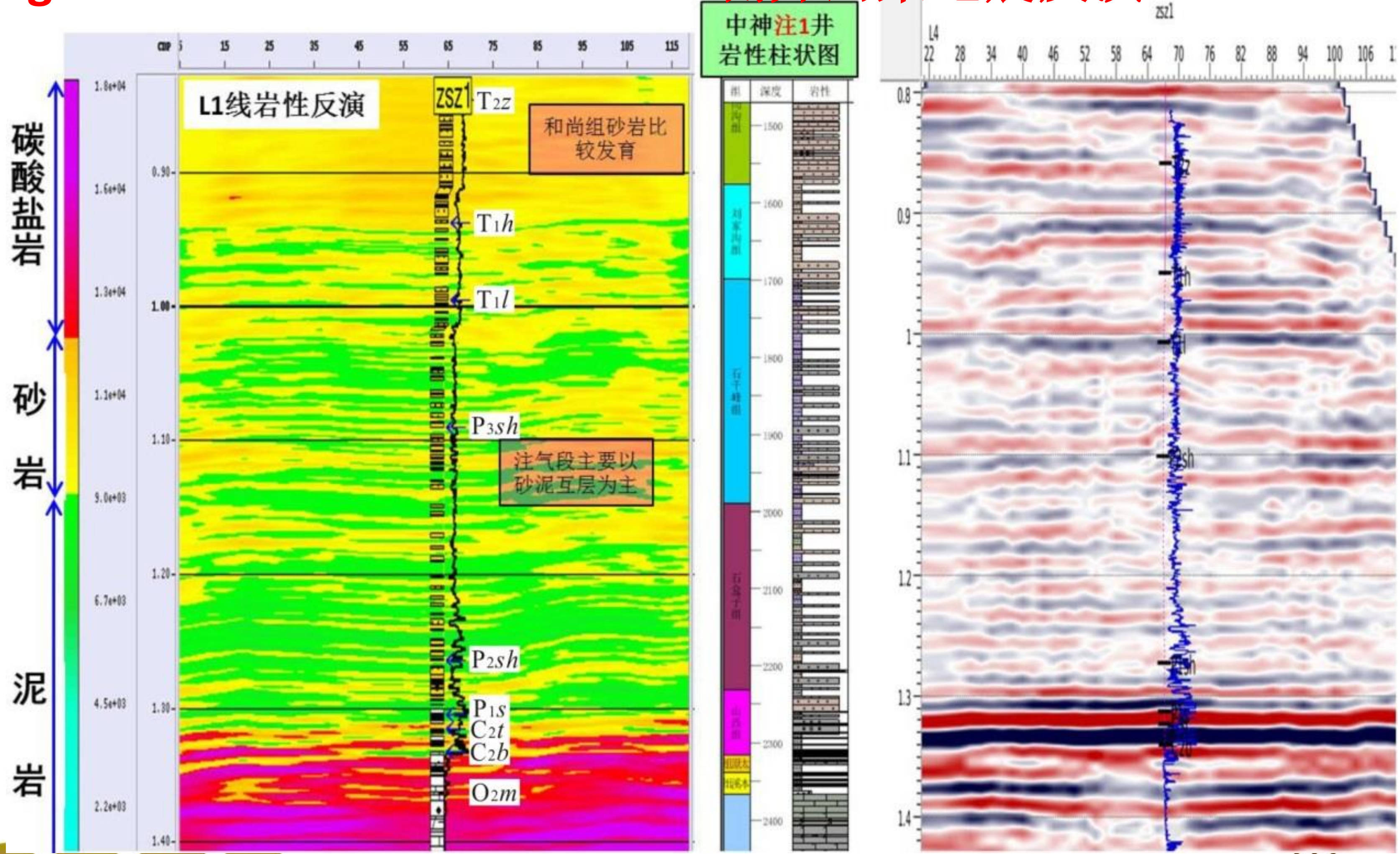
4.3 Reservoirs

Aquifer groups	Formation	Lithology and layer nambers		Total thickness/m
5	Bottom of Liujiagou	Sandstone	1	9
4	Upper Shiqianfeng	Sandstone	2	17
3	Middle and lower shiqianfeng	Sandstone	10	56
2	Shanxi—Shihezi	Sandstone	10	85
1	Majiagou	Carbonate rocks	10	36

- 本溪组底部发育的残积成因的铝土质页岩，上石盒子组和石千峰组中部发育厚度较大的泥岩和粉砂质泥岩，为中间盖层
- 由于示范工程各套储层CO2实施统注，刘家沟组中上部和和尚沟组整体以泥岩和砂质泥岩为主，可作为示范工程有效盖层封隔CO2泄露

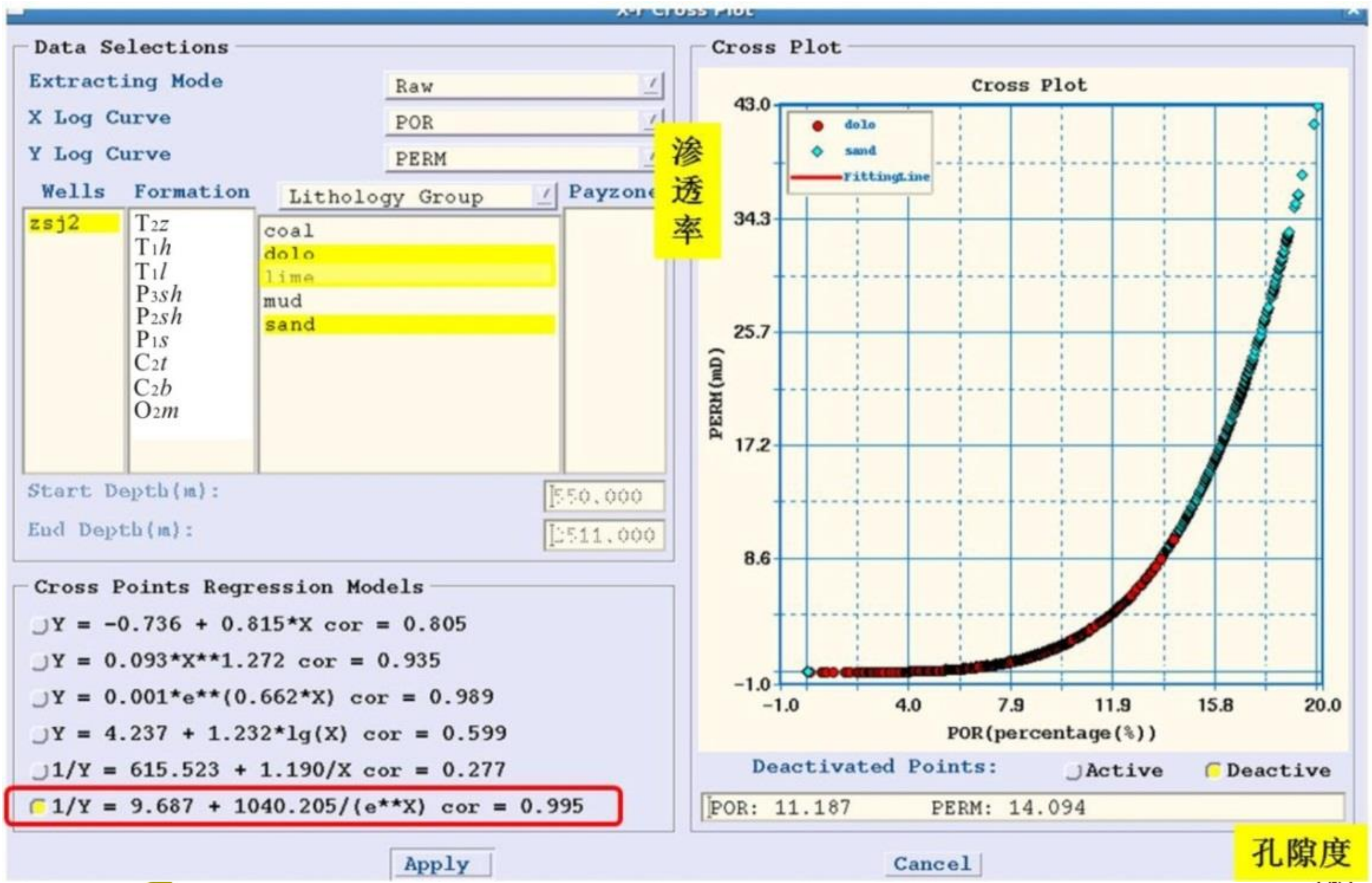
4.4 Lithology prediction

Log constrained seismic inversion测井约束地震反演

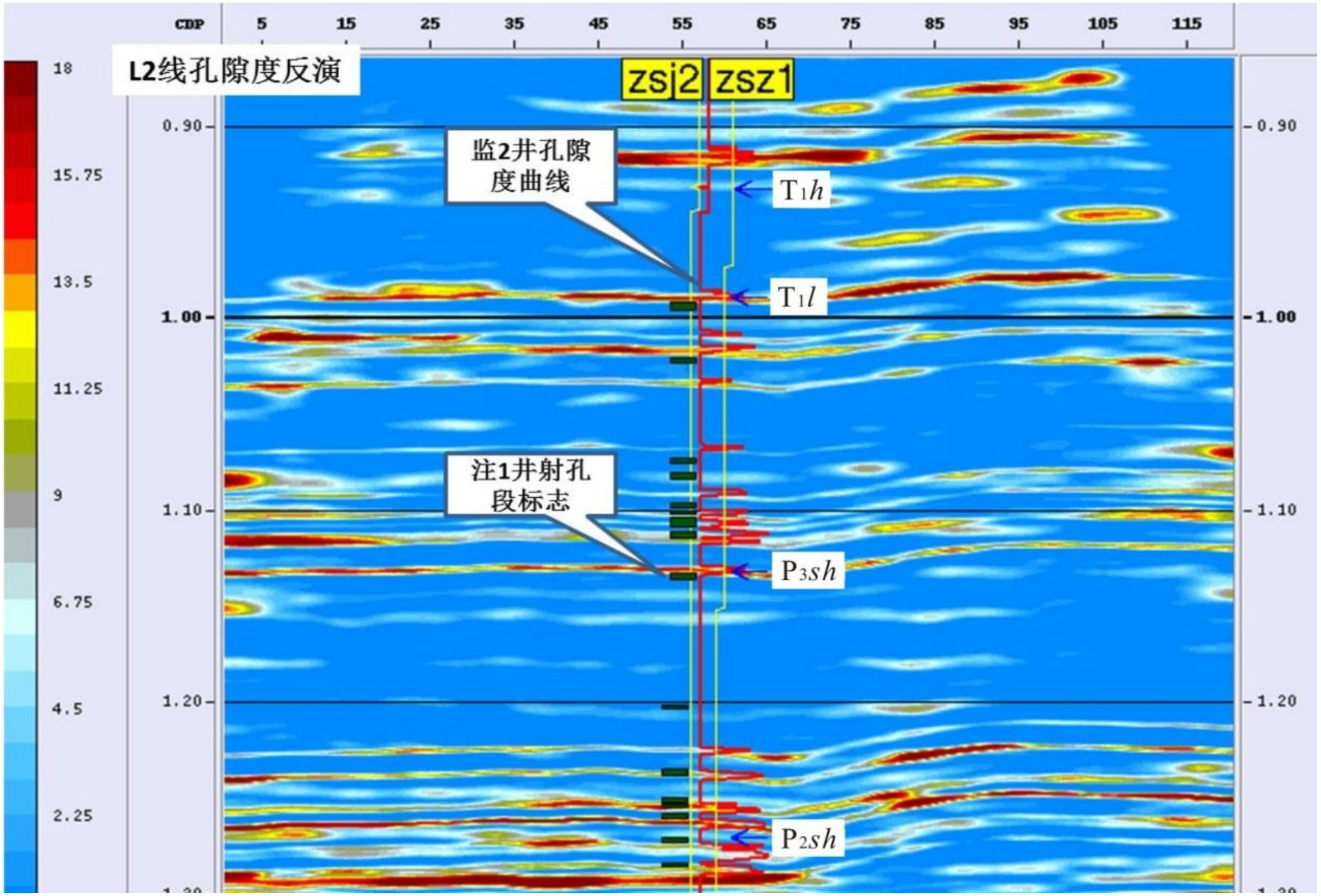


4.5 Porosity and permeability prediction

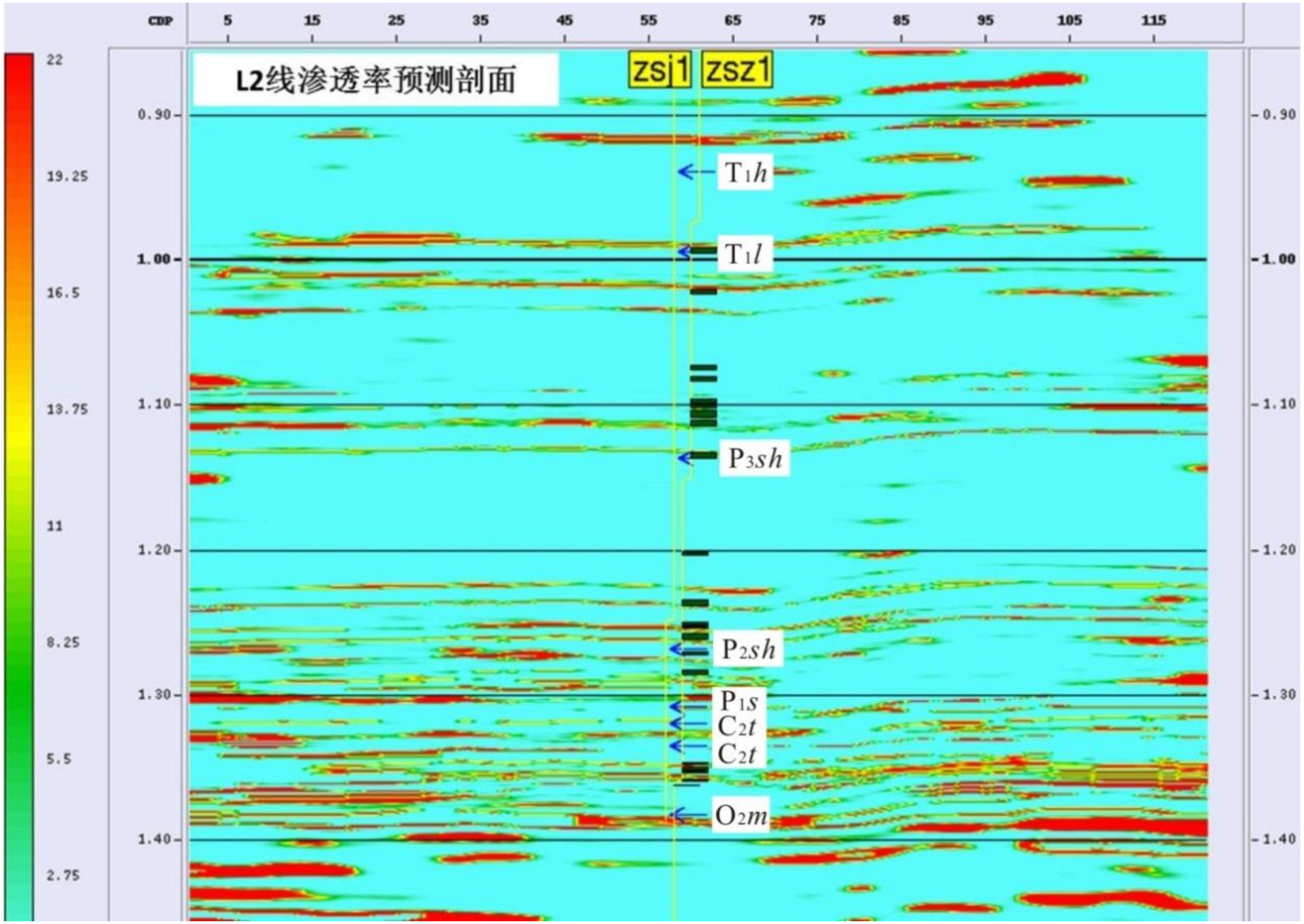
Log constrained seismic inversion测井约束地震反演



Porosity prediction

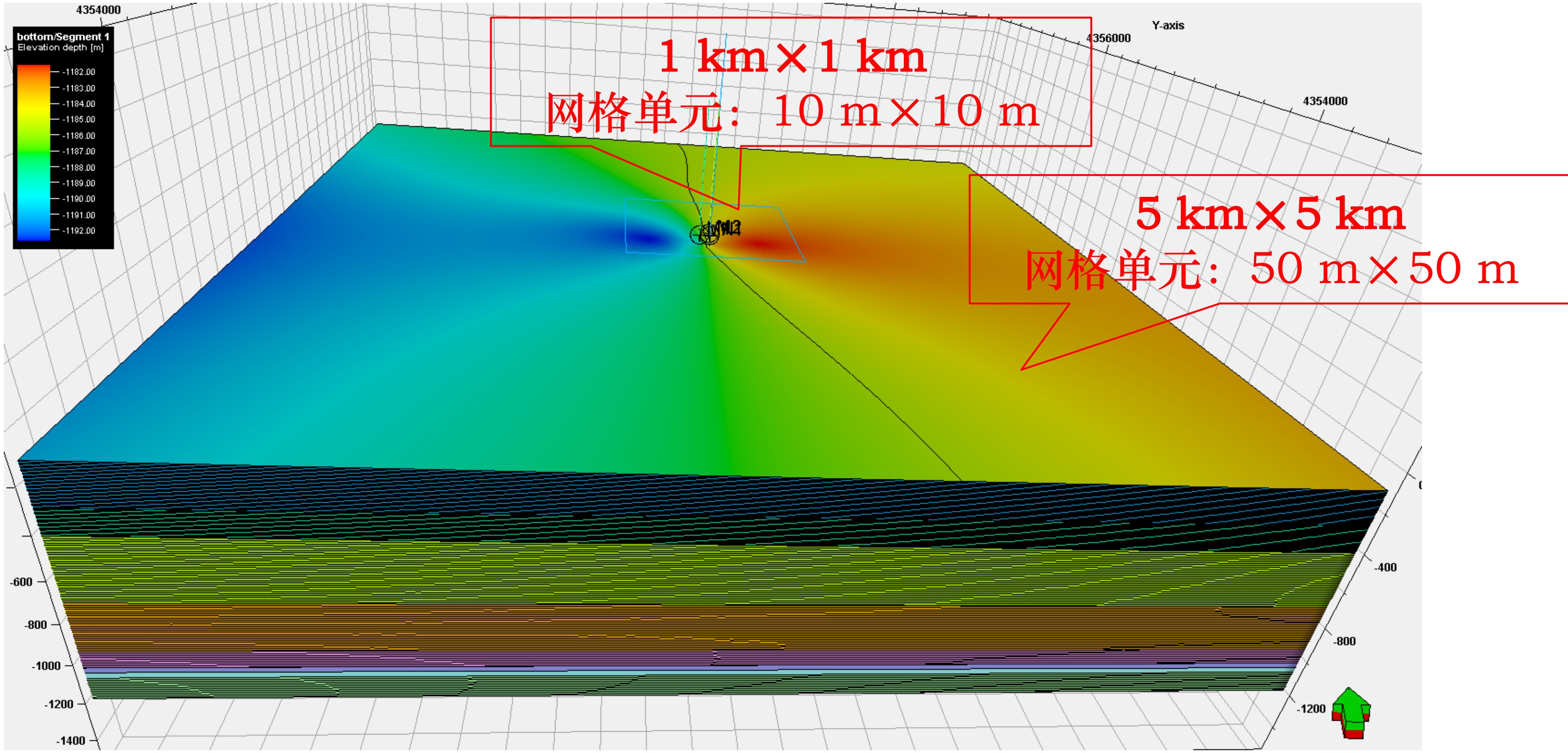


Permeability prediction

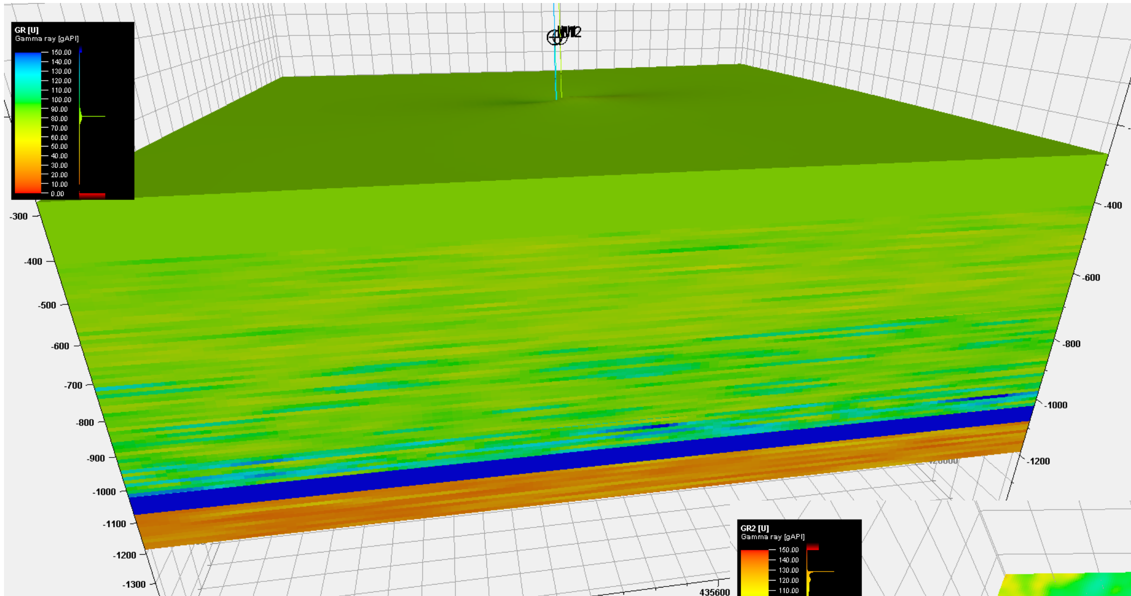


4.6 Geological modeling

- 建模软件：PETREL 2015 Geoscience Core模块
- 数据来源：钻井、测井、地震、实验等解释成果

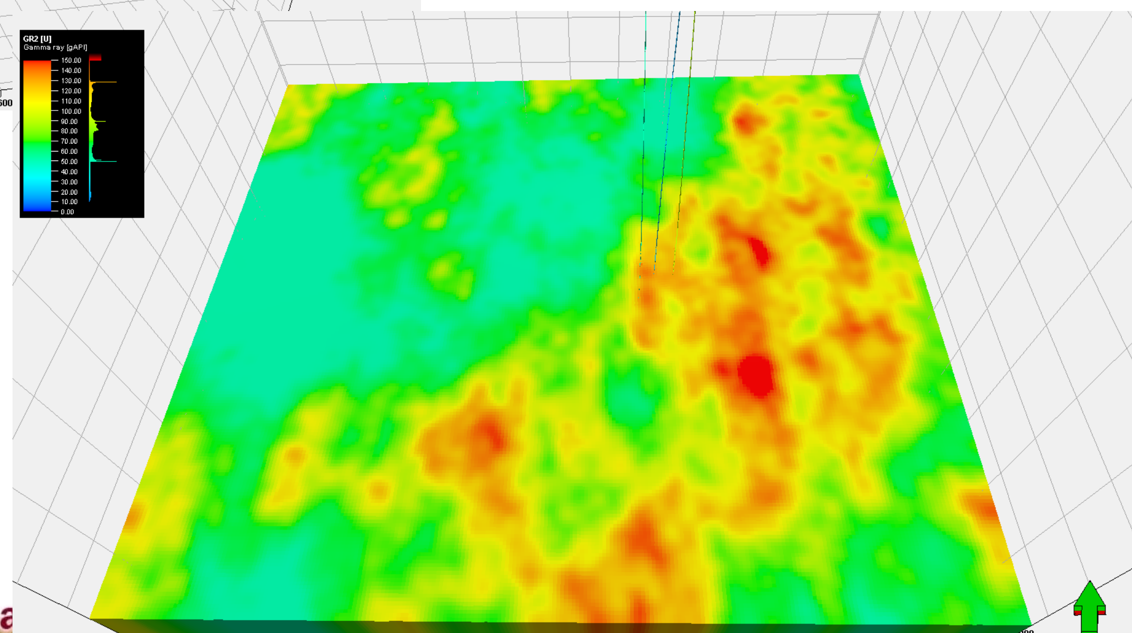


4.6 Geological modeling

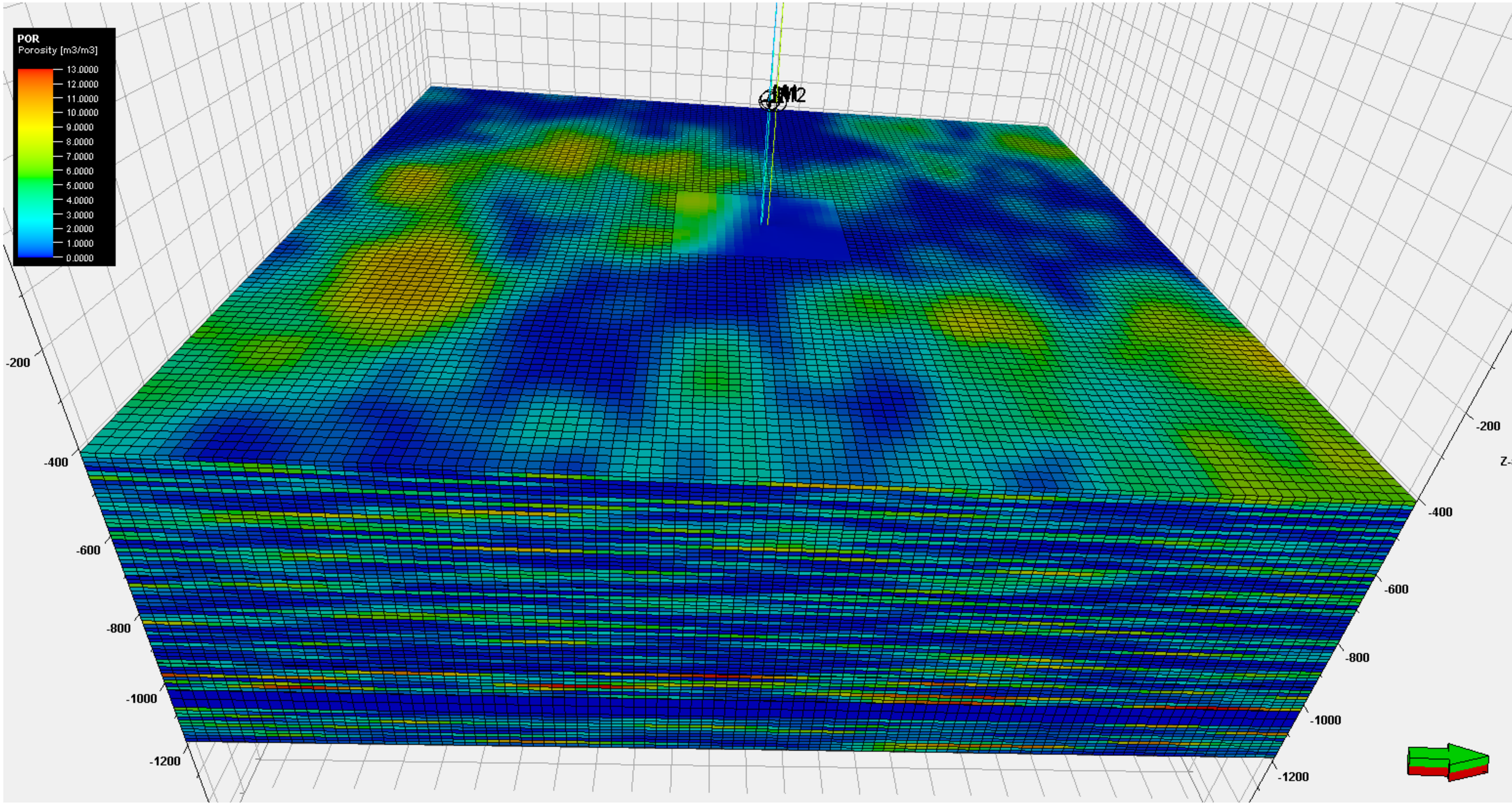


Lithological model

Shanxi Formation

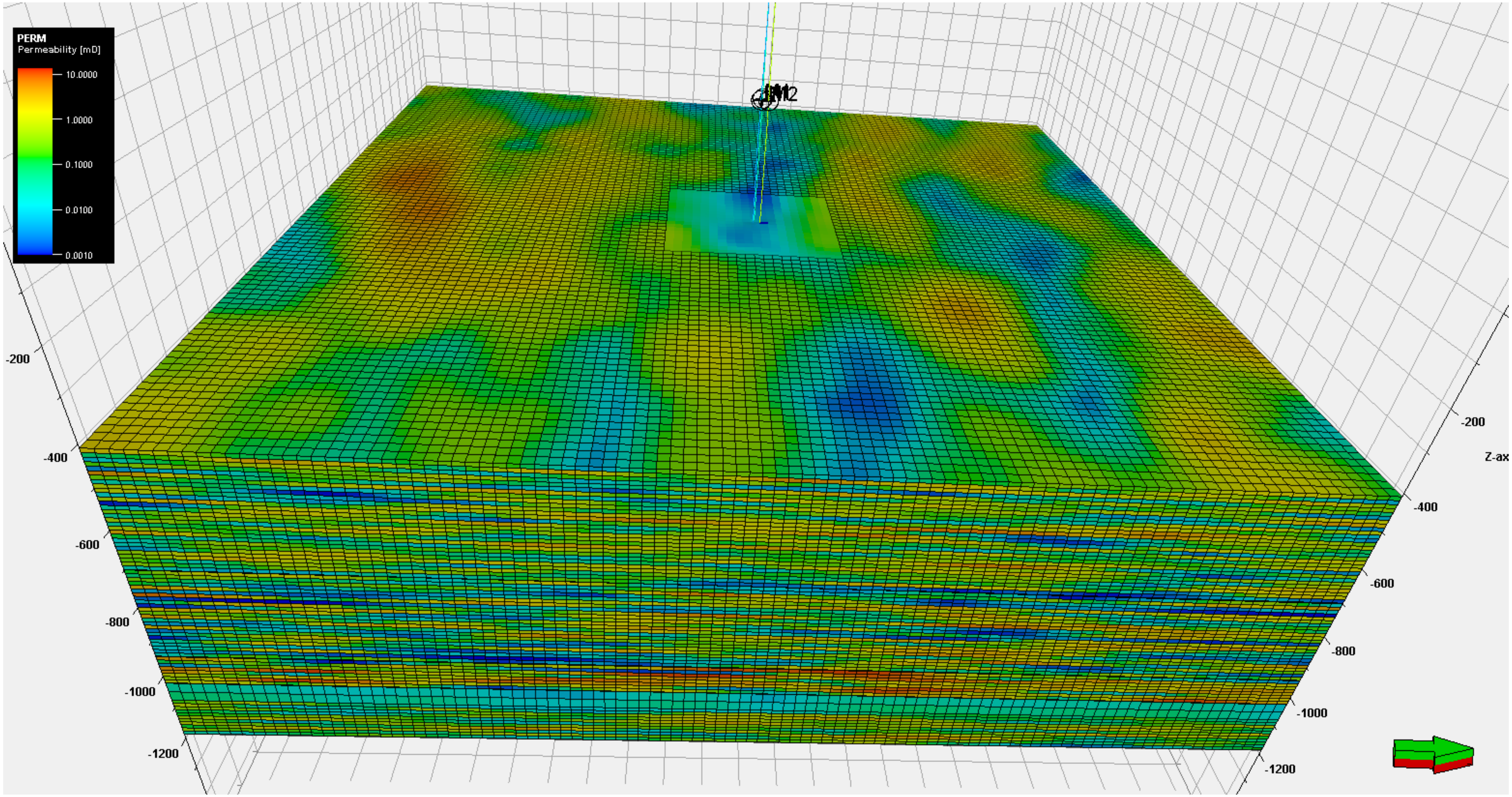


4.6 Geological modeling



Porosity model

4.6 Geological modeling

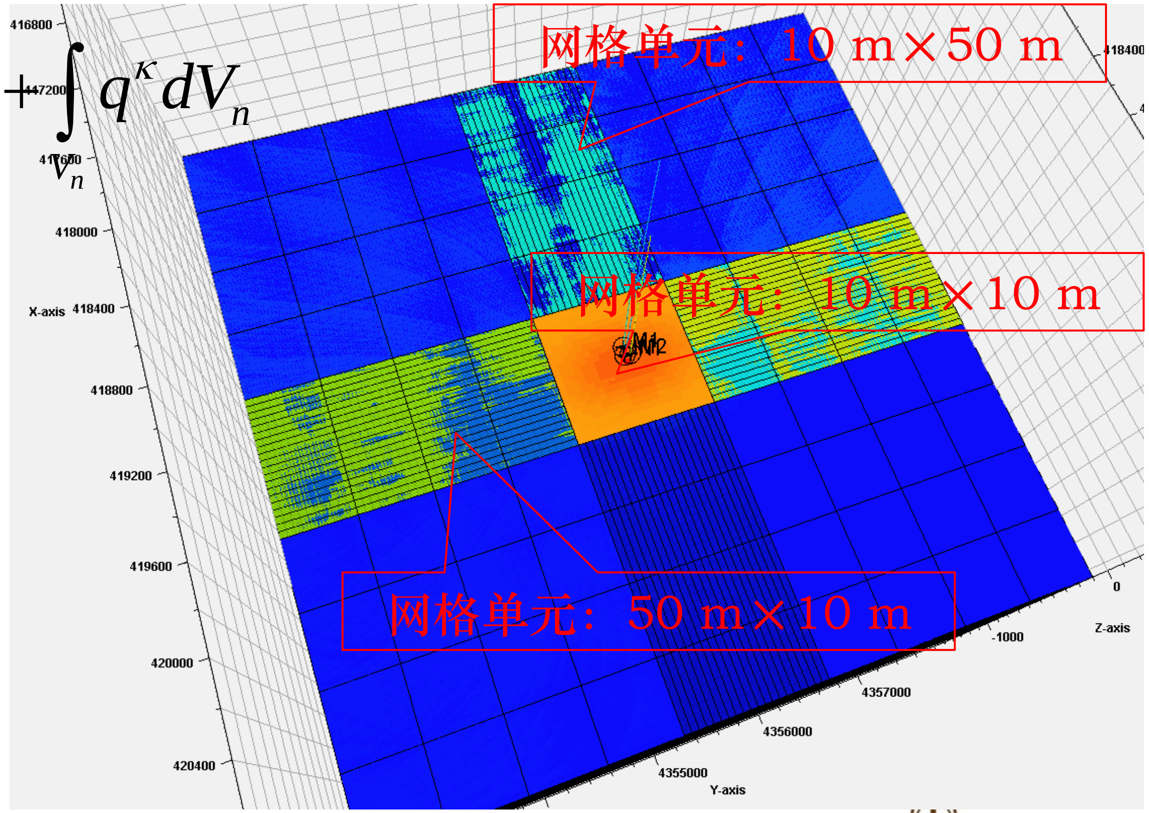


Permeability model

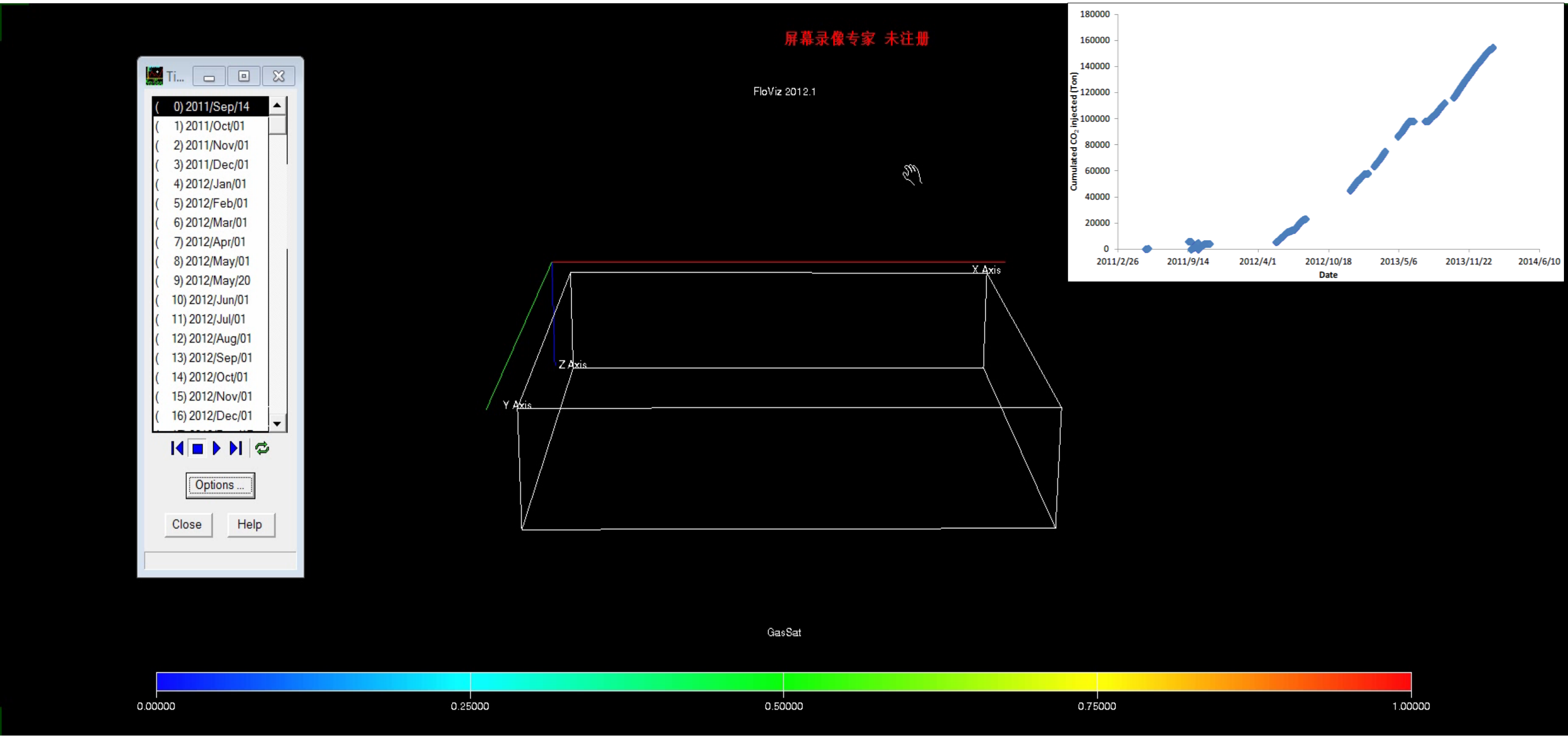
4.7 Numerical simulation

- 模拟软件：ECLIPSE 300 CO2STORE模块
- 数学模型：达西定律物质-能量守恒方程

$$\frac{d}{dt}\int_{V_n} M^{\kappa} dV_n = \int_{\Gamma_n} \mathrm{F}^{\kappa} \cdot \mathrm{n} d\Gamma_n + \int_{V_n} q^{\kappa} dV_n$$



4.7 Numerical simulation



CO2 migration characteristics

Thanks for your attention