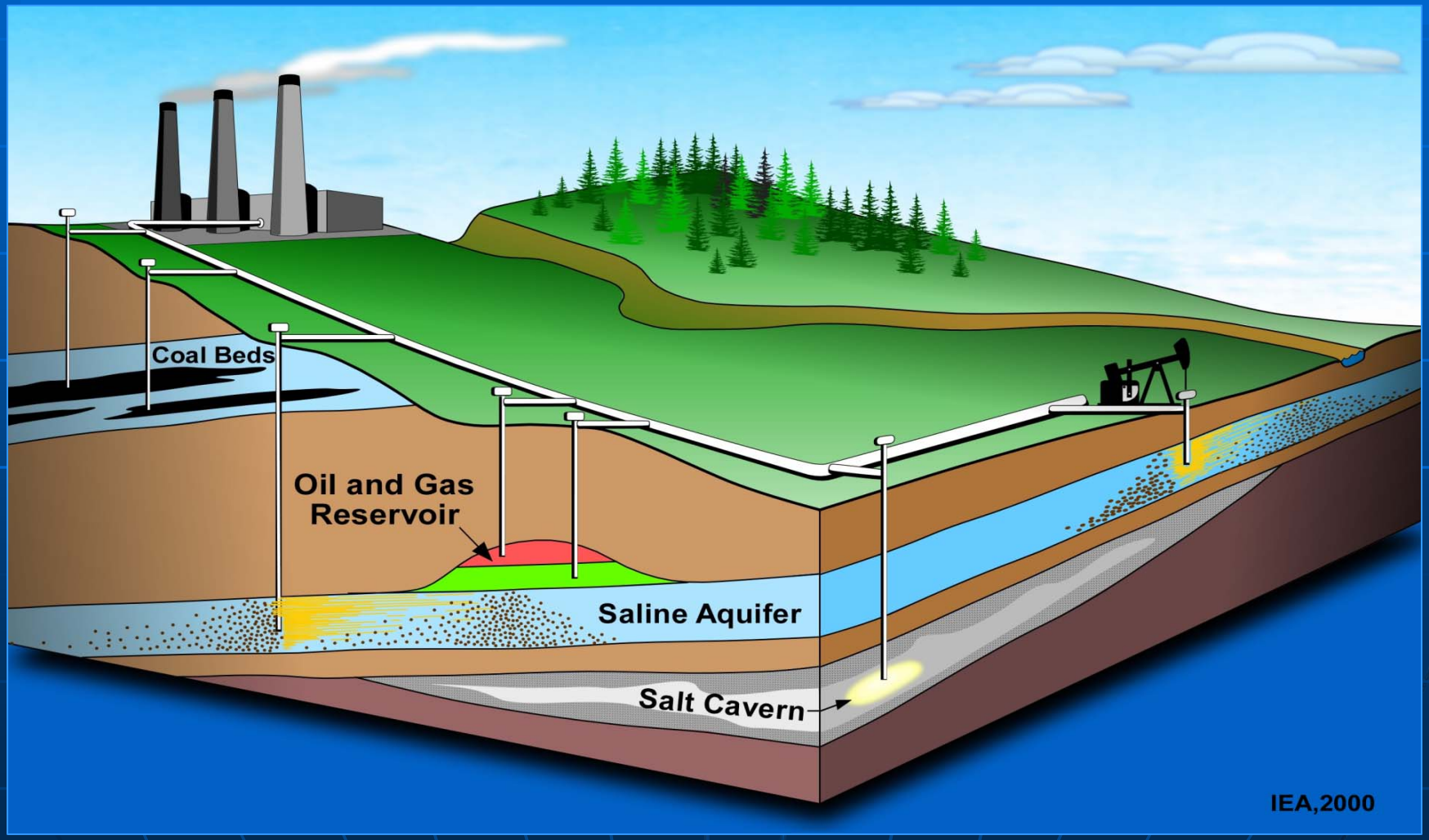
CO_2 sequestration in saline aquifers: the case of the Bohai Bay Basin

Prof. Dr. Pang Zhonghe
Institute of Geology and Geophysics, Chinese Academy of Sciences，Beijing, 100029 CHINA
z.pang@mail.iggcas.ac.cn
http://www.isoh2o.org/

Outline

- What's CO_2 Geological Sequestration ?
- Overview of CO_2 sequestration in China
- Case study—an example from the Bohai Bay Basin (BBB), China
- Future work: saline aquifer science

What's CO_2 Geological Sequestration ?



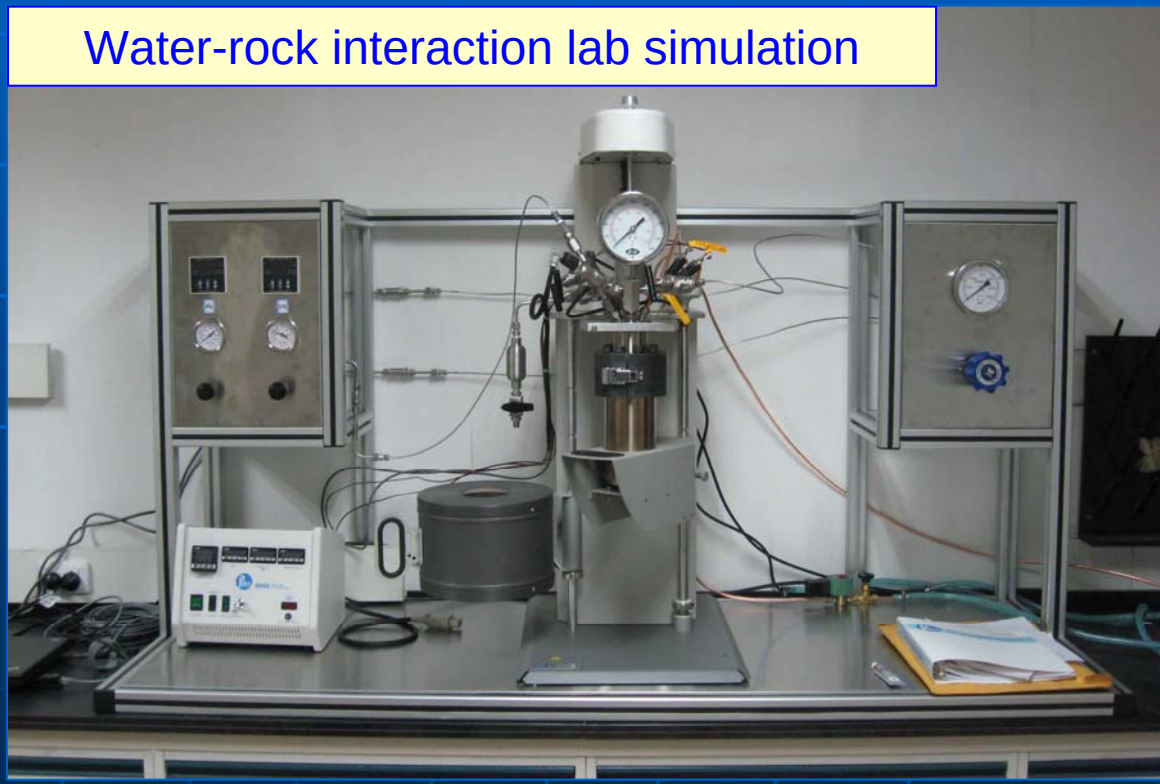
Overview of CO_2 saline aquifer sequestration in China

- Scientific research and field test on CO_2 geological sequestration
- CO_2 Geological Sequestration Atlas
- Projects of CO_2 sequestration in deep saline aquifers
- CO_2 Capture, Utilization and Sequestration (CCUS)

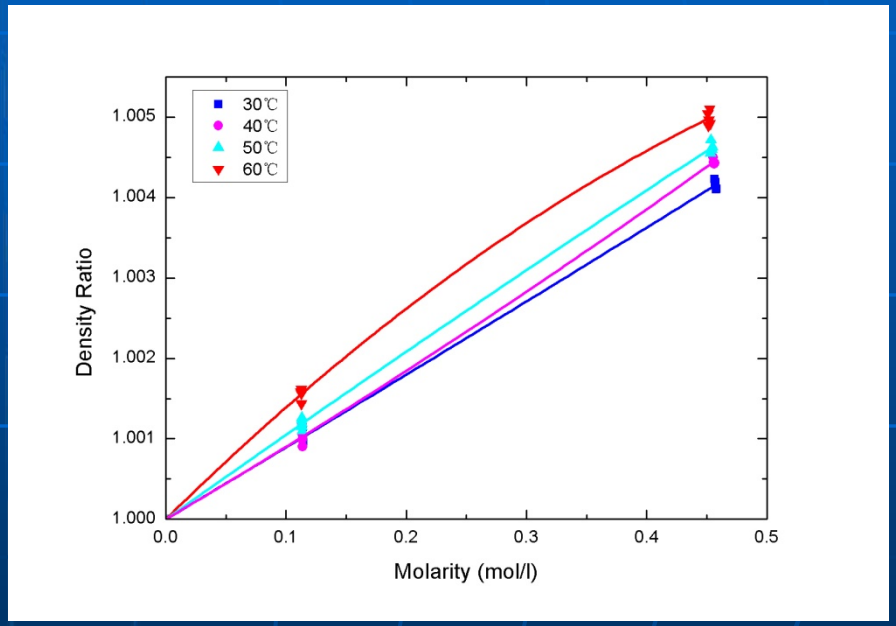
Scientific research on CO_2 geological sequestration

C-14 sampling at a test well

Water-rock interaction lab simulation

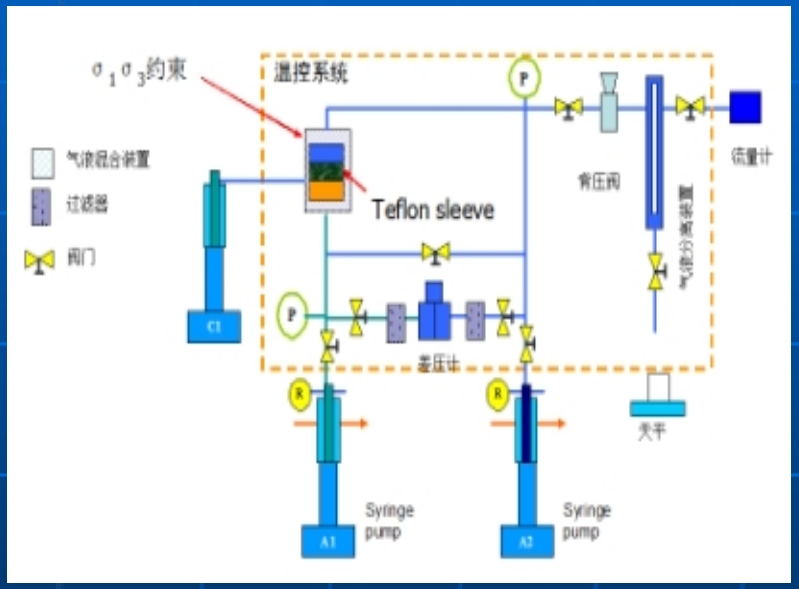


CO_2 solution: properties and transport at micro-scale and super-critical conditions



- Magneto-suspension balance

Cap-rock mechanics



- Bursting pressure

Natural analogue study ---CO_2 gas field

第 53卷 第 1期
2007年 1月

地 质 论 评 GEOLOGICAL REVIEW

Vol 53 No 1
Jan 2007

Characteristics and geological significance sandstone with dawsonite

含片钠铝石砂岩的基本特征及地质意义

Lithification of Dawsonite-Bearing Sandstone in the Qingshankou Formation in the Qian'an Oil Field of the South Songliao Basin

LI Fu-lai[1], LIU Li[1], YANG Hui-dong[1,2], QU Xi-yu[1], LIU Na[1], ZHAO Guo-xiang[1]

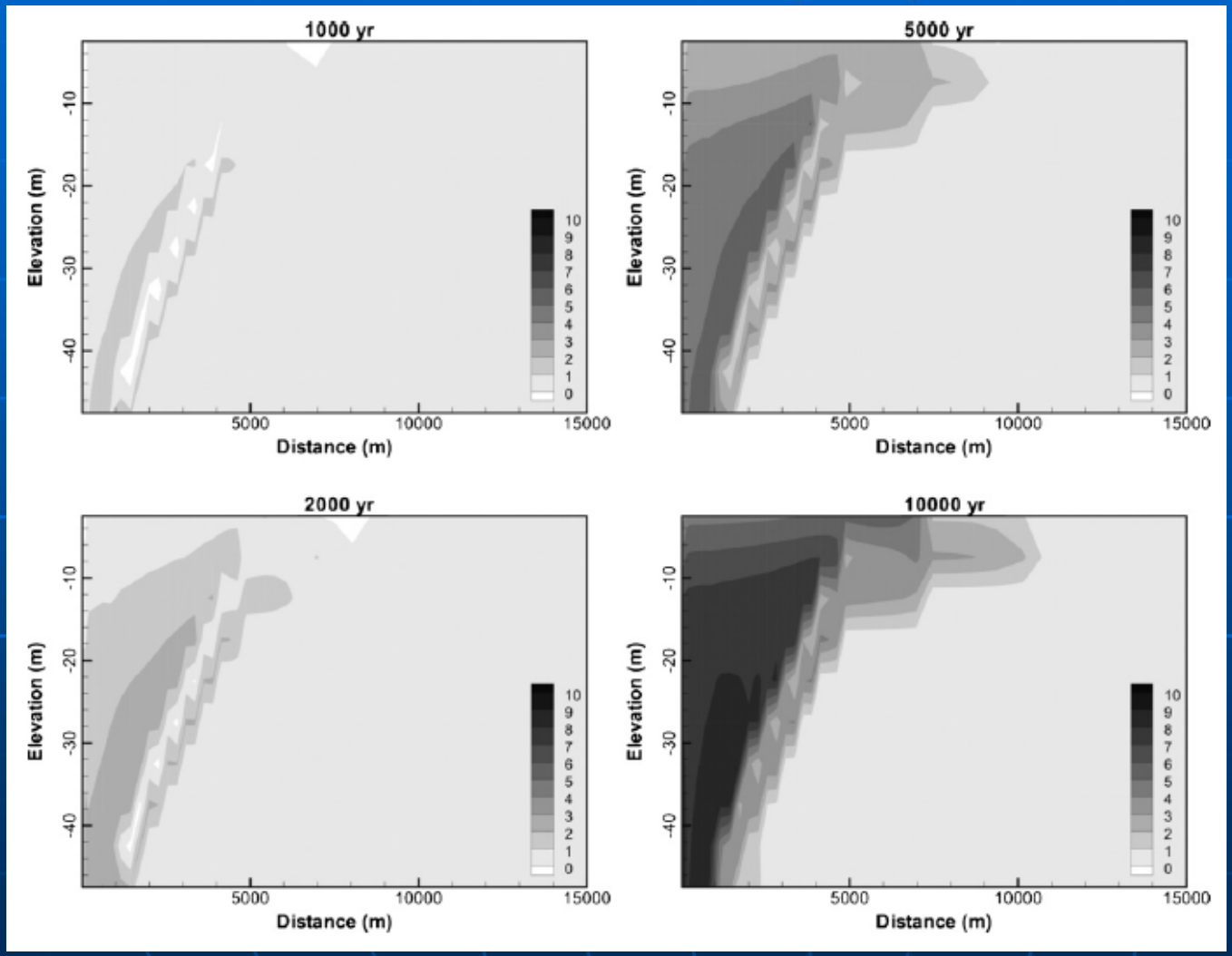
Characteristics and Stability Analysis of Dawsonite in Sandstone

QU Xiyu[1)], LIU Li[1)], GAO Yuqiao[2)], LIU Na[1)], PENG Xiaolei[1)]

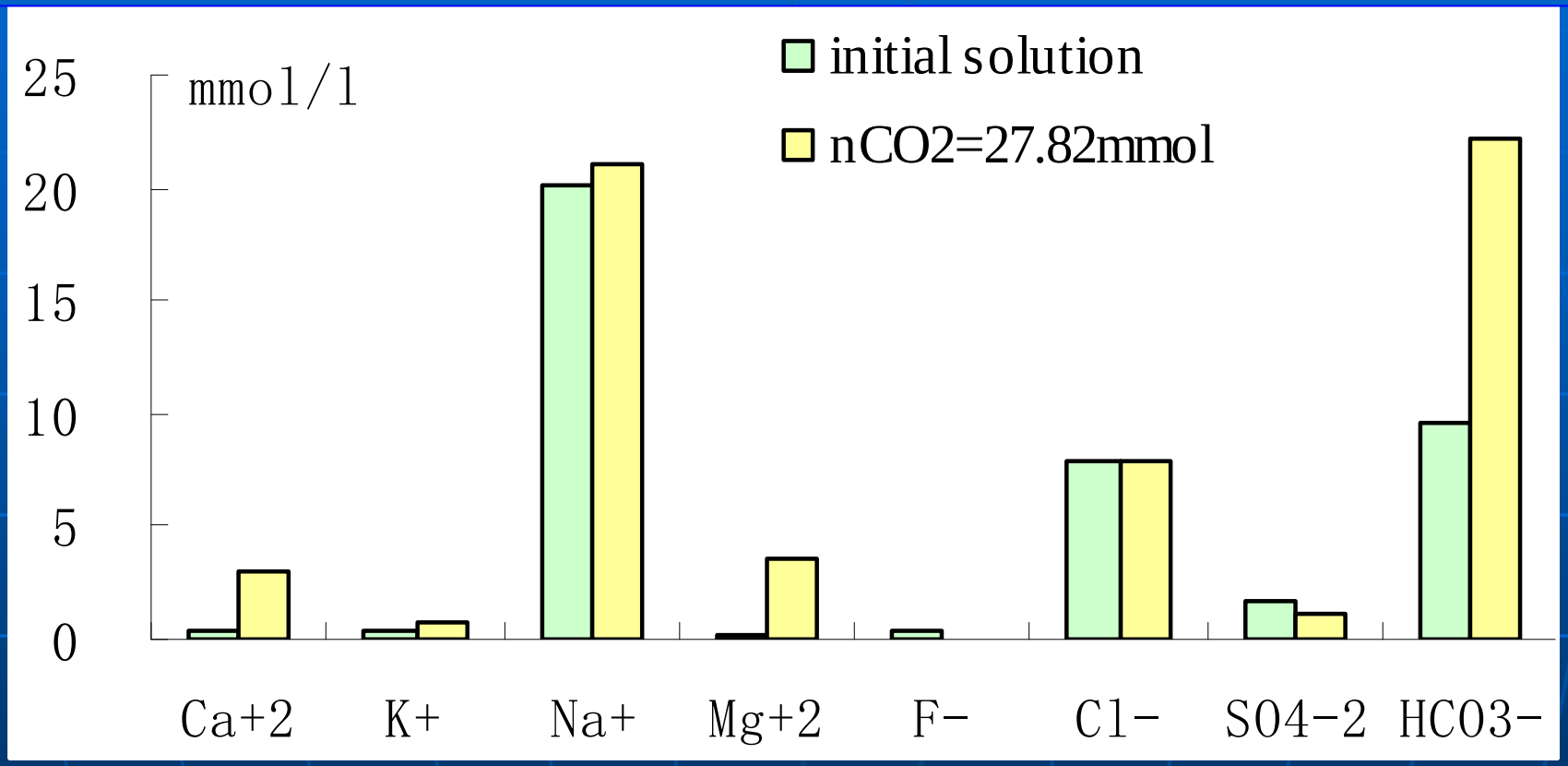
1) *College of Earth Sciences, Jilin University, Changchun,* 130061;

2) *State Key Laboratory for Mineral Deposit Research, Department of Earth Sciences, Nanjing University, Nanjing,* 210093

CO_2 sequestration numerical simulation



Spatial distribution of CO_2 mineral trapping per m3 media , from W. Zhang et al., 2009



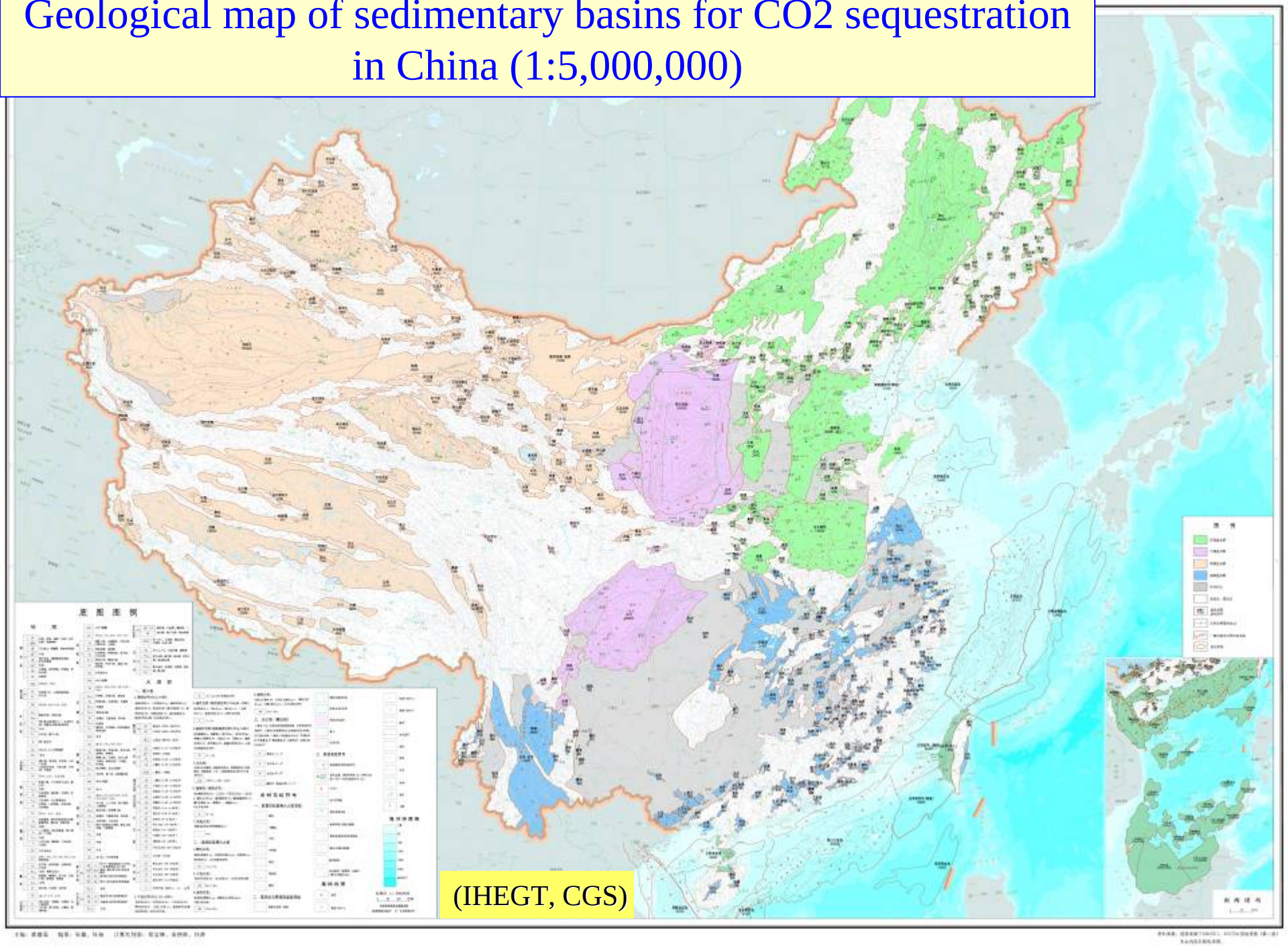
Changes of chemical constitutes of formation before and after CO_2 injection, Y. Li et al., 2010

CO_2 Geological Sequestration Atlas

The National CO2 Storage Capacity and Suitability Assessment Project which is in charged by the Institute of Hydrogeology and Engineering Geology Techniques, Chinese Geological Survey is implemented since 2010.

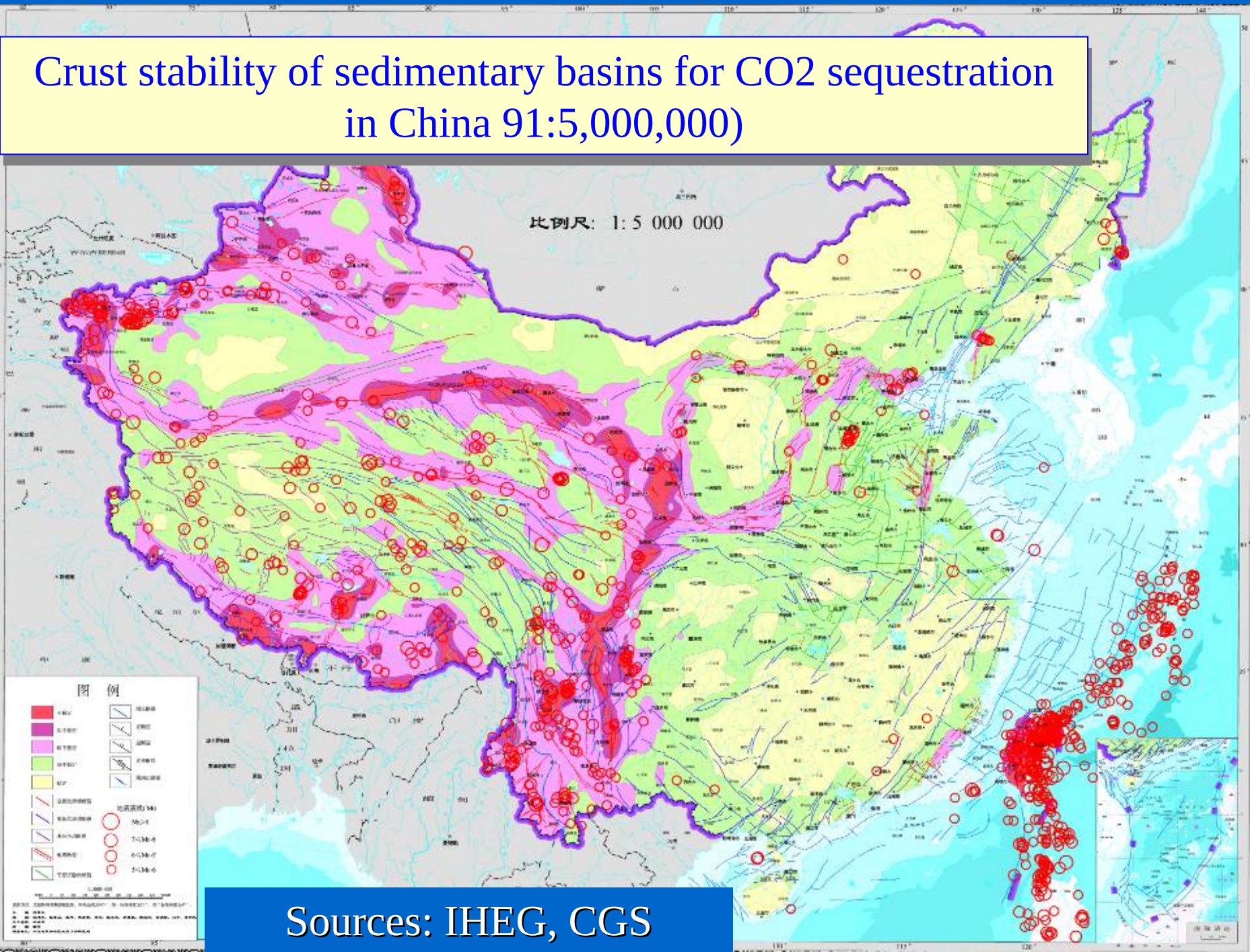
- National CO2 storage capacity and suitability assessment and mapping (1:5,000,000)
- Candidate sedimentary basins for CO2 sequestration assessment and mapping (1:1,000,000);
- Demonstration project of CO2 sequestration in deep saline formation in Ordos basin

Geological map of sedimentary basins for CO2 sequestration in China (1:5,000,000)



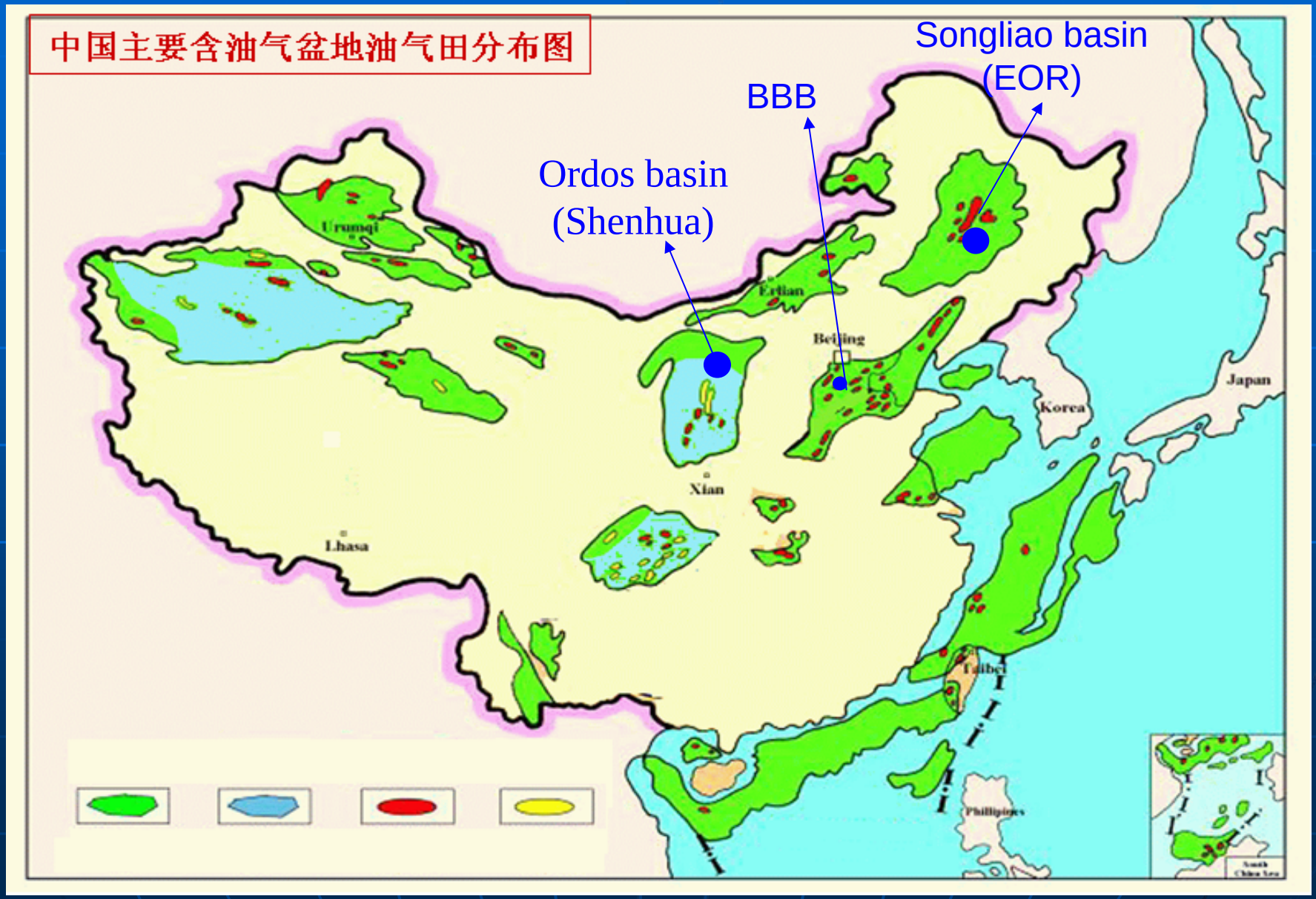
(IHEGT, CGS)

Crust stability of sedimentary basins for CO2 sequestration in China 91:5,000,000)



Sources: IHEG, CGS

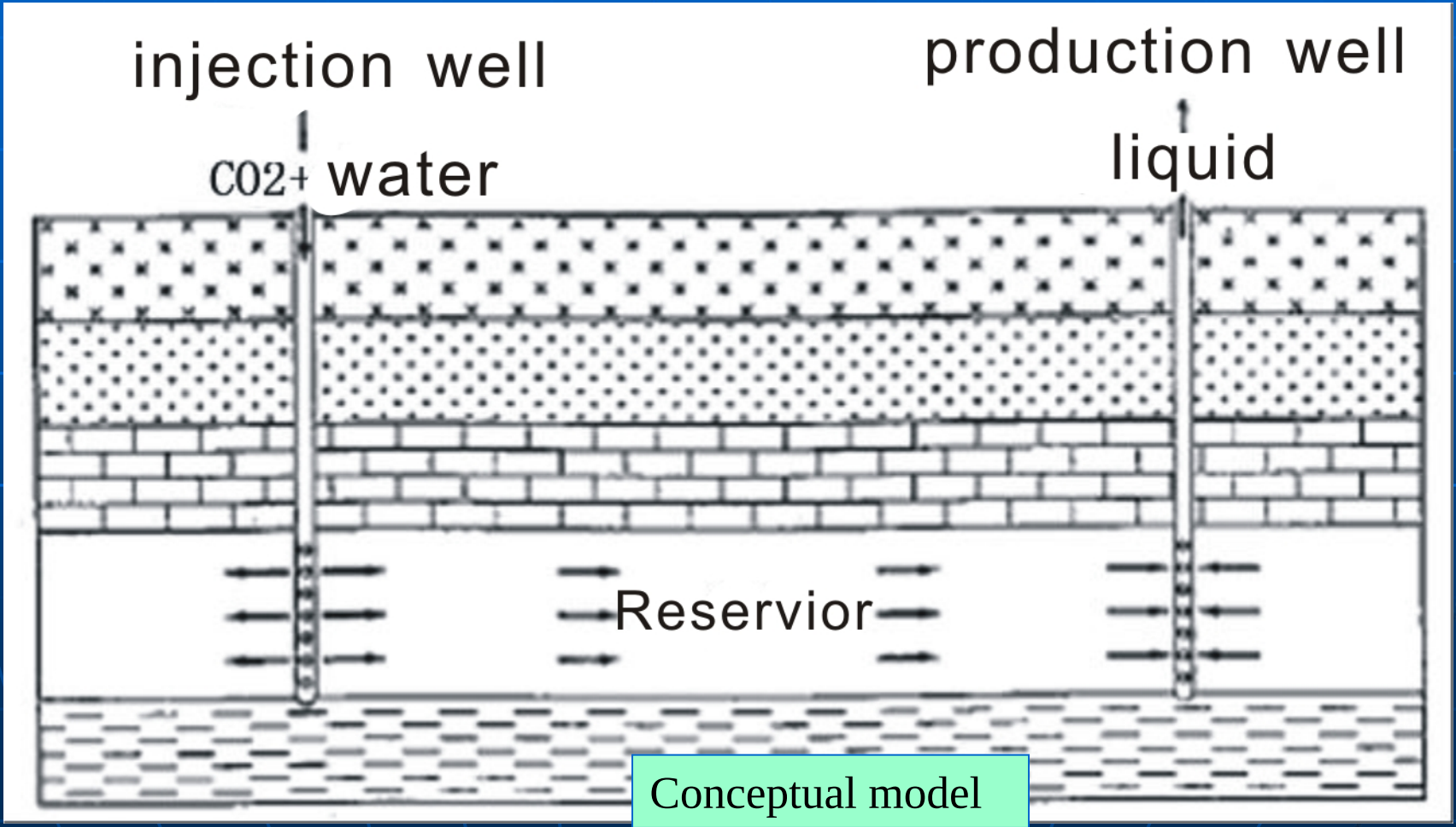
CO_2 sequestration in deep saline aquifers



CO_2 Capture, Utilization and Sequestration (CCUS) progresses

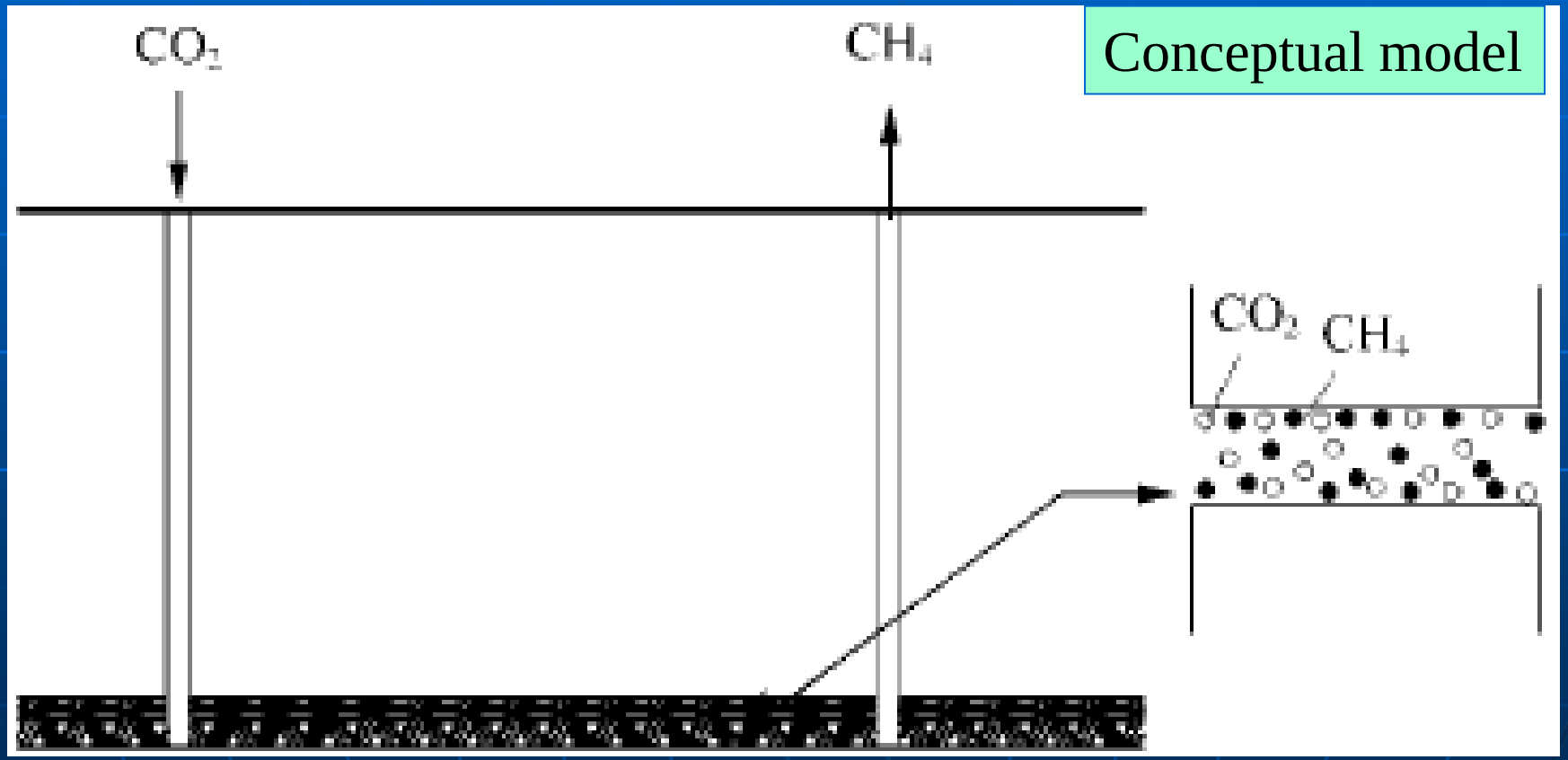
- CO2-EOR (e.g. Songliao basin)
- CO2-ECBMR (e.g. Qinshui basin)
- CO2 capture progresses in Clean Coal Technology (HuaNeng) and Transformation from coal to oil technology (ShenHua)
- CO2-EATER

CO2-EOR



Conceptual model

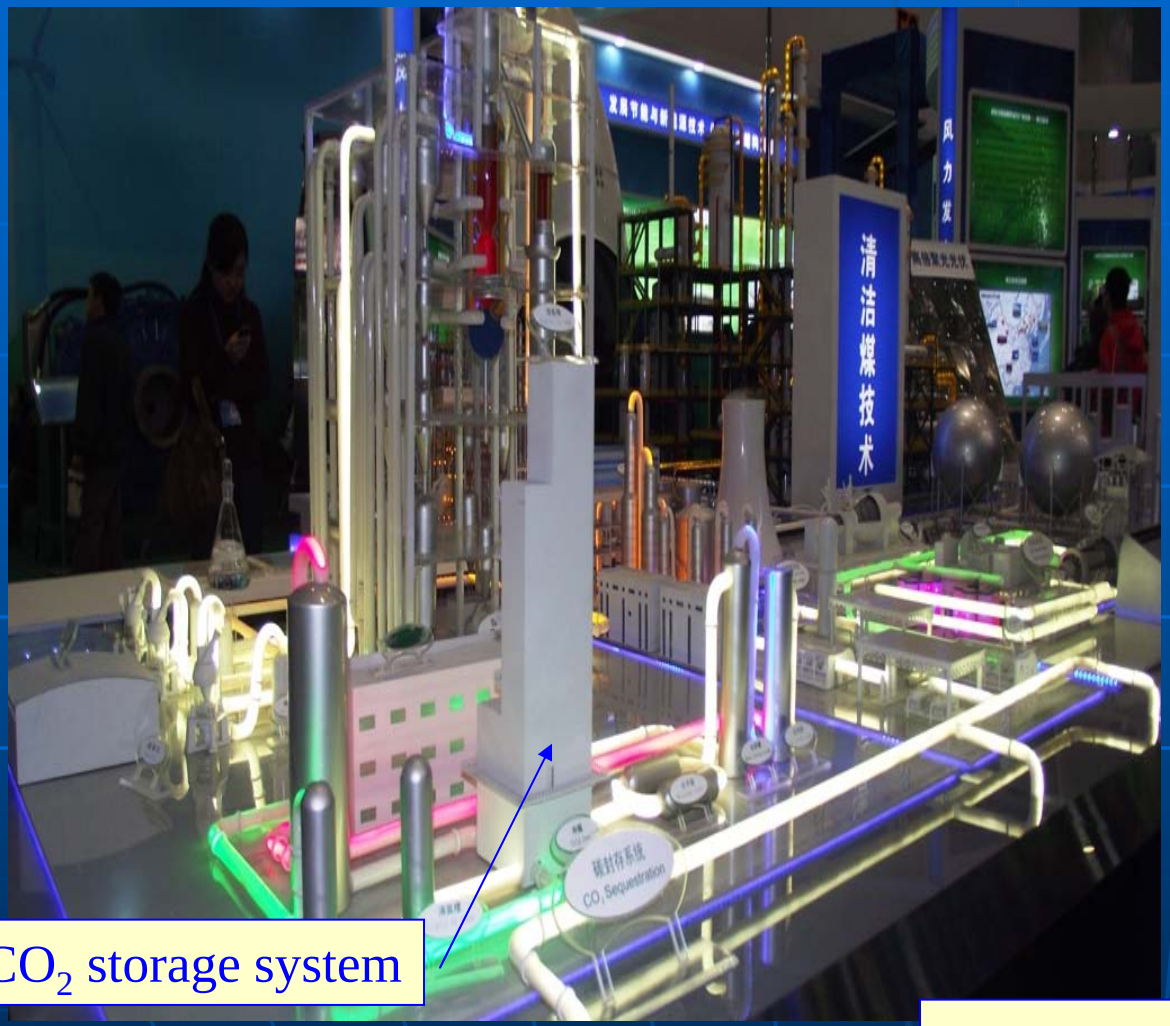
CO2-ECBMR



CO_2 capture progresses (HuaNeng)

Greengen group Ltd.: IGCC Power Plant 2011-2016, 250MW

IGCC conceptual model



CO_2 storage system

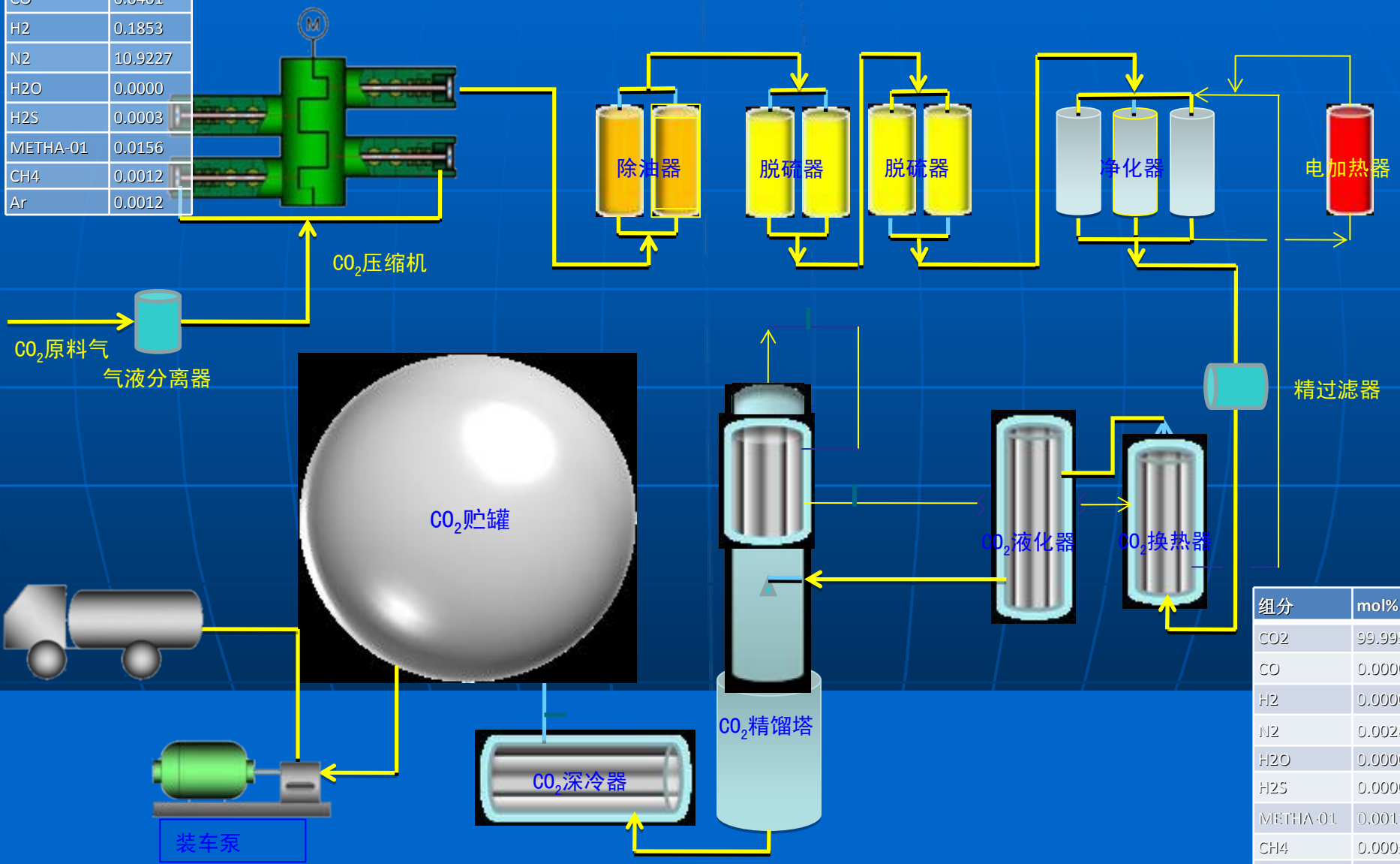
CO_2 capture demonstration project

Clean Coal Technology , from National Science Exhibition of

The Eleventh Five Year Plan

CO_2 Capture technology (ShenHua)

组分	mol%
CO2	88.8336
CO	0.0401
H2	0.1853
N2	10.9227
H2O	0.0000
H2S	0.0003
METHA-01	0.0156
CH4	0.0012
Ar	0.0012



组分	mol%
CO2	99.9954
CO	0.0000
H2	0.0000
N2	0.0028
H2O	0.0000
H2S	0.0000
METHA-01	0.0011
CH4	0.0005
Ar	0.0001

CO2-EATER

Field verification for CO2-EATER is ongoing.

Case study – Guantao saline aquifer in the Bohai Bay Basin (BBB), China

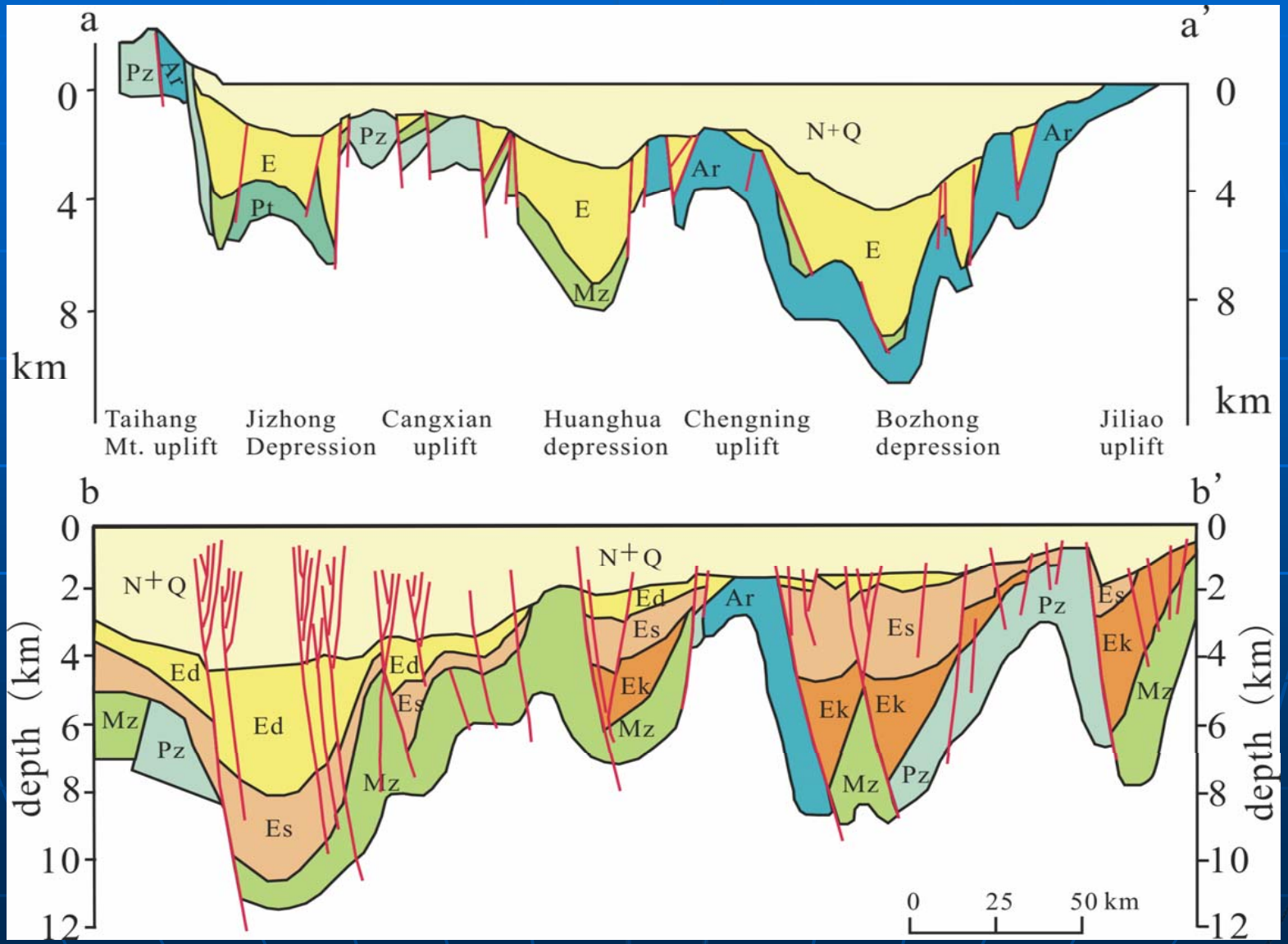
Location of the BBB

Latitute:35° ～42 ° 20′

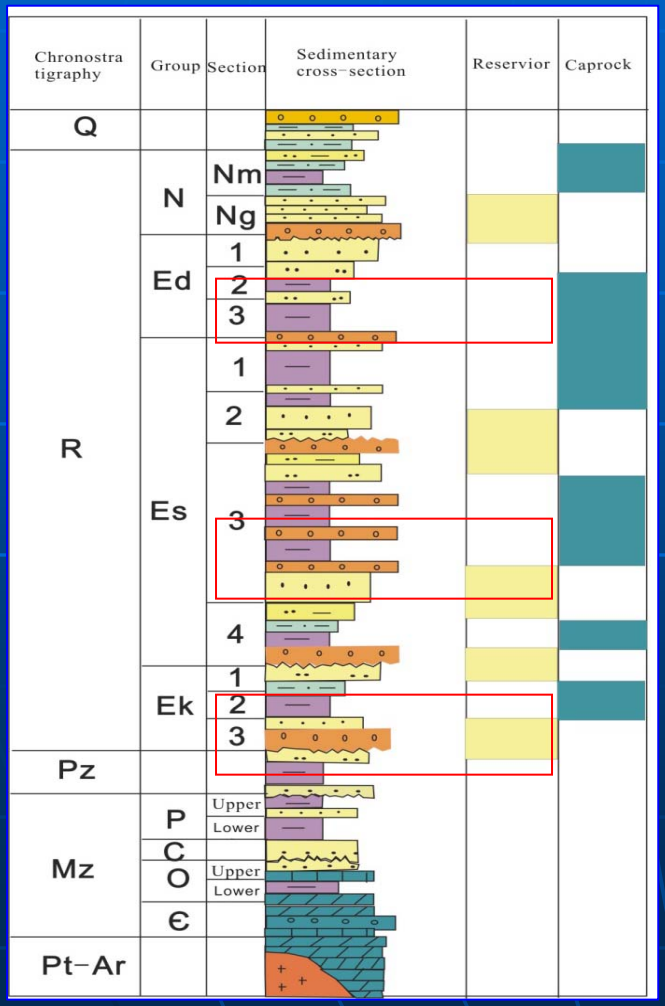
Longitude: 114° 30′ ～ 124°

Area: 200,000km^2 , and 40% are offshore

Geological cross section of the BBB



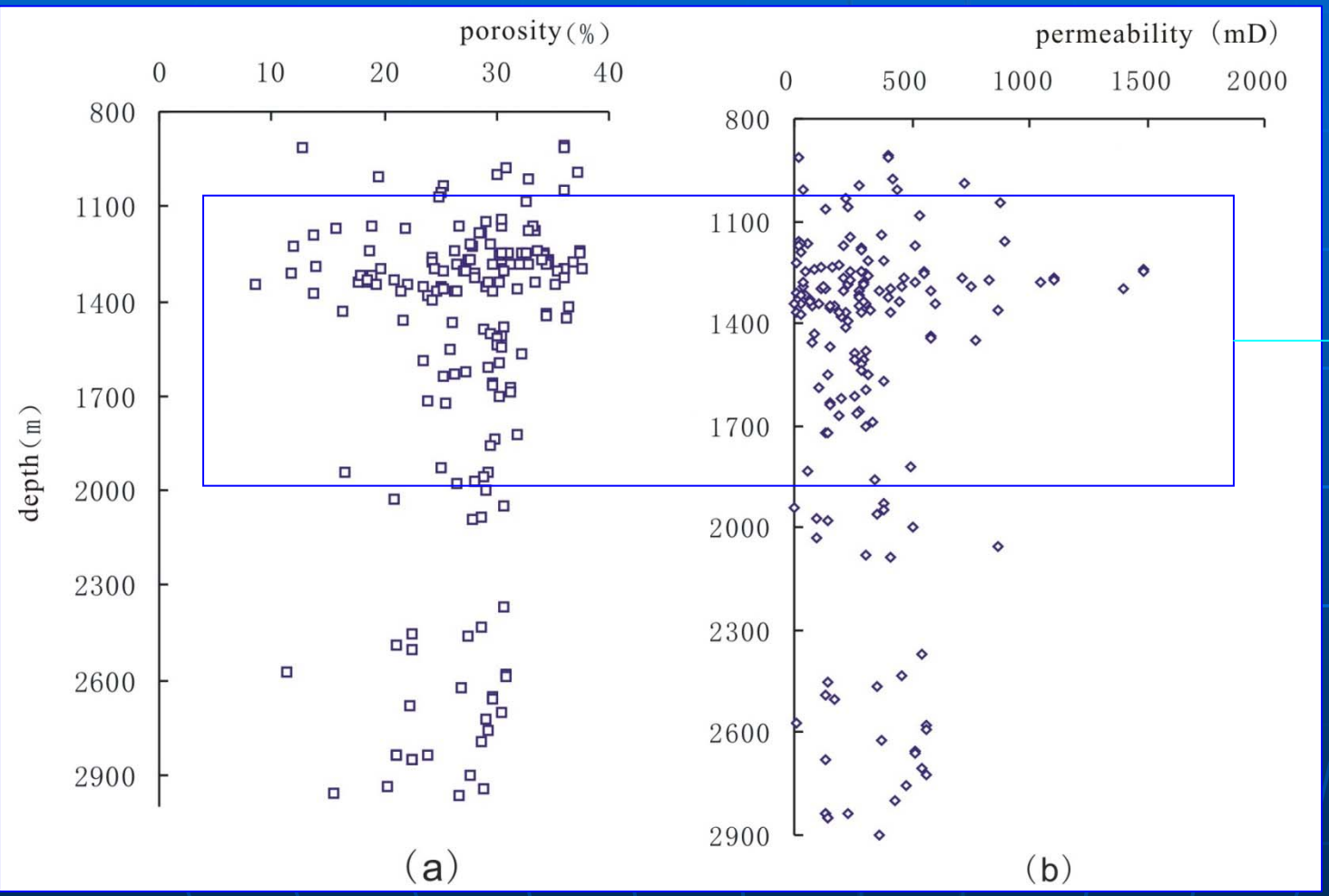
CO_2 storage capacity assessment of deep saline formations in the BBB



The suitable reservoir formations of each depression

Name of Depression	Target evaluation formation	Remarks
Liaohe	Ng，Es_2，Es_4	Evaluation depth ranging from 800m to 3500m subsurface
Liaodongwan & Bozhong	Ng，Ed (the upper parts)	
Jizhong	Ng, Ed	
Huanghua	Ng,Es_1,Es_2	
Jiyang&Changwei	Ng,Ed_1,Es_2,Es_3	
Linqing	Ng,Es_4	

Guantao formation (Ng) is a excellent reservoir for CO_2 sequestration for its physical properties and regional distribution over the basin.



Porosity vs depth (a) and permeability vs depth of Guantao formation in Jiyang Depression

CO_2 storage capacity evaluation of the deep saline aquifers in the BBB

Depression name	Solubility trapping (Mt)	Residual trapping (Mt)	Total (Mt)
Liaohe	4991.68	18.77	5010.46
Liaodongwan& Bozhong	42937.27	200.33	43137.60
Jizhong	19019.40	649.31	19668.71
Huanghua	24354.06	749.18	25103.25
Jiyang&Changwei	23152.05	82.21	23234.25
Linqing	33505.63	82.21	33587.84
total	147960.10	1782.01	149742.11

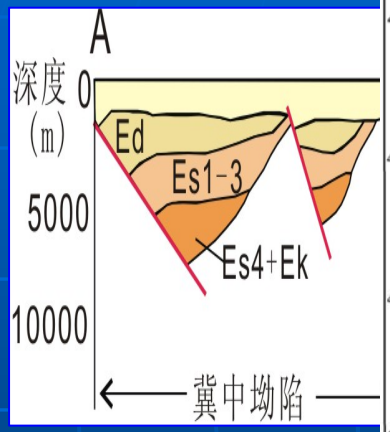
Suitability assessment of CO_2 sequestration in the BBB

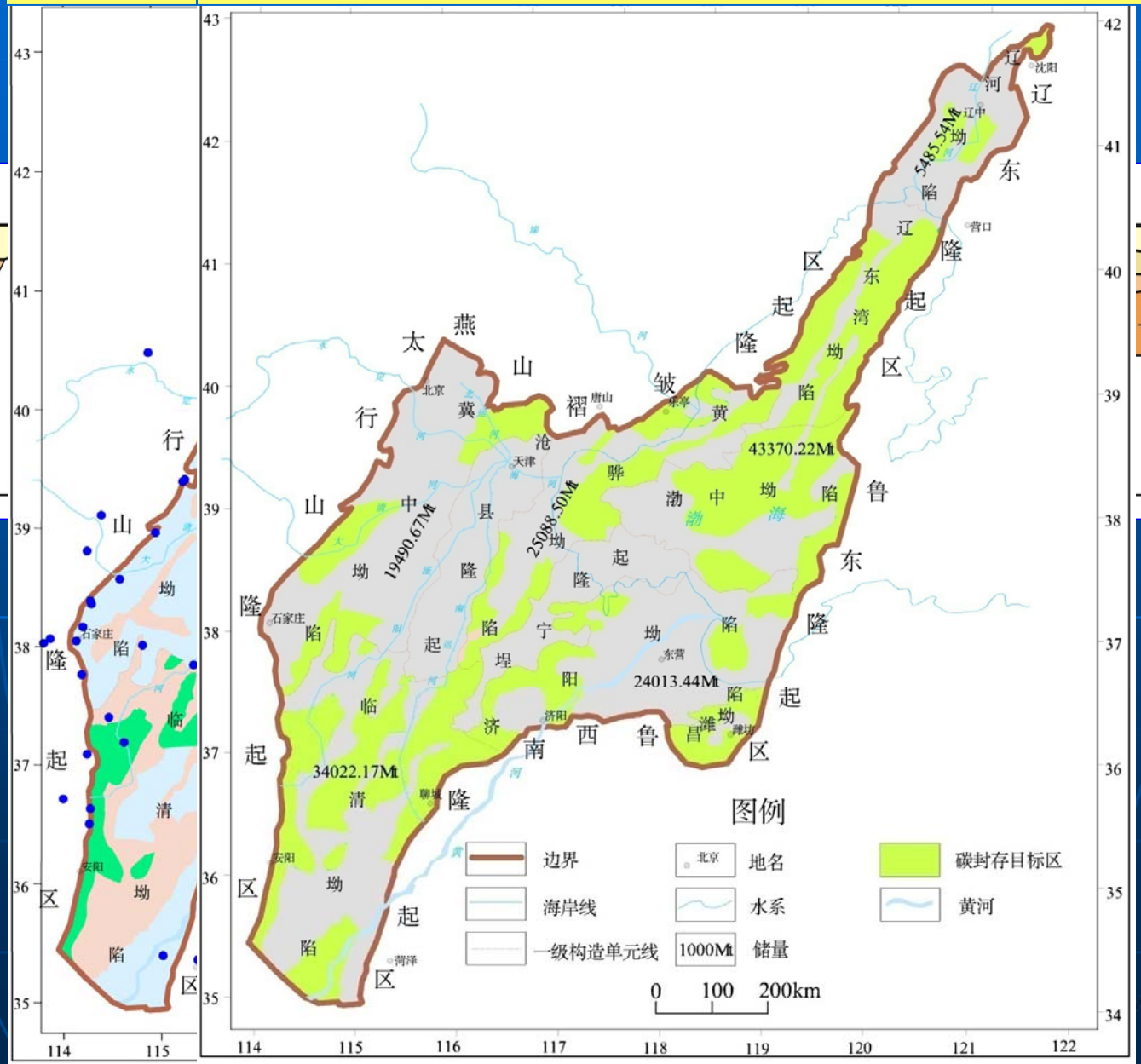
- CO2 geological storage size (or scale) assessment
- safety assessment
- geothermal conditions assessment
- hydrogeological conditions assessment
- resources utilization conflicts assessment (oil & gas, geothermal resources)
- ……..

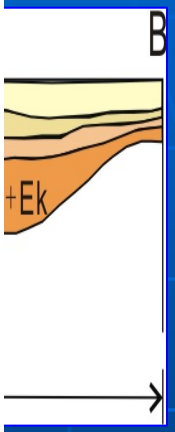
CO2 geological storage size (or scale) assessment

CO2 emis

D level CO2 storage capacity assessment of the BBB

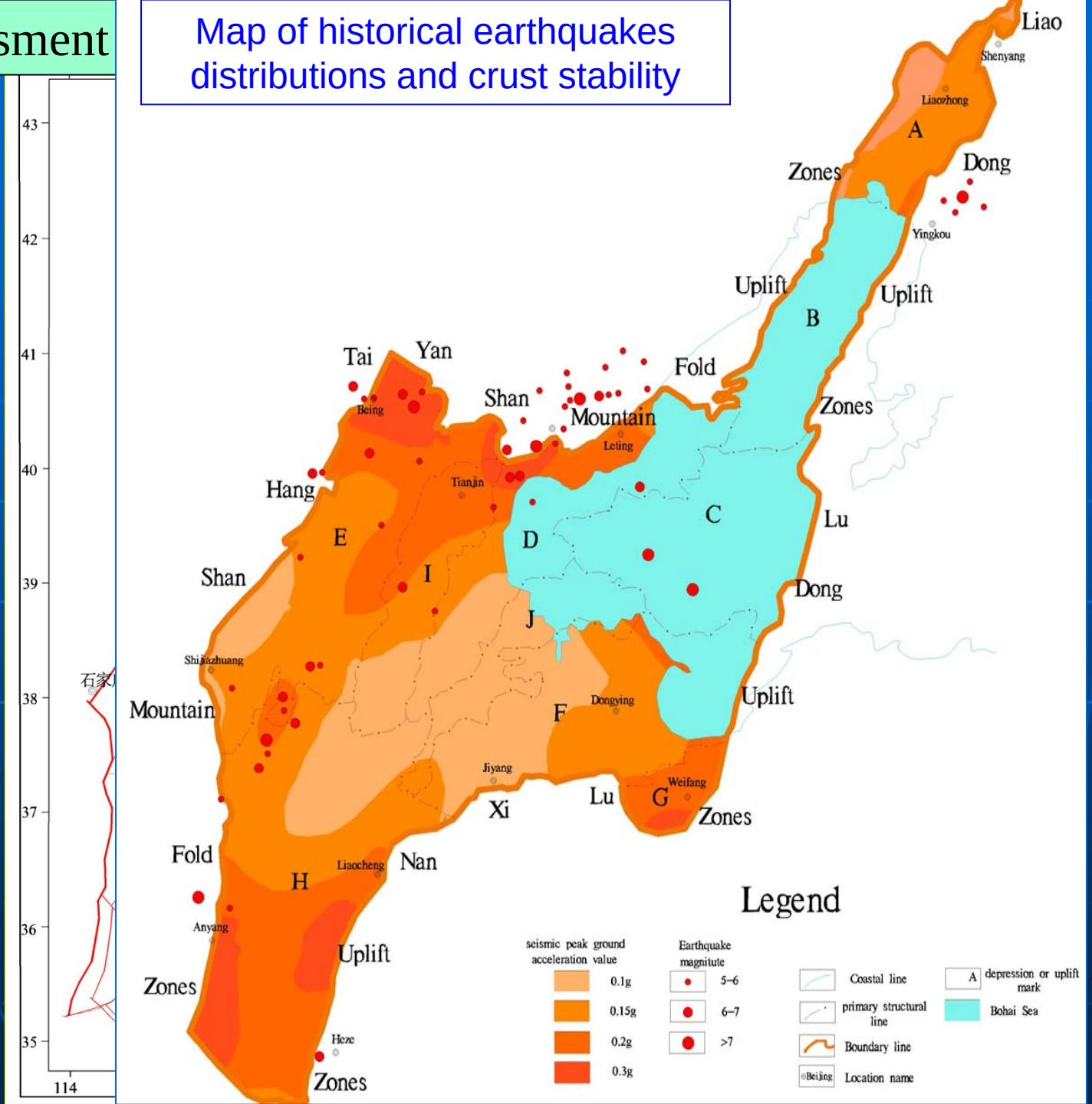






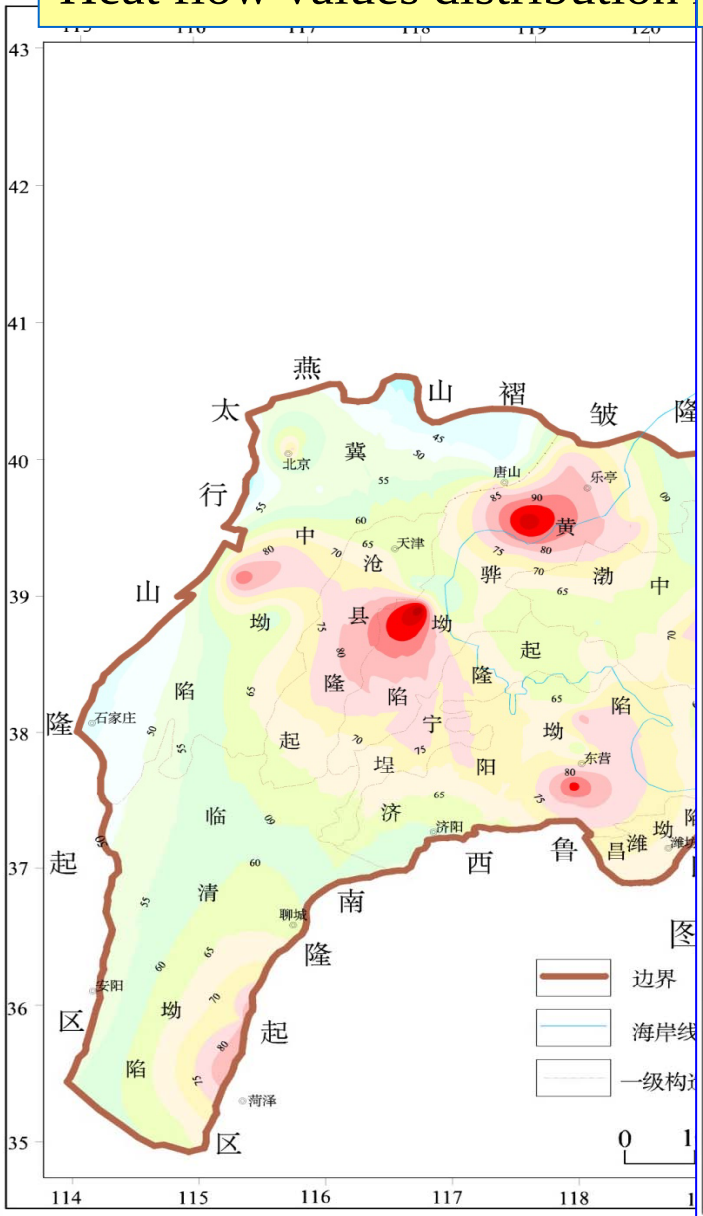
Safety Assessment

Map of historical earthquakes distributions and crust stability

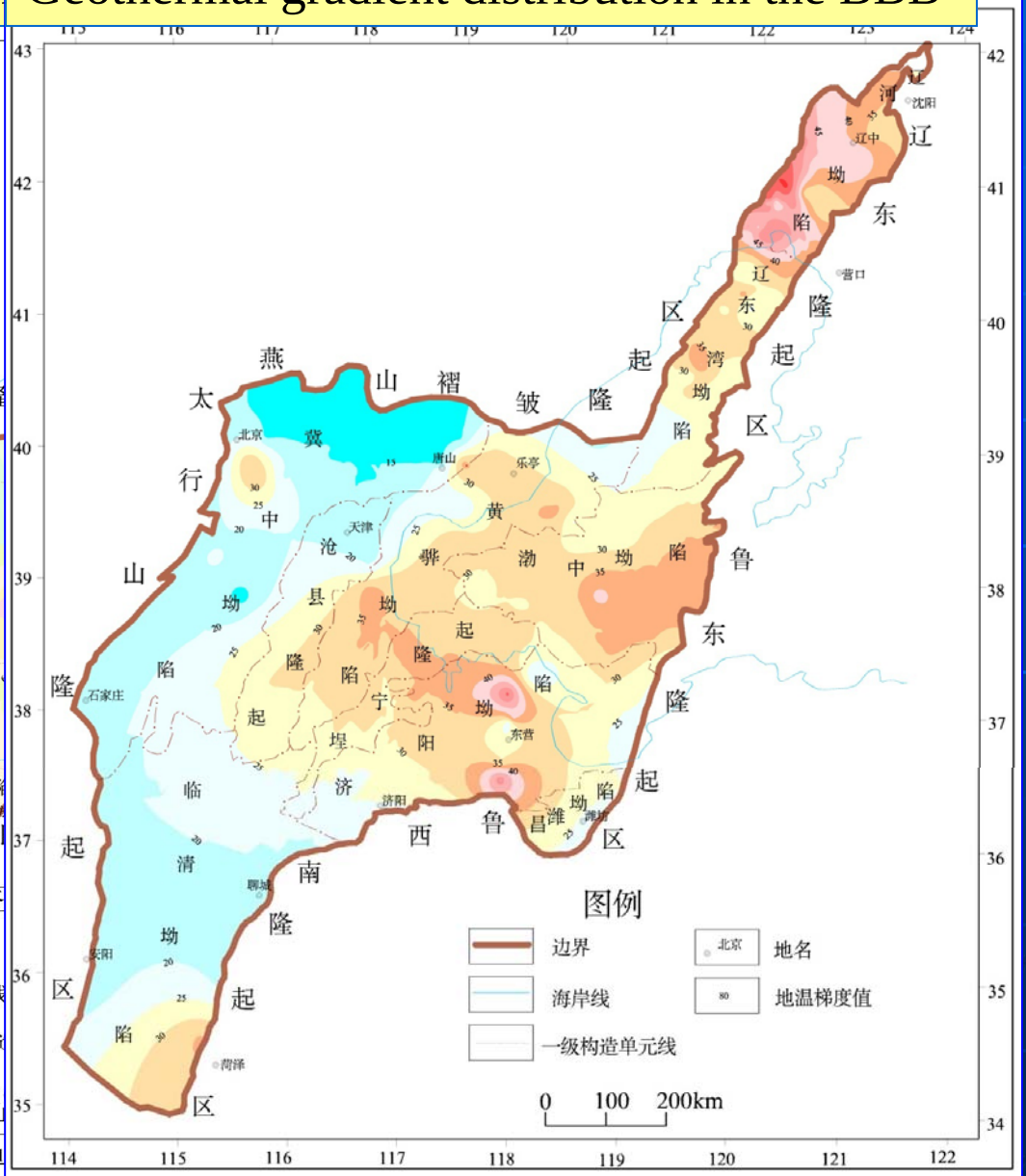


Geothermal conditions assessment

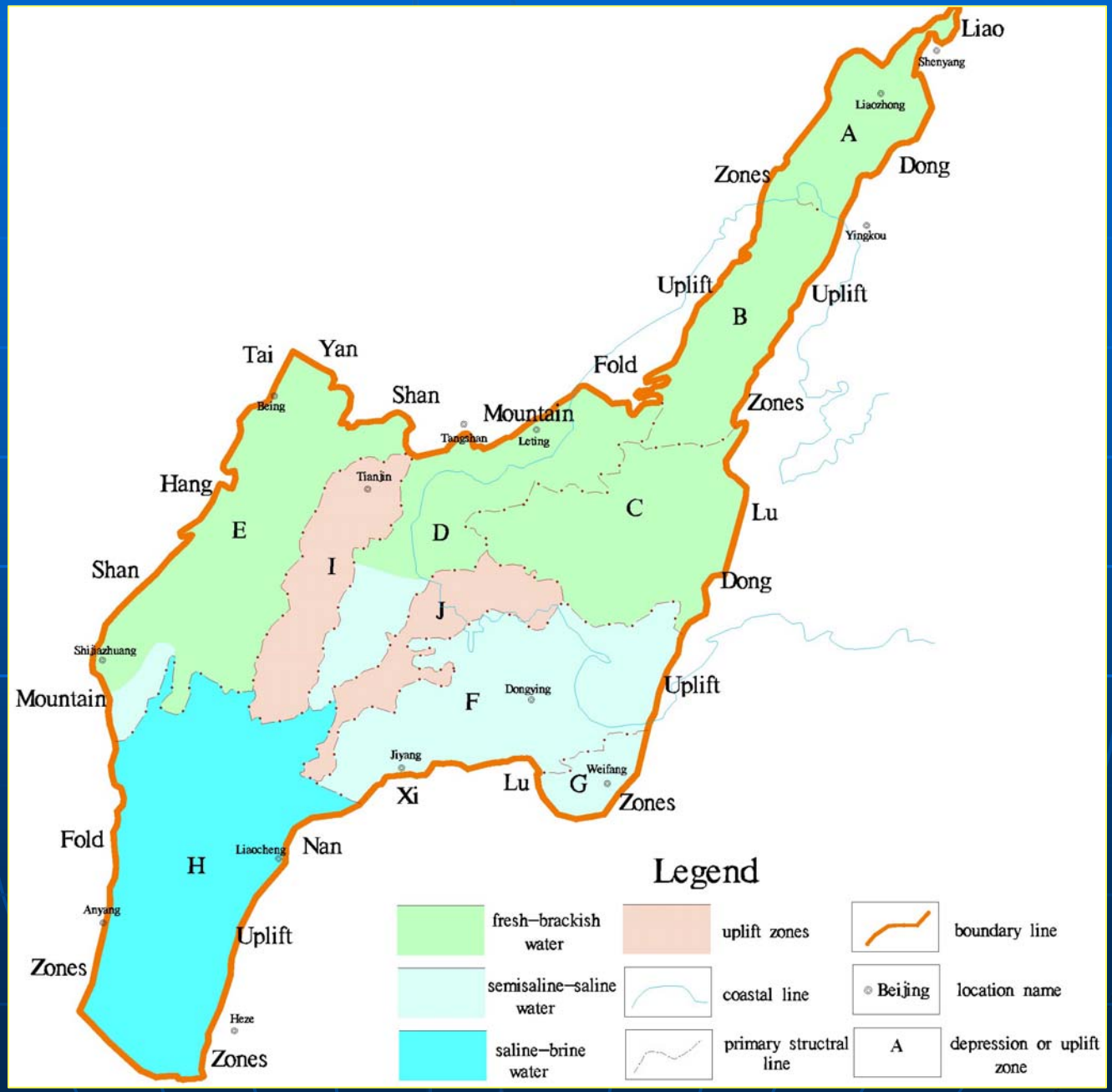
Heat flow values distribution



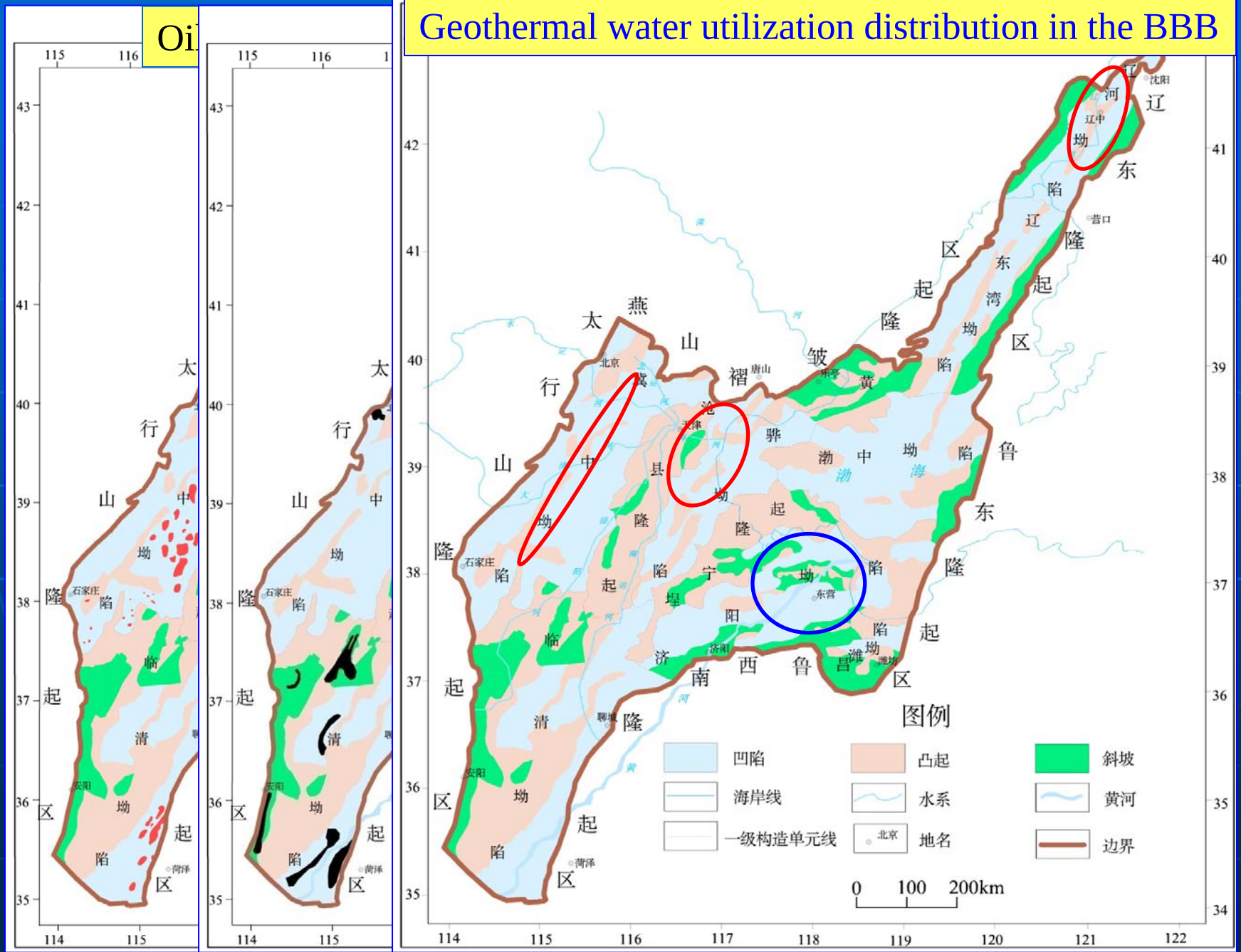
Geothermal gradient distribution in the BBB

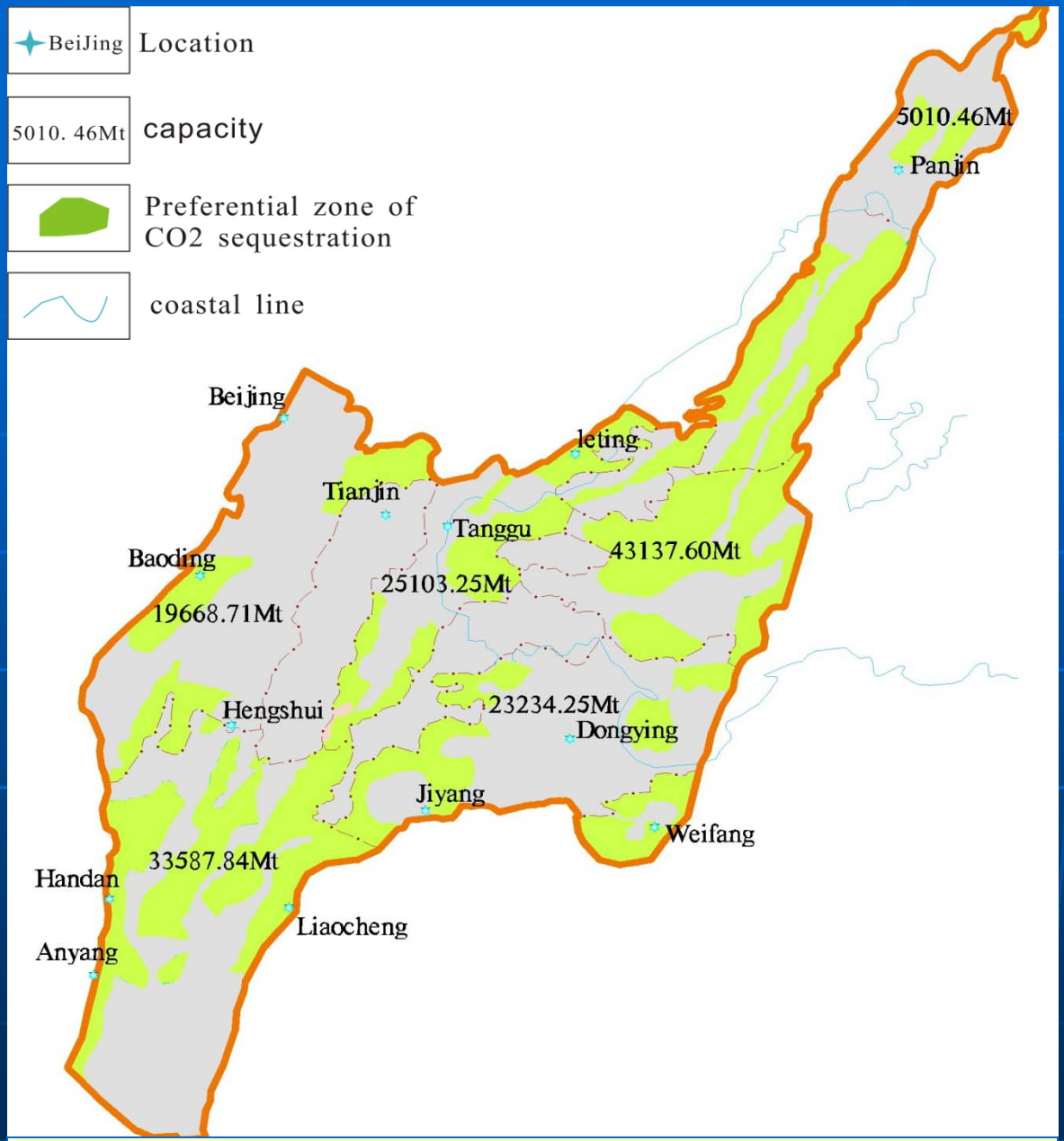


Saline water distribution in the BBB



Resources utilization conflicts

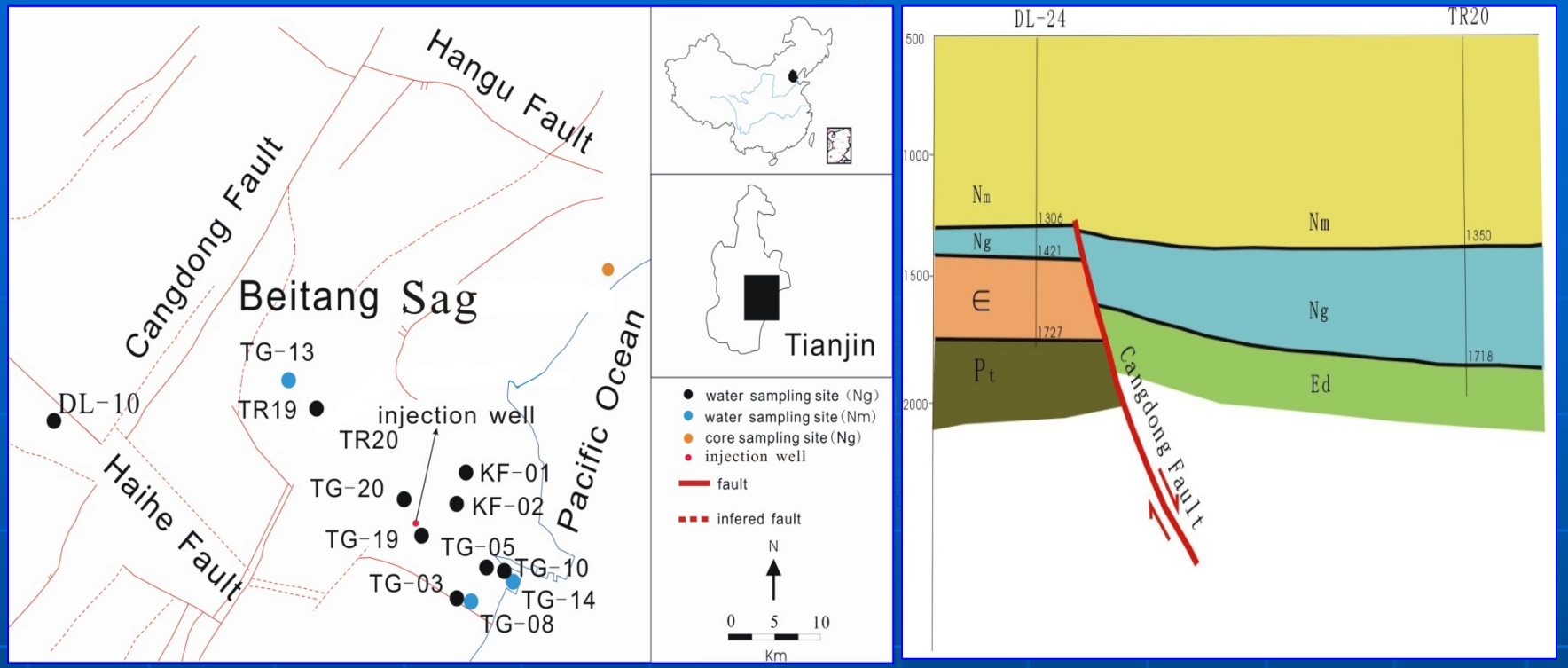




Map of preferential zone of CO_2 sequestration and corresponding capacity of each depression

By consideration of factors, e.g. CO_2 storage size, resources utilization conflicts, safety assessment, CO_2 capacity and geothermal & hydrogeological conditions, some much more preferential zones for CO_2 sequestration are figured out.

Characterization of Guantao test in Beitang sag, BBB

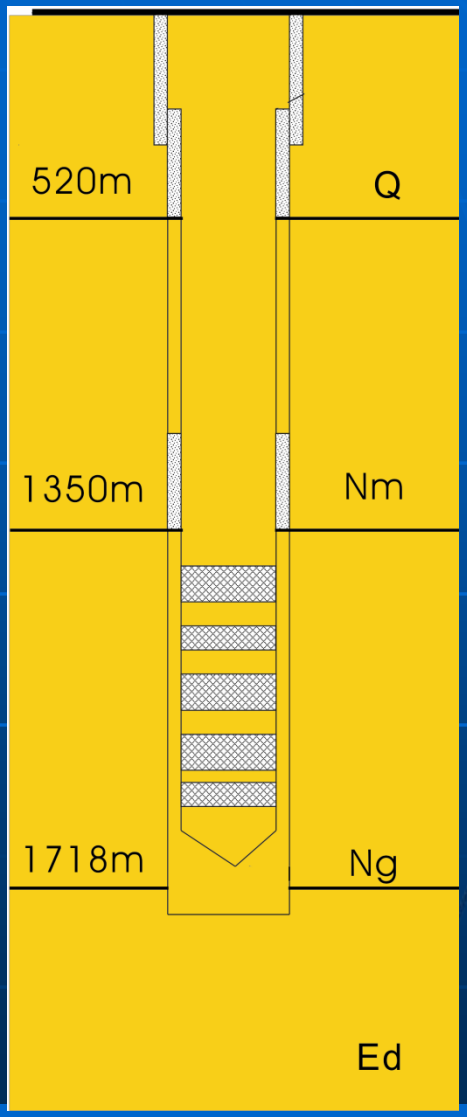


Location of test site in Beitang sag in the BBB and cross-section map

Hydrogeological parameters of the Injection well:

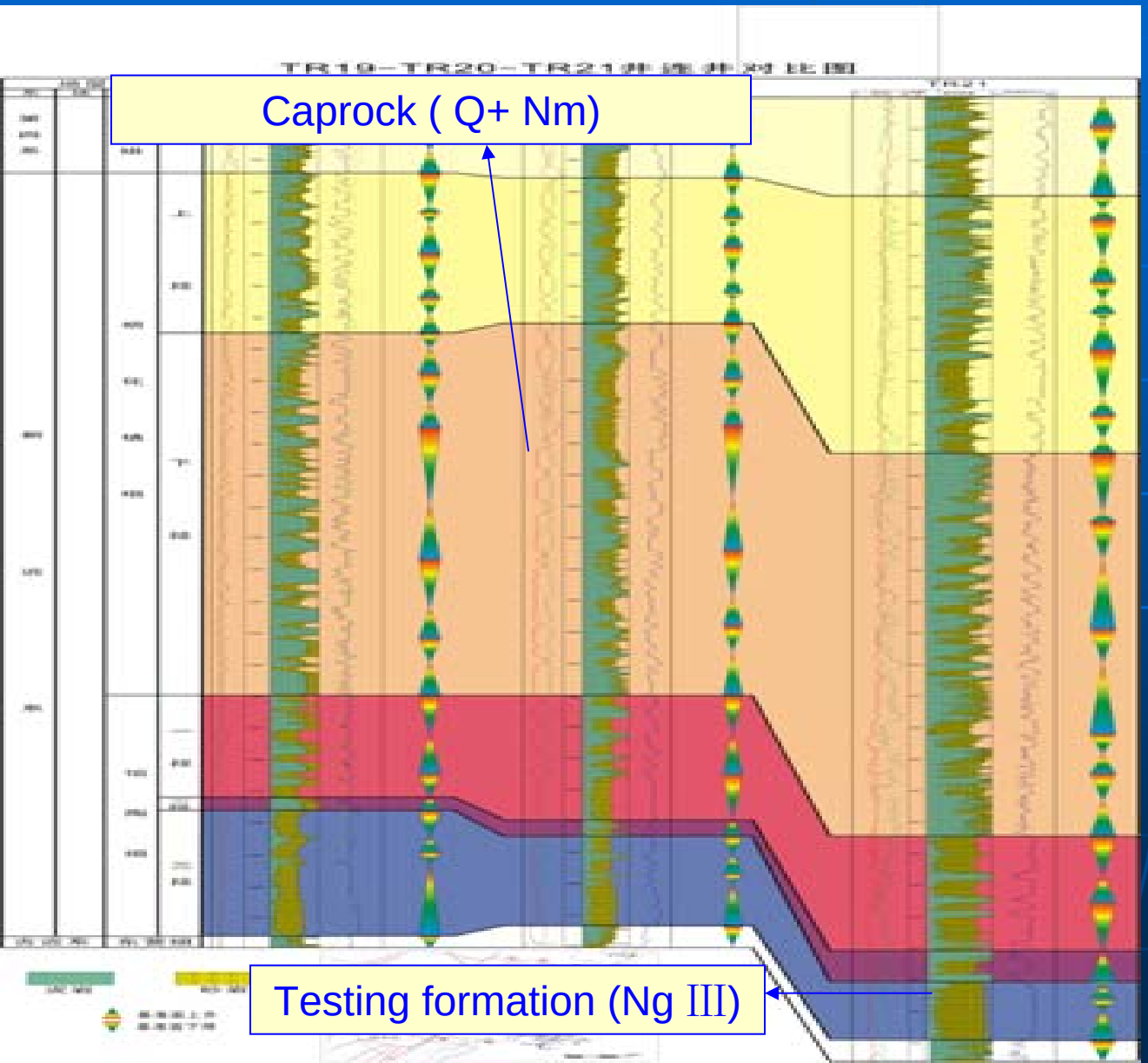
- Porosity: 22.75~36.05%;
- Permeability: $435.12\times10^{-3}\sim1483.18\times10^{-3}\ \mu m^2$
- Max. yield: $112.78 m^3/h$
- Well head temperature: 57.5℃
- water type: Cl·HCO3-Na
- TDS:1693.1mg/L
- pH:7.71

Field observation and sampling



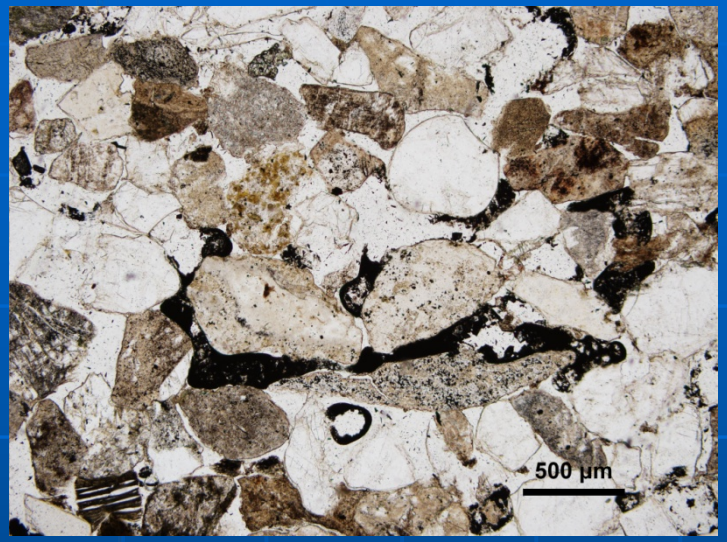
Drilling cores sampling and Characterization of the reservoir (Ng) and caprock (Nm)

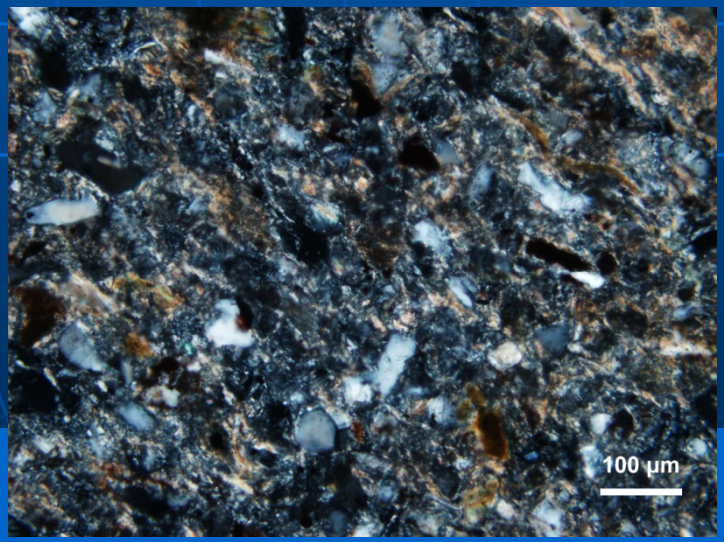
Study of stratigraphic sequence



Sedimentary sequence and dia-genesis of the reservoir rock have been studies to help evaluate porosity and permeability distribution in the reservoir

Thin section analysis of the rocks

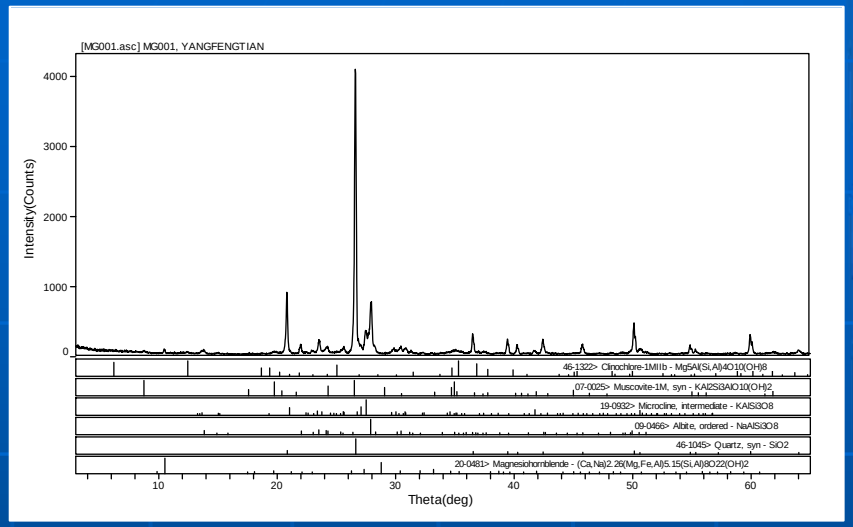


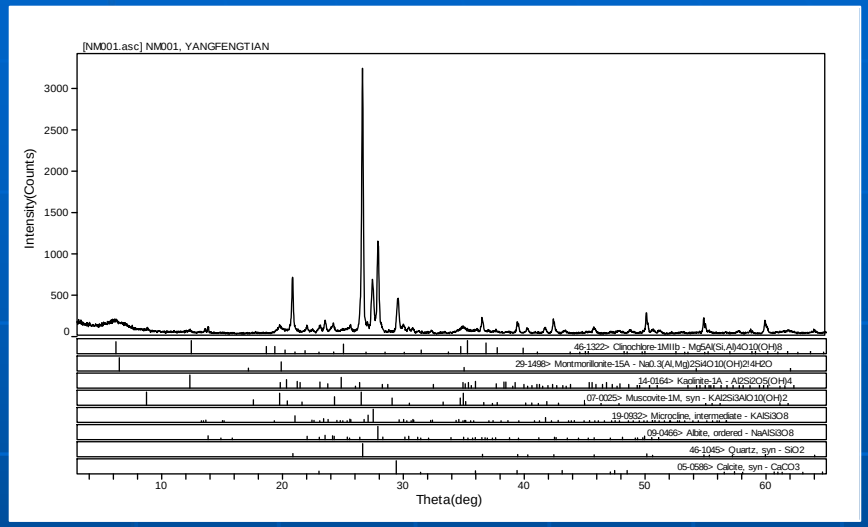


Caprock

Reservoir rock

Mineral composition of the rocks（XRD）





Samples	Mineral composition %						
	Quartz	Albite	Microcline	Biotite	Chlorite	Smectite	Others
Ng-1814m	55	12	6	3	2	_	Hornblende 3
Ng-1813.78m	60	13	10	3	2 +kaolinite	trace	_
Nm-1225m	30	13	8	4	4+kaolinite 1	trace	Dolomite 16
Nm-888m	45	20	10	3	2+ kaolinite	trace	Calcite 15
Nm-965m	40	19	8	3	3+ kaolinite	trace	Dolomite 10+Calcite 13

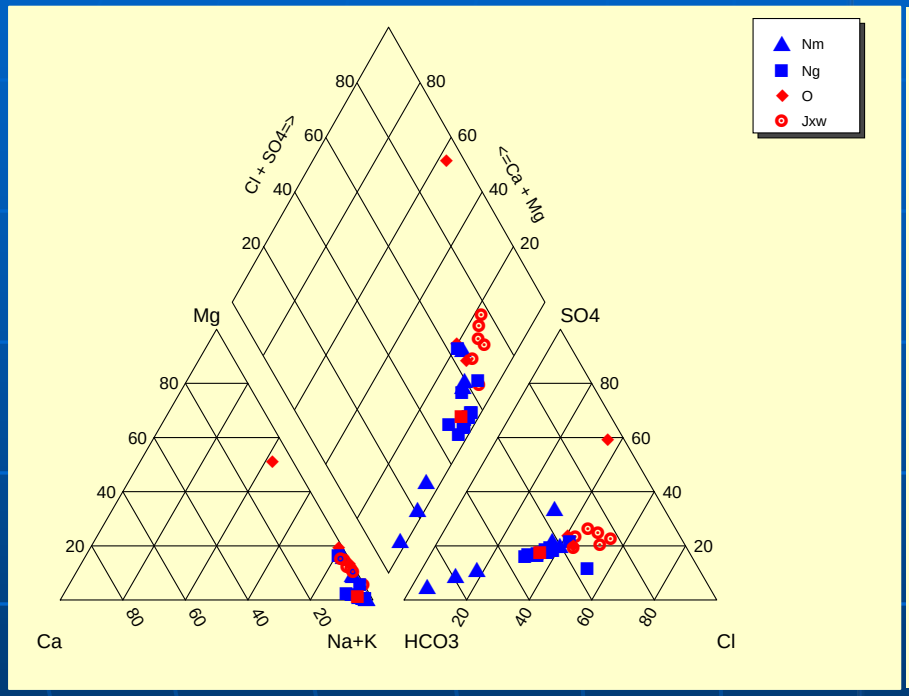
Chemical composition of the rocks（XRF）

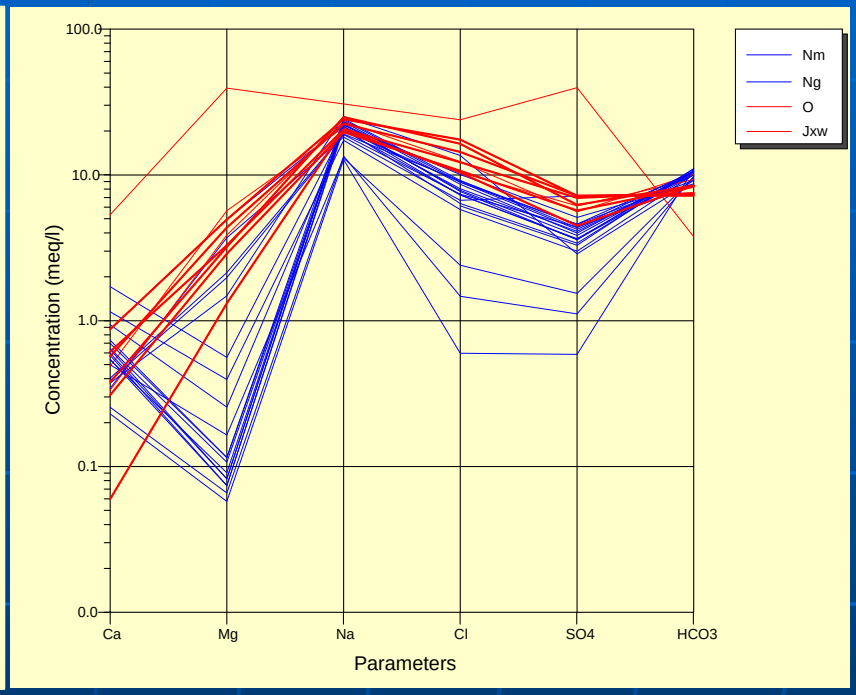
composition	SiO2	TiO2	Al2O3	Fe2O3	MnO	MgO	CaO	Na2O	K2O	P2O5	LOI	TOTAL	FeO
samples	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Ng-1814m	76.34	0.27	11.13	2.26	0.03	1.09	1.23	2.48	2.73	0.09	1.94	99.59	1.02
Ng-1813.78m	76.82	0.24	10.93	2.09	0.03	1.34	1.32	2.23	2.32	0.06	2.40	99.78	0.95
Nm-1225m	55.08	0.67	13.55	5.21	0.08	5.48	4.99	1.58	2.68	0.12	10.52	99.96	2.42
Nm-888m	65.43	0.60	13.85	3.83	0.31	1.12	4.04	2.06	3.05	0.13	5.62	100.04	0.31
Nm-965m	65.03	0.57	13.21	4.42	0.06	2.07	4.06	2.14	3.04	0.17	5.23	100.00	0.64

Formation water sampling

On site measurements: pH, EC,TDS, Eh, DO, Fe2+,Fe3+
2H, 18O, 3H, 13C, 14C, 87Sr/86Sr
Major ions, trace elements, SiO2

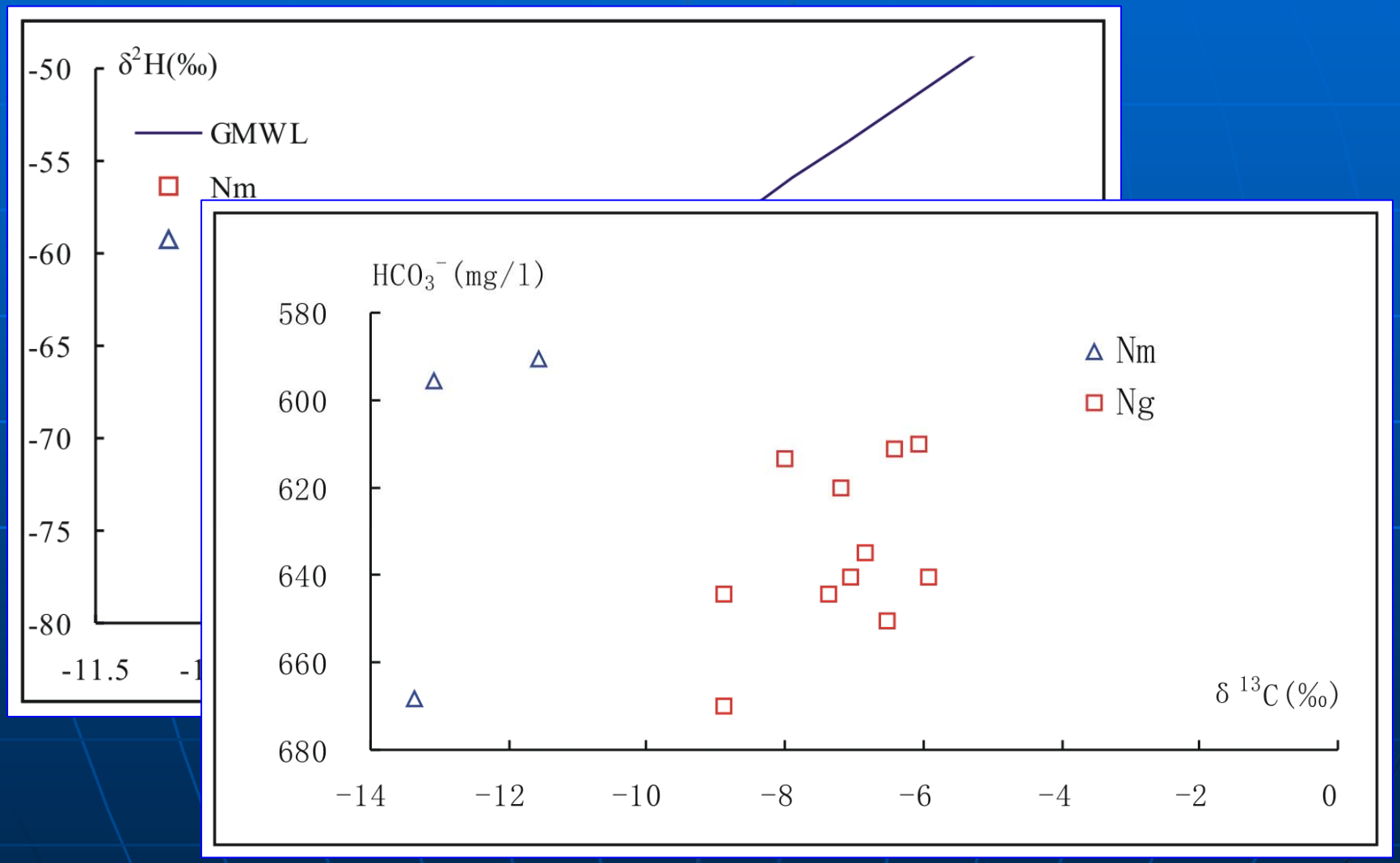
Hydrochemistry of formation waters





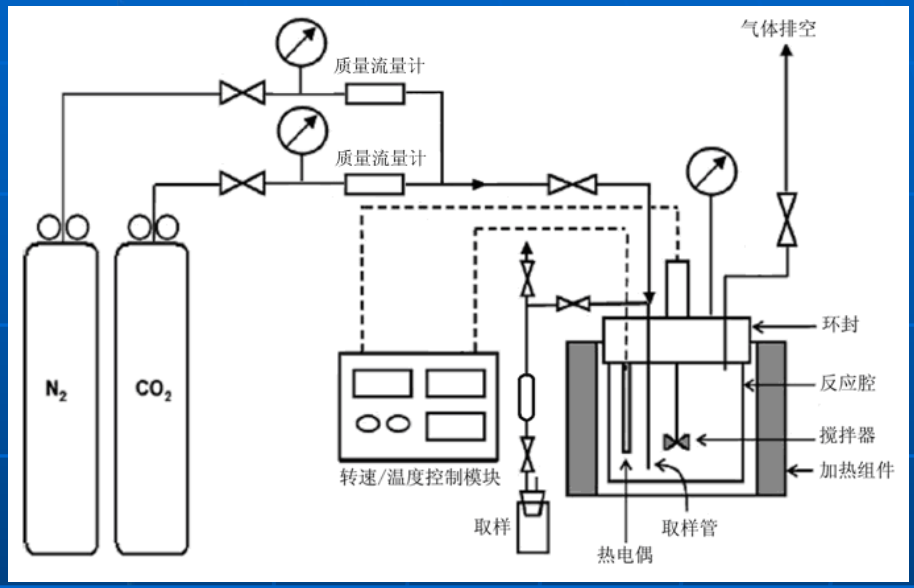
- Guantao formation (Ng) are typical of HCO3-Cl-Na type water
- TDS: 0.7-15 g/L
- Average pH 7.7

Isotopic composition of formation waters from Guantao formation, Bohai Bay Basin.



CO_2-water-rock interactions

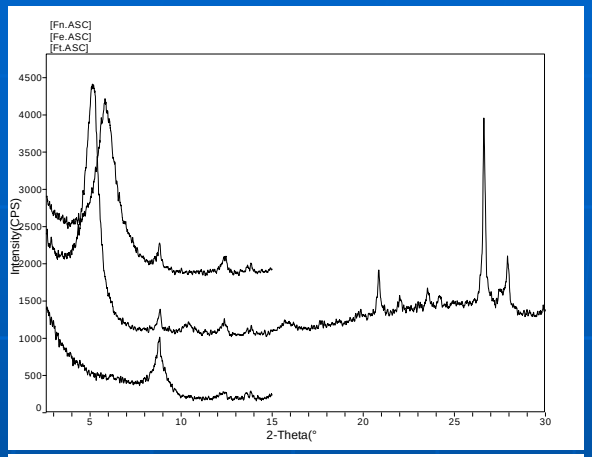
Batch type autoclave (Parr 4575A)

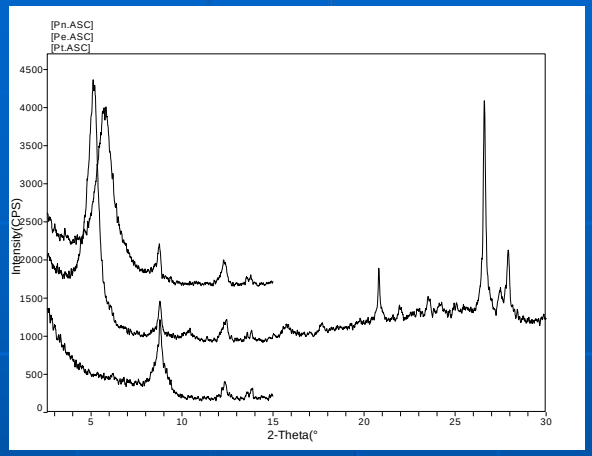


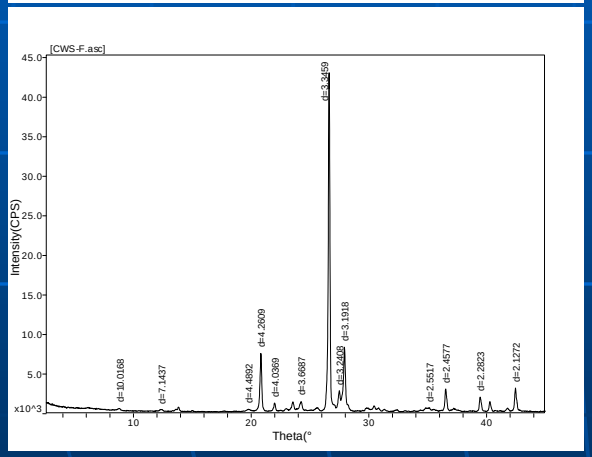
Schematic diagram of the autoclave

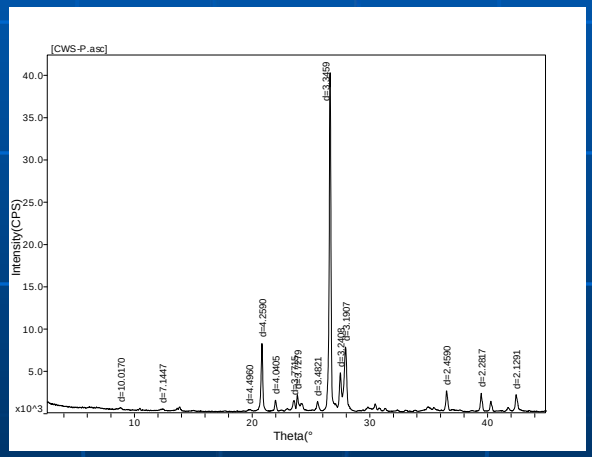
- Batch type reactor exploring into CO_2-water-rock interactions
- Max. pressure 345bar; max. temperature 500℃; bomb volume: 500ml

Preliminary results (200℃, 200bar, 15d)

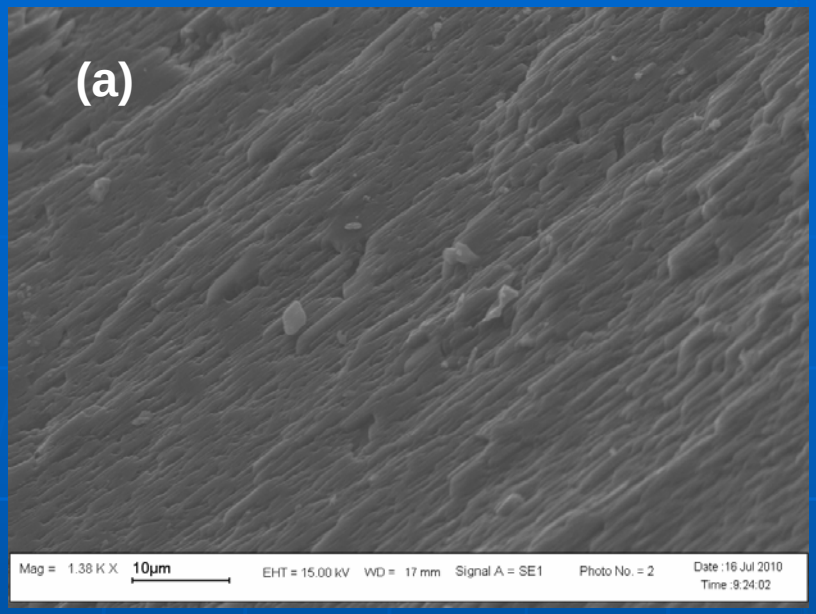


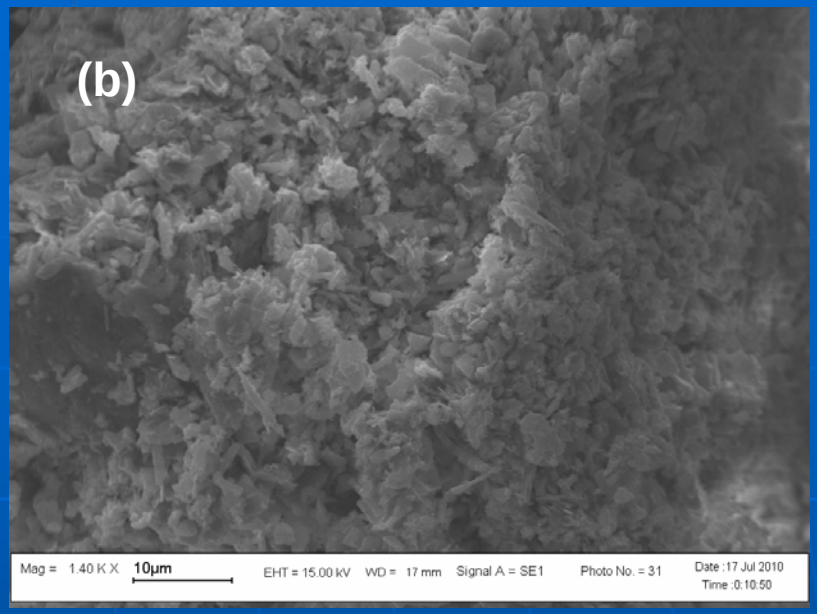




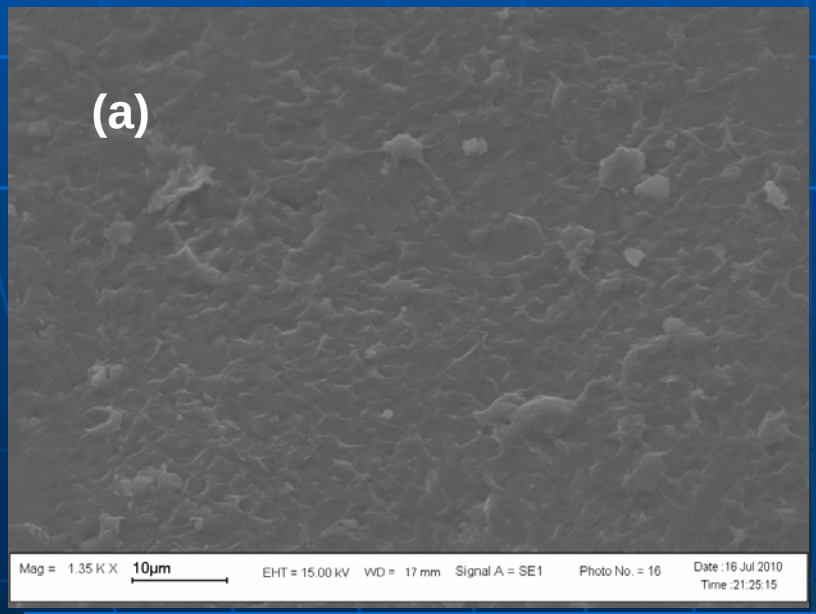


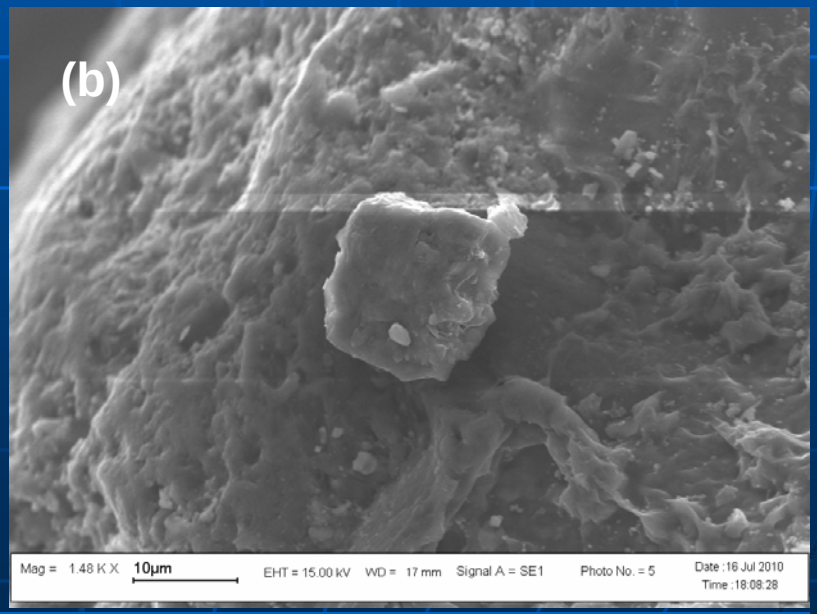
Mineral composition (%)	Quartz	Microcline	Plagioclase	Smectite	Illite	Kaolinite	Chlorite	Clay minerals
Before reaction	61.6	11.2	20.5	4.8	1.3	0.4	0.3	6.7
After reaction	63.3	8.8	20	6.1	1.2	0.4	0.2	7.9





SEM micrographs of microcline: (a) **before reaction; (b) after reaction**



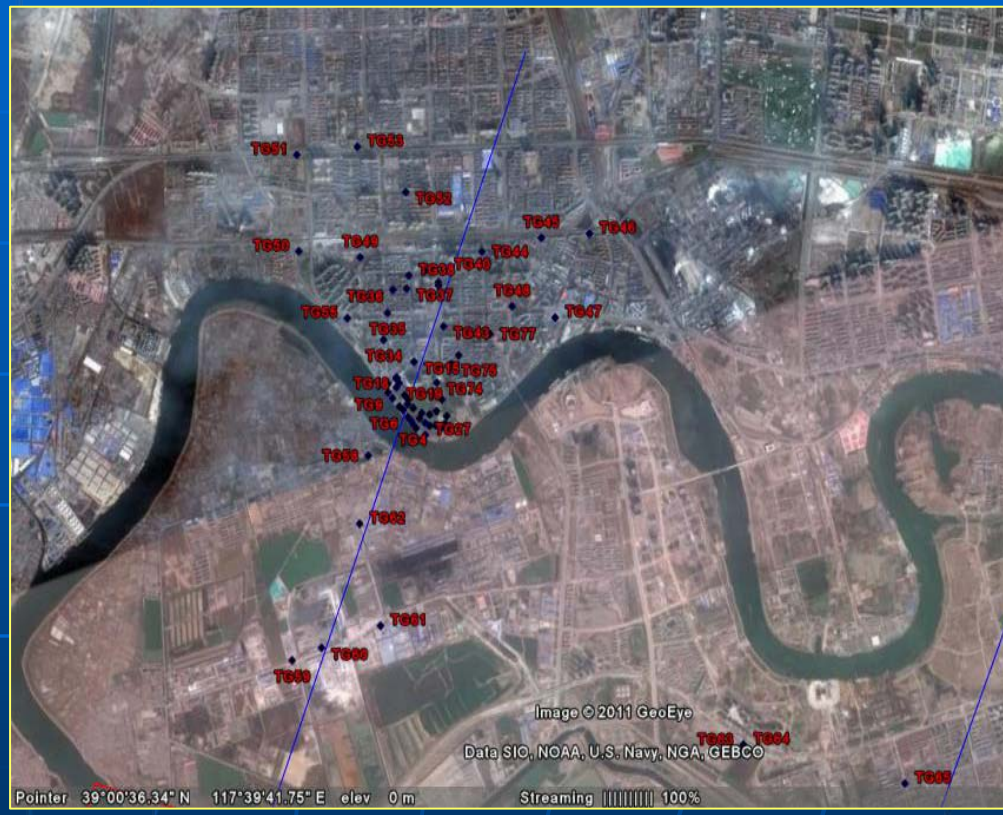


SEM micrographs of albite: (a) before reaction; (b) after reaction

Field monitoring work

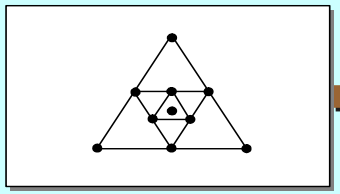
Soil gas monitoring

Soil gas sampling and measurement

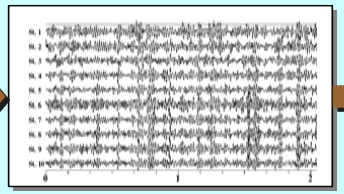


114 sample have been measured and the CO_2 concentration in the soil gas ranges from 1.0～10.4vol% with an average value of 2.64vol%.

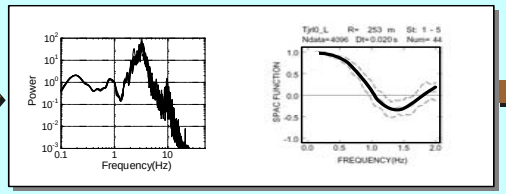
Microtremor technology monitoring



观测台阵

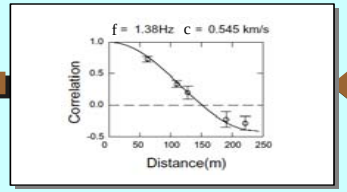


微动观测数据

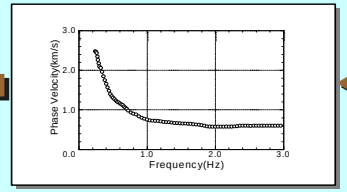


计算：功率谱 & 空间自相关函数$\rho_i(f, r_i)$ (i=1,5)

SPAC

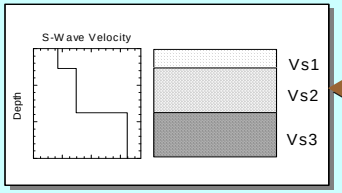


拟合贝塞尔函数，求得x_i；
计算相速度 $c_i = \frac{2\pi f_i r}{x_i}$



获得相速度频散曲线

反演



反演S波速度结构

Microtremor survey work flow

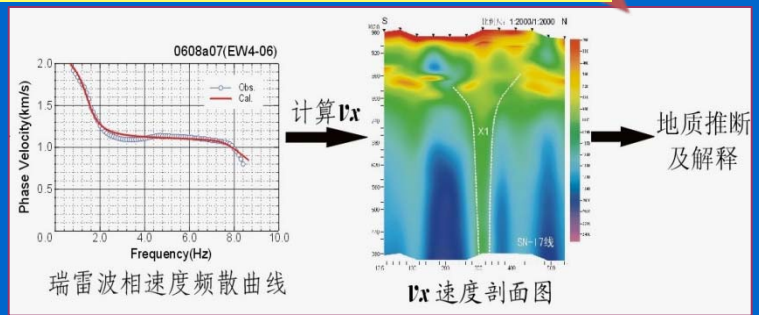
探测成果

数据处理

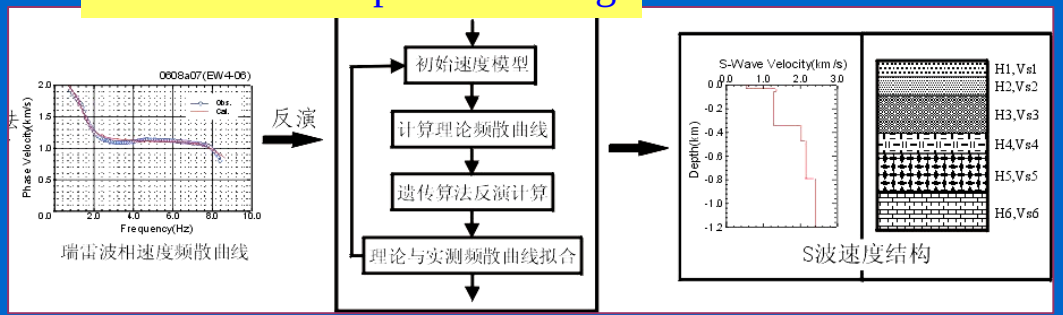
数据采集

$$V_{x,i} = \left(\frac{t_i \cdot V_{r,i}^{\ 4} - t_{i-1} \cdot V_{r,i-1}^{\ 4}}{t_i - t_{i-1}}\right)^{1/4}$$

Micro-shake cross section



Micro-shake depth measuring



Microtremor field measurement layout

Field data collection points

detection instruments

Hydrogeochemistry monitoring

- Water chemistry (including both major and trace elements)
- Isotopes (including $\delta\ ^{18}O_{H2O}$, $\delta\ ^{2}H_{H2O}$, $\delta\ ^{18}O_{CO2}$, $\delta\ ^{13}C_{DIC}$…)
- dissolved gas monitoring
- pH, Temperature, Pressure of monitoring wells around

Future work: saline aquifer science

- Deep saline aquifers (DSA): a most promising option for CGS
- Concept: field tests can be onshore, but commercial scale deployment offshore
- Geochemical response of DSA to huge amount of CO_2 injection: future focus!!
- CCUS-Utilizing CO_2 while sequestrating it
  - CO_2-EOR
  - CO_2-EATER (enhanced aquifer thermal energy recovery)

A new discipline to emerge:
Saline aquifer science and engineering !


谢谢！
Thanks ！
中国科学院地质与地球物理研究所
INSTITUTE OF GEOLOGY AND GEOPHYSICS CHINESE ACADEMY OF SCIENCES