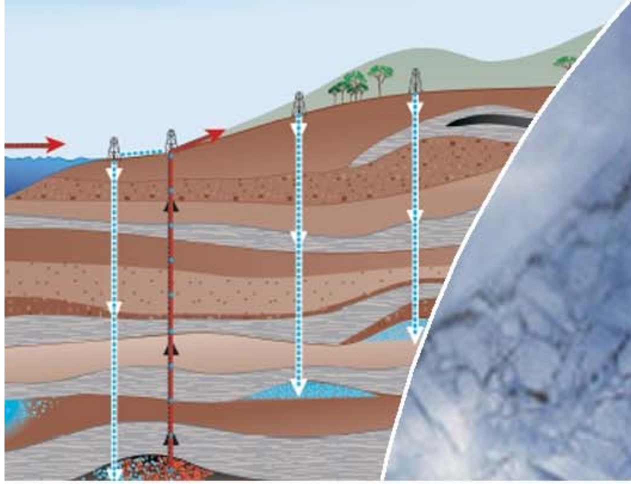
CAGS Closing Report



Environmental Impact and Risk Assessment of CO_2 Geo-storage

CO_2地质封存的环境影响和风险研究

QI LI

Institute of Rock and Soil Mechanics, Chinese Academy of Sciences

April 18, 2012

Outline

- Motivation
- Research output
- Acknowledgements

Motivation

- Support research for Chinese Academy of Environmental Planning
- Special for development of methods and tools of environmental impact and risk assessment of CCS

PART I: Literature Review

岡田陽	平成14年	HSE調査
West	2011	Environmental Issues in the Geological Disposal of Carbon Dioxi...
West	2011	Potential impact of CO2 storage on subsurface microbial ecosyst...
Wei	2011	Environmental consequences of potential leaks of CO2 in soil
Vong	2011	Reactive transport modeling for impact assessment of a CO2 intr...
US EPA	2011	Geologic Sequestration of Carbon Dioxide: Draft Underground Inj...
Singh	2011	Comparative impact assessment of CCS portfolio: Life cycle per...
Pistone	2011	The Significance of CO2 Solubility in Deep Subsurface Environm...
Koornneef	2011	The environmental impact and risk assessment of CO2 capture, t...
Keating	2011	The challenge of predicting groundwater quality impacts in a CO2...
Jackson	2011	Environmental impacts of post-combustion capture-New insights
Donlan	2011	Valuation of consequences arising from CO2 migration at candid...
Bouvart	2011	Environmental assessment of carbon capture and storage deploy...
刘兰翠	2010	碳捕获与封存技术潜在的环境影响及对策建议
Yu	2010	The analysis of the impacts of energy consumption on environme...
Quisel	2010	Environmental Assessment of CO2 Storage Site: Specific Monito...
Komai	2010	Enhanced CO2 Geological Storage System using Gas Hydrates ...
Eriksson	2010	Establishment of environmental criteria in connection to risk asse...
	2010	How to comply with your environmental permit Additional guidanc...
Wright	2009	NextGen Realised Newsletter - Issue 3: Environment and CCS
Underschultz	2009	Potential Impacts on Ground water: An Australian Perspective
Stenhouse	2009	Assessing environmental impacts from geological CO2 storage
Norton	2009	Potential Groundwater Quality Impacts Resulting From Geologic ...
Hill	2009	Environmental Impact Study of a Power Plant with Carbon Captur...
Feitz	2009	Potential Impacts on Ground Water: An Australian Perspective
F. Reguera	2009	An integrated approach to determine sediment quality in areas a...
Randolph	2008	Geologic CO2 sequestration in saline aquifers accounting for du...
Oldenburg	2008	Screening and ranking framework for geologic CO2 storage site ...
Long	2008	Site Selection and Environmental Concerns for Underground Co...
Liu	2008	Temporal-spatial climate change in the last 35 years in Tibet and i...
Garg	2008	A mathematical model for the formation and dissociation of meth...
Coombs	2008	Influence of biofilms on transport of fluids in subsurface granitic e...
Solomon	2007	Carbon Dioxide Storage: Geological Security and Environmental ...
Oldenburg	2006	Health, Safety, and Environmental Screening and Ranking Frame...
Lerche	2006	Environmental Risk Assessment: Quantitative Measures, Anthrop...
Holditch	2006	Geomechanical Performance of Hydrate-Bearing Sediments in O...
Holditch	2006	Geomechanical performance of hydrate-bearing sediments in off...
Eriksson	2006	Strategic Environmental Assessment of CO2 Capture, Transport ...
Damen	2006	Health, Safety and Environmental Risks of Underground CO2 Sto...
West	2005	Environmental Issues and the Geological Storage of CO2: A disc...
Poremski	2005	Possible impacts of CO2 storage on the marine environment
Pelovski	2005	Environmental Impact Assessment: Krumovgrad Gold Project Fin...
Benson	2005	Lessons learned from industrial and natural analogs for health, sa...
[illegible]	[illegible]	[illegible]
US DOE	2003	Environmental Assessment: Pilot Experiment for Geological Seq...
Johnston	2003	Carbon Capture and Sequestration: Potential Environmental Imp...
Heinrich	2003	Environmental assessment of geologic storage of CO2
Heinrich	2003	Environmental assessment of geologic storage of CO2
Heinrich	2003	Managing Environmental and Human Safety Risks Associated wi...
Damen	2003	Health, Safety and Environmental Risks of Underground CO2 Sto...
Koerner	2002	Anthropogenic and natural CO2 emission sources in an arid urba...
Jakubick	2002	Modelling of mine flooding and consequences in the mine hydrog...
Karman	2000	The Role of Time in Environmental Risk Assessment
Liu	1999	Environmental impacts and risks of CO2 injection for enhanced o...
Nabholz	1991	Environmental hazard and risk assessment under the United Stat...

Latest achievements of CCS EIA

研究机构	评价内容			评价方法	指标	工具	文献出处（作者，年代）	对象	备注
	注入	封存	闭场						
BSECEE[11]	√		√	1.对人口、健康风险评价：人口、疾病统计数据解读分析。 2.社会经济影响：从国家和地区经济水平、土地利用和重新设计、就业率、基础设施和社会服务方面进行资料数据解读分析 3.环境影响：在各指标分析基础上列出定性	1.社会经济指标包括了30个一级指标 2.环境影响评价指标：气候、环境大气、水、地下水、土壤、地下、风景、自然地点、矿物多样性、生物多样性、文化遗产		(Pelovski & Pipkov, 2005)		建设、运营、闭场评价

AIST			√	模拟手段进	LANL 开	(Sakamoto,		不同参数条件下

备注

发生环节，预测
沿井孔的泄漏
率

备注

捕集到封存，
地表地下部分
封存链的 HSE
评价。2）存在
对应措施。3）
展定量评价。

，未限

储存项
南

存场地
风险管

不同的方法

[11] BSECEE: Balkan Science and Education Centre for Ecology and Environment Protection

[5] AIST: National Institute of Advanced Industrial Science and Technology

[9] QRTT: Quantitative Risk Through Time

[6] INERIS: French National Institute for Industrial Environment and Risks
[7] NES: Normal Evolution Scenario
[8] AES: Alternative Evolution Scenarios

Category of EIA methods

- 定性法（FEP，VEF）

  1）结构化的数据评价过程，对风险给于定量的分级

  2）基于专家的意见

- 定量法（DRA，PRA，CO2-PENS，CO2RISKEYE）

  1）数值模拟定量刻画后果的发生概率和严重性

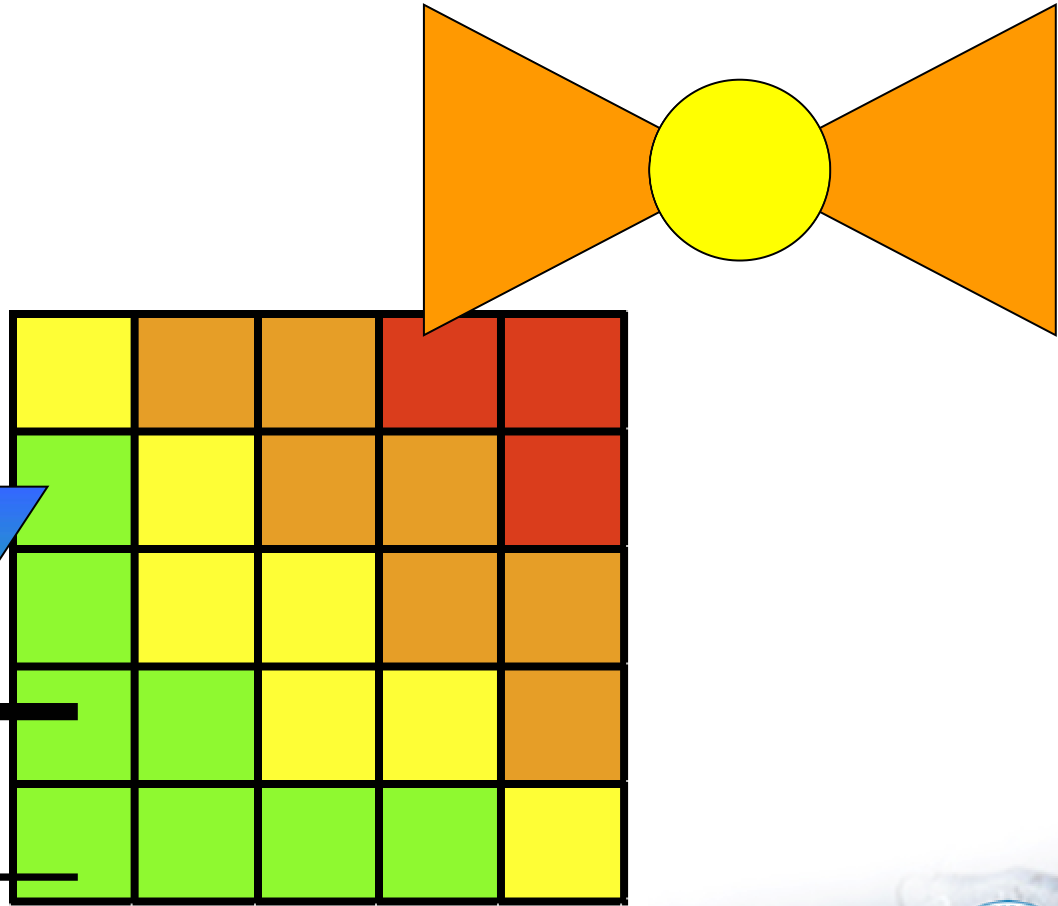
  2）如果有先验的历史匹配，可以建立方法的优化过程

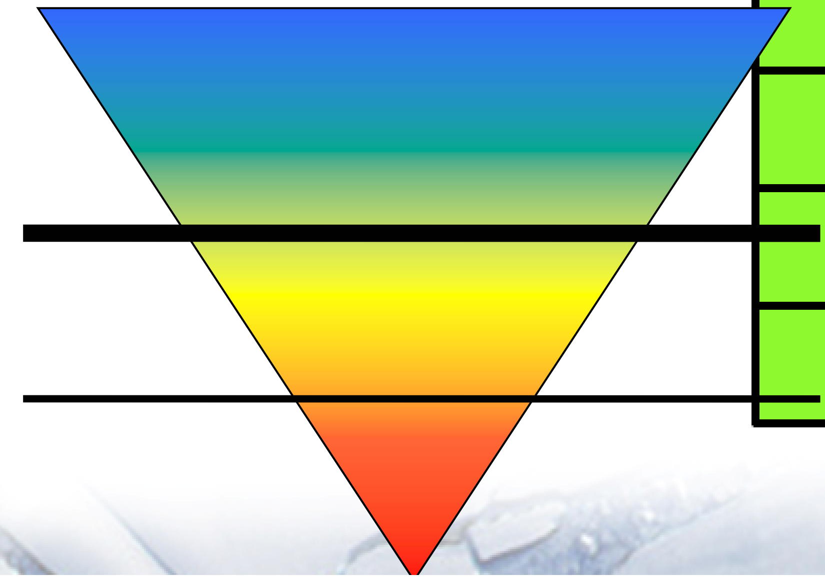
- 半定量法（Fuzzy-Logic，MATRIX）

  1）给与后果和可能性赋予半定量的评价刻度

Code solution of EIA methods

- Bow-Tie
- Matrix
- ALARP





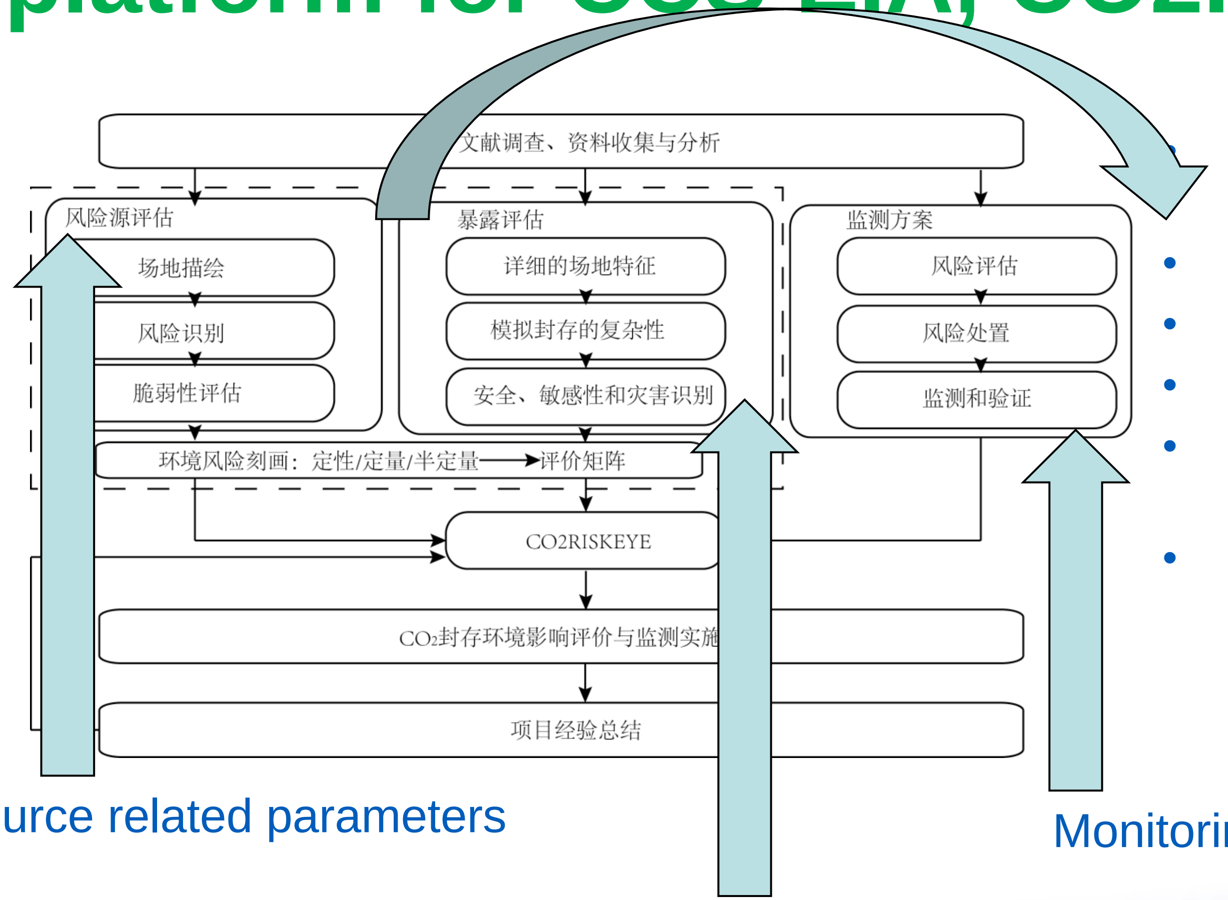
PART II: CO2RISKEYE

Research output (1): EIA Matrix for geological storage of CO_2

Category	1st level index	2nd level index	Pre-Injection	During Injection	Post-Injection
Atmosphere	Atmosphere	CO_2			
		SOx			
		NOx			
		Dust			
	Noise	Noise			
	Vibration	Vibration			
	Light	Light			
	Smell	Smell			
water	Surface/Ground Water	pH			
		HCO_3^-			
		Polution			
		Turbidity			
		Temperature			
		Heavy metals			
Soil	Soil Contamination	Soil Contamination			
Ecology	Animal	Animal			
	Plant	Plant			
	Biomicrobe	Ground			
		Underground			
Disposal wastes		Life			
		Solid			
		HLW			
Social Economics	Employment	Job			
	Energy Demand	Energy Demand			
Human	Nature Interface	Contact Chance			
	Health	Health			

Different codes considered different parametric indexes!

Research output (2): Assessment platform for CCS EIA, CO2RISKEYE



- Modified Oldenburg's HSE Method
- AITF Bachu's Method
- RITE Method
- AHP Method
- Dynamic Programming Approach
- …

Source related parameters

Monitoring related parameters

Leakage related parameters

GUI and Processing Flow

以CO2封存匹配度为评价方式的沉积盆地不同特征和等级对应的分值和权重

标准			等级 1	等级 2	等级 3	等级 4	等级 5	权重
1	构造背景	描述	克拉通前陆	内陆裂谷	扩散被动盆地	聚合山间	大洋凹陷	0.07
		分值	1	3	7	15	15	
2	面积	描述	小	中	大	巨大		0.06
		分值	1	3	5	9		
3	沉积深度	描述	浅(<1500m)	中等	深(>3500m)			0.07
		分值	1	3	5			

稀释潜力	均值线：		
-0.16	1.6986111	0	
	0.6283018	-2	

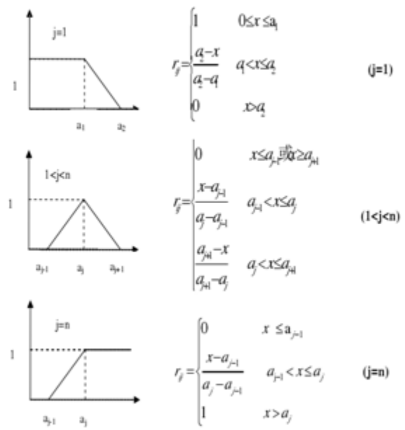
Summary of Risk Scores

0	-2
0	1.06
1.93	1.06
1.93	-2

x,y points of arcs or radius r.

y formula	r	x	y formula
		poor	
-0.542262	3	0.5	0.9154759
-0.561251	3	0.6	0.8774989
-0.58402	3	0.7	0.8319605
-0.596852	3	0.8	0.7784888
-0.610756	3	0.9	0.7166155
-0.641692	3	1	0.6457513
-0.677124	3	1.1	0.5651511
-0.717424	3	1.2	0.4738634
-0.763068	3	1.3	0.3706539
-0.814673	3	1.4	0.2538855
-0.873057	3	1.4999	0.1214618
-0.93934	3	1.6	-0.030228
-1.015114	3	1.7	-0.205564
-1.102782	3	1.8	-0.412549
-1.206275	3	1.9	-0.665834
-1.5	3	2	-1

- 隶属度矩阵R



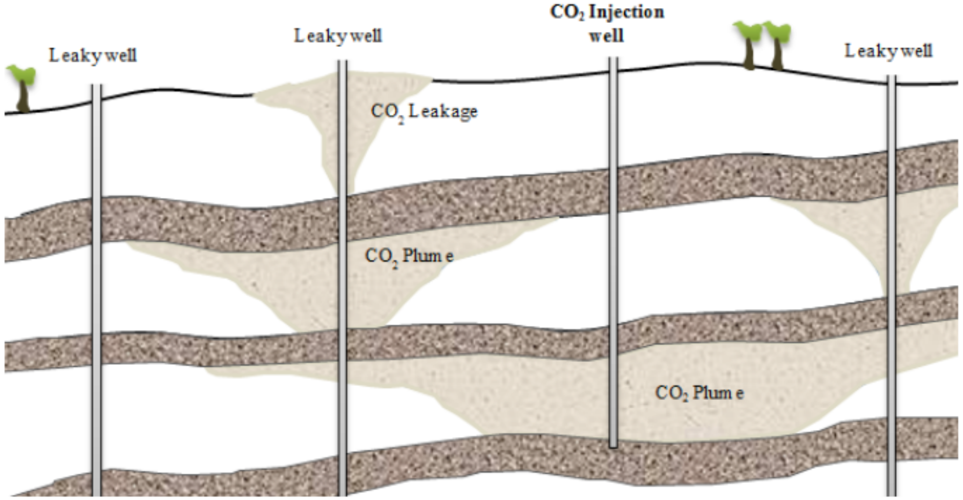
隶属函数分布图

式中：r_{ij}为隶属度；a_j为分区标准；x为实测值。

由实测值x代入上述公式即可确定出隶属度。

- Excel
- +
- Matlab

Dynamic Programming Approach



Cody, et al., 2011. AGU ,115-133.

❖ ***Geological Layer Information***
Number of aquifer layers
➢ Aquifer layer depths (m)
➢ Aquitard layer depths (m)
➢ Aquifer porosities
➢ Aquifer permeability (m^2)
➢ Aquifer compressibility (m^2 N^{-1})
❖ ***Temporal Information***
➢ Injection duration (s)
➢ Time step interval (s)
❖ ***Injection Well Information***
➢ Horizontal injection well position (x,y) (m)
➢ CO_2 injection rate (kg s^{-1})

❖ ***Leaky Well Information***
➢ Number of leaky wells
➢ Horizontal leaky well positions (x,y) (m)
➢ Leaky well radii (m)
➢ Leaky well permeability (m^2)
❖ ***Algorithm Parameters***
➢ Maximum CO_2 plume thickness (m m^{-1})
➢ Aquifer total mobility (Pa^{-1} s^{-1})
➢ Aquifer H_20 mobility (Pa^{-1} s^{-1})
➢ Residual brine saturation behind the invading front (/)
❖ ***Constants***
➢ Gravitational constant (m s^{-2})
➢ H_20 density (kg m^{-3})
➢ CO_2 density (kg m^{-3})
➢ CO_2 viscosity (Pa s)
➢ H_20 viscosity (Pa s)
❖ ***Initial Conditions***
➢ Initial aquifer bottom pressures (Pa)
➢ Initial CO_2 relative permeability
➢ Initial H_20 relative permeability
➢ Initial aquifer H_20 saturation

$$Objective: \min\left\{ LeakageCost = \sum_{i=1}^{n} c_i Mleak_i^{p_i} \right\}$$

$$Constraint\ 1: 0 \le Q_{inj} \le Q_{\max}$$

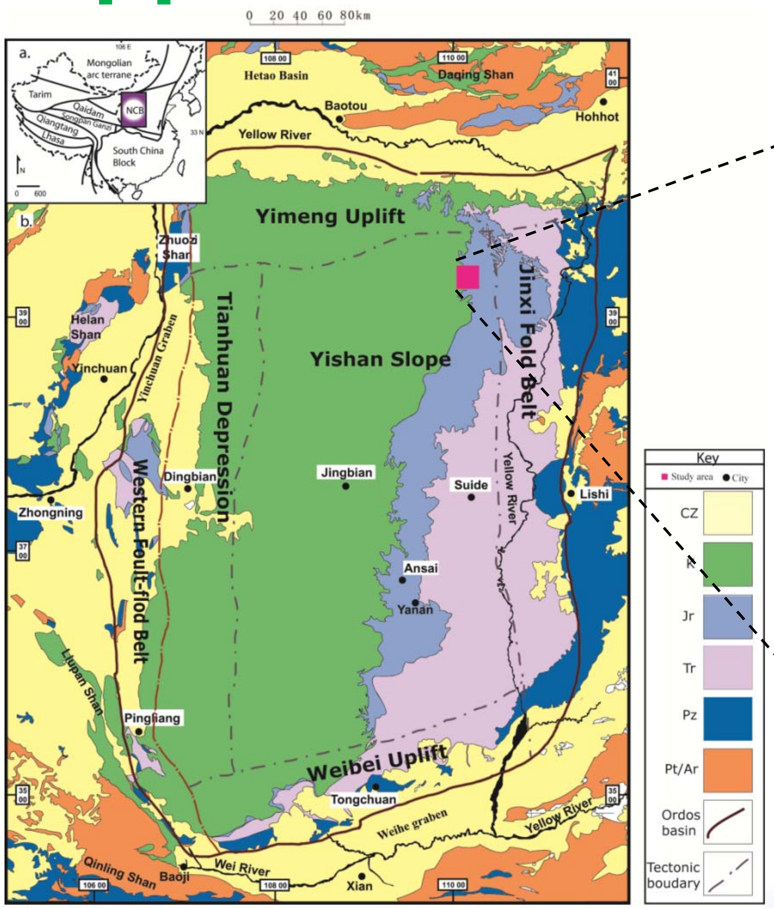
$$Constraint2: 0 \le T \le T_{\max}$$

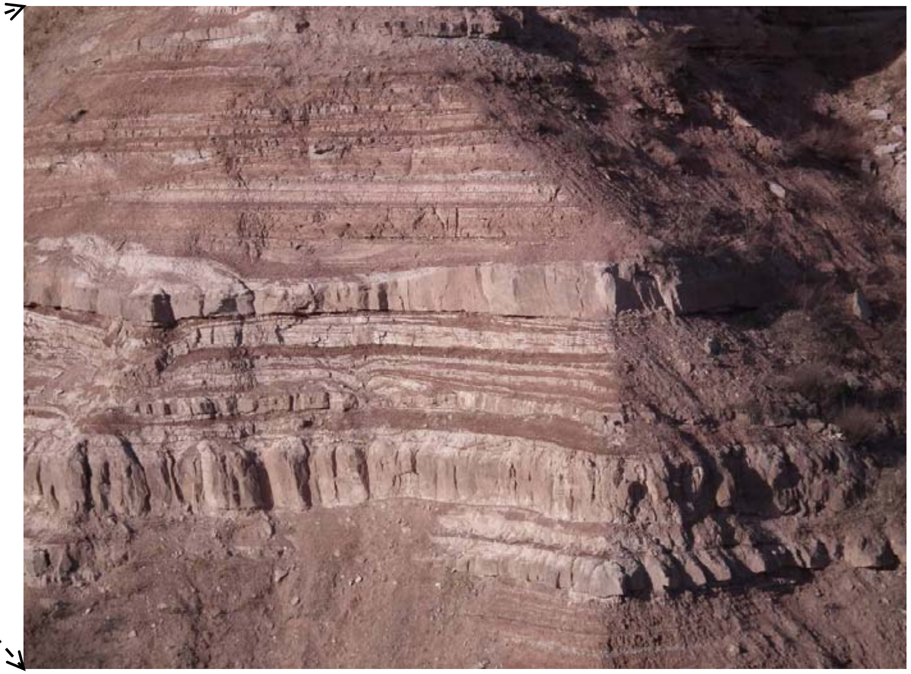
$$Constraint3: 0 \le t_{start} \le t_{\max}$$

$$Constraint4: 0 \le t_{end} \le t_{\max}.$$

$$Constraint5: t_{start} \le t_{end}$$

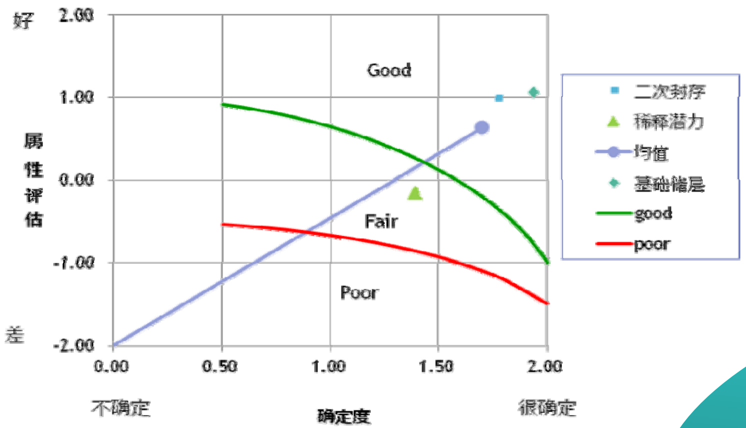
Research output (3): CO2RISKEYE Application to Ordos Basin

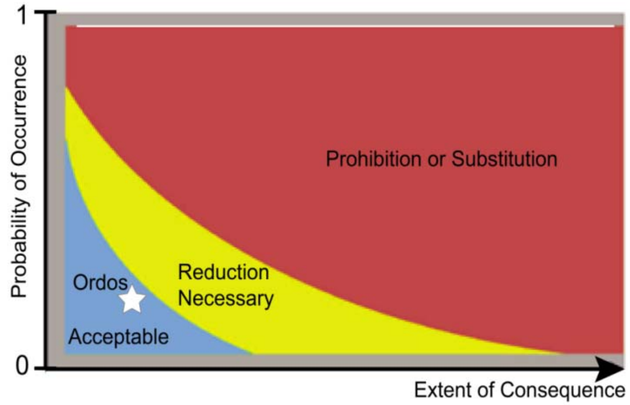


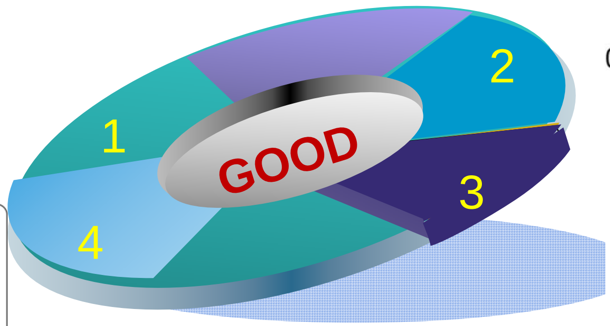


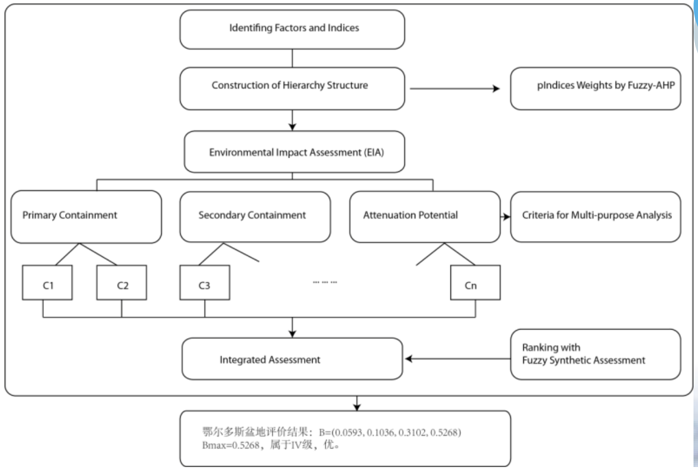
- Very low-permeability reservoir

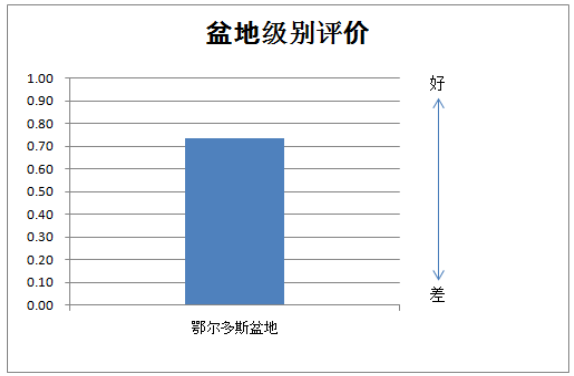
Research output (4): CO2RISKEYE Application to Ordos Basin





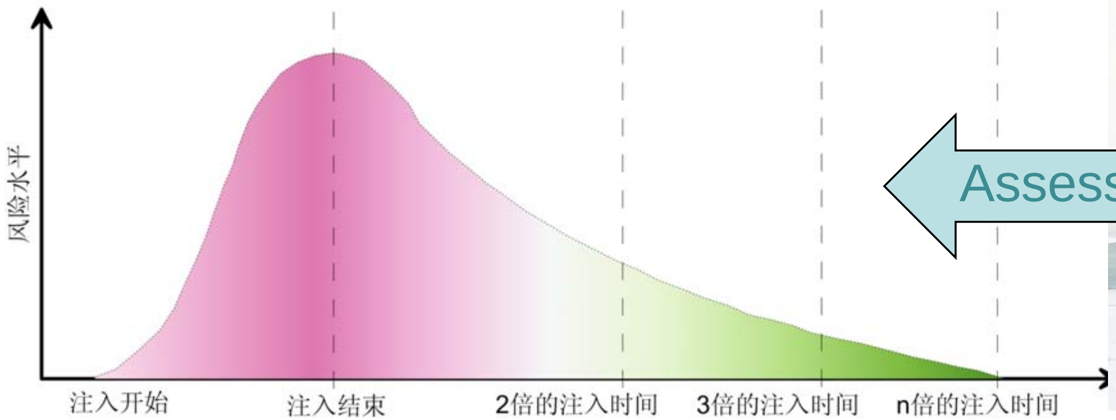






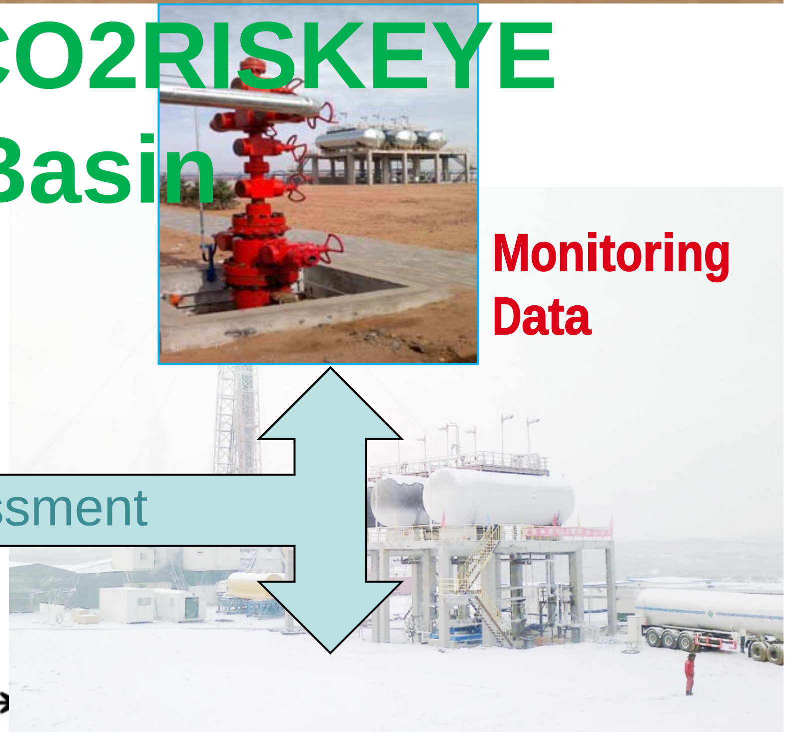
Research output (5): CO2RISKEYE Application to Ordos Basin

Future work



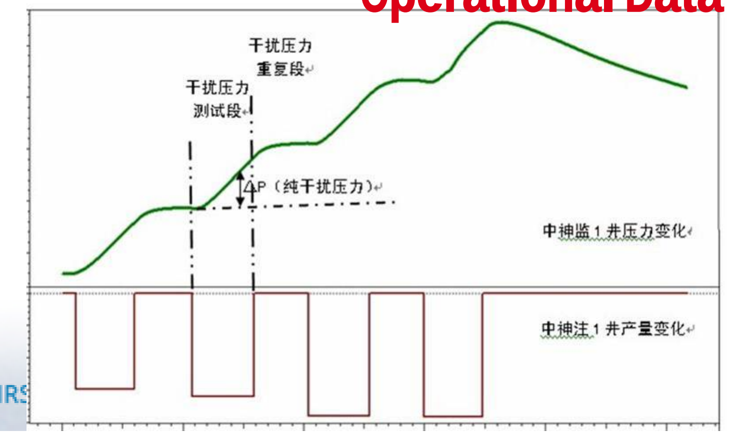
ERA of Lifetime

Assessment



Monitoring Data

Operational Data



Acknowledgements

- MOST ACCA21
- Geoscience Australia
- MEP Chinese Academy of Environmental Planning

- *Thanks for your attention!*

Thanks for your attention!

Qi LI, Ph.D.
Research Scientist and Professor

Institute of Rock and Soil Mechanics (IRSM),
Chinese Academy of Sciences

Xiaohongshan, Wuchang, Wuhan 430071, China

Tel./Fax: +86-27-87198126
URI: http://www.whrsm.ac.cn/

中国科学院
CHINESE ACADEMY OF SCIENCES