Institute of Rock and Soil Mechanics, Chinese Academy of Sciences
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Mechanical Stability Assessment of China's Sedimentary Basins for Industrial-Scale CO_2 Geological Storage

考虑场地力学稳定性的储存场地选址方法

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China Australia Geological Storage of CO_2

中澳二氧化碳地质封存

Outline of Talk

汇报提纲

1. Project root 项目来源
2. Research Background 研究背景
3. Methodology 研究方法
4. Technical accomplishment 技术实现
5. Results and Products 结论与产出
6. Acknowledgements 致谢

1. Project Root

项目来源

科技部国际合作项目：中—澳二氧化碳地质封存合作项目

第一课题：二氧化碳地质储存选址方法及其指标研究

第三子课题：考虑场地力学稳定性的储存场地选址方法

中国科技部21世纪议程管理中心

ACCA21 CAGS Program

中国地质调查局水文地质环境地质调查中心

CEHG/CGS: Research of CCS site selection method

中国科学院武汉岩土力学研究所

IRSM: Research of CCS site selection method based on mechanical stability

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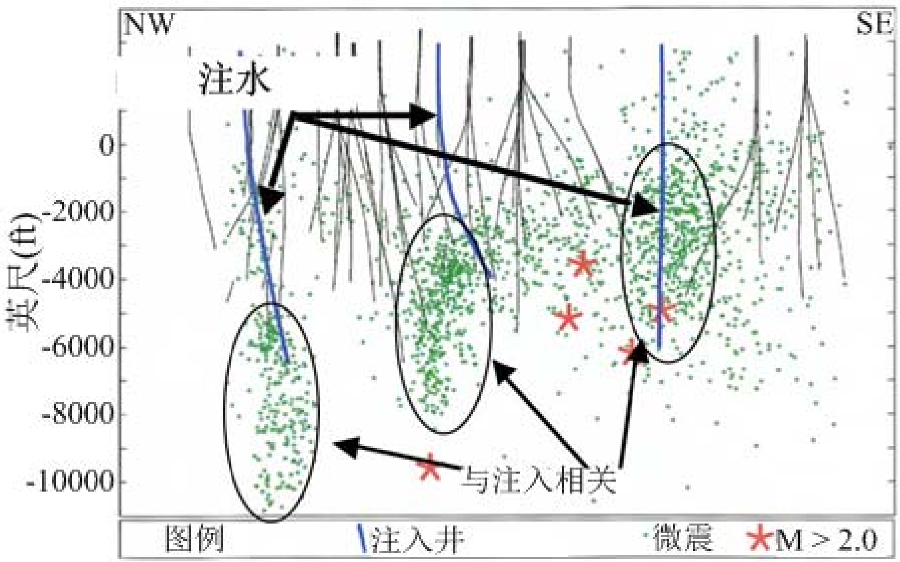
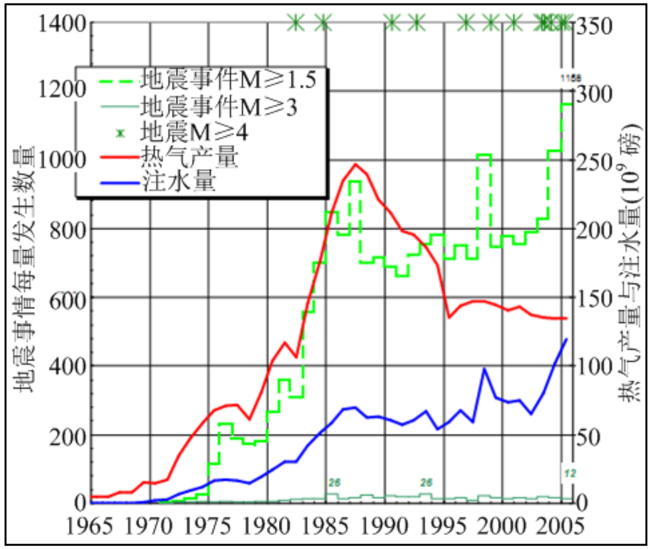
2. Research Background of Geomechanics

2.1 Geomechanical Baseline Associated with CO_2 Injection





4.4.5 Baseline geomechanical characterization

Geomechanical characterization of at least the storage unit and the primary seal (caprock) shall be conducted based on well logs, in situ testing, or laboratory testing on preserved core material (where possible, other overlying units should be characterized). Geomechanical characterization shall include the following:

(a) evaluation of the natural seismicity and tectonic activity of the region where the prospective storage unit is to be located. In some cases, natural seismicity and tectonic activity can cause fracturing or fault reactivation, processes that can create or enhance permeable leakage flow paths. Accordingly, the available information related to seismicity and tectonic activities shall be collected and analyzed;

(b) characterization of the in situ stress regime (magnitude and orientation of principal stresses). Wireline logs (especially density, sonic, and oriented caliper and borehole imager logs), small-scale hydraulic fracture tests (i.e., micro-fracture or mini-fracture tests), and leak-off tests can provide this information and should be performed prior to injection of the CO_2 stream. In the case of mature oil fields, the reservoir pressure at the time these measurements are made should also be recorded, given that pressure change generally induces changes in stress magnitudes. This information, used with the geomechanical modelling procedures described in Clause 4.5.5 can be used to assess injection pressure limits. Similarly, although the minimum in situ stress in the storage unit (often referred to as the fracture pressure) may be used to define injection pressure limits in some cases, given that tensile fracturing or natural fracture reopening can occur once the injection pressure exceeds this stress magnitude, pressure limits should be assessed on the basis of a broader range of possible fracturing modes, as described in Clause 4.5.5;

(c) determination of rock mechanical properties, which include (i) strength and deformation properties (e.g., Poisson's ratio and Young's modulus); (ii) thermal properties (e.g., thermal expansion coefficient, specific heat capacity, and thermal conductivity); and (iii) the attributes (e.g., orientation,

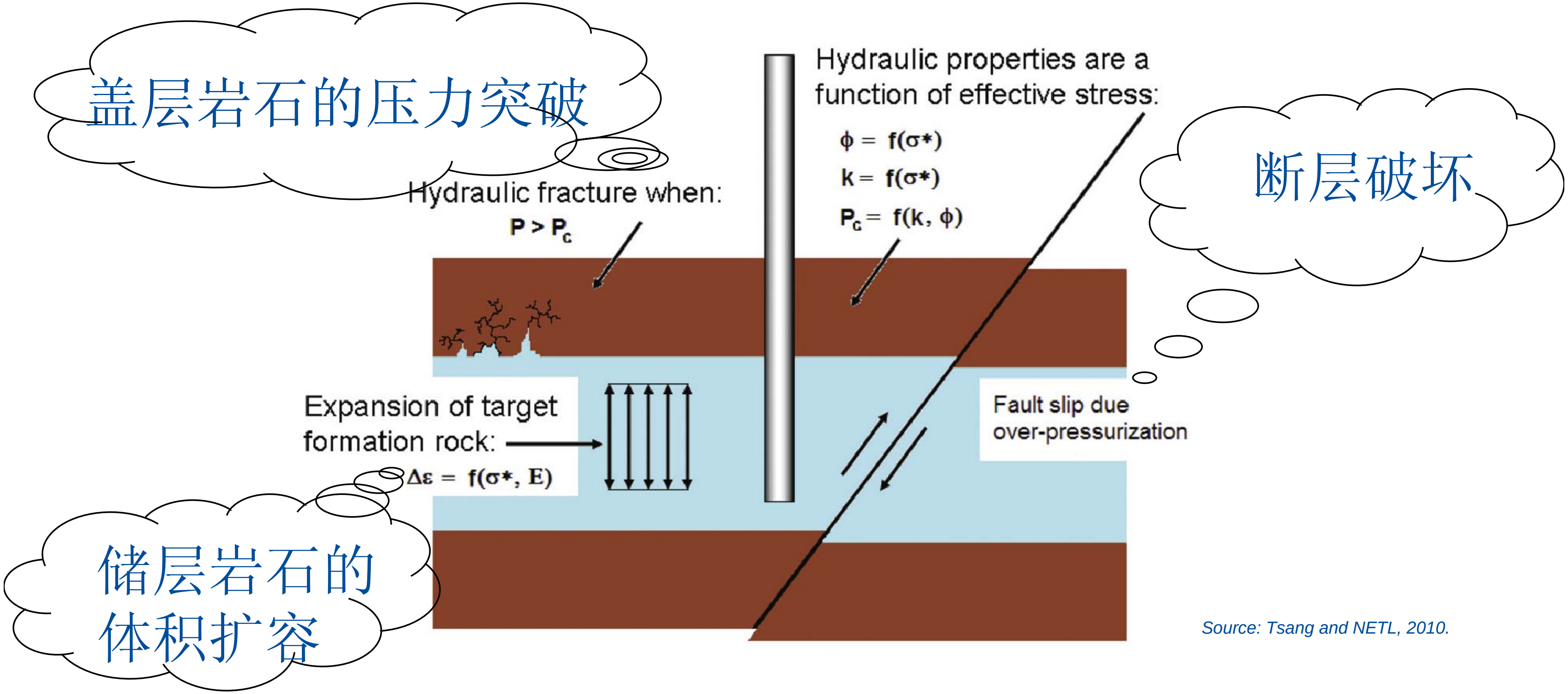
从本底调查阶段到场地关闭后，都必须进行详细的力学评价！

Guidelines for Initial Characterization.

COMPONENT		ELEMENT	GUIDELINES FOR INITIAL CHARACTERIZATION
Baseline Data	Subsurface Data Analysis	Geological	Develop site specific geologic baseline of Qualified Site(s) including type log/stratigraphic column; detailed correlation of reservoir architecture including injection intervals within the injection zone and potential confining intervals within confining zone; detailed structural maps; interpreted depositional model and facies distribution; porosity maps for potential injection and confining intervals and zones; and porosity/permeability log transforms. This evaluation should be updated as additional information is acquired (seismic and well data). During Initial Characterization any additional data from a new well test should also be integrated into previous analyses.
		Geochemical	Develop baseline of groundwater in all overlying aquifers using fluid and fluid level data collected in shallow aquifer formations in offset wells. If available, collect rock and fluid property data (composition, geochemistry, pH, conductivity, mineralogy) from the injection zone to model formation fluid-CO_2-rock reactions in the injection zone and at confining zone interfaces.
		Geomechanical	Develop baselines for injection rates and pressures utilizing drilling data on formation strength and modeling. Analyze advanced logging suites from offset wells and characterization wells (if any exist) to identify faults and fractures. Analyze new or existing core to determine the existing stress state and assess the impact of changes in pore pressure on stress.
		Hydrogeological	Determine fluid compositions and injection zone flow units from new or offset well data, fluid samples, and hydrologic and other testing. Integrate into dynamic injection zone models and compare to the existing hydrological model. Conduct multi-well tests where possible. Injection zone fluids and hydraulic tests should be further investigated during the Site Characterization Phase and fluid samples should be collected if a new well is drilled or an existing well(s) is further tested.
		Flux Baselines	Plan a monitoring system to establish baseline readings of near surface, ground level, and shallow subsurface fluxes. Baseline monitoring could be conducted during Initial Characterization and conducted for at least a year to account for changes in flux reading due to seasonal changes. Nearby urban, industrial or agricultural expansions and developments may require re-establishing a baseline prior to injection.
Regulatory Requirements	Regulatory Issue Analysis	Determine Applicable Regulations	Review the current state, regional and federal regulatory requirements for Initial and Site Characterization activities including permitting and acquiring seismic data; permitting stratigraphic, injection, or monitoring wells. Identify data gaps requirements, lead agencies and timelines for permitting process; update project timelines accordingly. Review all requirements for carbon storage (e.g., pipeline development, land access, pore rights) in site area, plan for compliance and understand cost implications to project.
		Develop Well Plan	Develop plan for well design, construction, testing, injection and monitoring in compliance with current and anticipated state, regional and federal regulations for all types of wells being planned. Update cost estimates for wells and booster compressors, if needed.
		UIC Permit Planning	Collaborate with identified agencies for initial approval for both the well plan and any potential development plans to confirm that assessments are in alignment with UIC and other regulations. Identify and assess existing well bores (locally and regionally) within the planned AoR for well integrity.

2. Research Background of Geomechanics

2.2 Geomechanical Processes Associated with CO_2 Injection



Source: Tsang and NETL, 2010.

ϕ represents porosity of the confining zone, k represents confining zone permeability, Pc represents the minimum pressure that would induce confining zone fracture, P represents the current formation pressure, E represents rock compressibility, $\Delta\varepsilon$ represents the expansion of the target formation rock, and σ^* represents shear stress. Values for these variables can be determined through a combination of laboratory and field-generated data. The geomechanical variables in the model should be regularly updated, as in situ monitoring data from the project becomes available.

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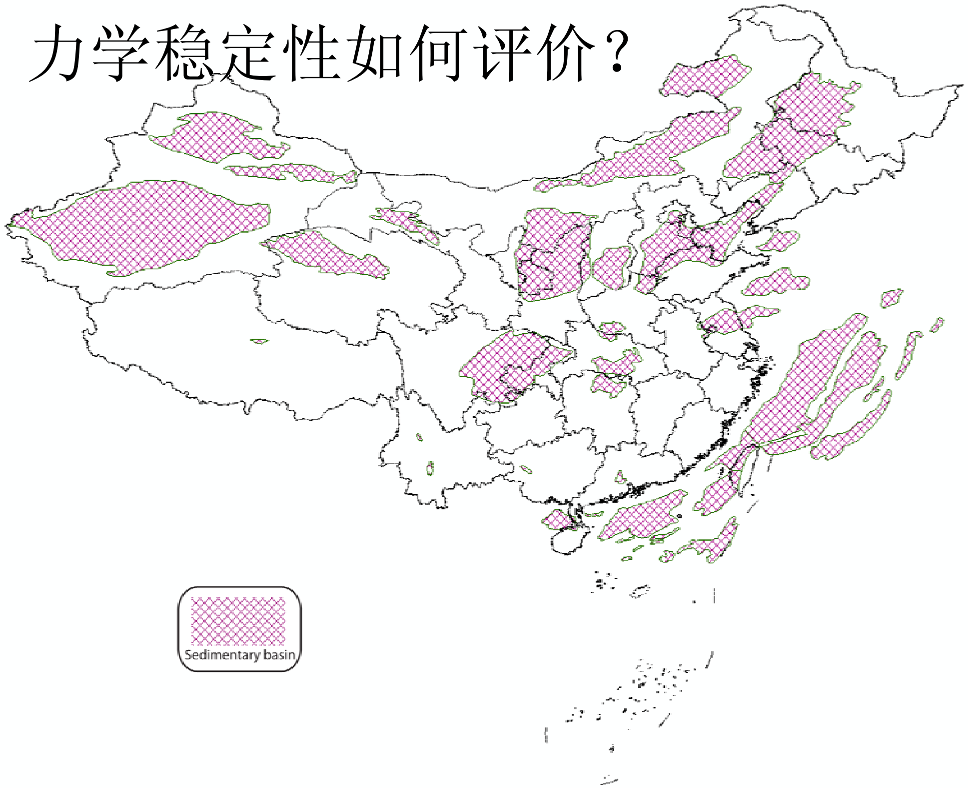
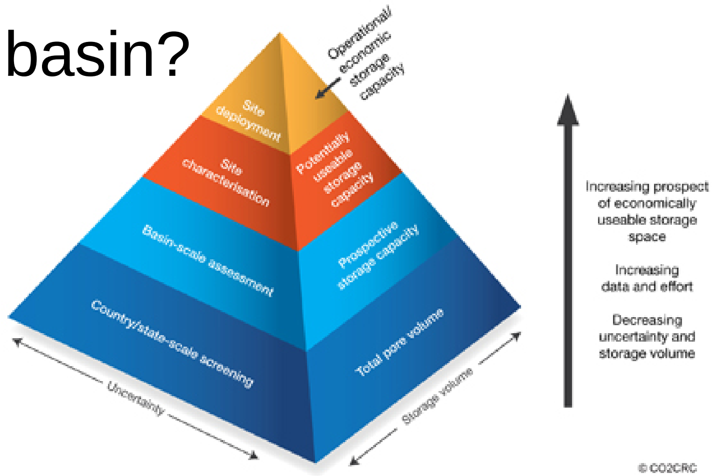
2. Research Background of Geomechanics

2.4 Question

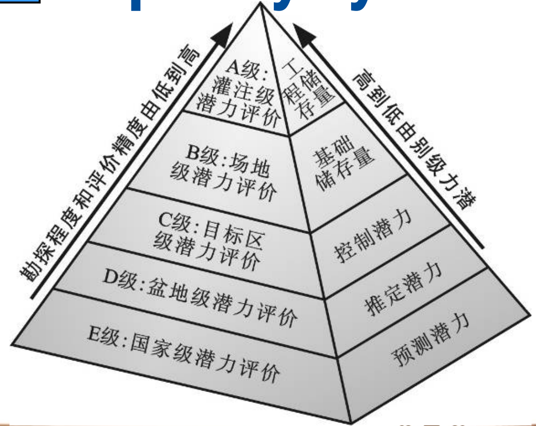
How to assess mechanical certainty of a basin?

力学稳定性如何评价？





Capacity Pyramid



3. Methodology

3.1 Prerequisite

Killer criteria:

1. Potential theoretical capacity of basin (less than 2500 Mt)
2. Maximum thickness of potential storage basin greater than 1500 m)
3. Temperature of storage aquifer (less than 373 K)
4. Active fault to the injection well (R_f no less than 10 km)

必要条件：

1）盆地理论容量小于2500 Mt

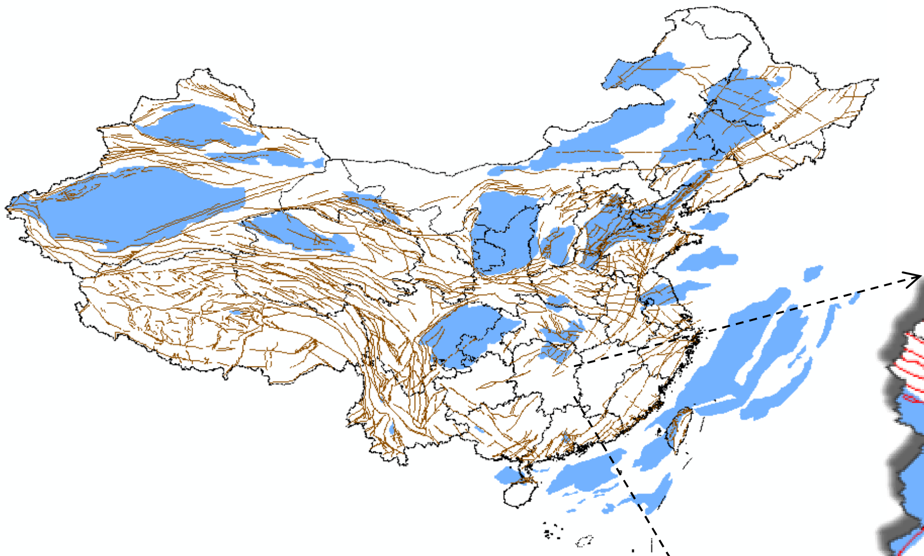
2）沉积盆地厚度大于1500 m

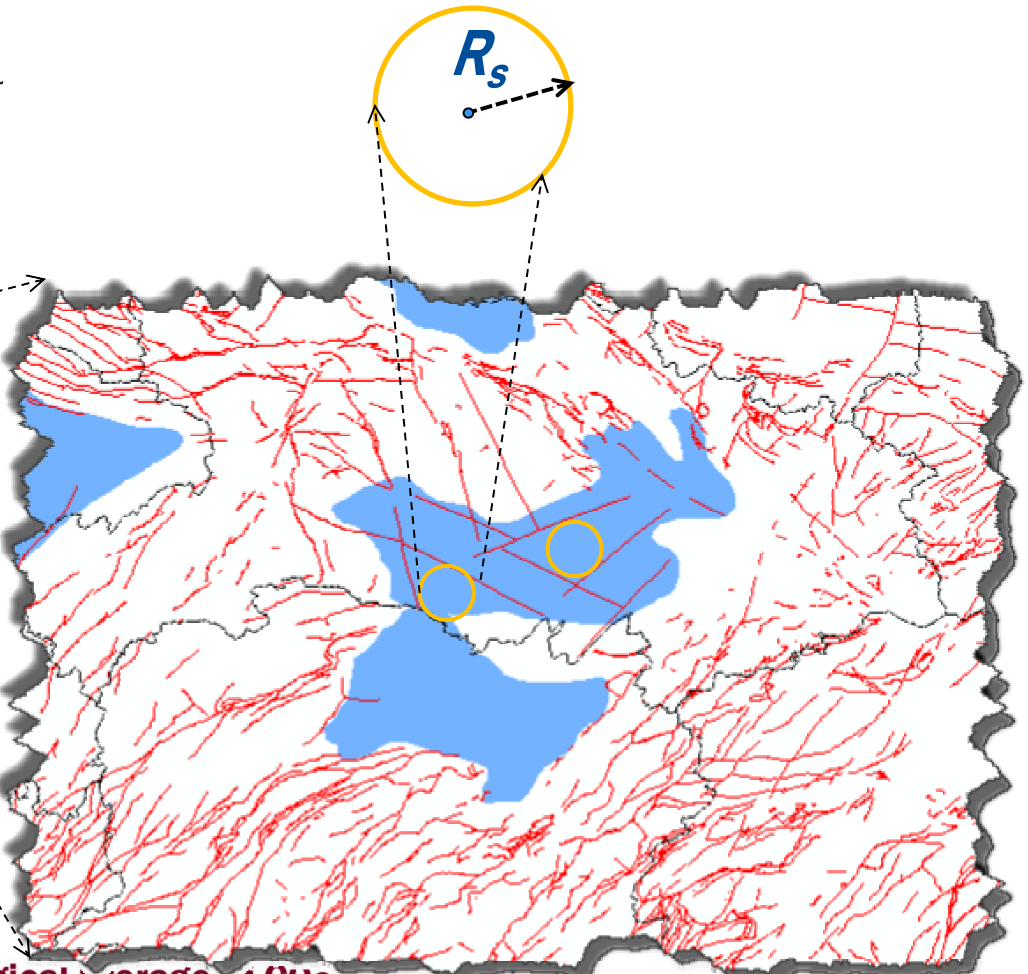
3）储层温度高于373 K

4）活断层到注入井最短距离R_f小于10 km

3. Methodology

3.2 Prerequisite



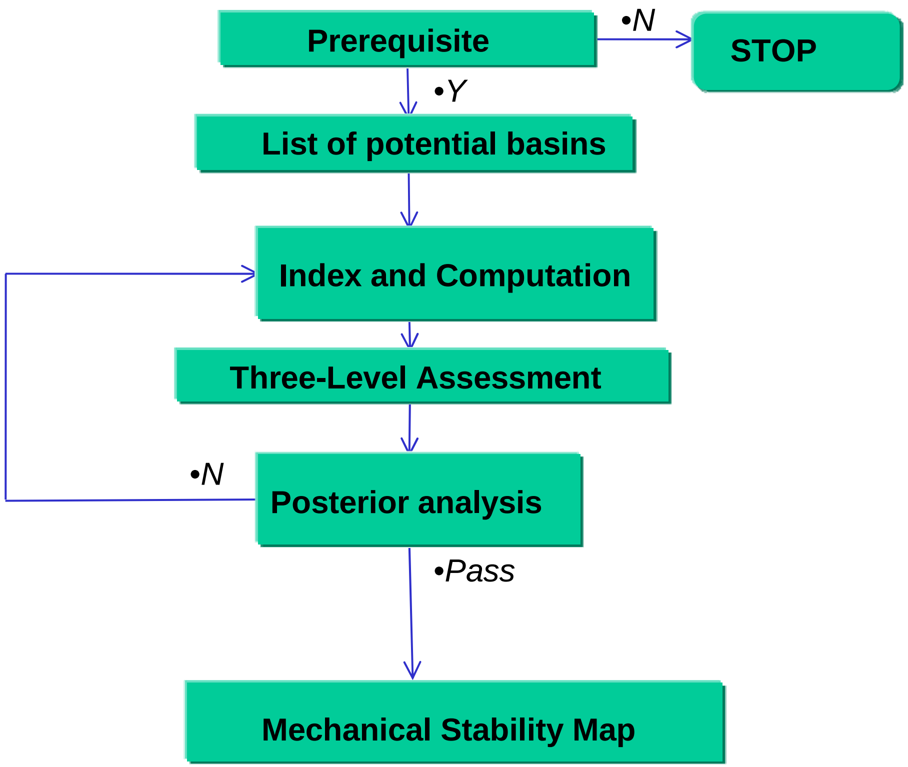


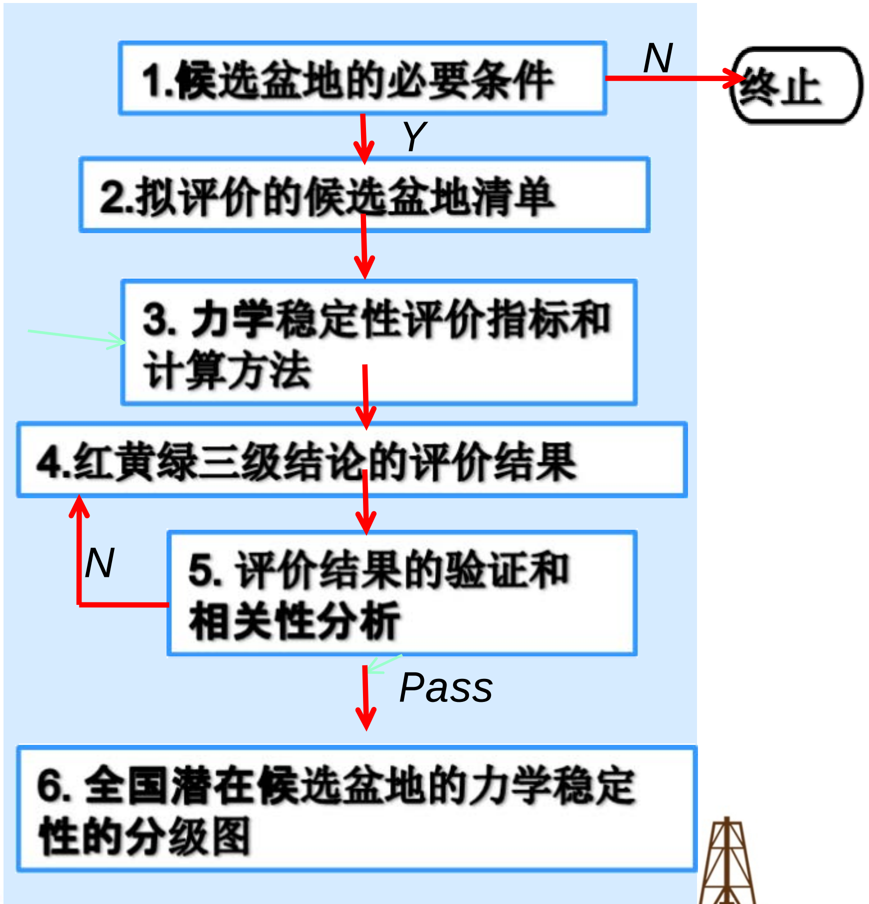
$$R_s \begin{cases} >= 2R_f \\ > R_f \ \& < 2R_f \\ <= R_f \end{cases}$$

- Certainty (blue): $R_s >= 2R_f$
- Uncertainty (yellow): $R_s > R_f \ \& < 2R_f$
- Very uncertainty (red): $R_s <= R_f$

3. Methodology

3.3 Logical flow of assessment





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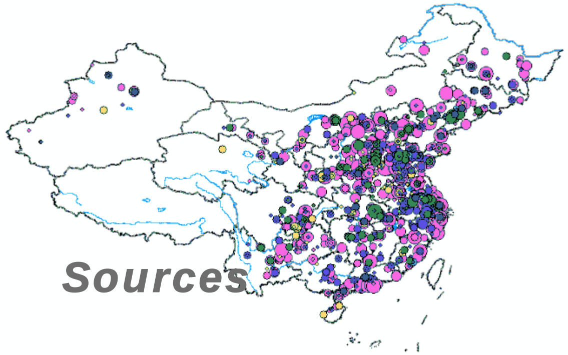
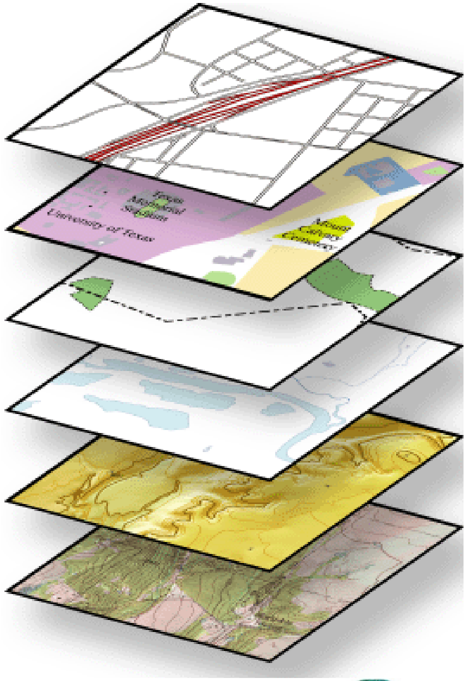
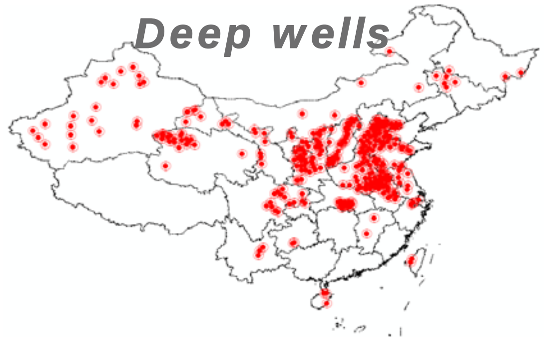
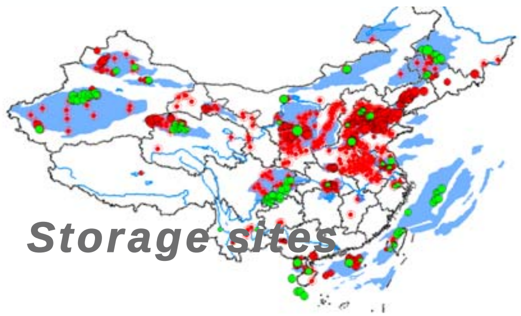
3. Methodology

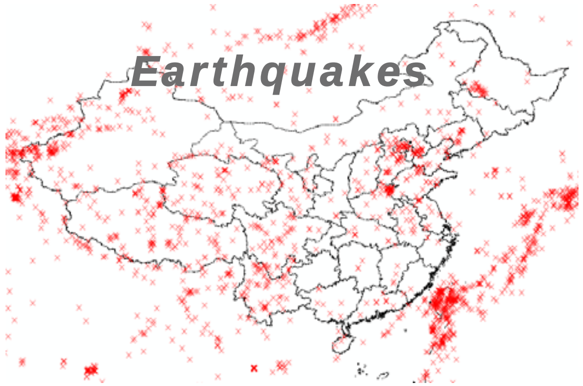
3.4 Database Sources

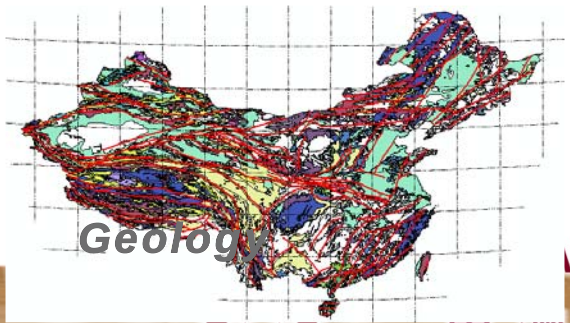


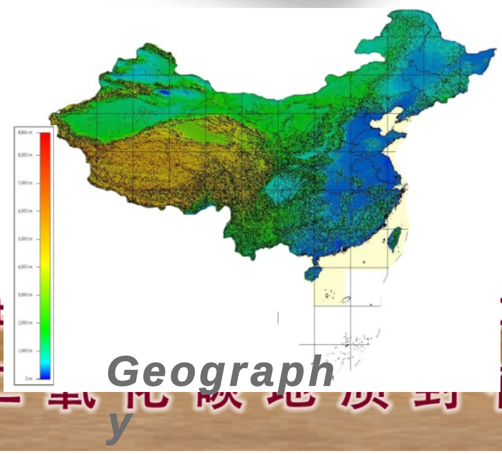


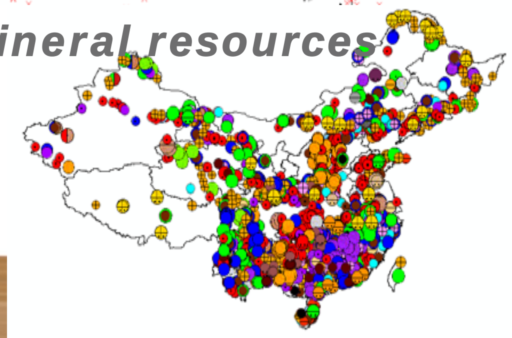






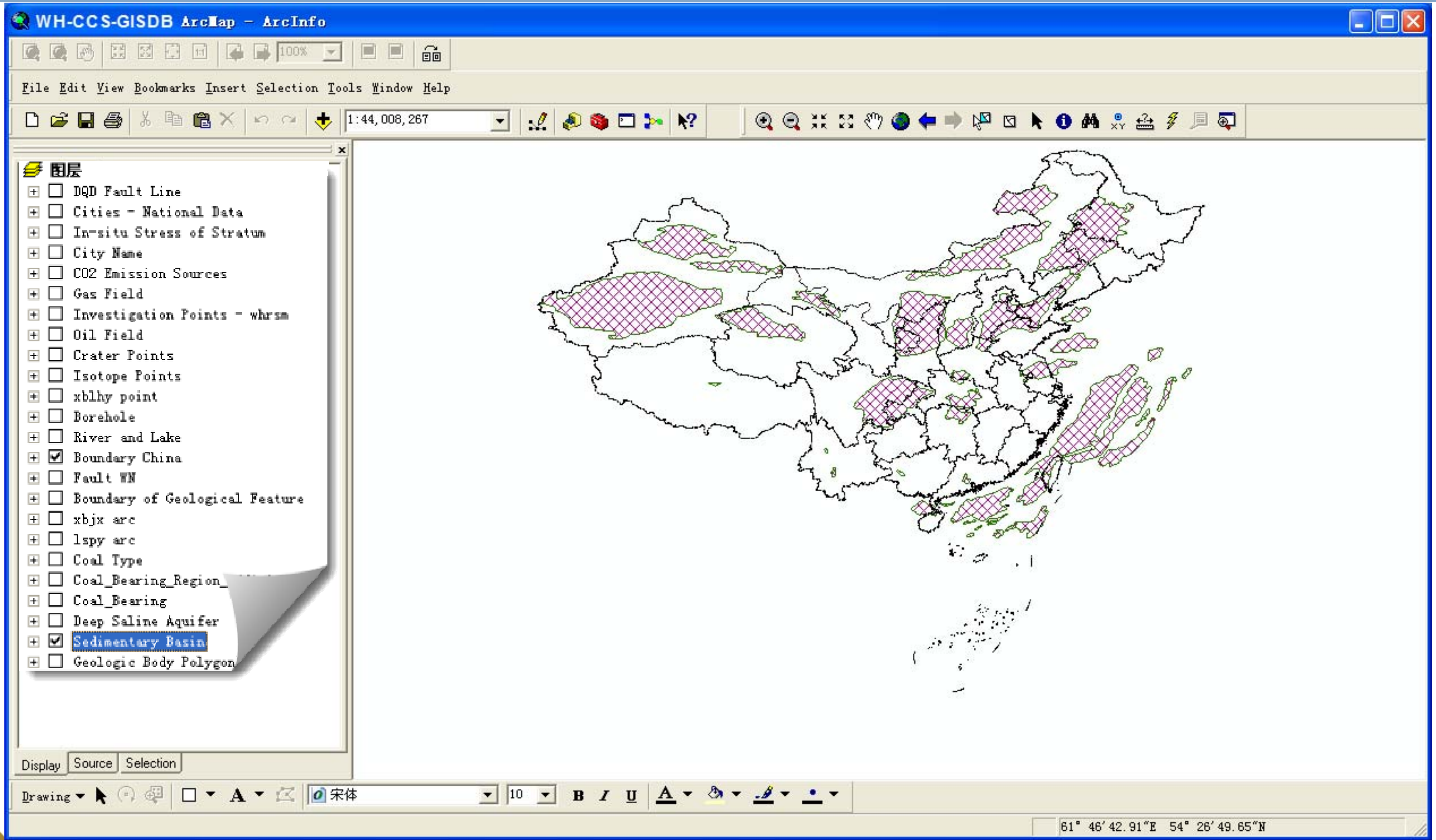






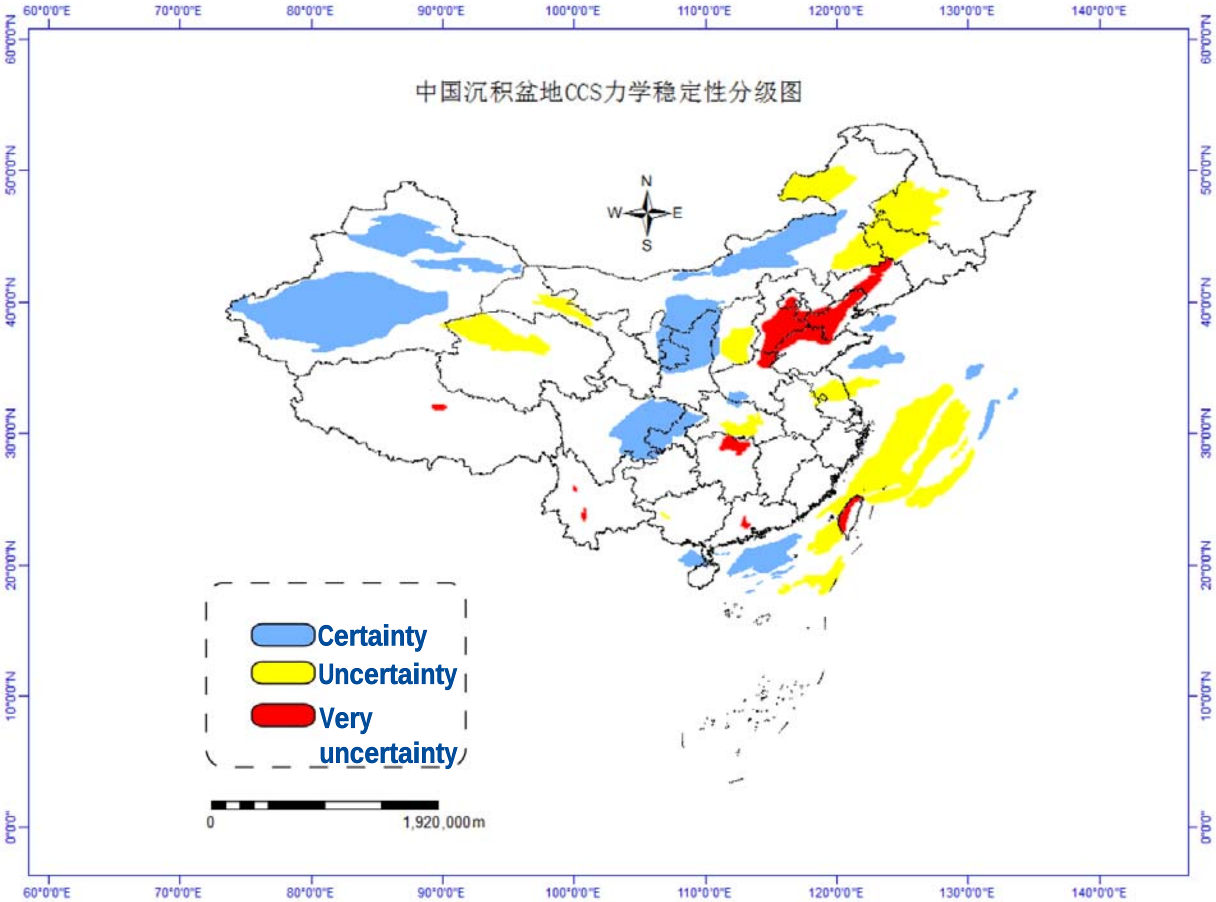
4. Technical accomplishment

Index→Flow→Mapping



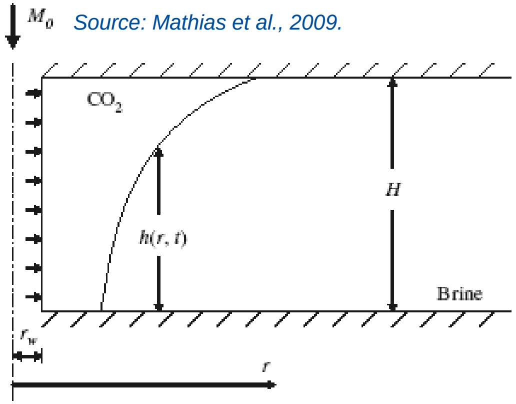
5. Results and Products

5.1 Resultant Mapping



6. Results and Verification

Computation models and numerical analyses: Verification



Source: Mathias et al., 2009.

$$P_t \approx P_e\left\{-\frac{1}{2}\ln\left(\frac{t_e}{2\gamma t}\right)-1+\frac{1}{\gamma}-\frac{1}{2\gamma}\left[\ln\left(\frac{\alpha}{2\gamma^2}\right)+\xi\right]+\beta\right\}$$

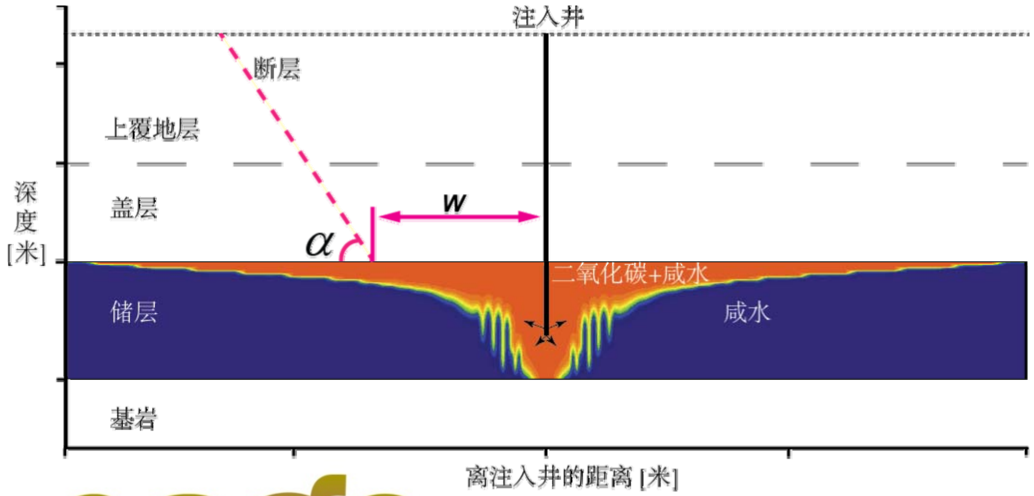
$$P_e=\frac{M_0\mu_0}{2\pi H\rho_0 k}$$

$$t_e=\frac{2\pi\phi H r_w^2\rho_0}{M_0}$$

$$\gamma=\frac{\mu_0}{\mu_w}$$

$$\alpha=\frac{M_0\mu_0(c_r+c_w)}{2\pi H\rho_0 k}$$

$$\beta=\frac{M_0 kb}{2\pi H r_w\mu_0}$$



参数	取值
杨氏模量, [Pa]	3.0x10^{9}
波松比, [-]	0.25
岩石密度, [kg/m^3]	2800
流体密度, [kg/m^3]	980
初始孔隙度, [-]	0.23
比奥系数, [-]	0.28
比奥模量, [Pa]	1.3x10^{10}
孔隙压缩性, [1/Pa]	1.0x10^{-9}
摩擦角, [°]	28
粘聚力, [Pa]	2.0x10^{7}
初始渗透率, [m^2]	5.0x10^{-13}
注入压力, [Pa]	5.0x10^{7}
粘性系数, [Pa-s]	1.3x10^{-3}
注入温度, [K]	293
流体热容, [J/kg/K]	1160
固体热容, [J/kg/K]	920
流体热扩展系数, [1/K]	5.0x10^{-4}
固体热扩展系数, [1/K]	1.0x10^{-5}
热导系数, [W/m/K]	2.63
热扩散系数, [m^2/s/K]	6.0x10^{-12}
注入浓度, [mol/m^3]	628
有效溶质扩散系数, [m^2/s]	5.0x10^{-9}
地球化学反应率, [1/s]	1.0x10^{-9}
地球化学反应热, [J/mol]	1.3x10^{-6}

6. Results and Verification

Future work

- 构造断裂密度 **Active Fault**
- 活动构造（活断层，活火山，活褶皱，地震震级和事件频度）
- 构造分区和地壳稳定性

→ 评价指标 **Assessment Index**

- 地应力分布 **GeoStress**
- 地形形变和地貌变迁

→ 一级验证指标 **Verification Index**

- 自然温泉和地热分布 **Hot spring**

→ 二级验证指标

6. Acknowledgements

致谢

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Geoscience Australia	澳大利亚地球科学局
AITF Canada	加拿大阿尔伯塔研究理事会
CHEG CGS	中国地调局水环中心

Thank you!

All questions and comments to: qli@whrsm.ac.cn