Geomechanical Issues of CO_2 Storage for Performance and Risk Management

CO_2地质封存的力学稳定性及其风险管理

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cags China Australia Geological Storage of CO_2

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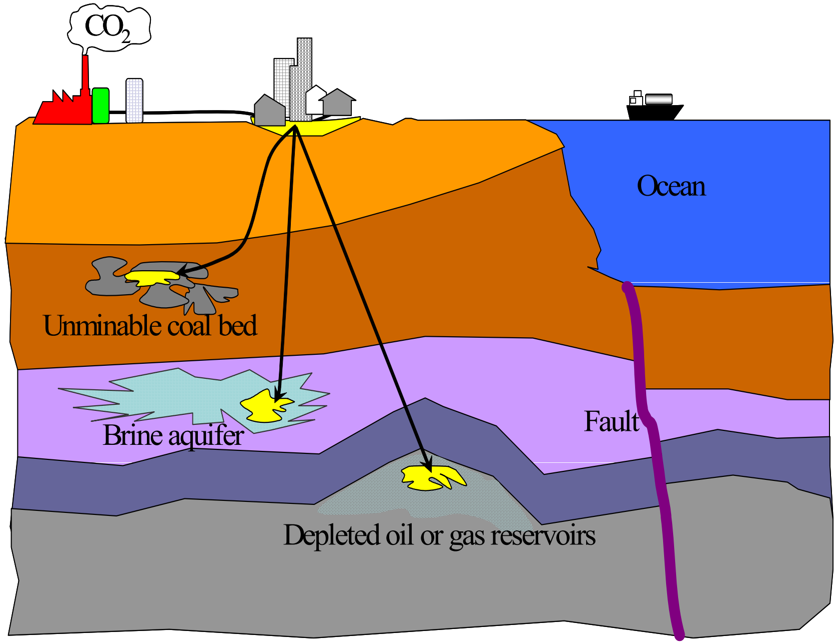
Outline
报告提纲

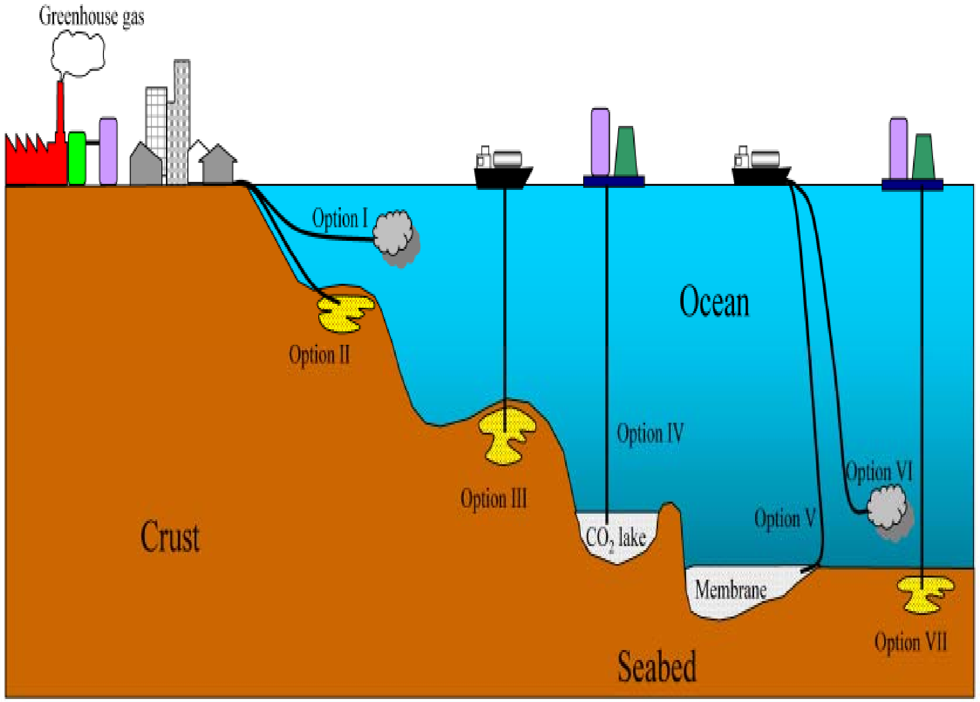
- Geo-storage options of CO_2
- Intrinsic mechanisms of geological failure
- Coupled simulation methods and tools
- Mechanical experiments related CCS
- Risk monitoring items

- Concluding remarks

Terrestrial and ocean storage of CO_2



(Source: Li et al., PAGEOPH 2006)



(Source: Li et al., ECM 2008)

Leakage risk related to CO_2 storage

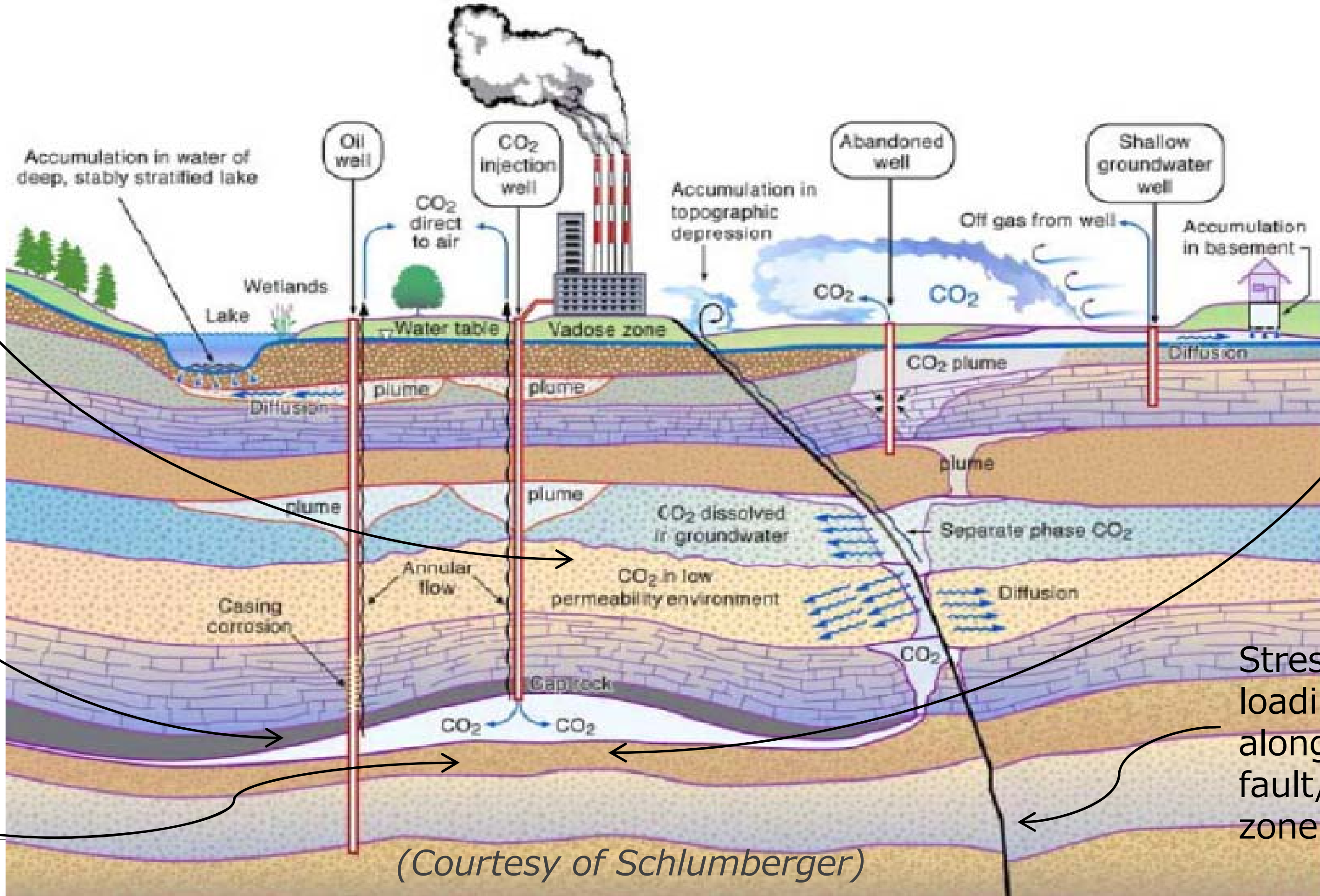
Gas breakthrough stress loading

Density driven stress loading

Hydraulic fracturing

Increased pressure caused by injection

Stress loading/transfer along fault/fractue zone



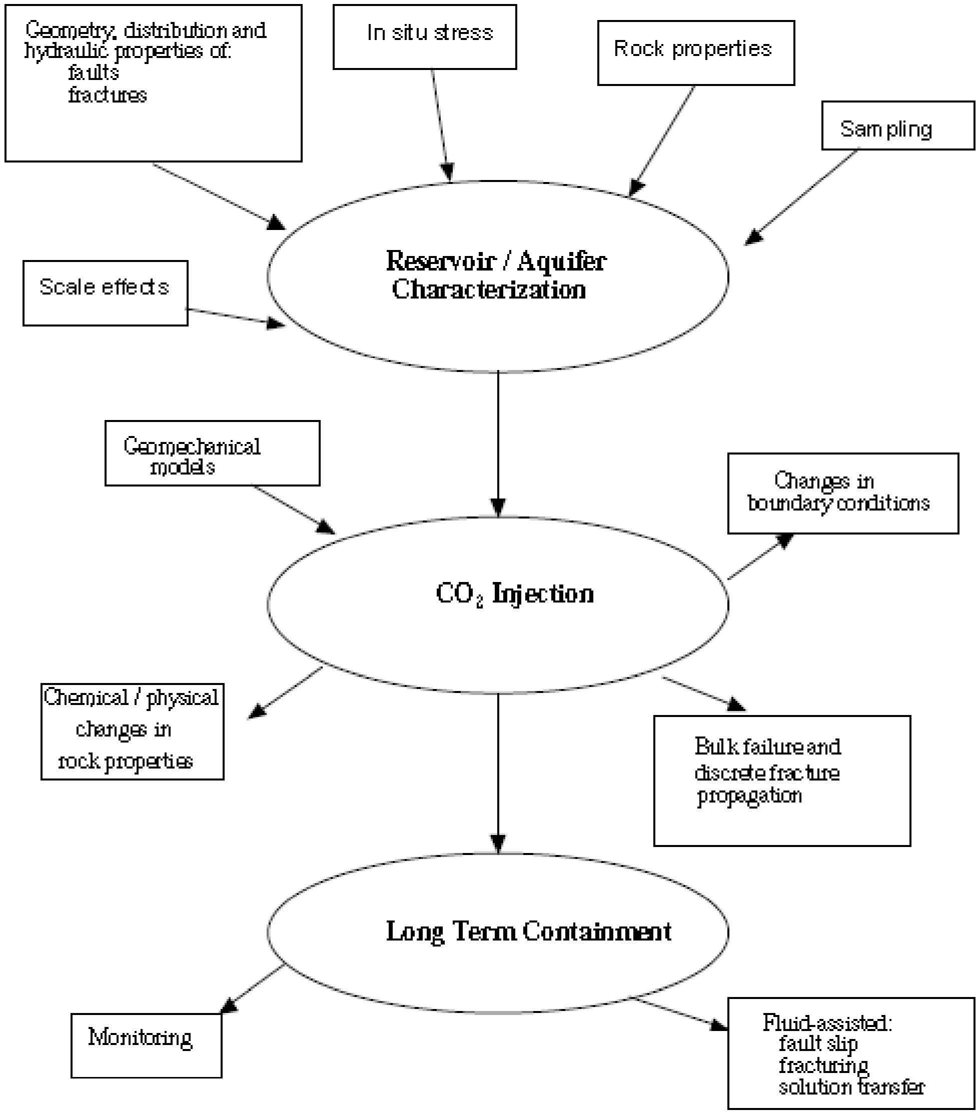
(Courtesy of Schlumberger)

Hazard related mechanical failure

Hazard	**Atmospheric release**	**Groundwater contamination**	**Mechanical deformation**
Mechanism	Well leakage	Well leakage	Well failure
Feature	Fault leakage	Fault leakage	Fault reactivation
Condition	Cap rock leakage	Cap rock leakage	Cap rock failure
	Pipeline leakage		
			Induced seismicity
			Subsidence/heave

(Source: Friedmann, 2008)

Geomechanical perspective

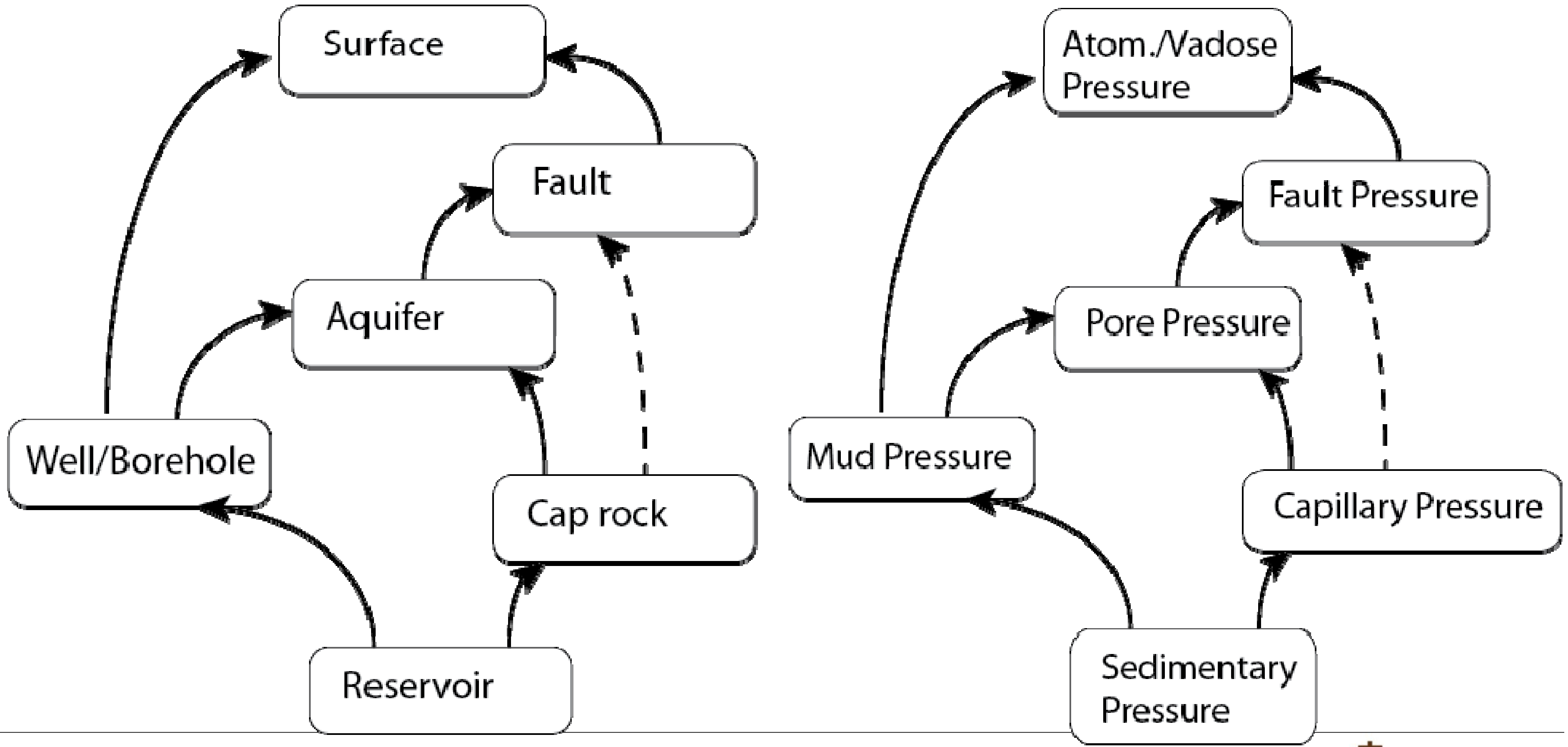


(Source: Logan et al., 1998)

(Source: Li et al., GREEN 2008)

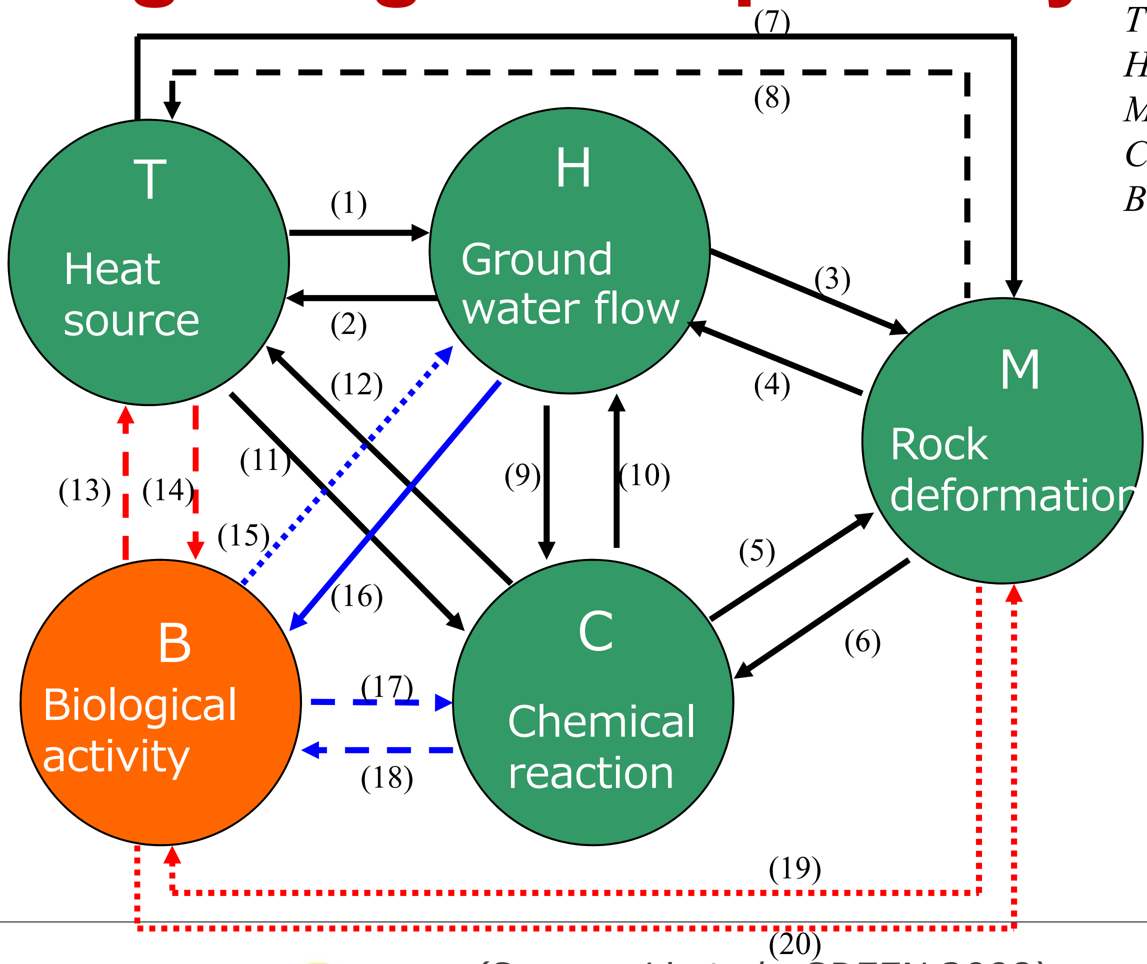
Hydraulic and mechanical system

Mapped CCS site into an equivalent hydraulic and mechanical system



(Source: Li et al., 2011)

Coupled THMC^B simulator of geological disposal system



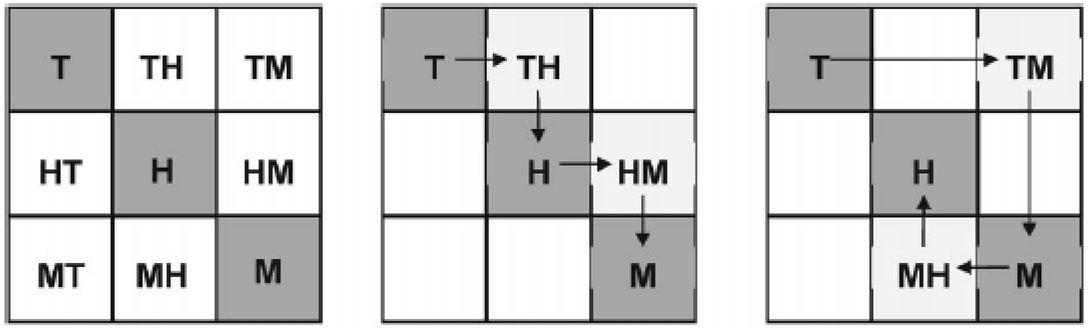
T: Fourier's law for energy balance
H: Darcy's law for mass balance
M: Hooke's law for force equilibrium
C: Fick's law for mass balance
B: Empirical law for mass balance

Coupling processes, e.g.:
…
(15) Growth and decay; porosity reduction
(16) Solute transport
(17) Adsorption isotherm; biomineralization
(18) Redox; Irreversible limited desorption
…

Solid-line: strong coupling
Dash-line: medium coupling
Dot-line: weak coupling
Line-in-black-color: developed
Line-in-blue-color: developing
Line-in-red-color: planning

(Source: Li et al., GREEN 2008)

Coupled approach for different encoding



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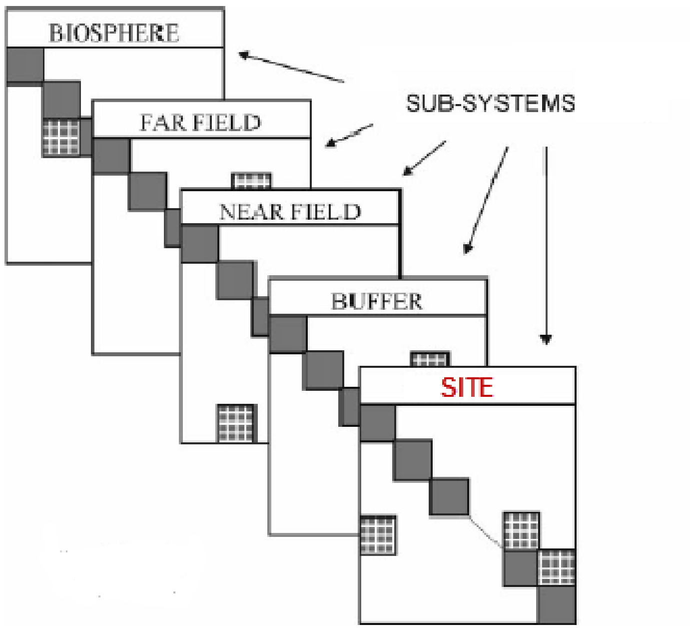
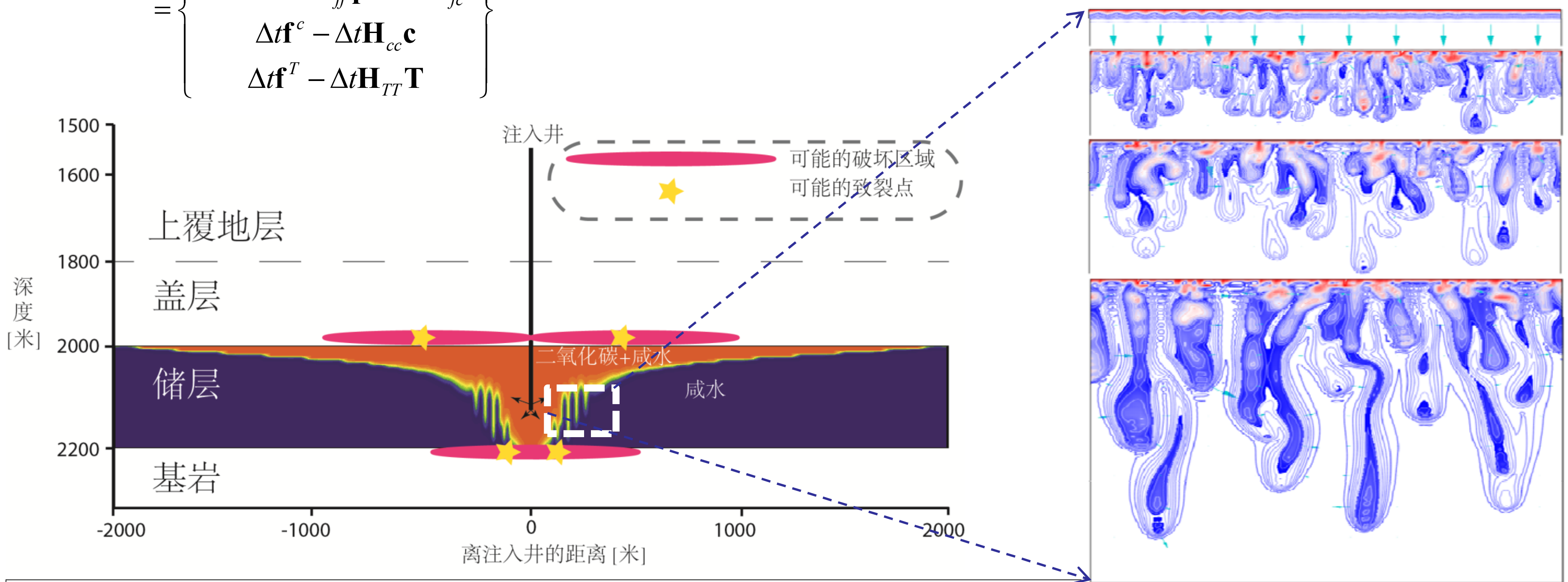


- The storage system and the sub-systems can be decomposed as depicted in the left illustration. Highlighted off-diagonal terms are the mechanisms identified as the components of the process system. Some of these mechanisms will be THM mechanisms; some will be other types, e.g. geochemical mechanisms.

T-H-C-M Coupled Analysis

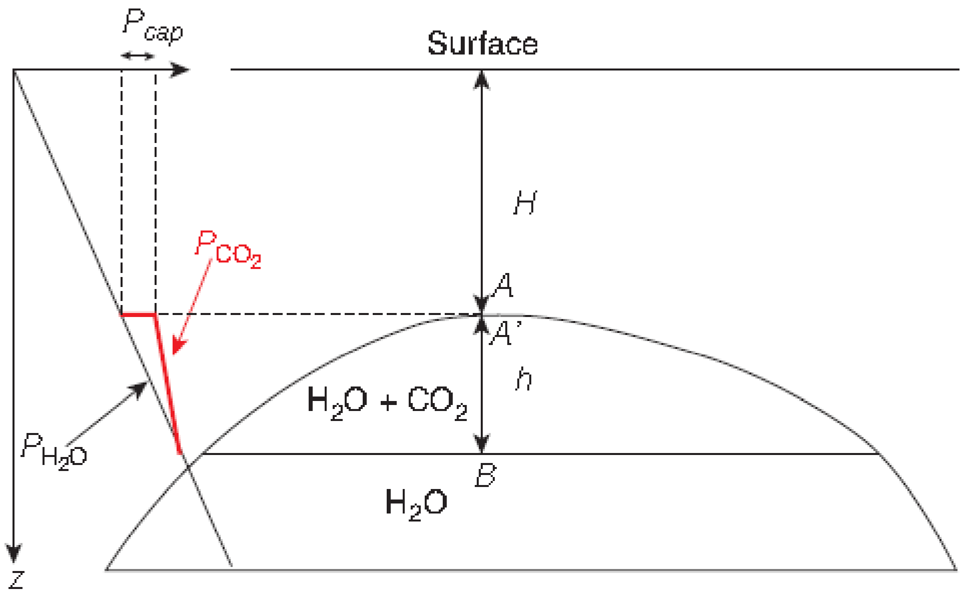
$$\begin{bmatrix} \theta \mathbf{M}_{ss} & -\theta \mathbf{c}_{sf} & -\theta \mathbf{c}_{sc} & -\theta \mathbf{c}_{sT} \\ \mathbf{c}_{fs} & \mathbf{R}_{ff} + \theta \Delta t \mathbf{H}_{ff} & \mathbf{c}_{fc} + \theta \Delta t \mathbf{H}_{fc} & \mathbf{c}_{fT} \\ 0 & 0 & \mathbf{R}_{cc} + \theta \Delta t \mathbf{H}_{cc} & 0 \\ 0 & \mathbf{c}_{Tf} & 0 & \mathbf{R}_{TT} + \theta \Delta t \mathbf{H}_{TT} \end{bmatrix} \begin{Bmatrix} \Delta \mathbf{u} \\ \Delta \mathbf{p} \\ \Delta \mathbf{c} \\ \Delta \mathbf{T} \end{Bmatrix}$$

$$= \begin{Bmatrix} \Delta \mathbf{f}^{s} \\ \Delta t \mathbf{f}^{f} - \Delta t \mathbf{H}_{ff} \mathbf{p} - \Delta t \mathbf{H}_{fc} \mathbf{c} \\ \Delta t \mathbf{f}^{c} - \Delta t \mathbf{H}_{cc} \mathbf{c} \\ \Delta t \mathbf{f}^{T} - \Delta t \mathbf{H}_{TT} \mathbf{T} \end{Bmatrix}$$



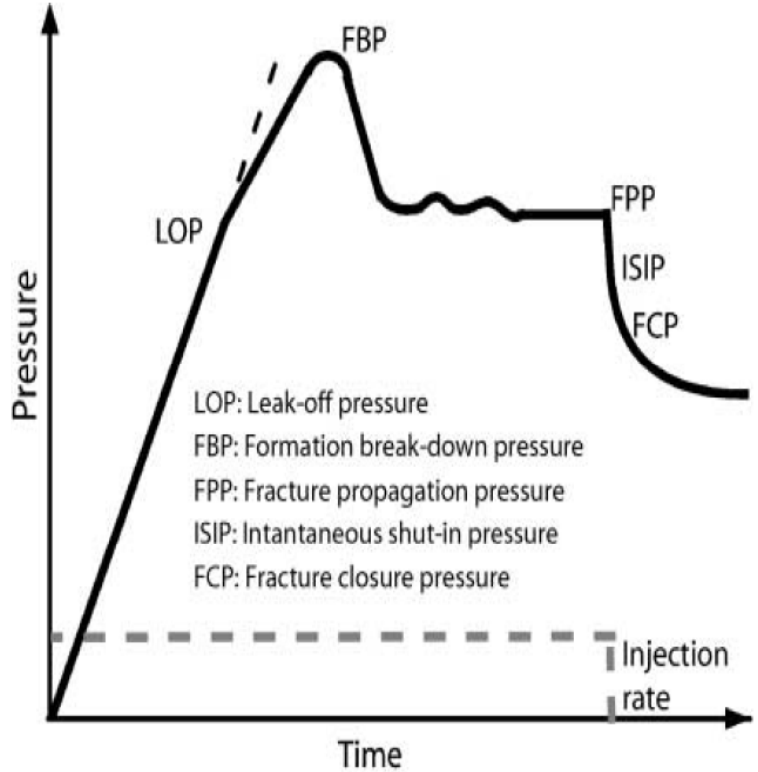
(Source: Li et al., 2011)

Capillary pressure and overpressure



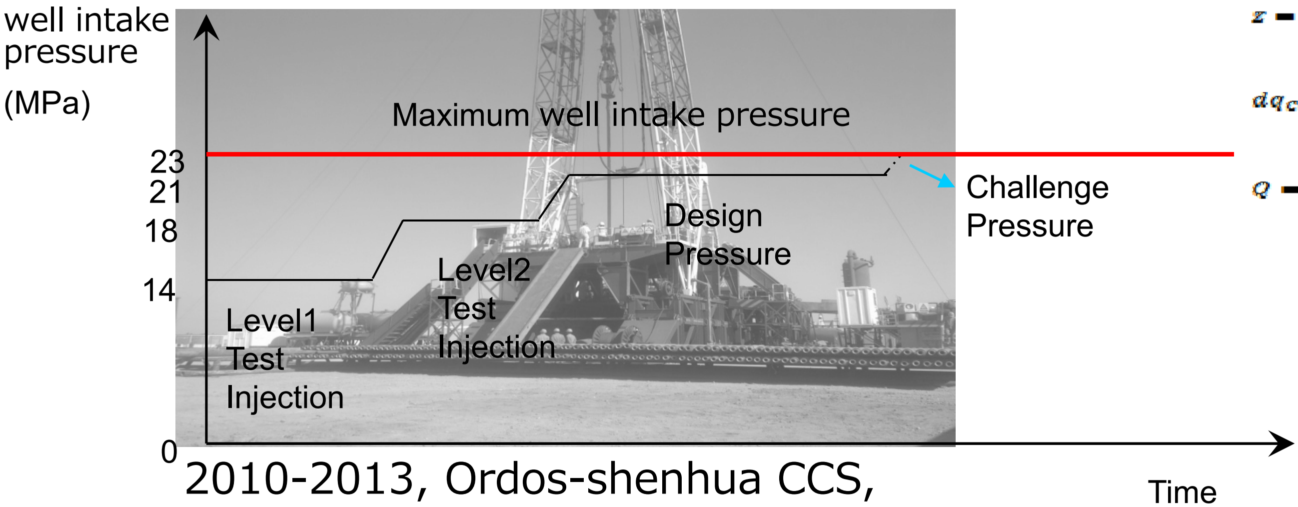
CO_2 and H_2O pressure evolution with depth in aquifer storage.

(Source: Bildstein et al., 2010)



(Source: Lucier et al., 2006)

Injection pressure of shenhua-ordos



2010-2013, Ordos-shenhua CCS, 10Mt/a

$$z = \frac{P_{wt} - P_{bt}}{\Delta \rho g}$$

$$dq_{co2} = -2\pi \frac{k k_{rw}}{\mu \ln\left(\frac{r}{r_w}\right)} \{(P_{wt} - P_{bt}) - \Delta \rho g z\} dz$$

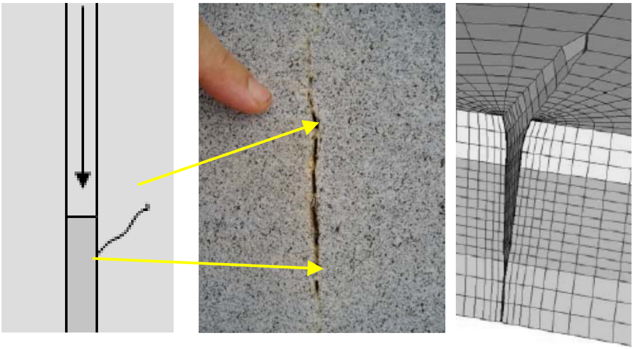
$$Q = \int_0^z dq_{co2}$$

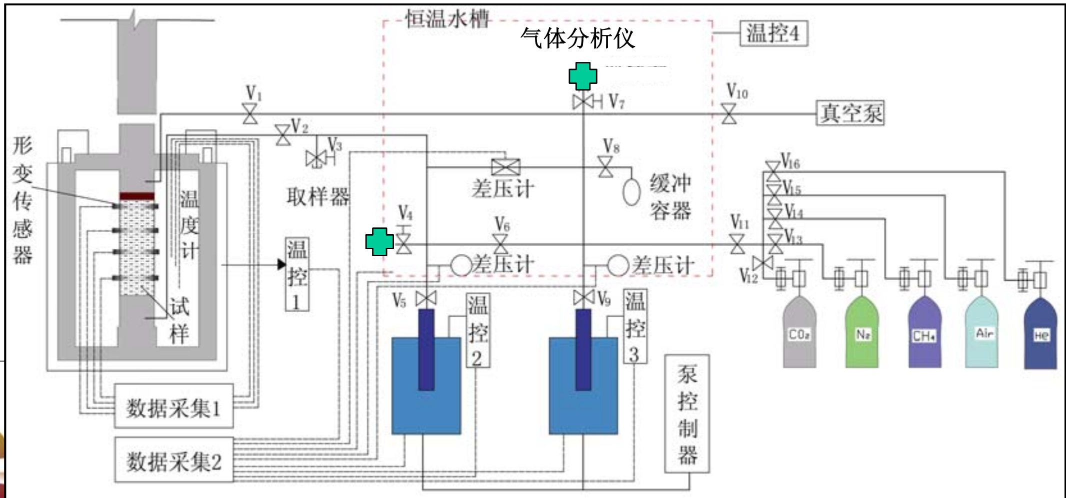
How to determine P_{wt}:

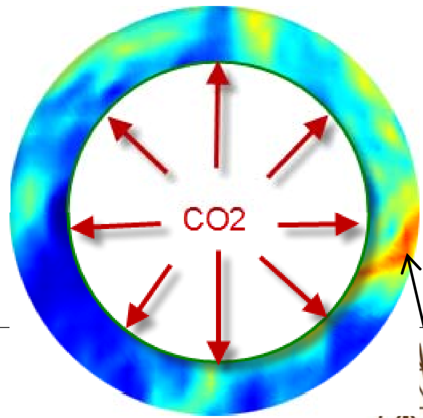
1) Test start with $P_{wt} > P_{bt}$ and calculate z;
2) Calculate Q;
3) If Q<injection rate, increase Pwt to next higher step and repeat 1 and 2. If Q>injection rate, decrease Pwt to a lower step and repeat 1 and 2.

(Source: Li et al., 2011)

Hydraulic fracturing experiment and simulation





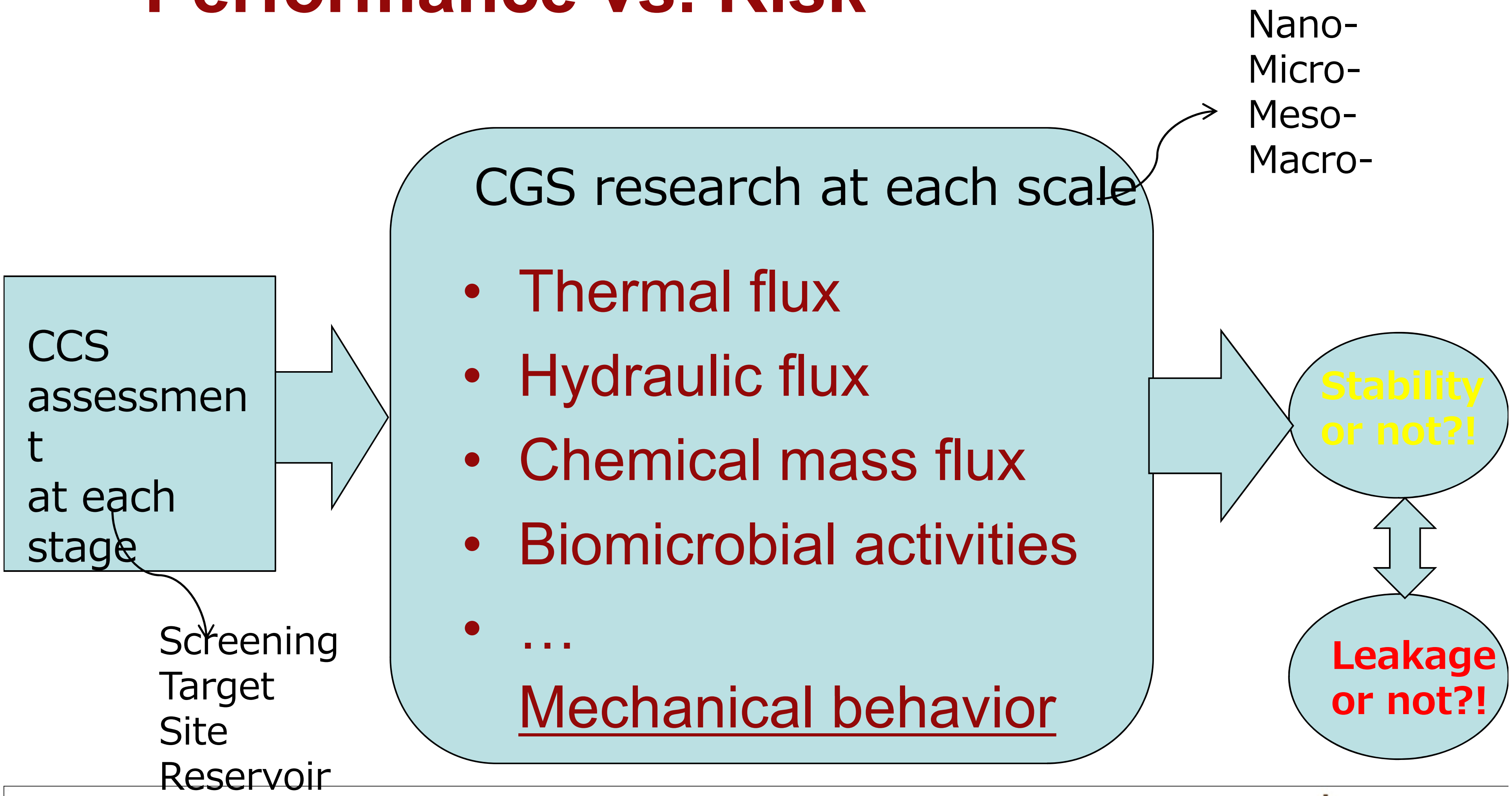


(Source: Li et al., 2011)

Experimental apparatus

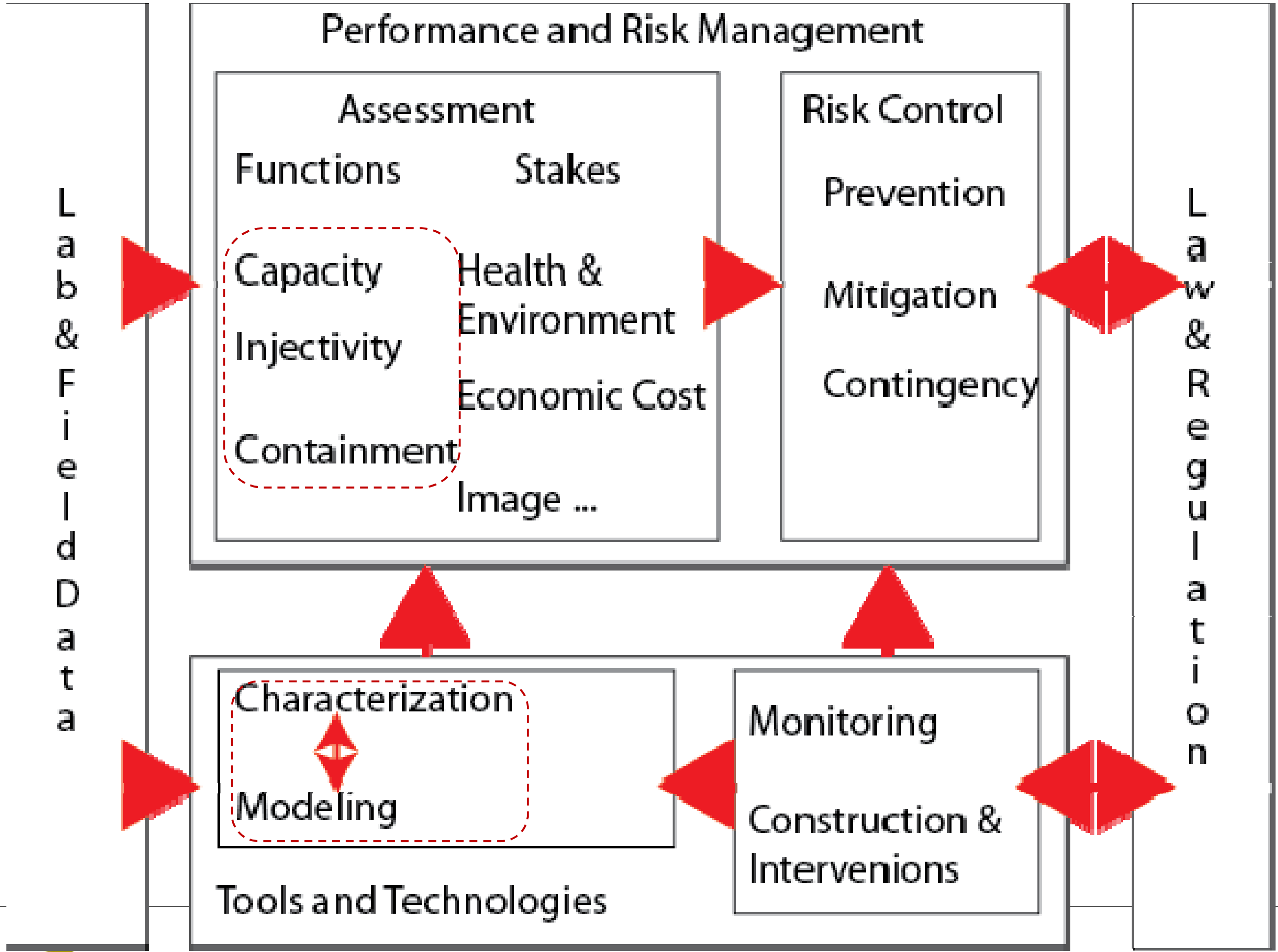
- Fracture pressure testing apparatus of cap rock
- Capillary pressure testing apparatus
- Flow-reaction-mechanics coupling testing apparatus
- Improved pulse decay permeability testing apparatus
- Mechanical testing apparatus
- Micro-scope mechanics-flow testing system
- And so on

Performance vs. Risk



(Source: Li et al., 2008)

Framework of performance and risk management



(Modified from Berard et al., 2007)

Monitoring items for DSF storage of CO_2

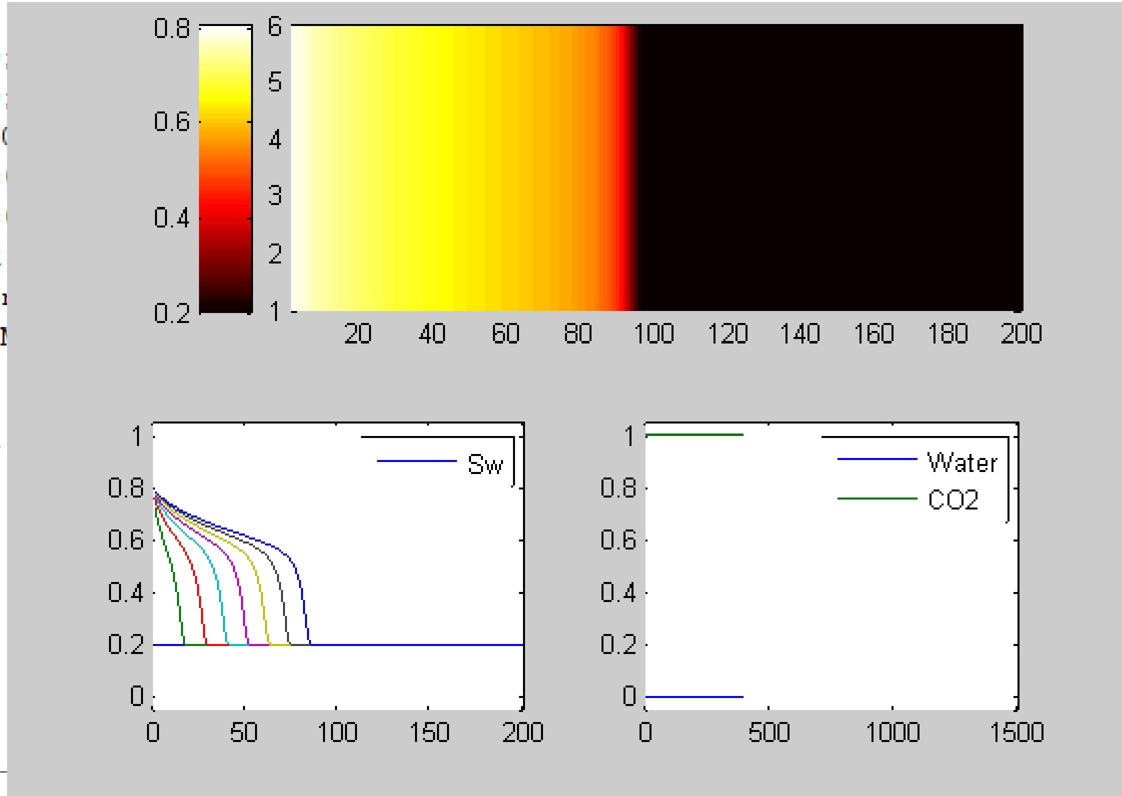
Monitoring Category	Monitoring Items
Everywhen	Pressure and temperature of bottom hole
	Injection rate, pressure and temperature
	Annulus pressure
	If monitoring well existed, pressure, temperature and well intake pressure of injection formation layer
	If monitoring well existed, its annulus pressure
	注入地点及周边区域的微震事件
Periodic	注入CO_2的性状（浓度、不纯物浓度）
As possible	Pressure and temperature of overlay formation
	比抵抗、波速、饱和率等易于检知CO_2存在与否的有效物性
	观测井等采样地下水的化学特性
	地下流体在地表涌出的情况下，涌出点流体的流量及化学特性

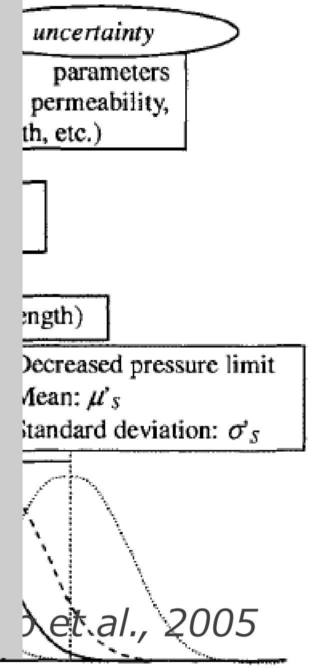
(Source: Li et al., 2011)

CO2RISKEYE • Risk assessment of Injection related pressure

```
Fluid.vw=2e-3; Fluid.vo=3e-3;          % Viscosities
Fluid.swc=0.2; Fluid.sor=0.2;          % Irreducible saturations

%%
St = 10;
Pt = 50;
ND = 15(
Q=zeros(
IR=795*(
IR = IR
Q(1,1:Gr
Q(Grid.N
Q=Q(:);
```





(Source: ... et.al., 2005

$$SI = \frac{\mu_G}{\sigma_G} = \frac{\mu_S - \mu_P}{\sqrt{\sigma_S^2 + \sigma_P^2}}$$

Reduction safety index SI

$$\Delta SI = \frac{\Delta\mu_S - \Delta\mu_P}{\sqrt{\sigma_S^2 + \sigma_P^2}}$$

Concluding remarks

- The key point for short- and long- term assessment of CCS site is prominently mechanical problem, though the disposal site is a very complicated $THMC^B$ coupled geological system.
- The geomechanics related monitoring items are lab- and field- efficient for performance and risk management.

Acknowledgements

- RET and GA, Australia

- ACCA21, MOST, China
- Hundred of Talents Program, CAS, China
- CHEG, CGS, Baoding, China

- AITF and DBR, Canada
- Geological Survey of Japan

Thanks for your attention.

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