CO_2 Storage and Monitoring:

Assessment of injection induced earthquake and strong motion effect on storage ability of CO_2 reservoir

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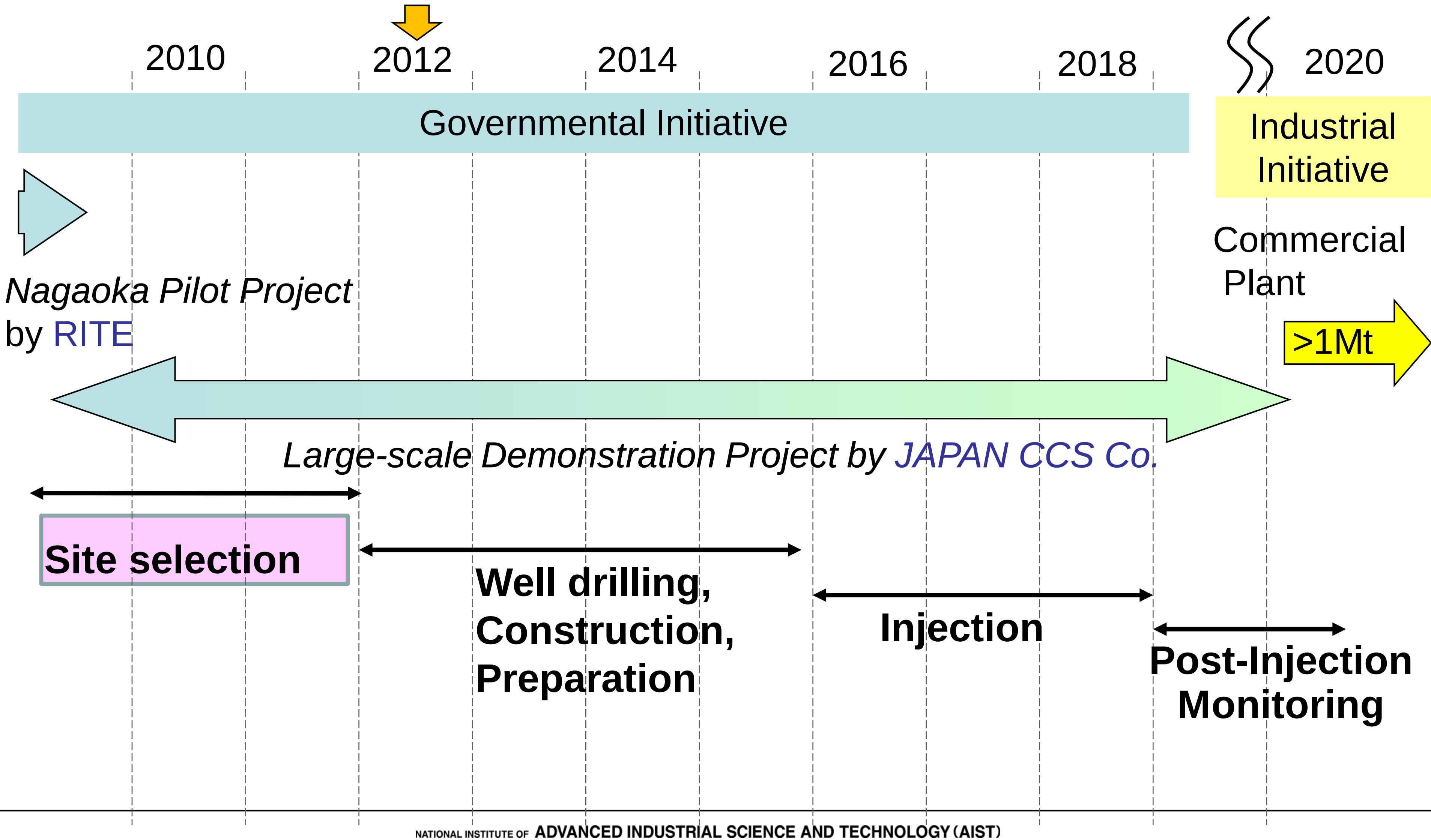
1. Background and Objectives

Schedule of CO_2 Geol. Storage Demo. Project in Japan



1. Background and Objectives (Cont.)

As the site selection criteria, the following points were examined based upon the data at Tomakomai candidate site.

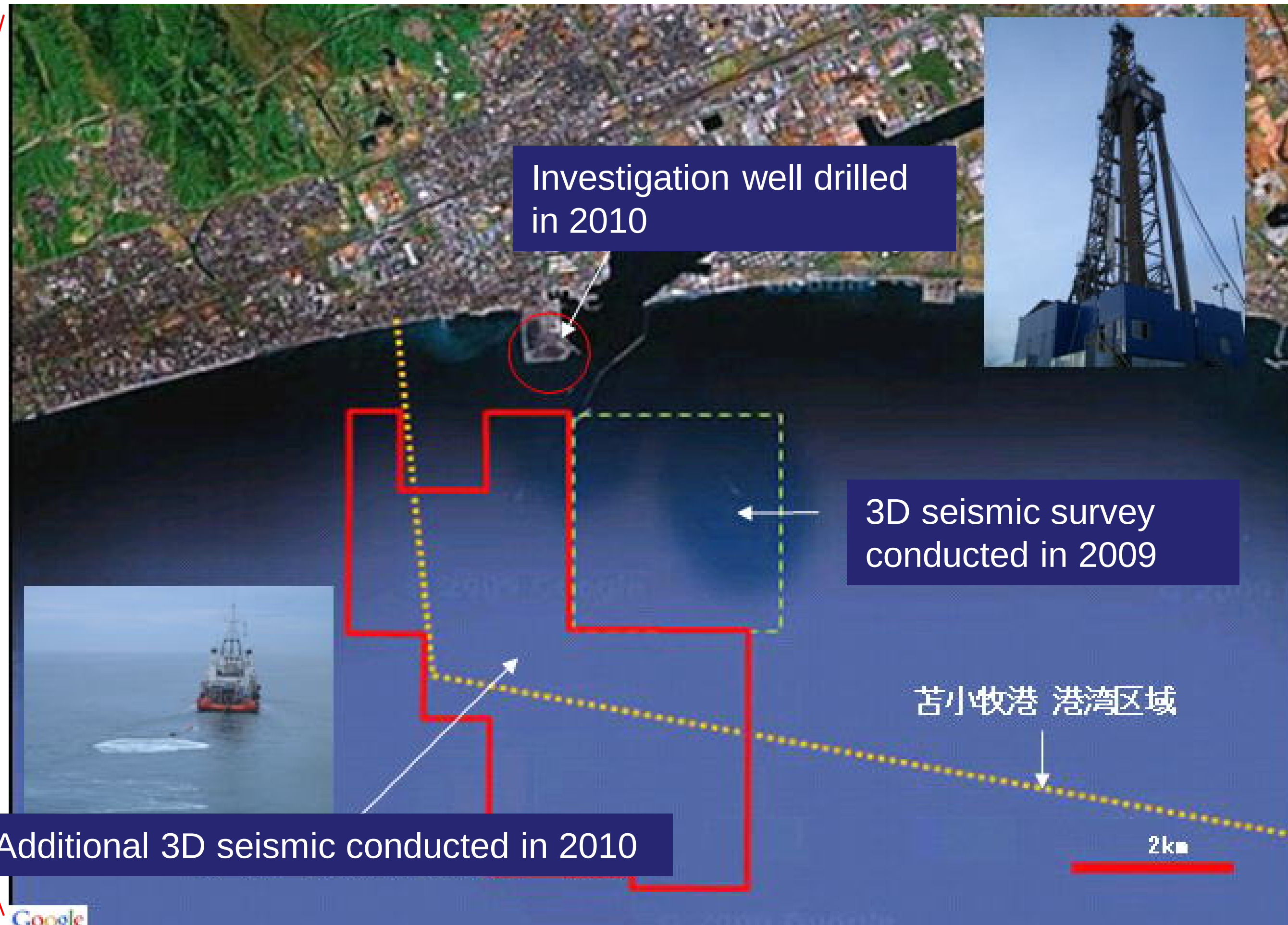
(*METI-funded research works*)

- Possibility of inducing earthquakes by CO_2 Injection
  - Is there any possibility of inducing events due to planned CO2 injection rates and amount ?

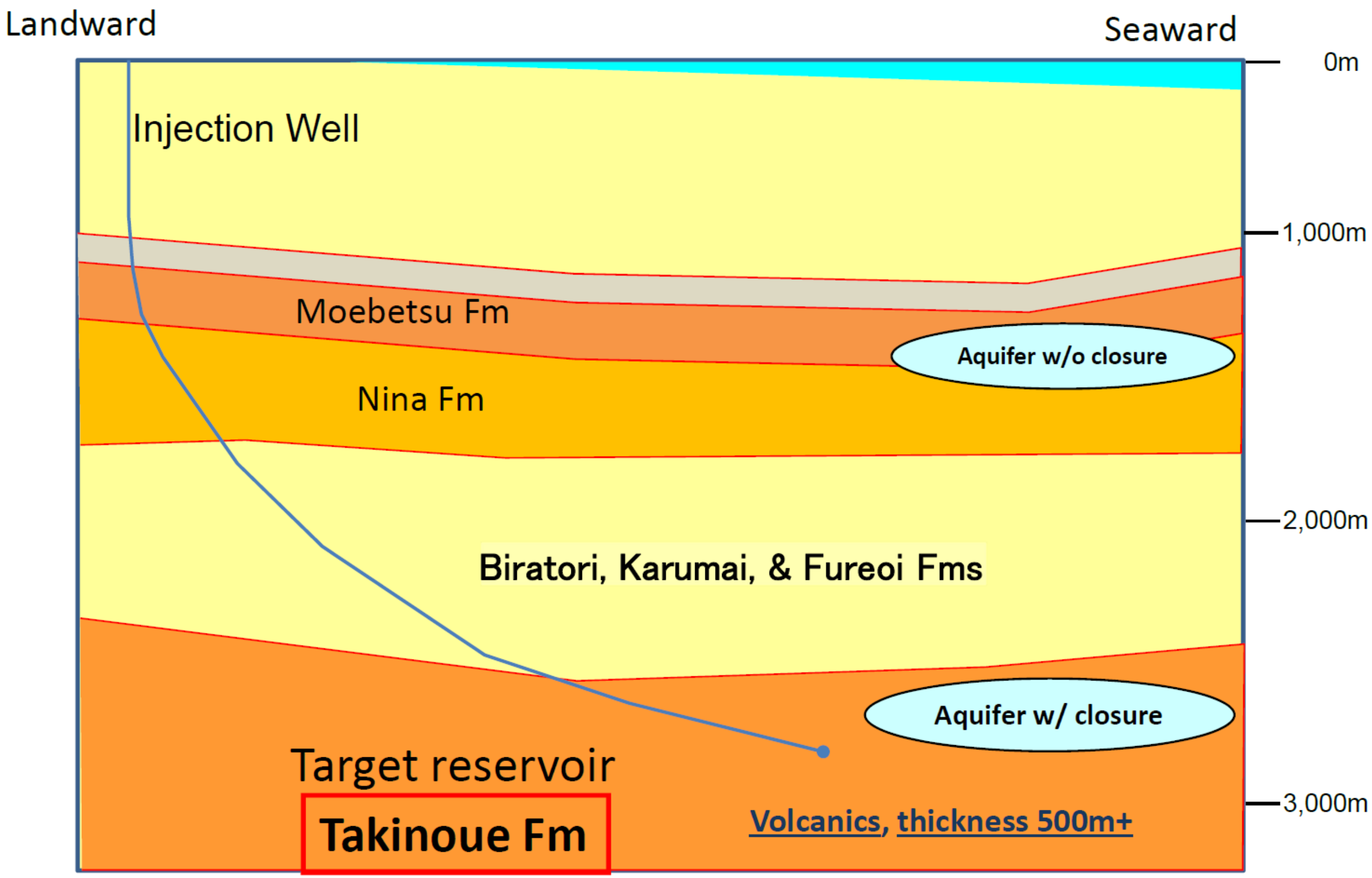
- Effect of strong motion to reservoir integrity
- If there is a strong earthquake outside the site, how about the damage to the reservoir ?

Tomakomai candidate site

0.25 Mt CO_2 /yr will be injected in two reservoir formations for 3 years from 2016 to 2018.



Schematic cross section at Tomakomai candidate site



(M. Abe, *CCS Technical Workshop 2010*, Dec. 2010)

2-1. Types of induced earthquakes : Review of previous studies

（1） CO_2 injection may induce earthquakes due to hydro-fracturing or pore-pressure buildup, but the seismicity can be controlled by proper operation of injection pressure ($M < 1.5$).

（2）Seismic risk should be managed based on ALARA（As Low As Reasonably Achievable）

- ･It is necessary to assess possibility of induced events before starting the CO_2 injection

･Seismic monitoring should be done at least one year before the CO_2 injection

･Injection operation should reflect monitoring results

･Disclosure of seismic monitoring results to public is essential

2-2. Evaluation of the possibility of induced events in Tomakomai site - Procedure -

<u>Method</u>

Evaluating the possibility of seismic events based on slip tendency（Shear stress on the frictional plane／frictional strength）

<u>Procedure for obtaining a slip tendency</u>

Pore pressure p
from reservoir simulation

Tectonic stress σ
from extended leak-off test data

Friction coefficient and cohesion μ, C
from direct shear test

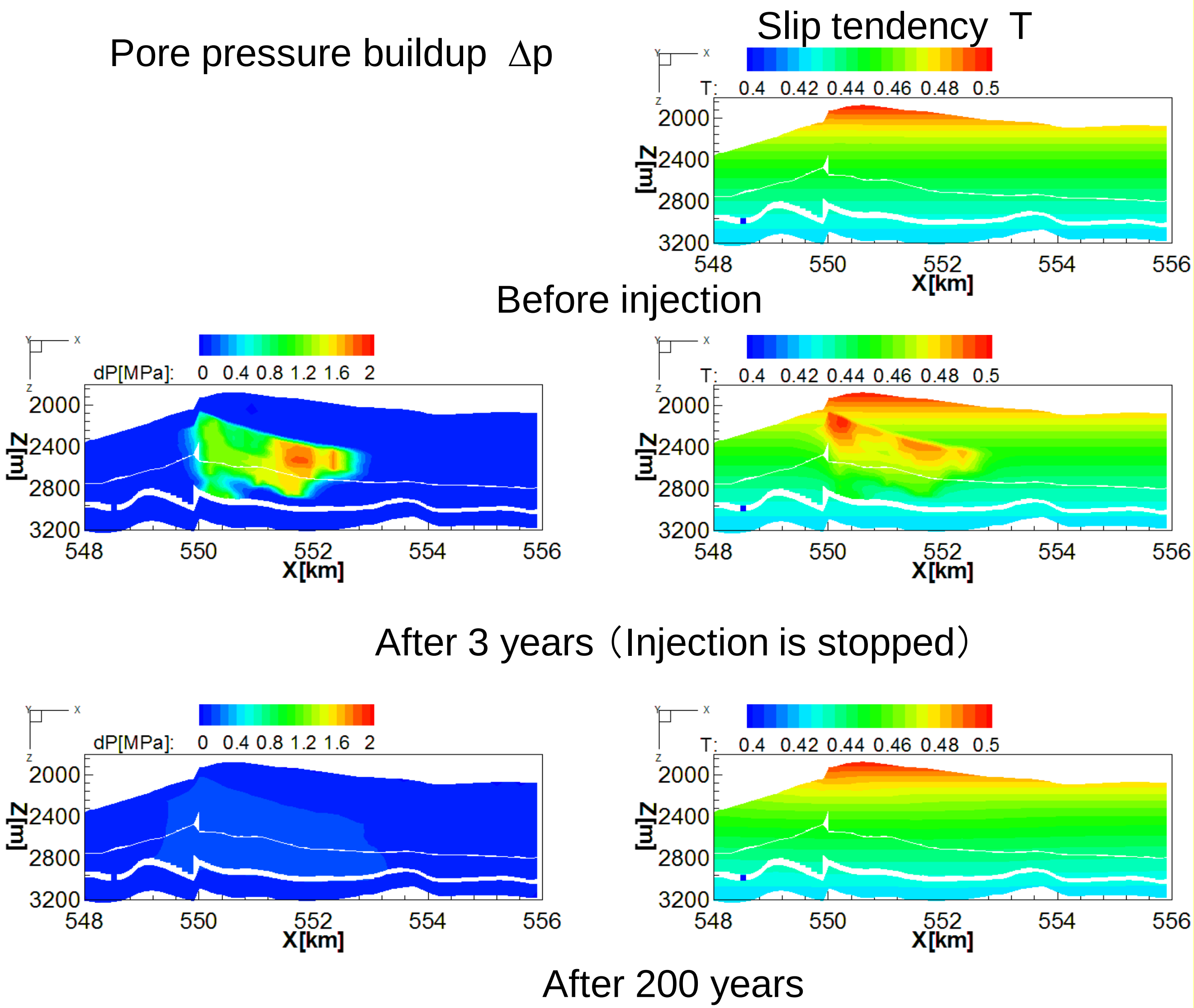
3D spatial distribution of slip tendency

$$T = \frac{\tau}{C + \mu(\sigma_n - p)}$$

T : slip tendency
τ : shear stress along a fault
C : cohesion of a fault
μ : friction coefficient
σ_n : normal stress on a fault
p : pore pressure

2-2. Evaluation of the possibility of induced events in Tomakomai site

Results: Distribution of Slip tendency in lower reservoir



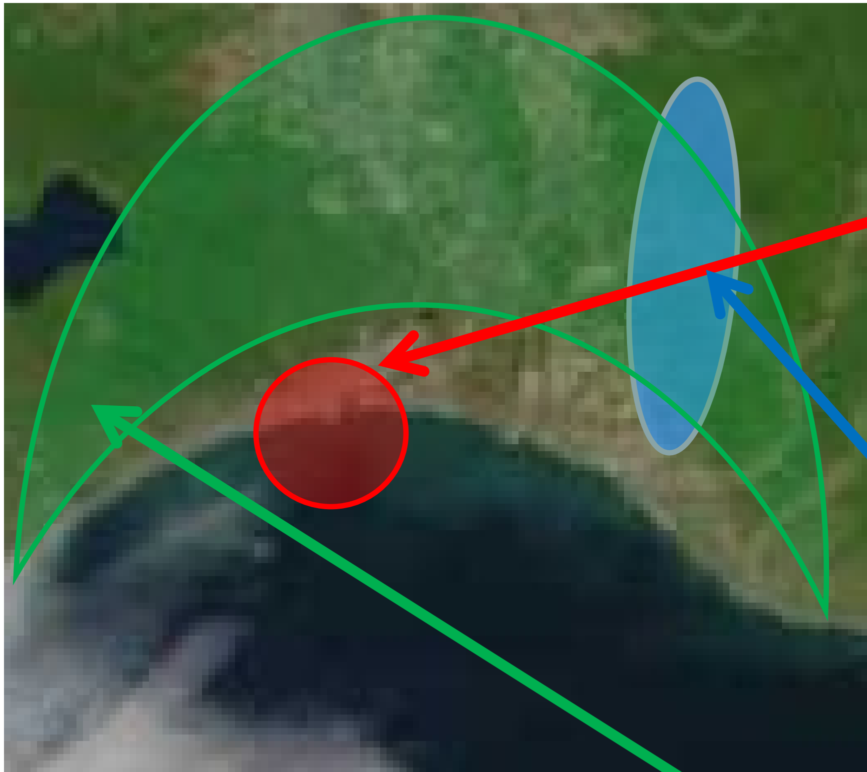
Results:

1)Even after 3 years (end of injection) of 0.25Mt/yr injection, slip tendency T does not exceed 1.0

2)After 200 years of injection, the pressure distribution returns to the condition before injection

3)T values are higher in the shallower sealing layers, because the layers are confined (over- pressurized).

2-3. Recommendation on seismic monitoring network

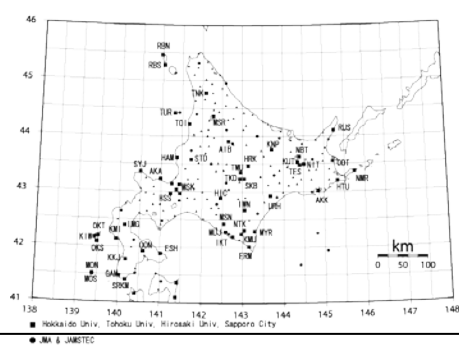


Candidate test site:
Net work for induced events.
Requires：
・Real-time observation.
・High frequency sensors, dense distribution of observation points.
・Seismometer at reservoir level depth

Net work for monitoring seismic activity along near-by active fault (southern part of Eastern boundary fault zone of the Ishikari lowland).

Net work to monitor seismic activity covering more than 20km from the test site. (by using existing seismic networks)

Existing seismic networks by JMA, NIED and Hokkaido university



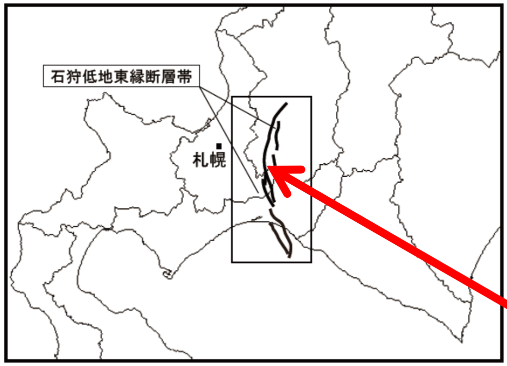
3. Effects of strong motion

1. **Nagaoka Case:**

Nagaoka was struck by 2004 Cyuetsu and 2007 Cyuetsu-oki earthquakes. That was the only CO_2 Injection site that suffered MM*9 strong motion.

2. **Effects of a strong motion by a distant earthquake on existing fault as a leakage path from reservoir at Tomakomai candidate site:**

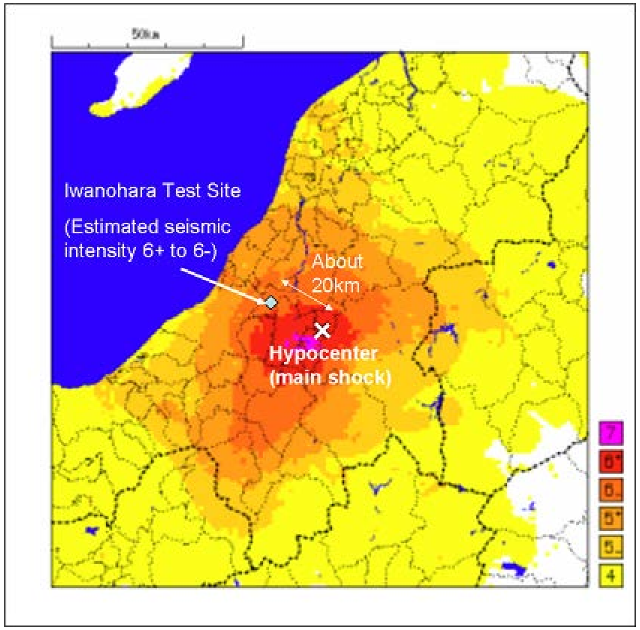
(numerical simulation of the extreme case)



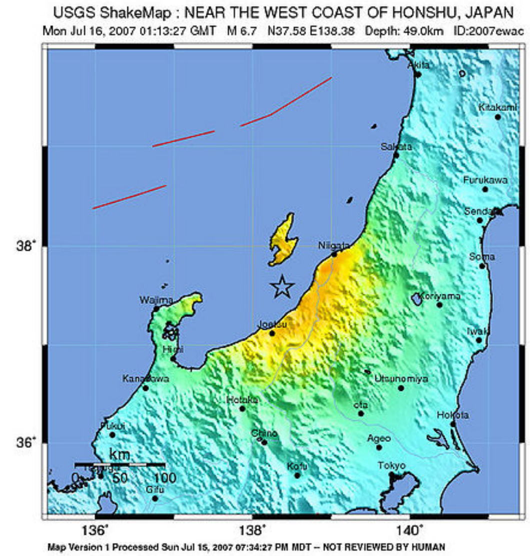
*: Modified Mercalli Intensity scale

Eastern boundary fault zone of the Ishikari lowland (Active fault)

2004 Chūetsu earthquake and Chūetsu Offshore Earthquake



2004 Chūetsu earthquake
Date October 23, 2004 (2004-10-23)
Magnitude: 6.6
Casualty toll: 40



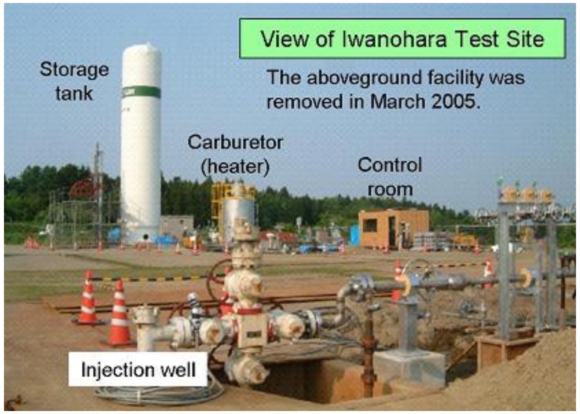
PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE Resistant Structures	none	none	none	V. Light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy
POTENTIAL DAMAGE Vulnerable Structures	none	none	none	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy	V. Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
ESTIMATED INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

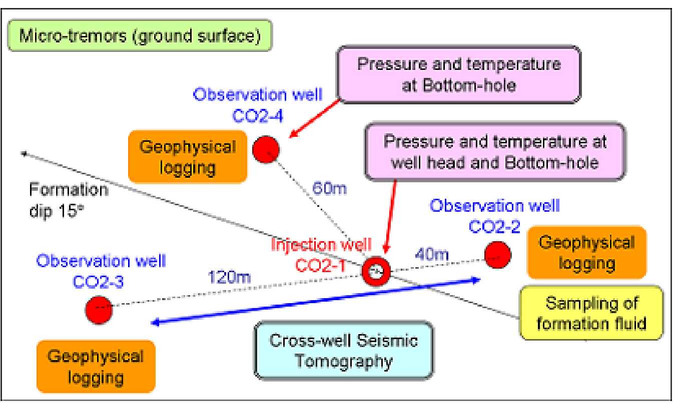
Chūetsu Offshore Earthquake
Date July 16, 2007 (2007-07-16)
Magnitude: 6.6
Depth: 10km

(Pictures: http://www.google.co.jp)

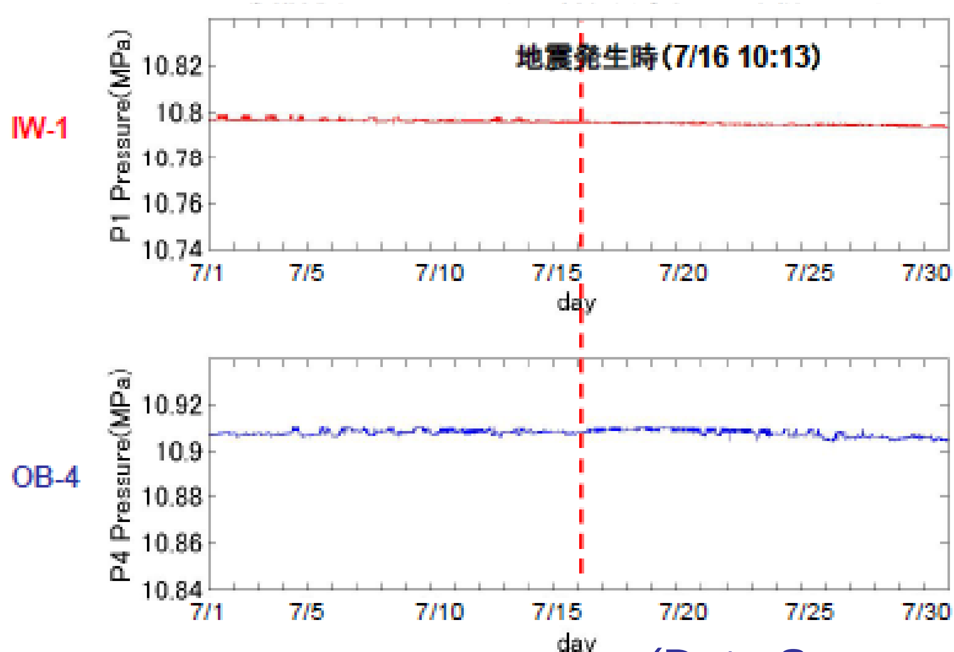
3. Effects of strong motion

3-1. Pressure data at Nagaoka site





Downhole pressure histories in July 2007

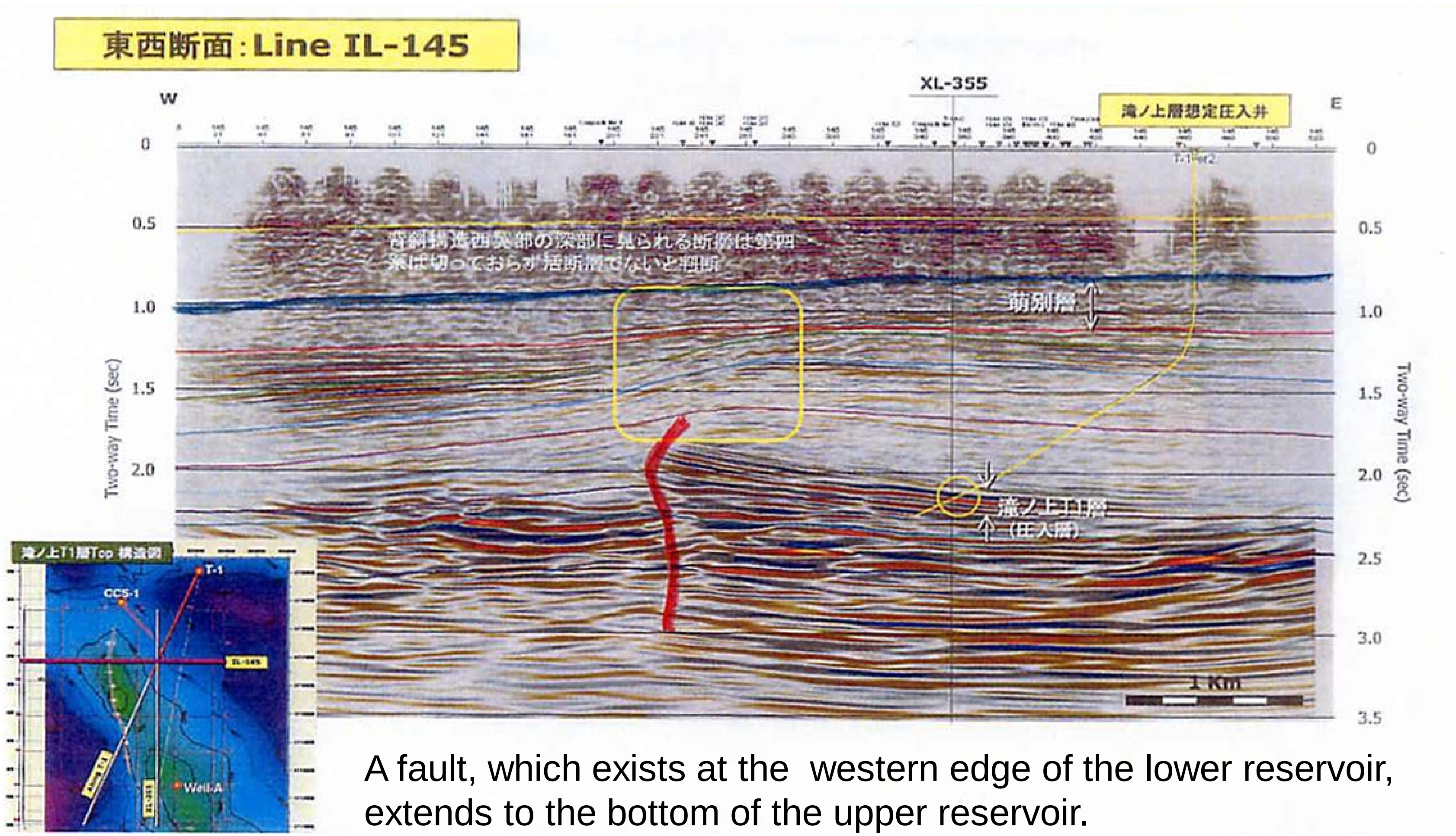


(Data Source: RITE)

Nagaoka was struck by two big earthquakes ; 2004 Cyuetsu and 2007 Cyuetsu-oki earthquakes and experienced MM*9 strong motion on the surface. (*: Modified Mercalli Intensity scale)

But downhole pressure data did not show any pressure change, suggesting no damages of the sealing ability.

3-2. Assessment of Tomakomai candidate site



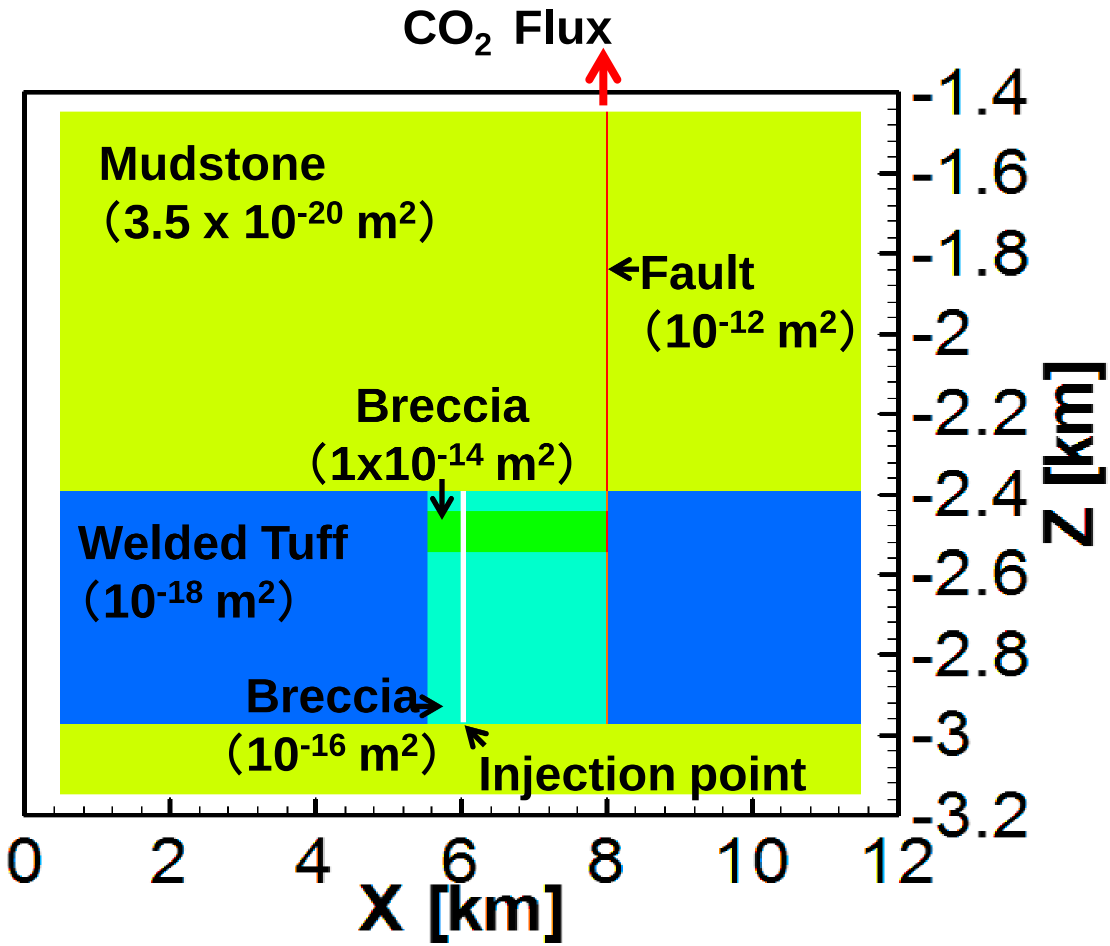
(Data Source: JCCS)

A fault, which exists at the western edge of the lower reservoir, extends to the bottom of the upper reservoir.
The displacement can not be recognized within the upper formation, so that the only lower reservoir is examined.

**This fault is judged to be not active.*

3-2. Assessment of Tomakomai site
- Numerical model of the extreme case -

Numerical Model for the leakage simulation



ZX-section of the 3D model.

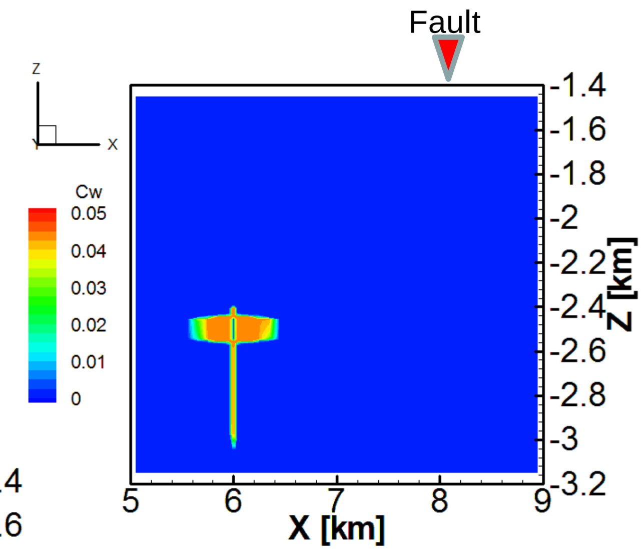
A fault exists 2km apart from the injection point.

We assume that strong motion attacked the reservoir and permeability of the fault (with the aperture of 0.1-m) suddenly changes to 10^{-12} m^2 at 3 years after starting the injection; the final stage of injection test..

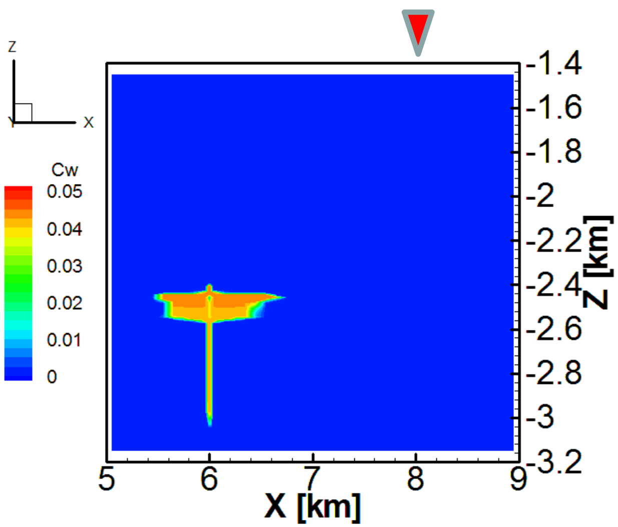
**Note that it is not realistic assuming the opened fault keeps its permeability because of the tectonic stress. However, we investigated it as the extreme case.*

3-2. Assessment of Tomakomai site
Results: Dissolved CO_2 distribution

3 years after injection start (Operation stops)

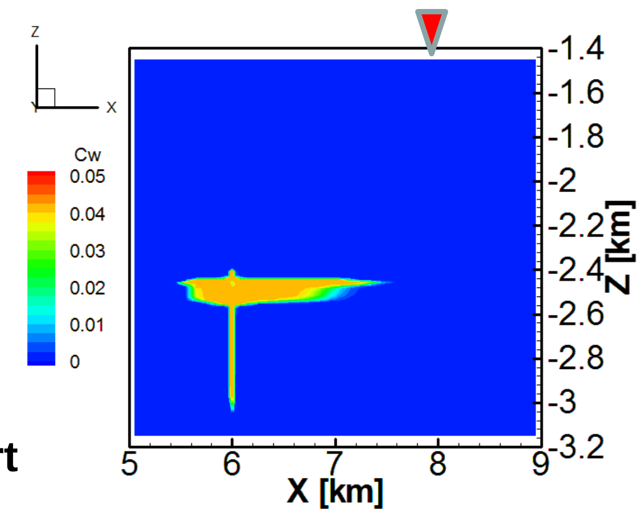


Without effect of strong motion



200 years after injection start

Permeability changed by strong motion



In case of fault permeability changes due to strong motion, although the dissolved CO2 expands to the fault direction at 200 years, but it does not reach the fault, resulting no CO2 leakage from the reservoir.

4. Conclusion

◆ Earthquakes induced by CO_2 Injection

(1) From the evaluated slip tendency, earthquakes are not likely to occur from CO2 injection at Tomakomai.

(2) Seismic monitoring network should be designed to target the area where the slip tendency is high. The monitoring results should be fed back to operation.

(3) Monitoring the activity along the Eastern Boundary Fault Zone of Ishikari Lowland (active fault) is strongly recommended.

(4) Using existing network (by JMA, NIED and Hokkaido Univ.) is beneficial for monitoring seismic activity of wider area .

◆ Effects of strong motion

(5) Based on the experience at Nagaoka site, strong motion from distant earthquakes does not affect the storage ability of a reservoir formation at depth.

(6) At Tomakomai candidate site, there exists the fault at the western edge of the lower reservoir (Takinoue formation). Just in case, we considered the extreme numerical cases. However, the fault does not become a leakage path.

AIST's R&D subjects commissioned by METI

- Multi-Disciplinary Monitoring Techniques Complement to 3D/4D Seismic Reflection Survey
  - (1) Multi-lateral Geophysical Monitoring Tools
  - (2) Optimal Modeling Technologies (Geophysical Post-processor)
- Evaluation and Prediction of Seal Integrity of Caprocks and Faults
  - (3) Seal Integrity
  - (4) Fault Modeling Method with Geomechanial Processes

Thank you for your attention

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