Overview of the Nagaoka Pilot Project

Storing CO_2 in Saline Aquifer

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Purpose of Nagaoka Pilot Project

➢World CCS Projects（@2000）

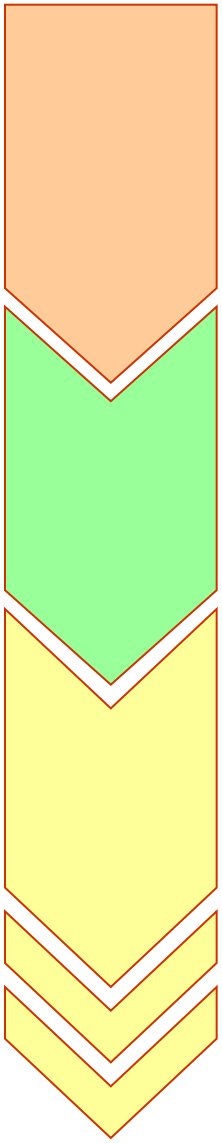
- Sleipner（Norway, Aquifer, Associated CO_2）
- Weyburn（Canada, EOR, Coal Gasification）

—Nagaoka Project—

1st on-shore aquifer CO_2 injection test

⇨（Verification of CO_2 Storage in Complex Geology）

Nagaoka CO_2 Storage Project Workflow



Commercialized CCS

Pre-Injection Phase: 3-5 years
- Site selection
- Characterization
- Design

Injection Phase: 10-50 years
- Construction
- Monitoring
- CO_2 injection

Post-Injection Phase: 100+ years
- Ceasing injection
- Decommissioning
- Surveillance

Nagaoka (pilot test site)

2000.12

(2.5 years)

2003.7

(1.5 years) ***10,400 Ton***

2005.1

(10 years)

2015.3

The First Case on Post-Injection Monitoring

Overview and Objectives of the Project
- A Pilot-scale Demonstration -

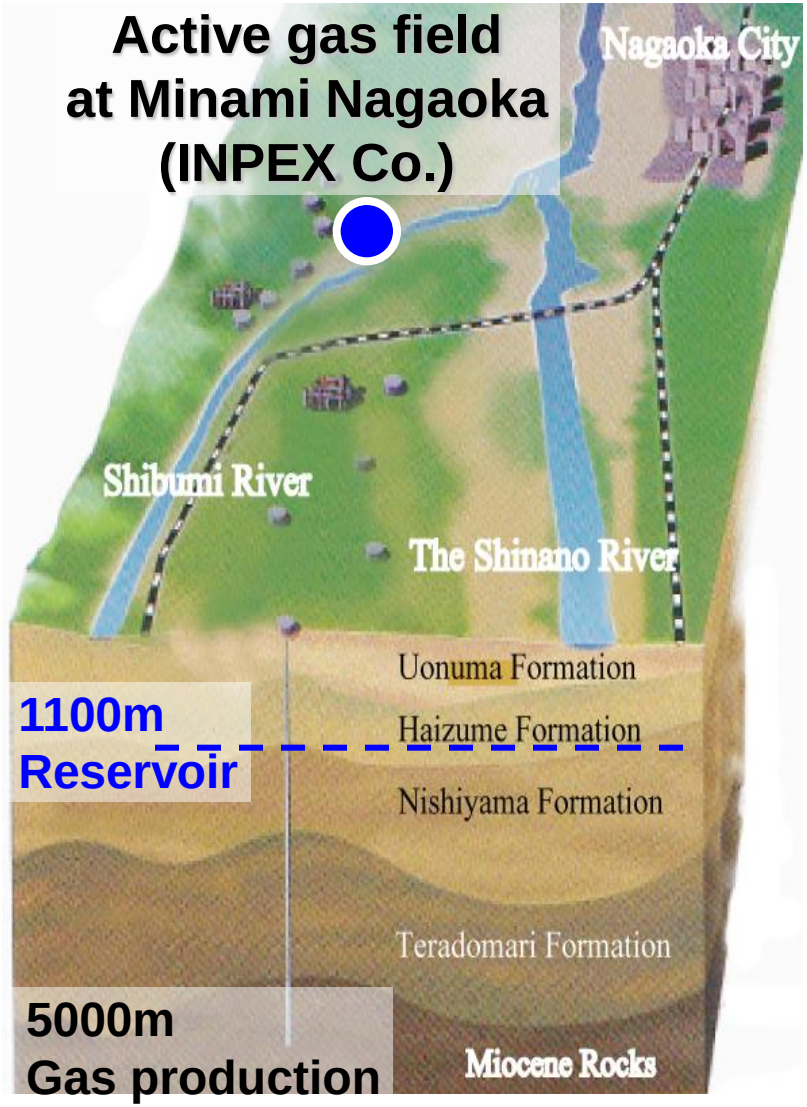
♦ **Improved Understanding of the CO_2 Movement in the Porous Sandstone Reservoir**

- Seismic Wave Velocity Response to CO_2 Injection
- Mechanism for the Injected CO_2 Displacing the Formation Water

- Crosswell Seismic Tomography and Well Logging
- Measurements of the Formation Pressure Buildup
- 3D Surface Seismic Survey

- a simulator for the long-term behavior predication
- system studies on modeling and public outreach

Site Selection



Geological Factors

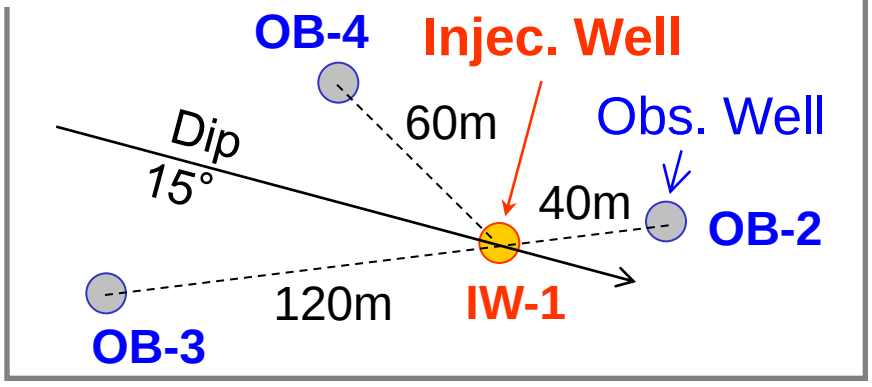
- Continuity of cap rock
- Gentle tilted reservoir
  - Depth（800-1200m），
  - Thickness（>10m）
- No faults within 1.5km^2
- Details data for subsurface

Operational Factors

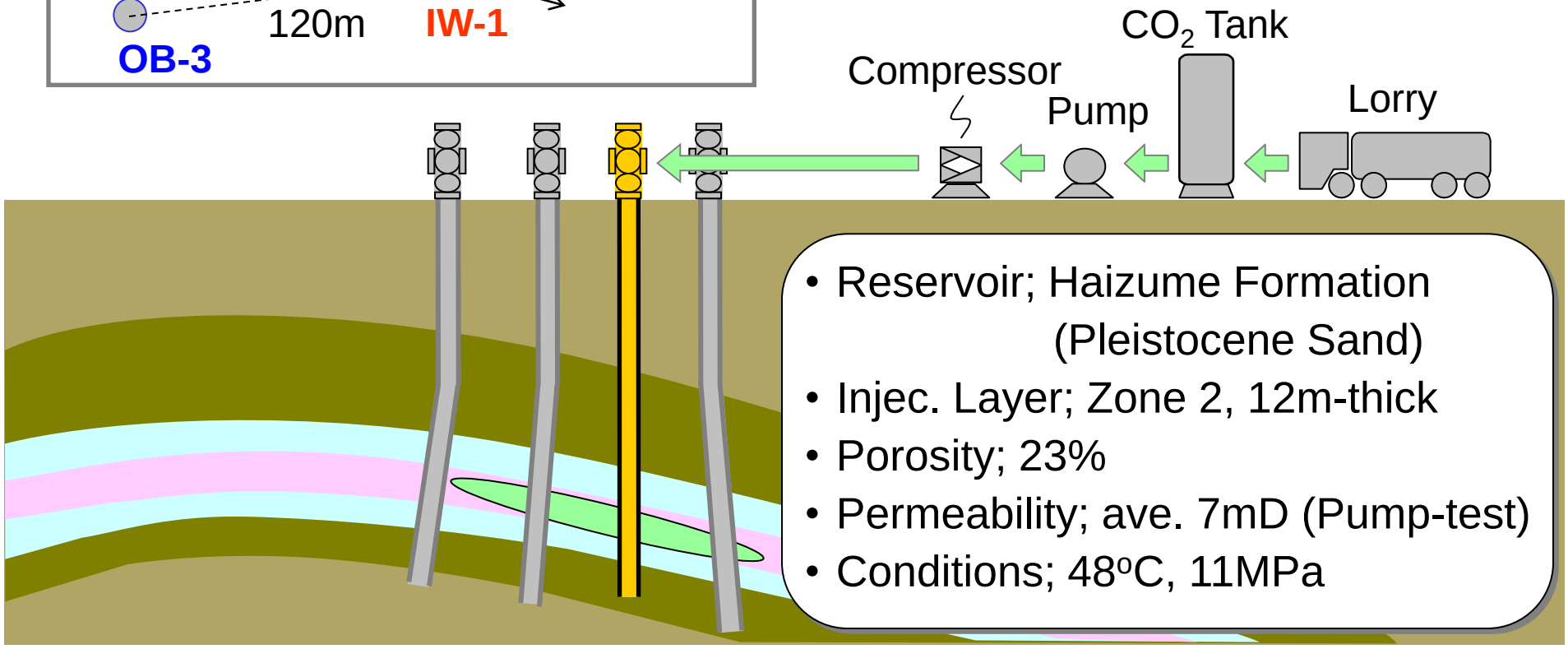
Social Acceptance, Well yard etc.

Overview of the Nagaoka Site

Well Configuration
at the Reservoir Depth

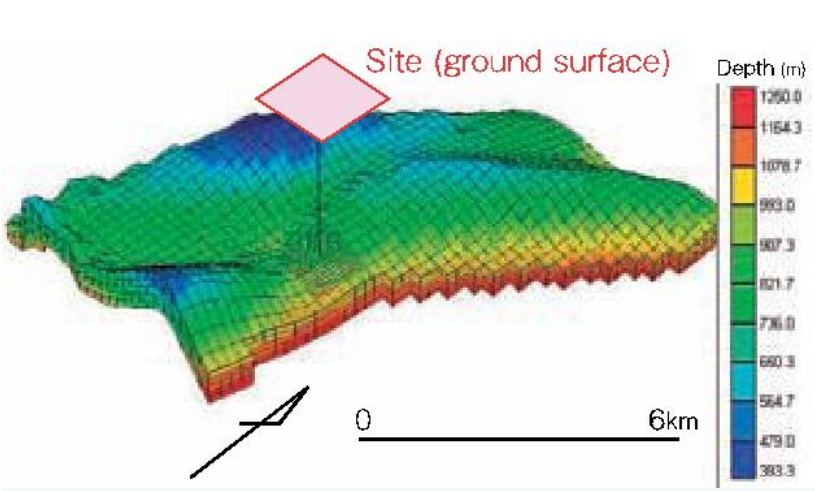


- Injec. Period; Jul. 2003~Jan. 2005
- Total amount; 10,400 ton CO_2
- Rate; 20~40 ton/day



- Reservoir; Haizume Formation (Pleistocene Sand)
- Injec. Layer; Zone 2, 12m-thick
- Porosity; 23%
- Permeability; ave. 7mD (Pump-test)
- Conditions; 48°C, 11MPa

Reservoir Modelling & Simulation
- Summing up all Knowledge of Injection Site -



Based on seismic, logging, and core

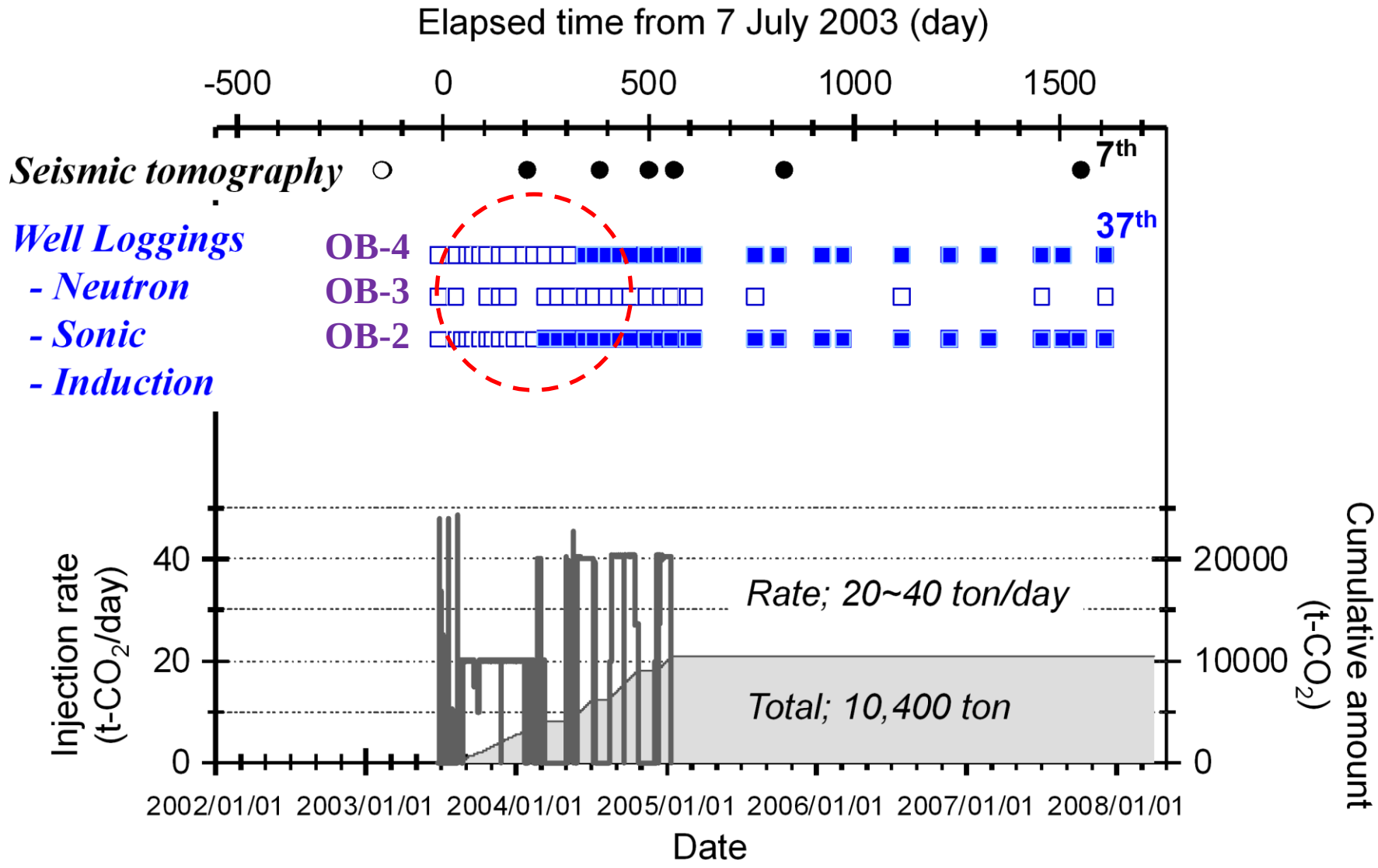
Reservoir (Haizume Formation)
✓Injection point is Edge of Anticline

Pre-Injection：Evaluate injection plan (Injectivity)
（Reservoir model is build based on the seismic and well data）

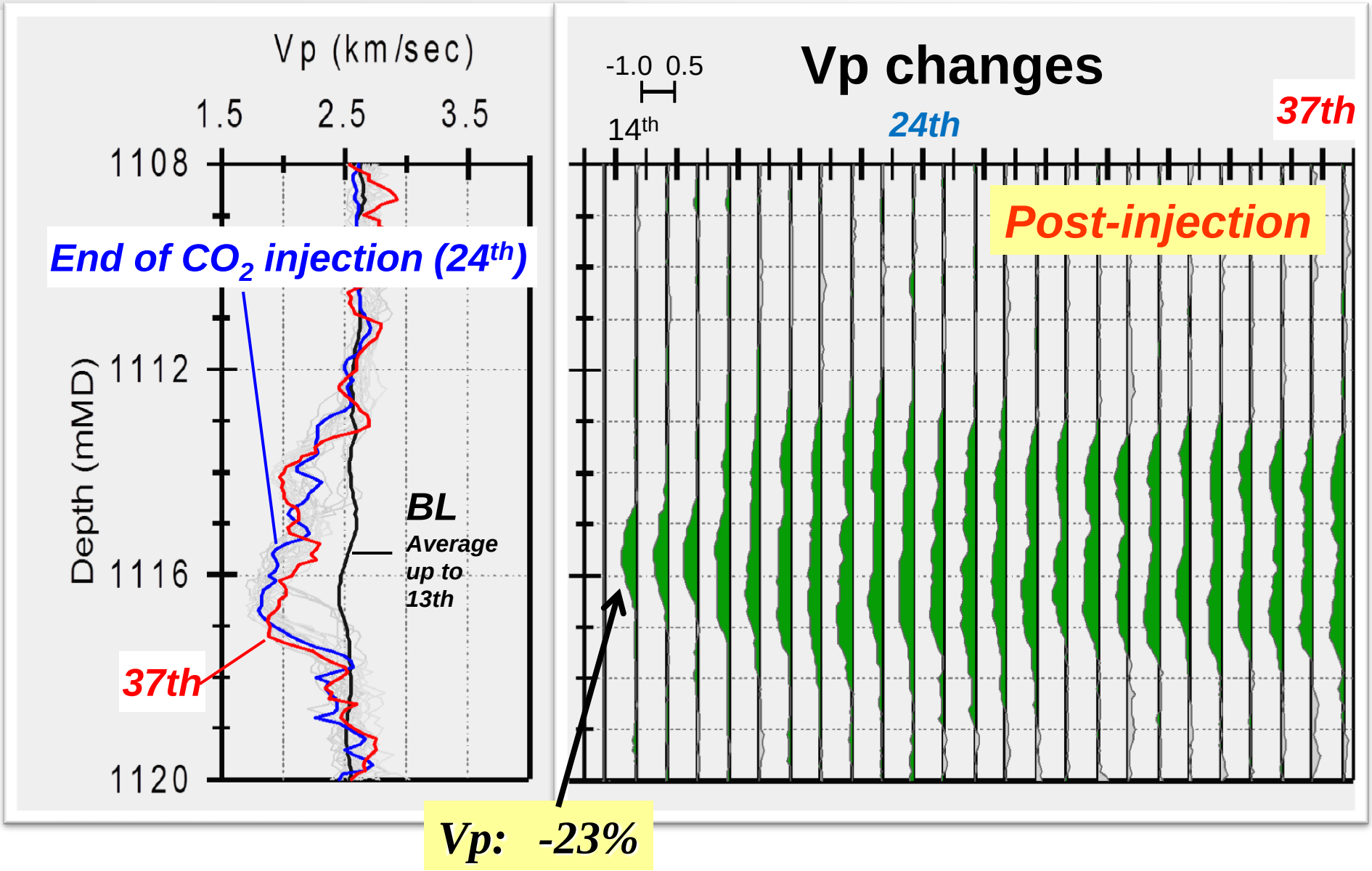
During Injection：History matching with pressure & logging data
（Reservoir model is updated by the monitoring data）

Post-Injection：Long-term prediction of CO2 distributions
（Based on the accurate reservoir model considering with trapping mechanisms, long-term prediction is acceptable）

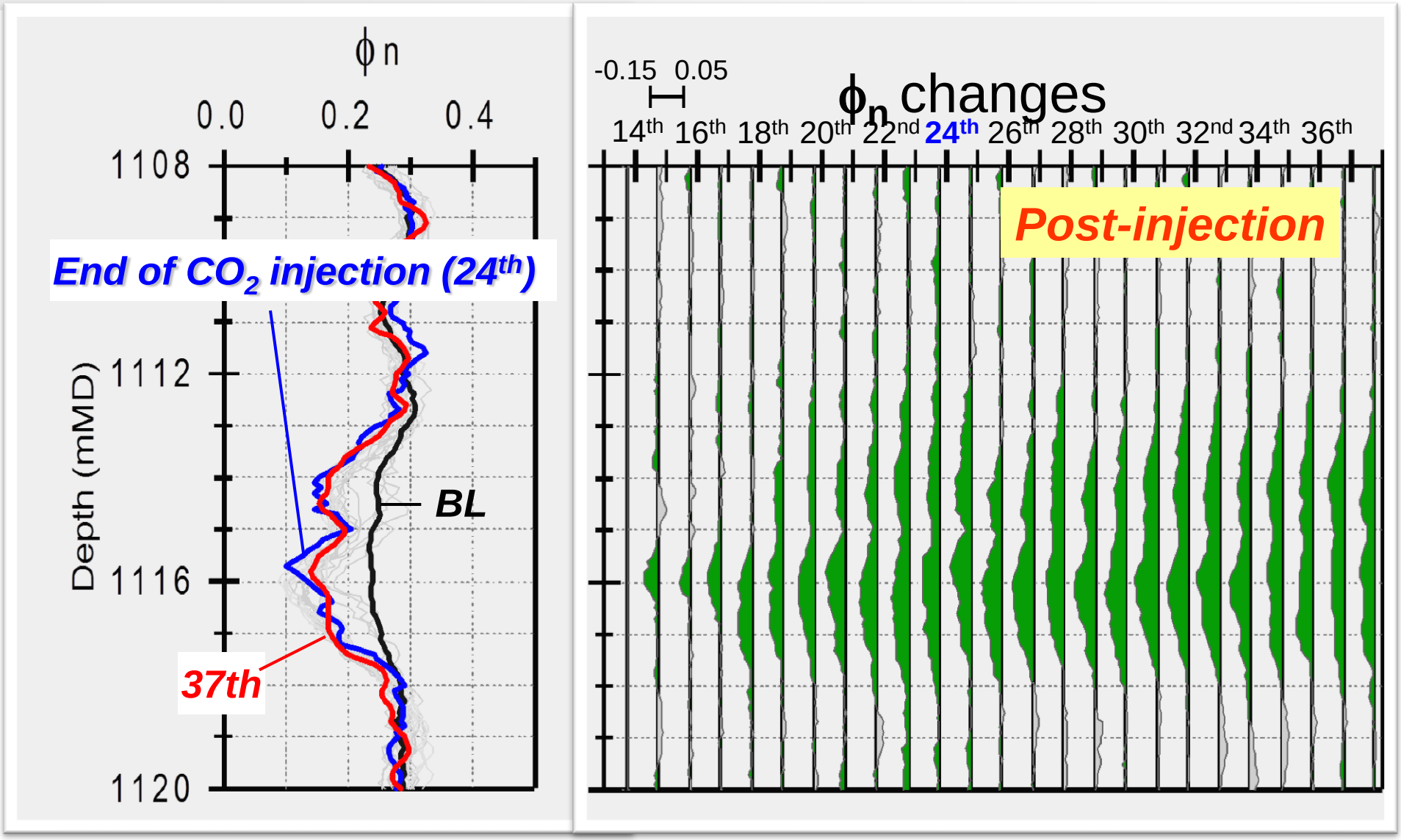
Detection of CO_2 breakthrough by time-lapse logging



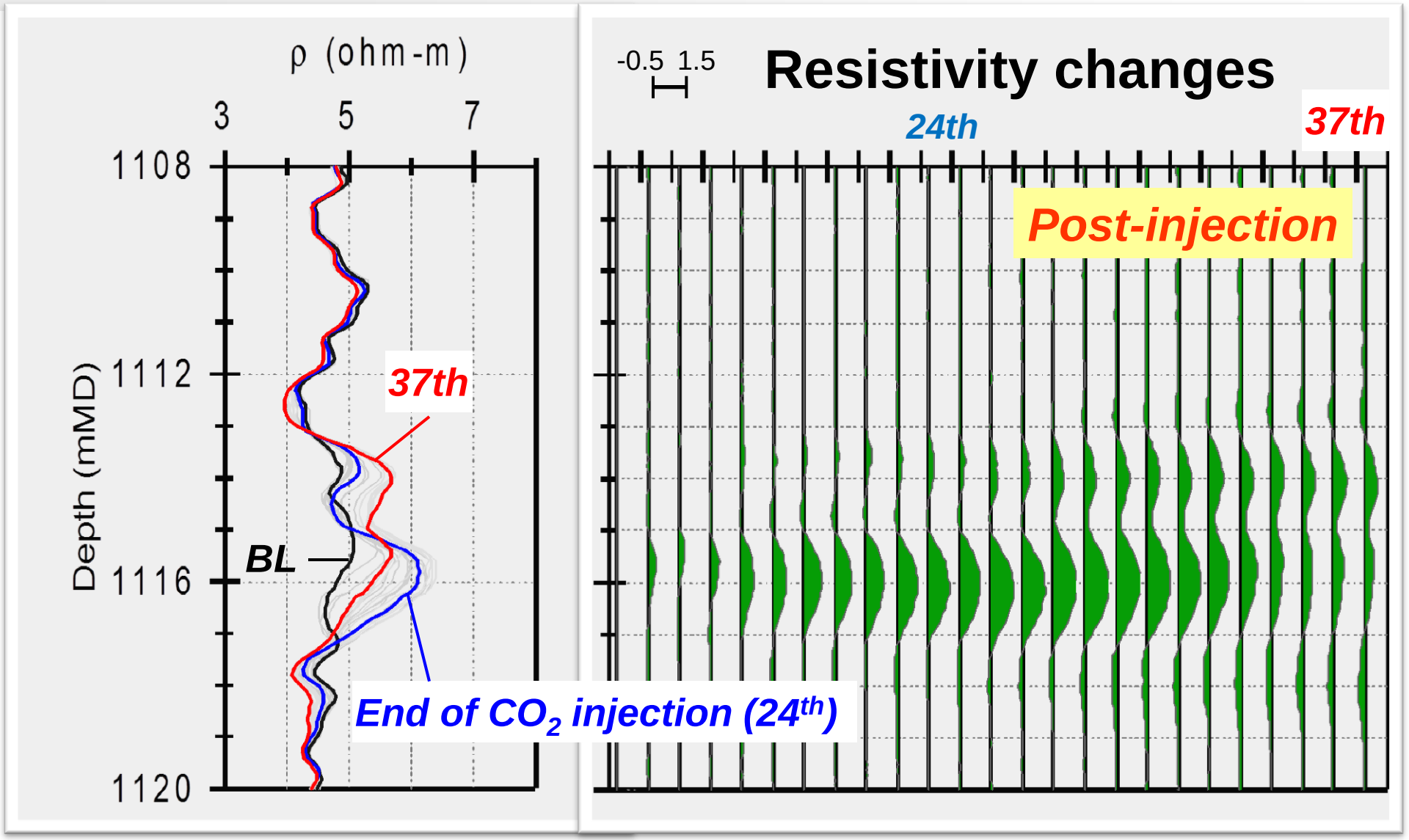
Sonic Logging @ OB-2



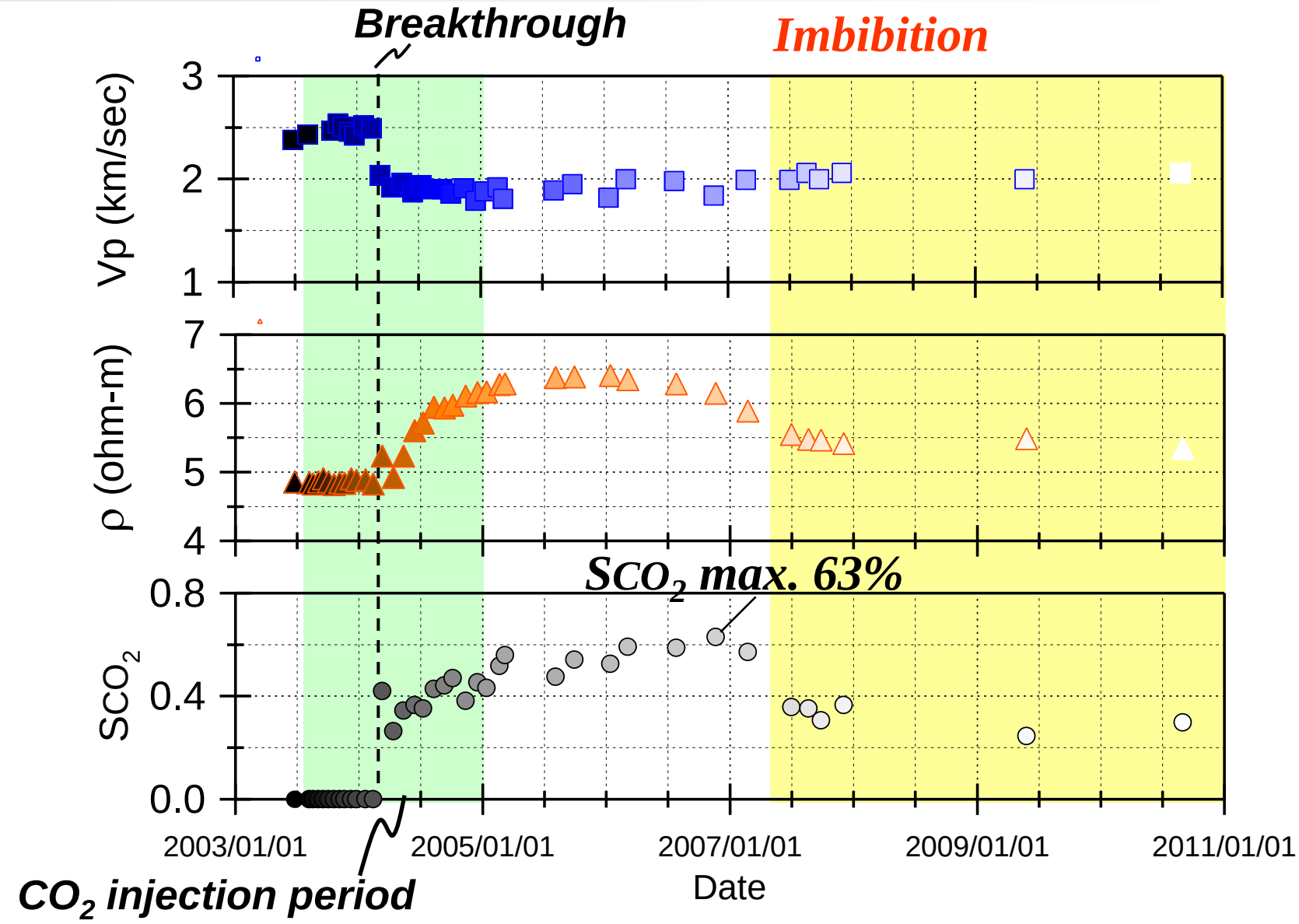
Neutron Logging @ OB-2



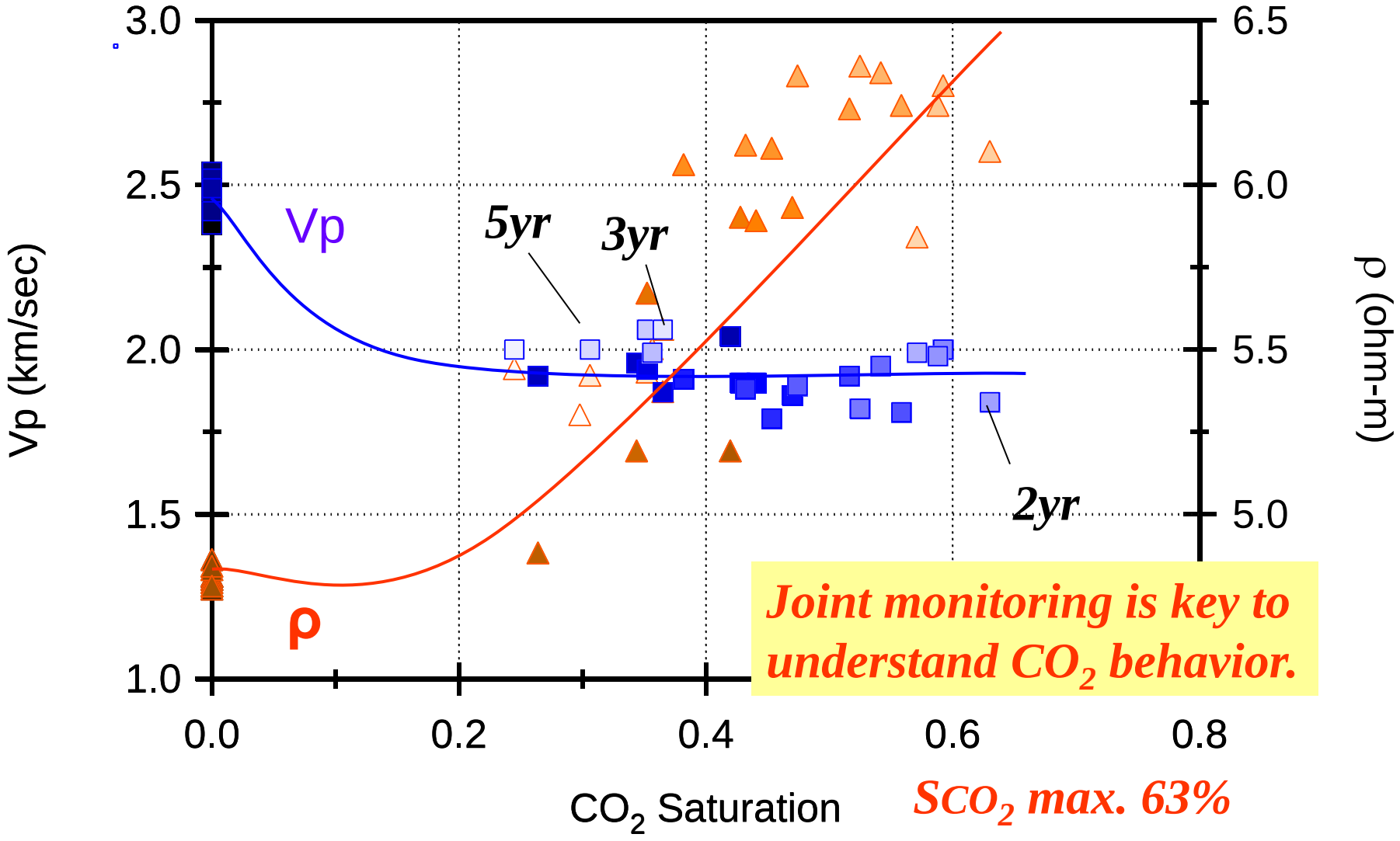
Induction Logging @ OB-2



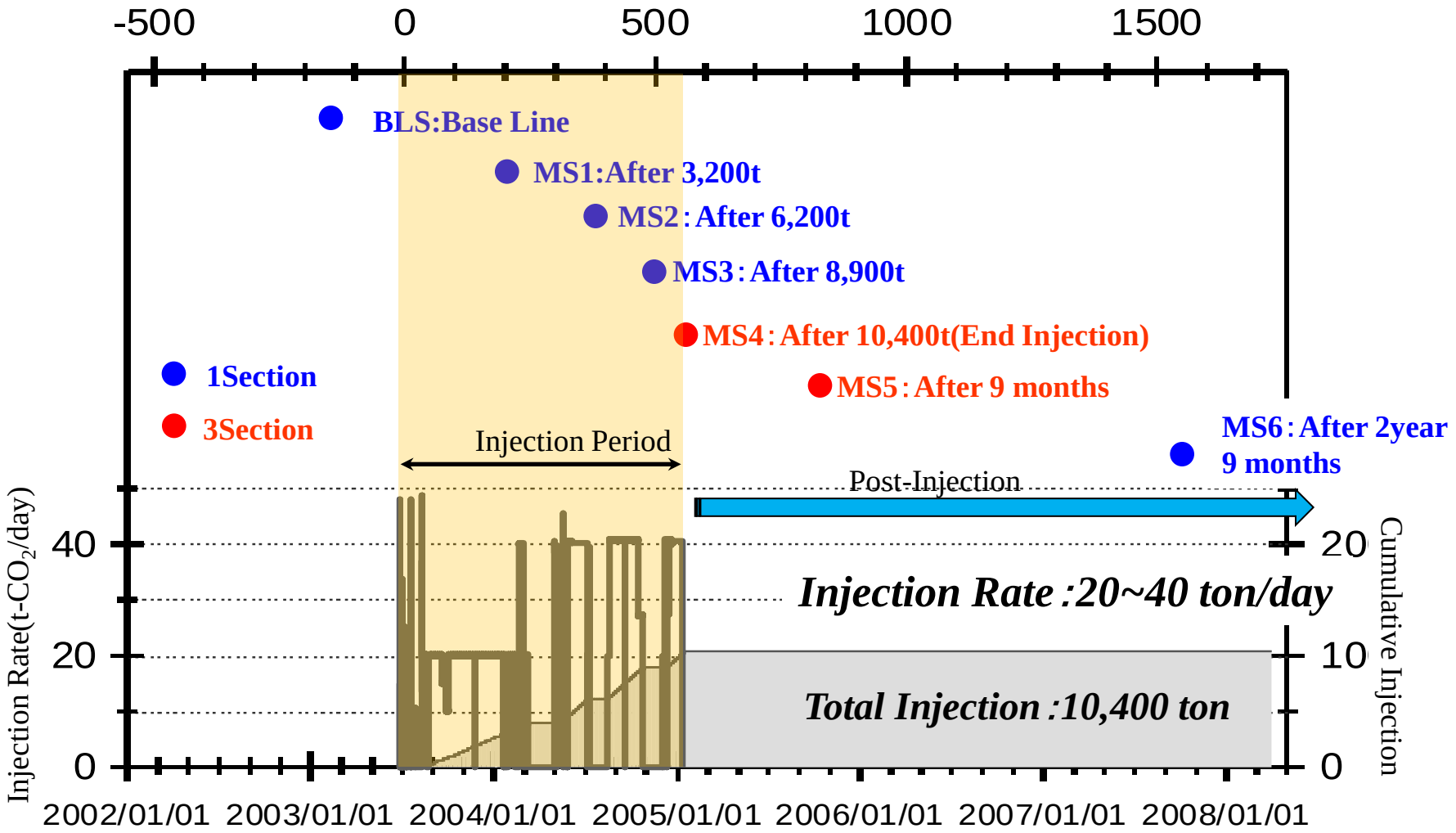
Time Series of Logging Data (1116.0m @ OB-2)



P-wave Velocity and Resistivity vs CO_2 saturation (1116.0m @ OB-2)

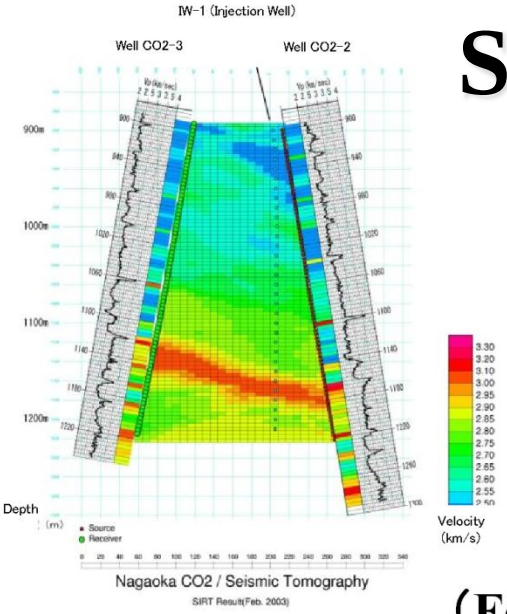


Time-lapse Tomography
OB2 – OB3 Section (160m)

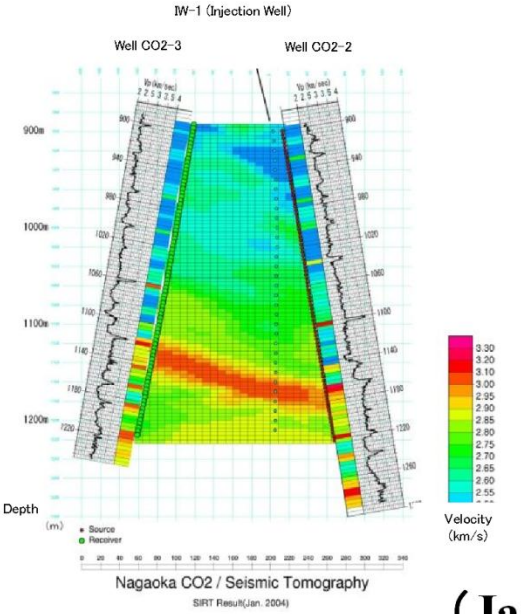


Seismic Tomography

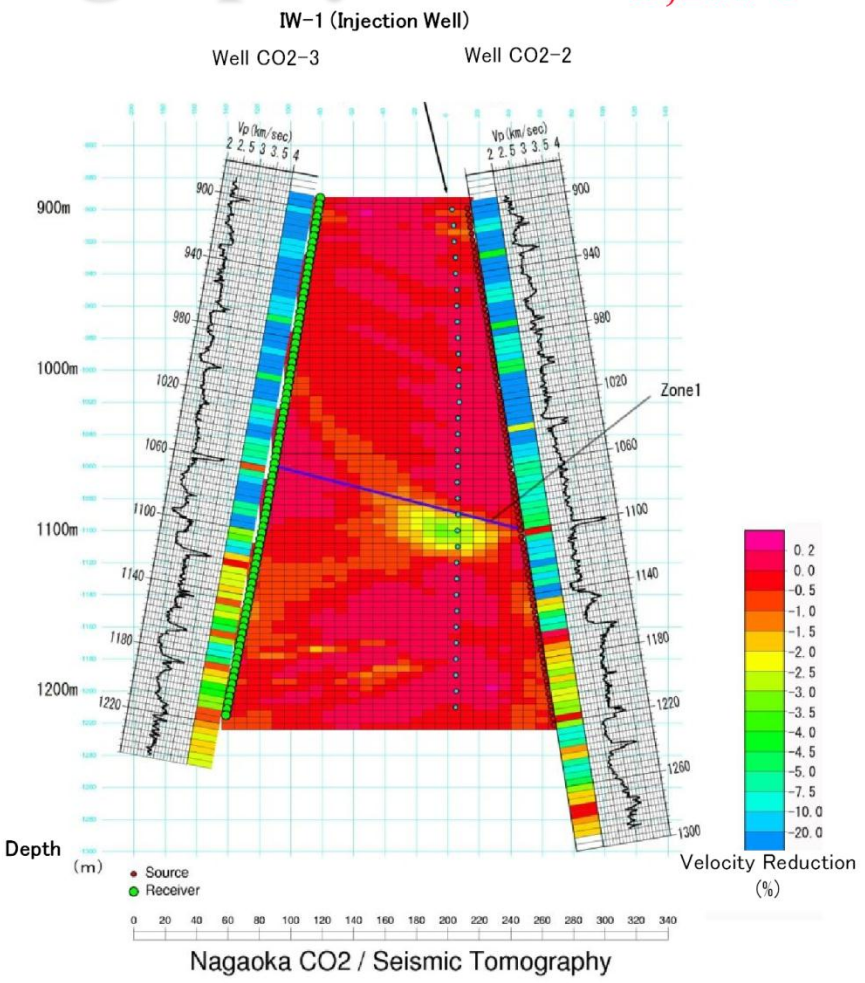
3,200 t



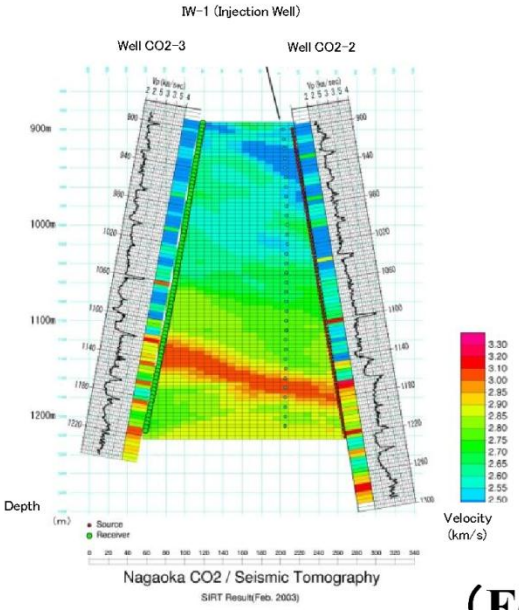
(Feb. 2003 :BLS)



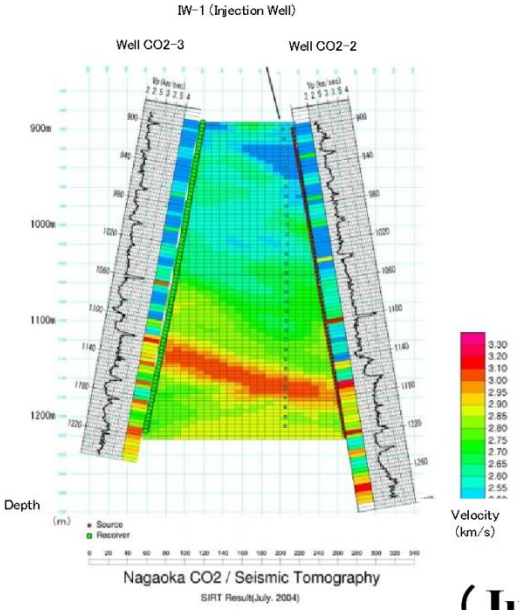
(Jan. 2004 :MS1)



Max: - 3. 0%

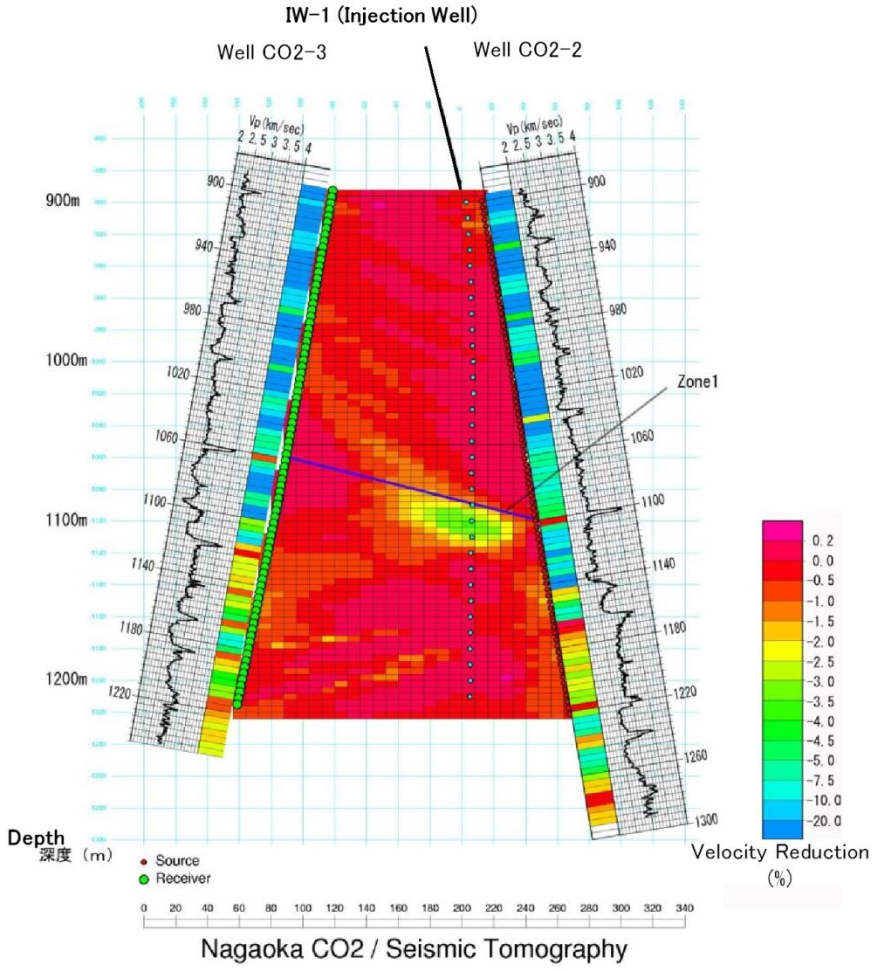


（Feb. 2003 :BLS）

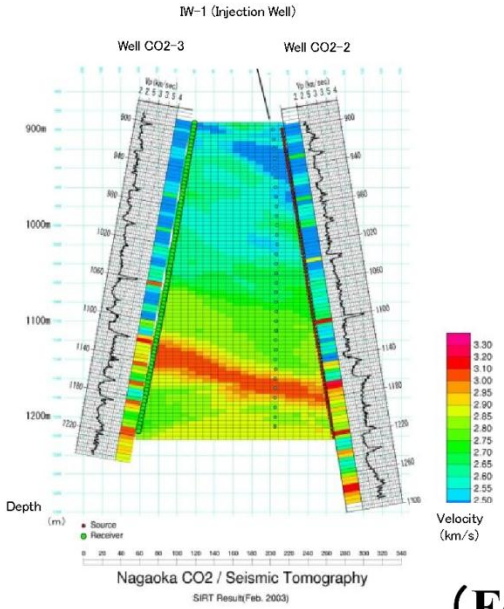


（July. 2004 :MS2）

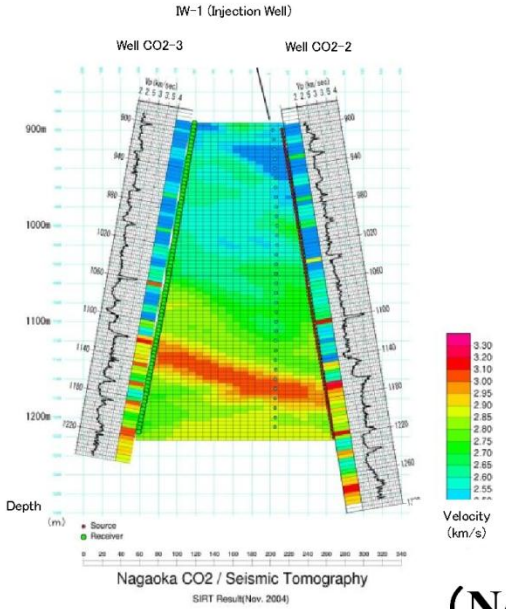
6,200 t



Max: - 3. 5%

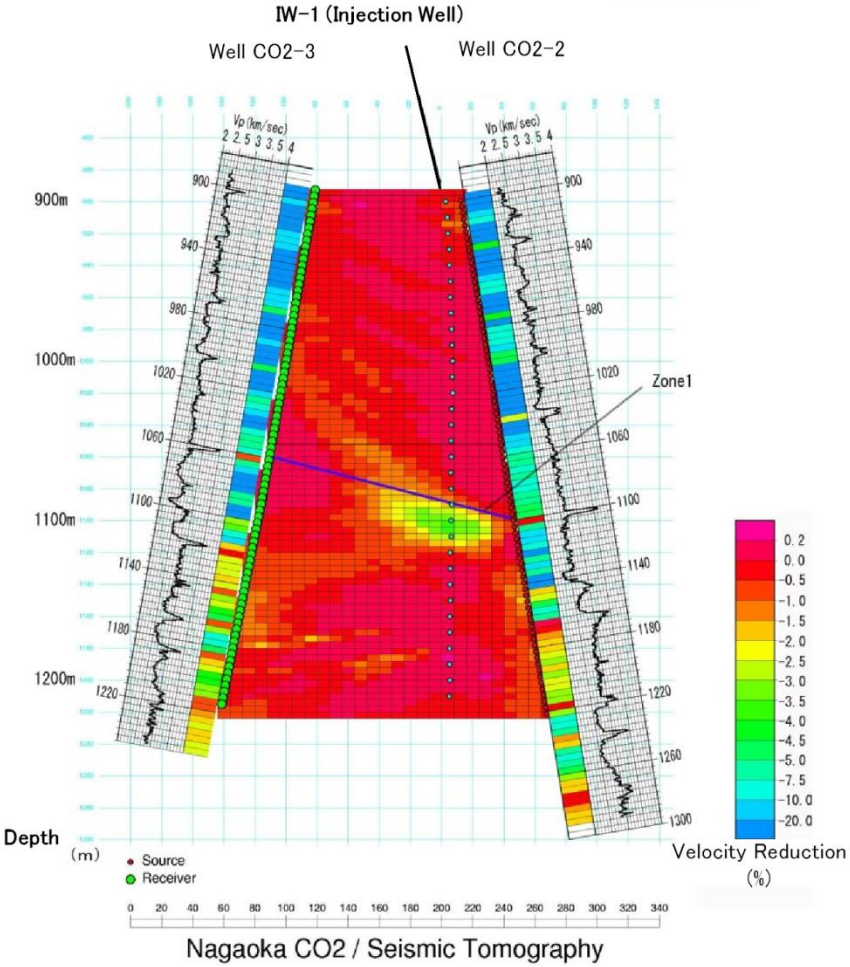


(Feb. 2003 :BLS)



(Nov. 2004 :MS3)

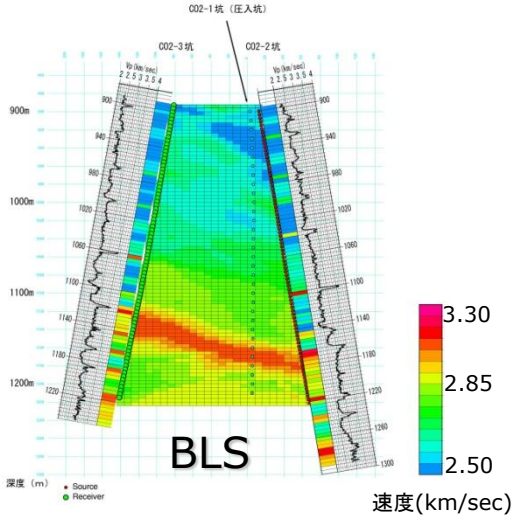
8,900 t

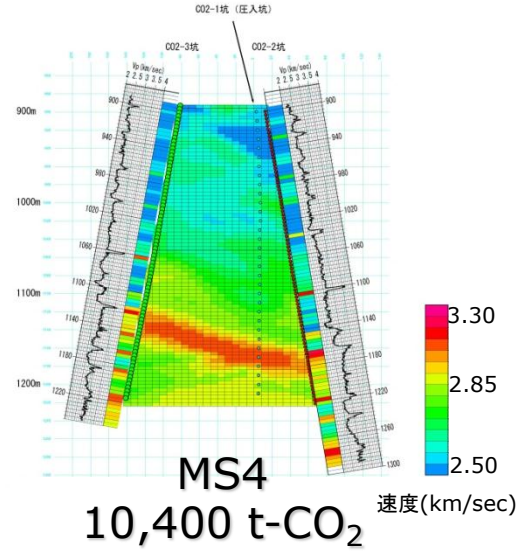


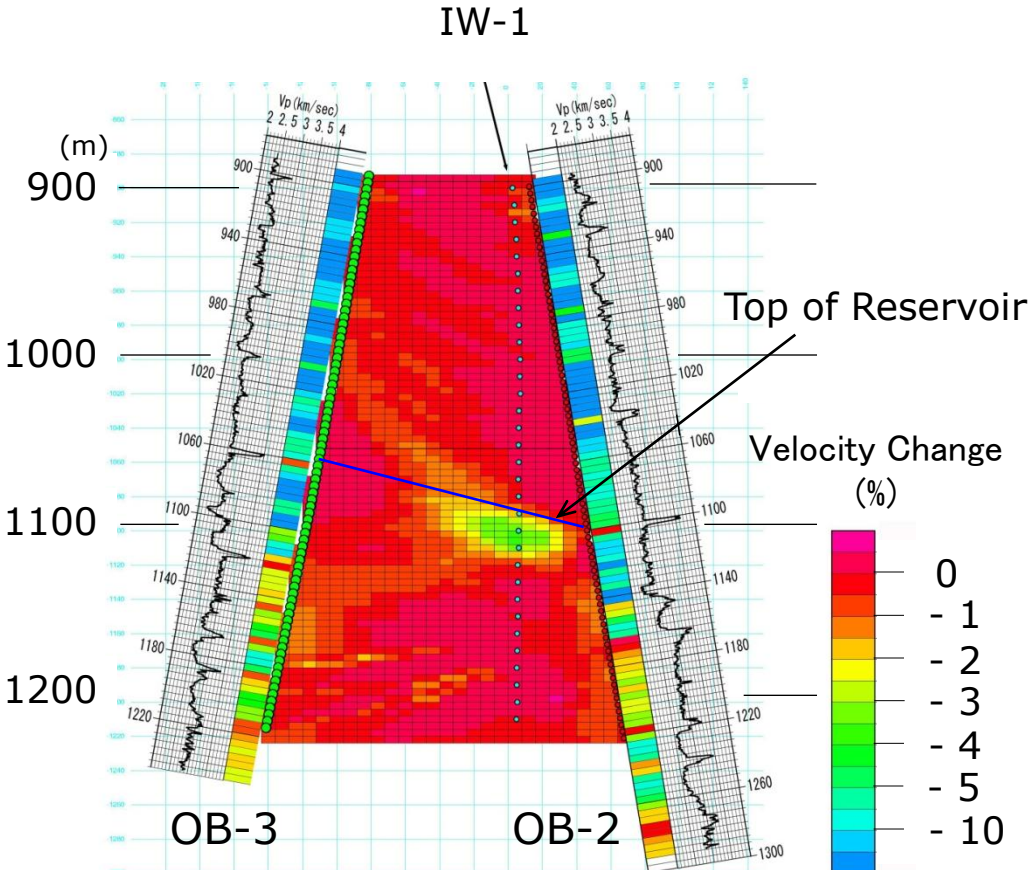
Max: - 3. 5%

Time –lapse seismic tomography

Post-Injection： 10,400 t-CO_2



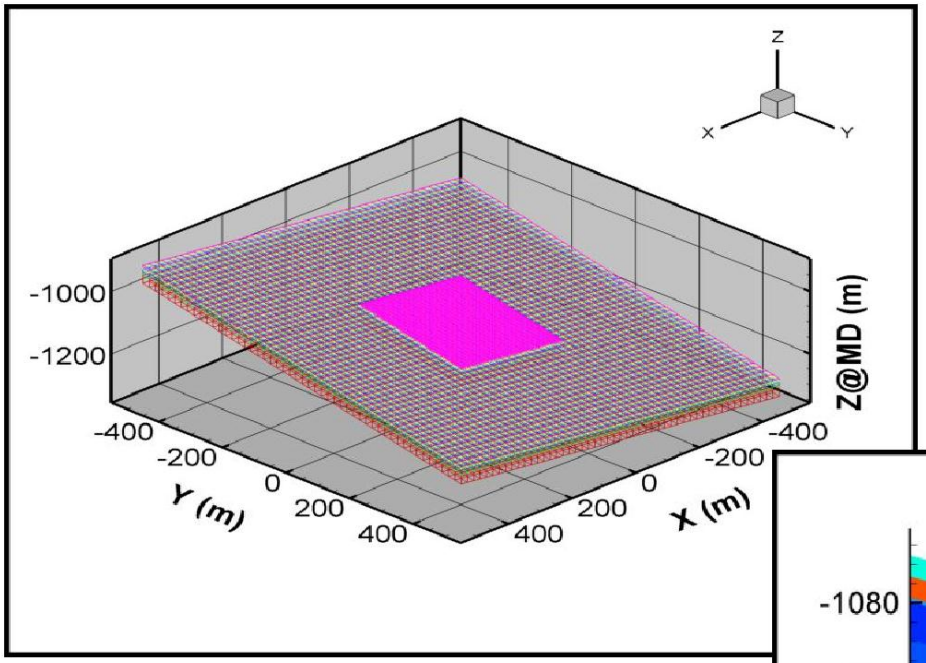




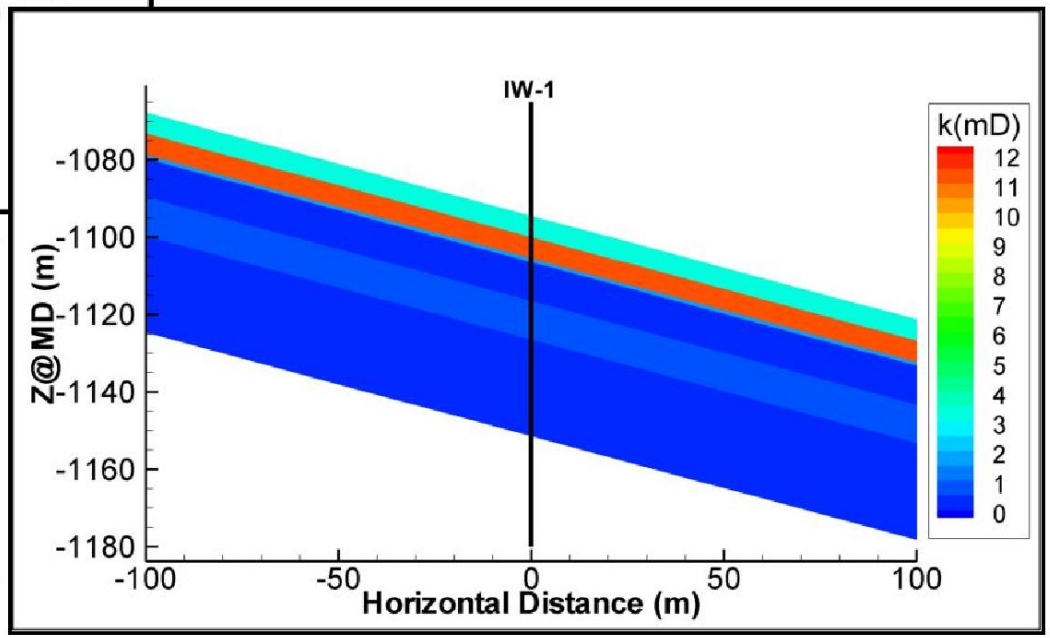
Max. Velocity Change= -3.5%

Velocity Change= $(V_{MS4}-V_{BLS}) / V_{BLS}$

3D Reservoir Model



Area Name	Area Size (m^2)	Gridblock Size (m^2)
Outer Area	1000x1000	20x20
Inner Area	320x320	5x5



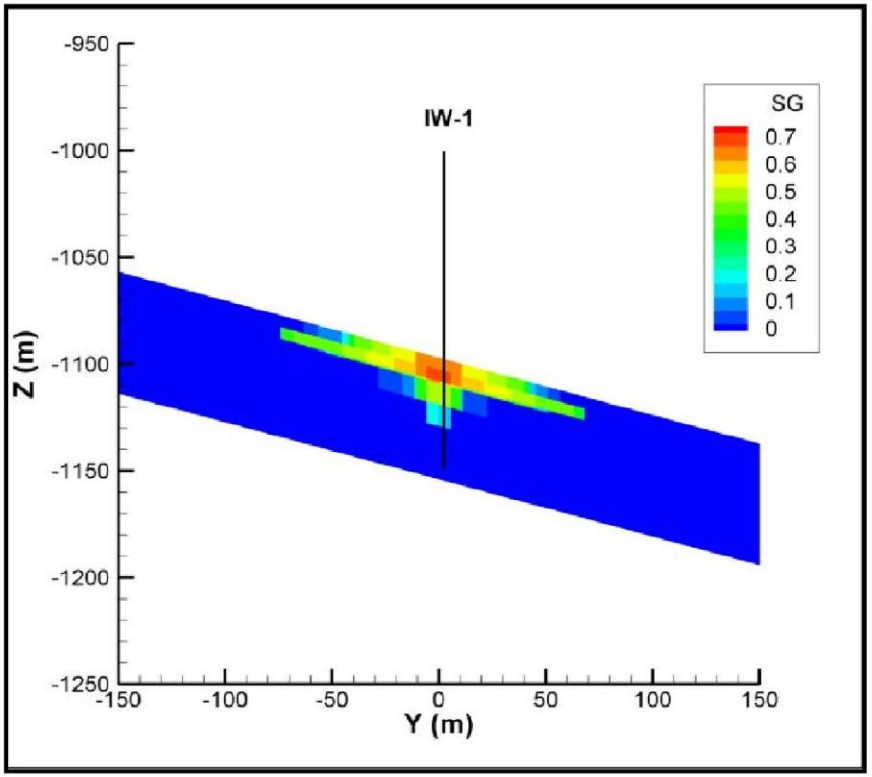
Layer	ϕ	Thick. (m)	Kh (mD)	kv/kh	β (1/Mpa)
Zone 2 U.	0.225	5.5	3.19	0.25	$2.9x10^{-3}$
Zone 2 M.	0.225	5.5	11.15	0.25	$2.9x10^{-3}$
Zone 2 L.	0.225	1.0	1.59	0.25	$2.9x10^{-3}$
Zone 3 U.	0.204	10.0	0.330	0.25	$2.9x10^{-3}$
Zone 3 L.	0.204	10.0	0.660	0.25	$2.9x10^{-3}$
Zone 4&5	0.234	25.0	0.460	0.25	$2.9x10^{-3}$

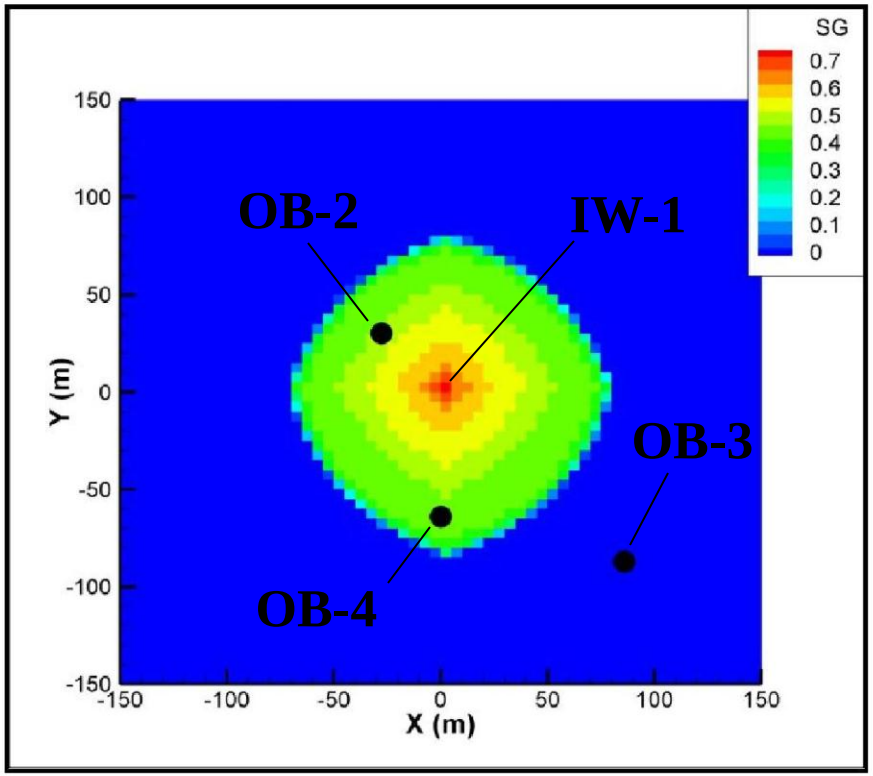
Ohkuma, H. (2008)

$$k_h = (k_x \cdot k_y)^{-0.5},\ k_y/k_x = 1.2$$

Results of Reservoir Simulation

CO_2 Distribution at Terminating Injection

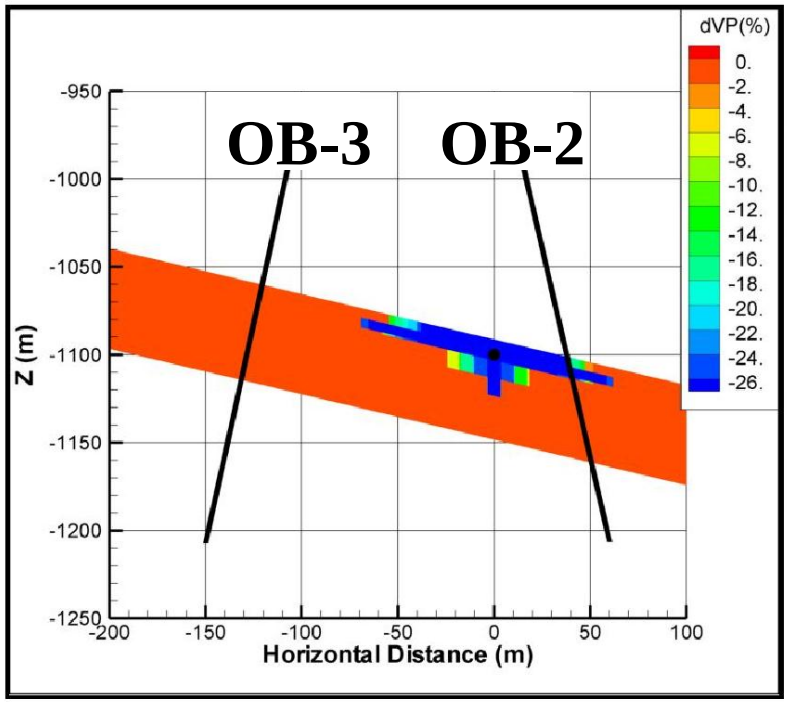




Distribution of Injected CO_2
（Comparison Reservoir simulation and Tomography）

Simulation Results

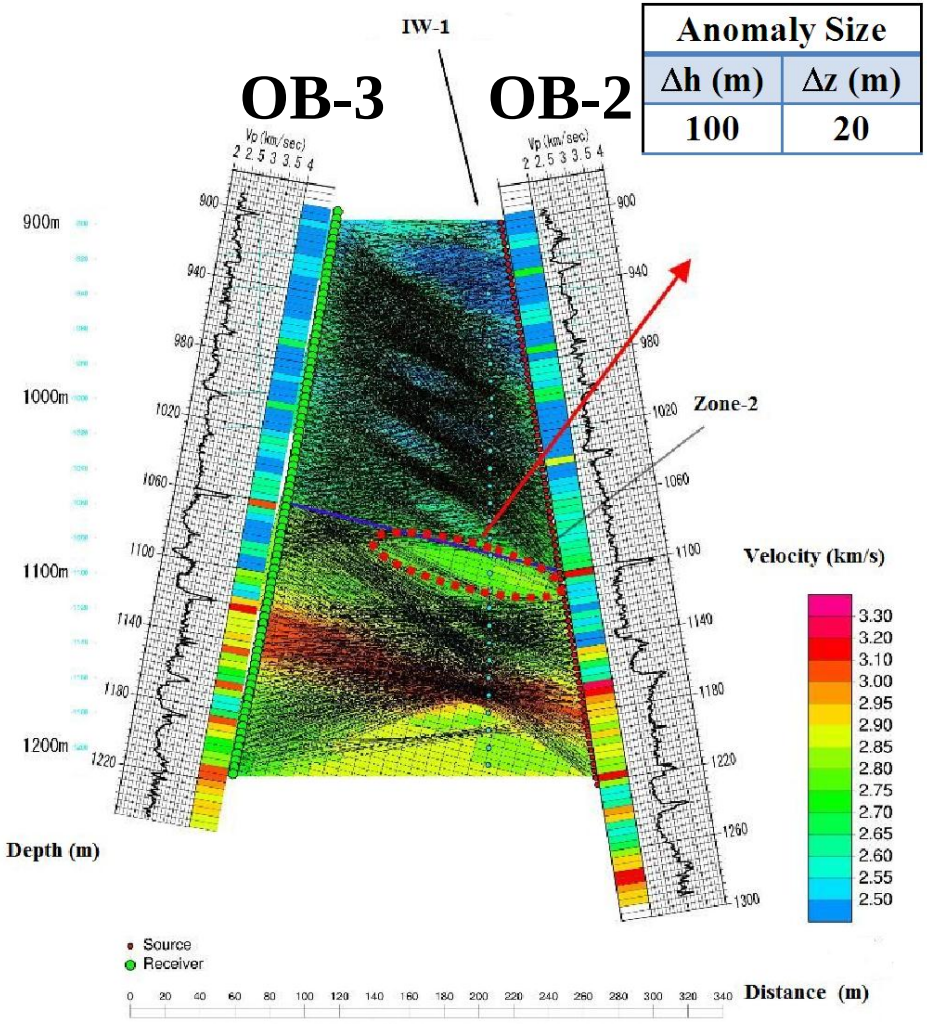
Anomaly Size	
Δh (m)	Δz (m)
105	22



Garcia (2009)

Ray paths : no travel time difference

Anomaly Size	
Δh (m)	Δz (m)
100	20



Nagaoka CO2 / Seismic Tomography

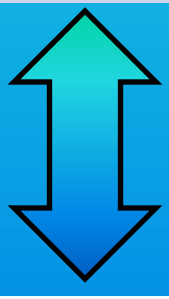
Evolution of Reservoir Model by History Matching

➢ **Reservoir Model**

→ **CO_2 Distribution Simulation**

→ **History Matching**

- Bottom hole pressure
- Reservoir pressure



- CO2 Breakthrough time
- Seismic tomography

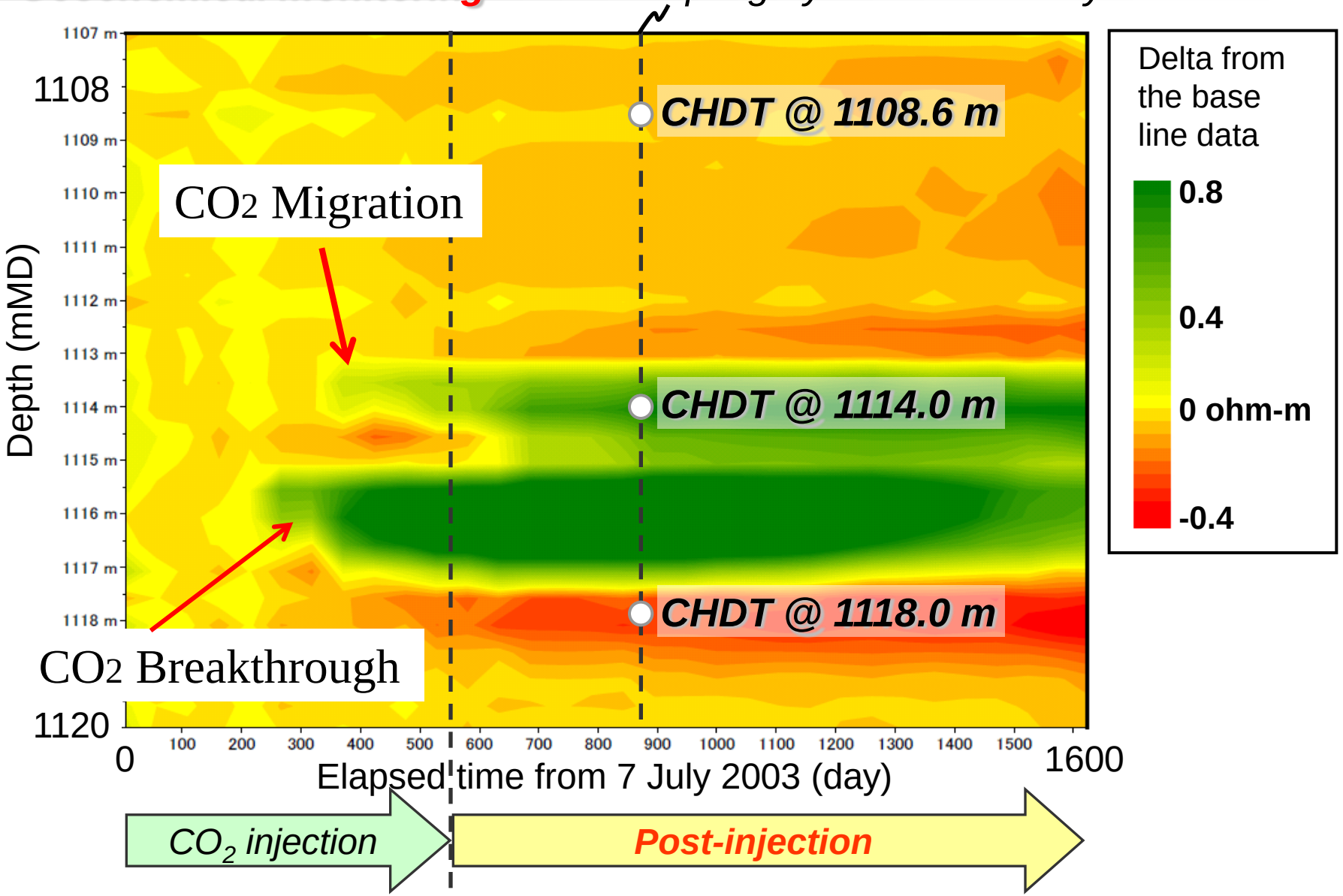
✓ **Accurate Reservoir Model**

✓ **Anisotropic Permeability**

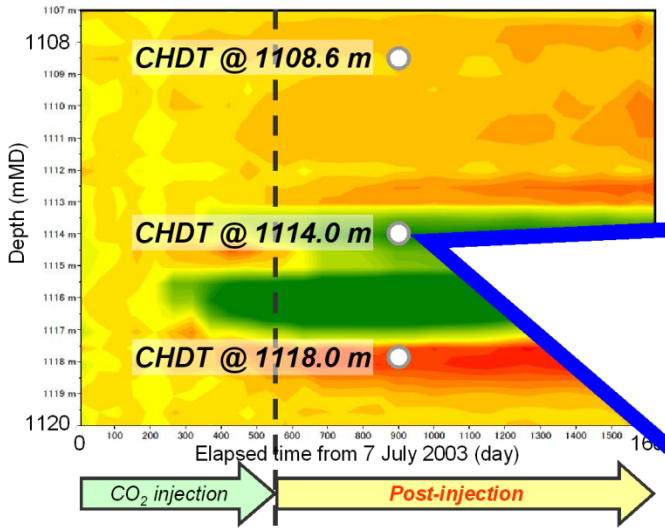
Evolution of Reservoir Model

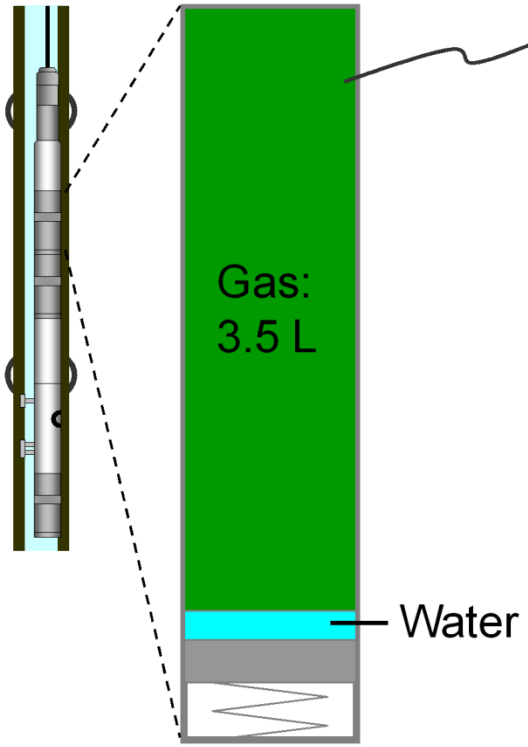
Resistivity Changes with Time @ OB-2

***Geochemical monitoring**: Fluid sampling by Cased Hole Dynamics Tester*



OB-2 @ 1114m: Mostly free CO_2



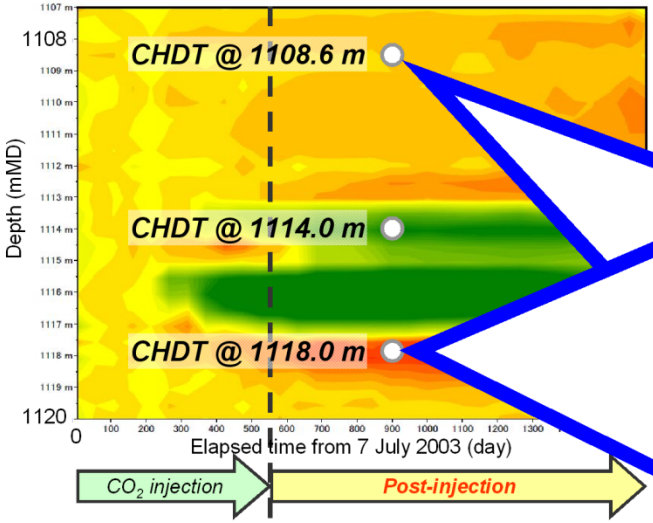


Sample Chamber
(volume 3.8 L)

Gas composition

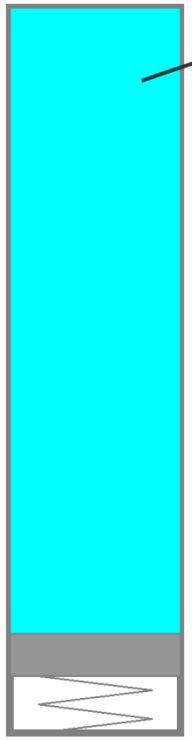
Comp.	mol%
H_2	0.0
O_2	0.2
N_2	0.7
CH_4	0.3
C_2H_6	0.0
CO_2	98.8

OB-2 @ 1108.6m & 1118m: Mostly Formation Water



Gas:
None

Water:
3.4~
3.5 L



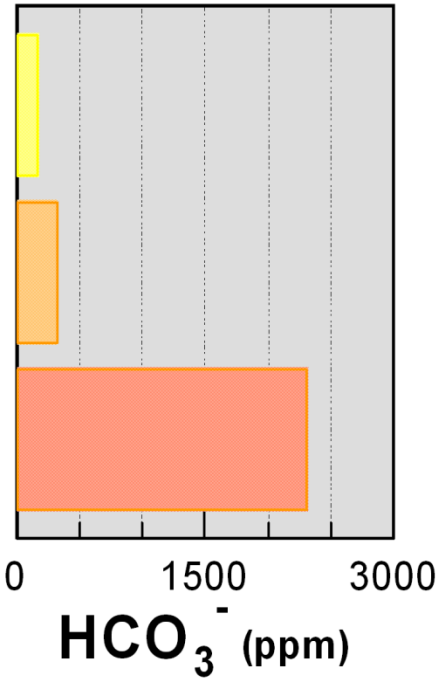
Sample Chamber
(volume 3.8 L)

Water Composition

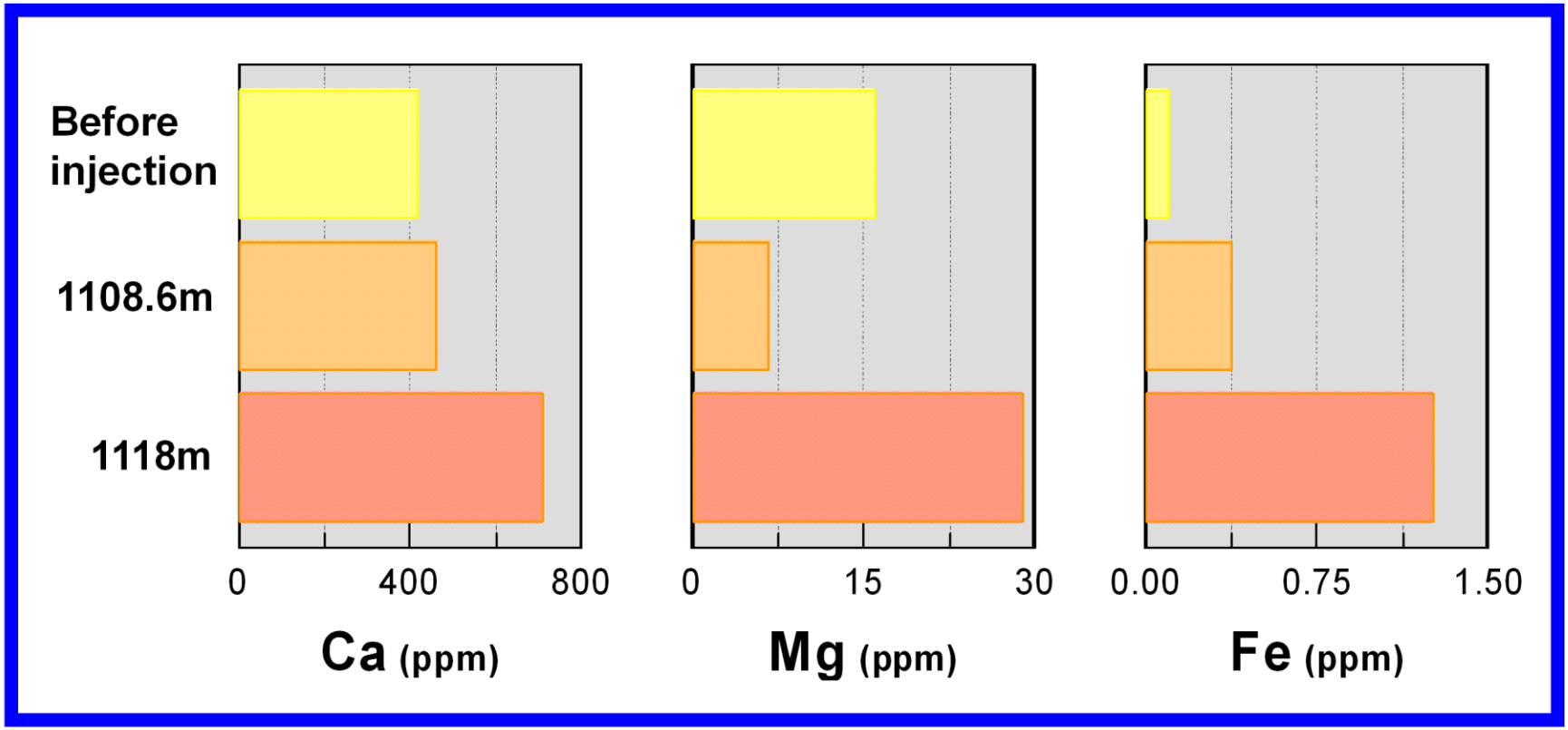
Before injection

1108.6m

1118.0m

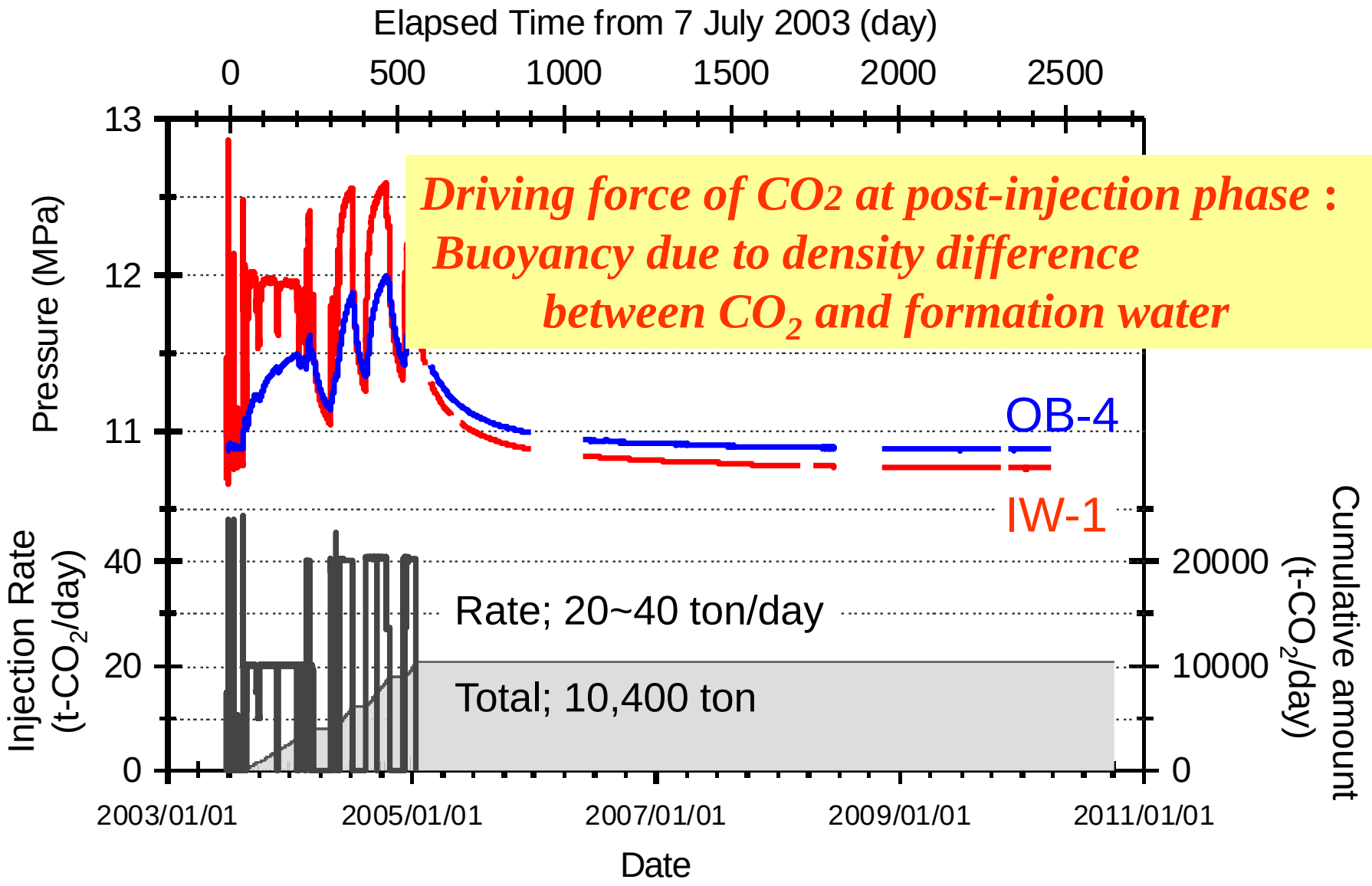


OB-2 @ 1108.6m&1118m:
Cations in the formation water

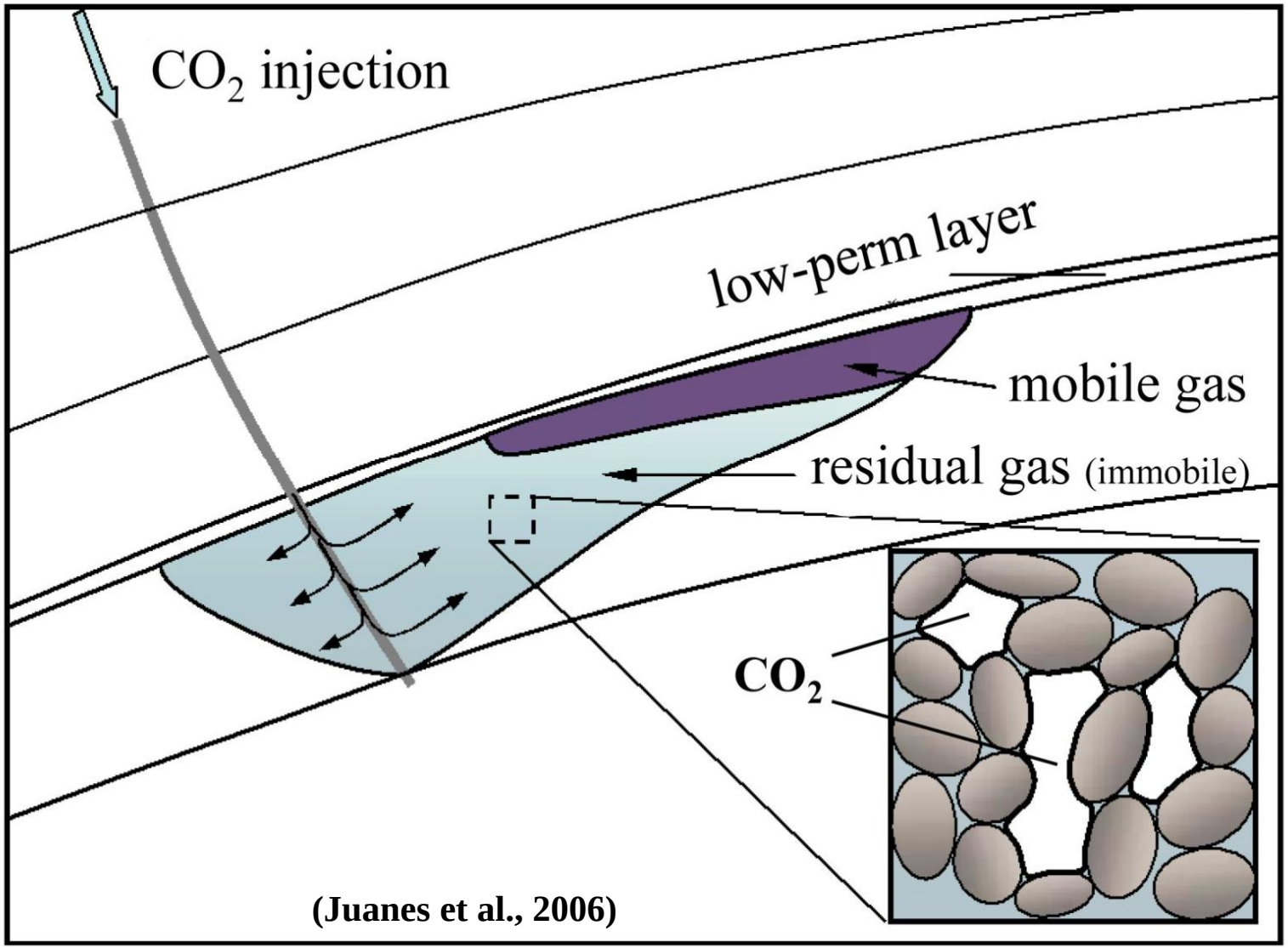


Increased: HCO_3^-, Ca, Mg and Fe @1118m

Injection History and Formation Pressure

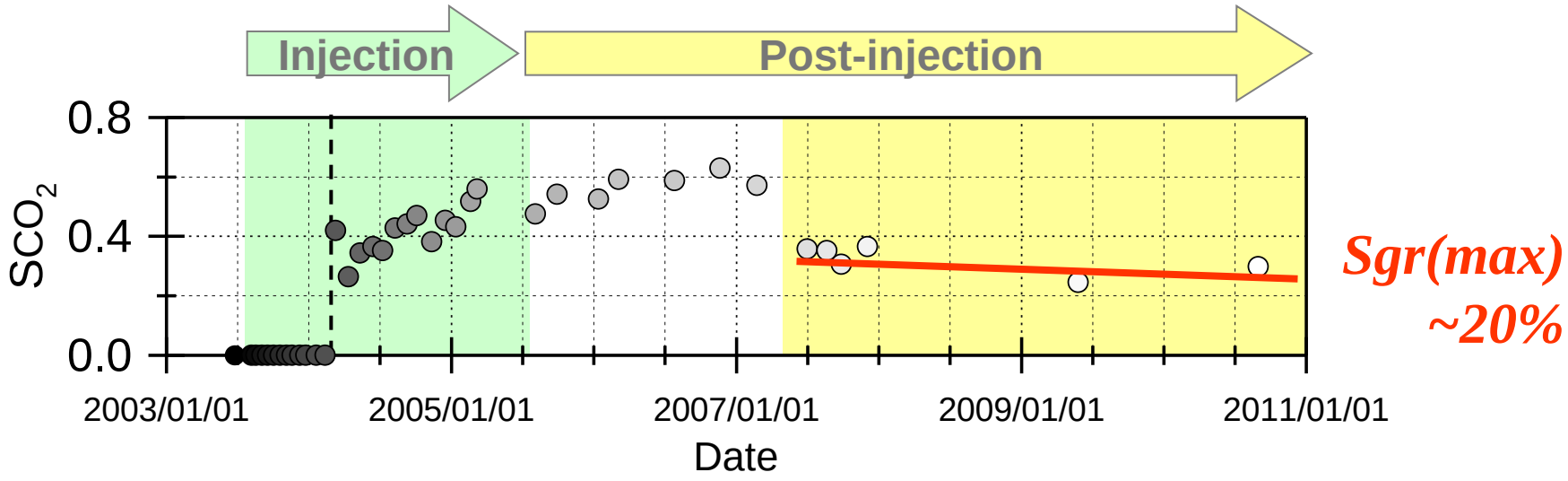


Residual CO_2 trapping is happening at Nagaoka?

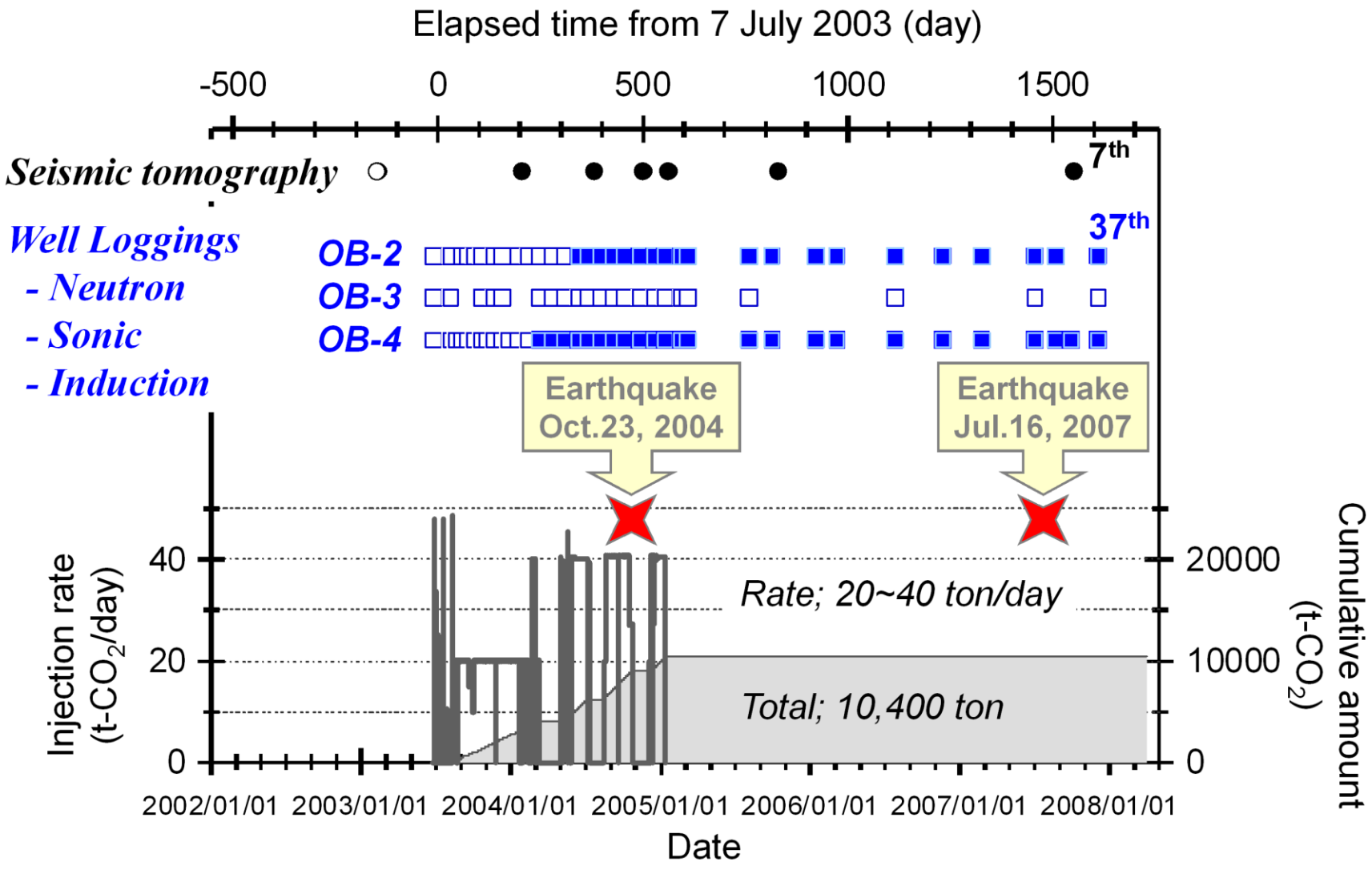


(Juanes et al., 2006)

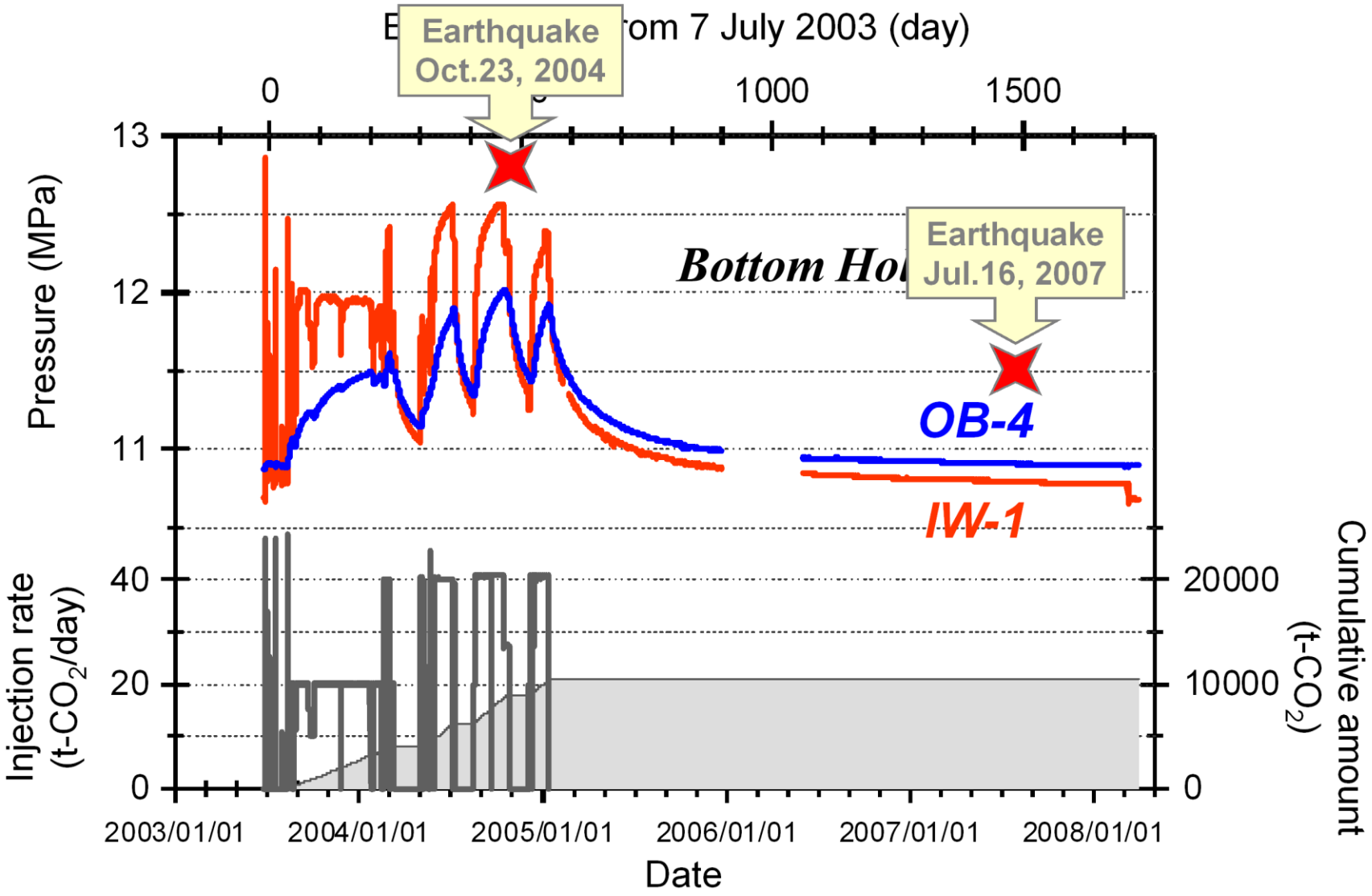
Residual CO_2 at the down-dip in the reservoir (1116.0m @ OB-2)



Field measurements during and post CO_2 injection (*Geophysical monitoring*)



Changes in Bottom Hole Pressure



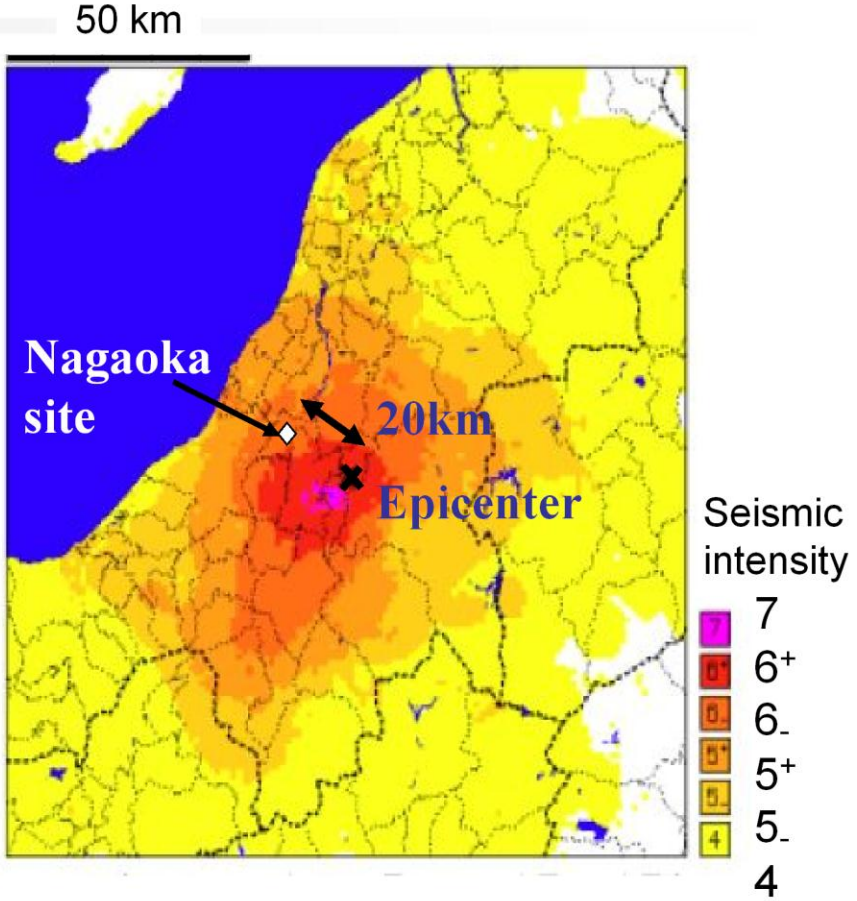
The Mid Niigata Prefecture Earthquake in 2004

Main shock: 23 Oct 2004
M6.8 at 10km depth
Seismic intensity: 7
→Injection was automatically stopped at the main shock.

Access road was damaged.

CO_2 detector (No leak)

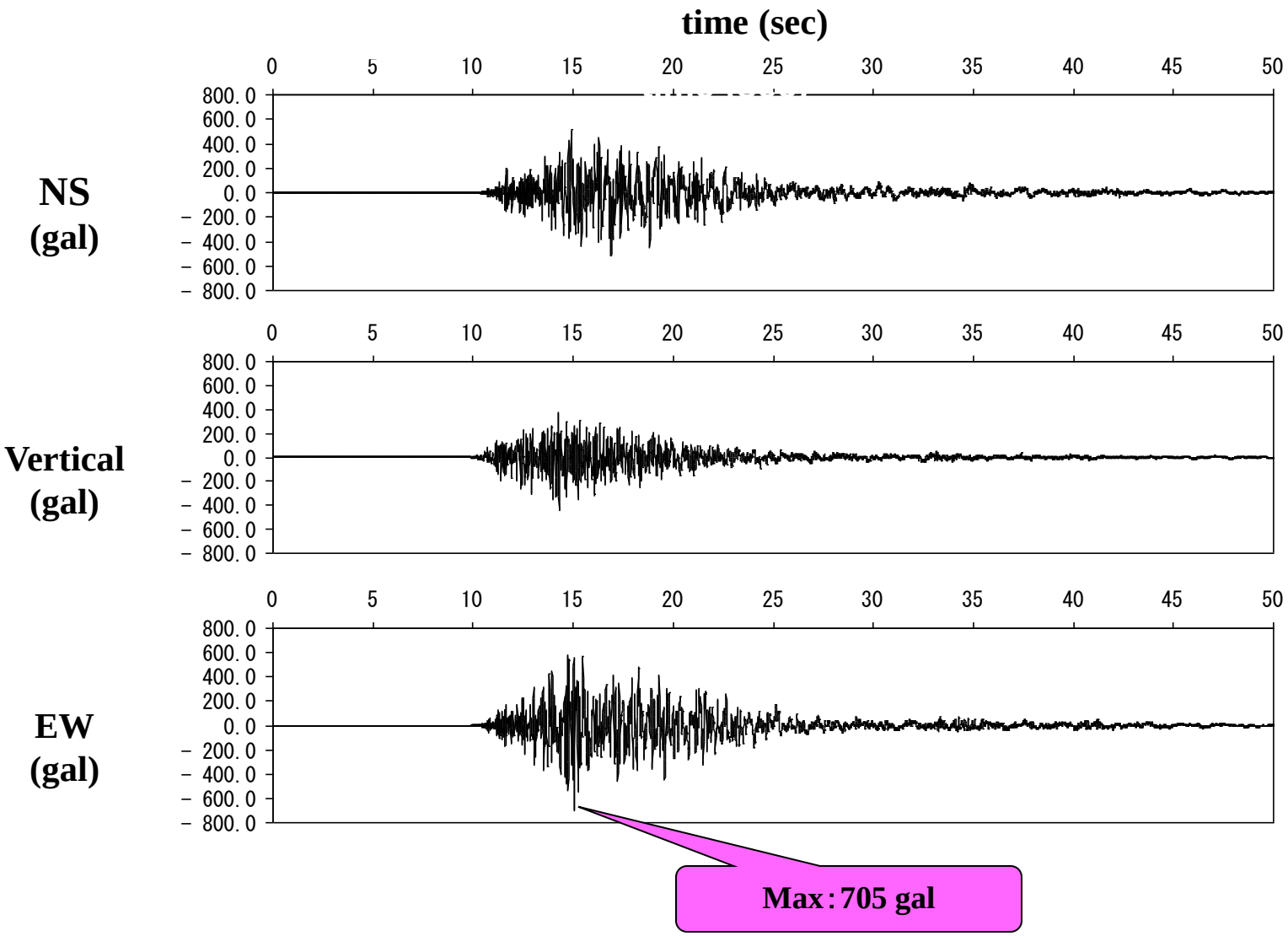
Injection was carefully resumed after confirming safety (6 Dec 2004)
injection rate: 40t-CO_2/day



(GSJ, 2004 http://www.gsj.jp/jishin/chuetsu_1023/)

For detail: Xue et al. (2006)
3rd Monitoring Network Meeting (Melbourne)

Main Shock:　2004/10/23 17:56 M6.8



Liquid CO_2 Tank

Diameter: 3.8 m
Height : 18 m

No Damages !

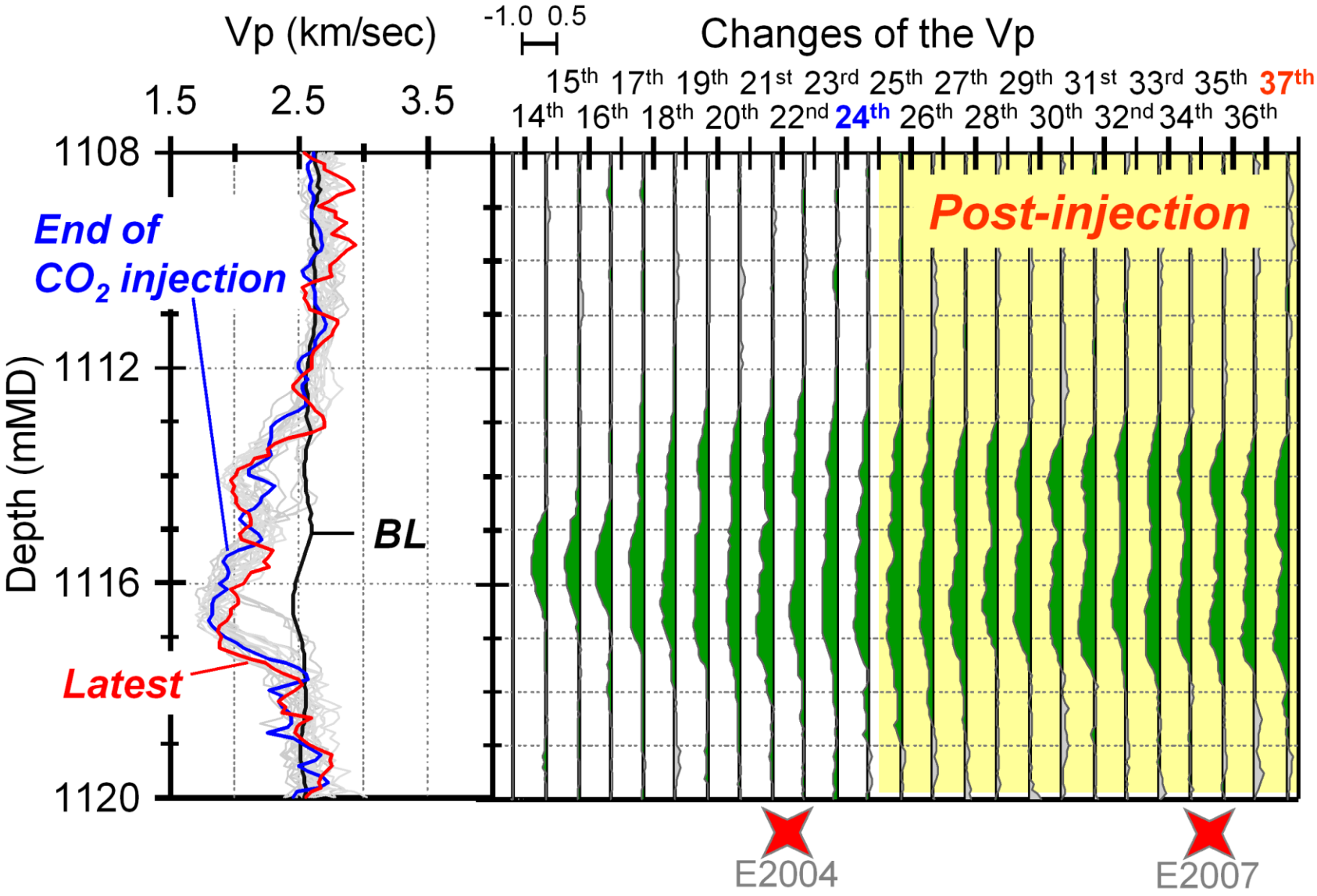
Injection Well

Observation Wells

CO_2 Pipeline

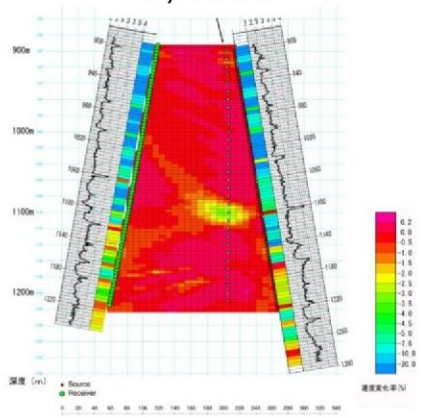
After the Earthquake (Oct. 25, 2004)

Sonic Logging (Vp) @ OB-2

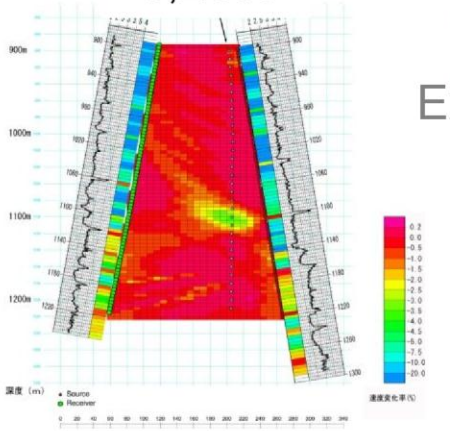


Results of Crosswell Seismic Tomography

MS1/BL
3,200t

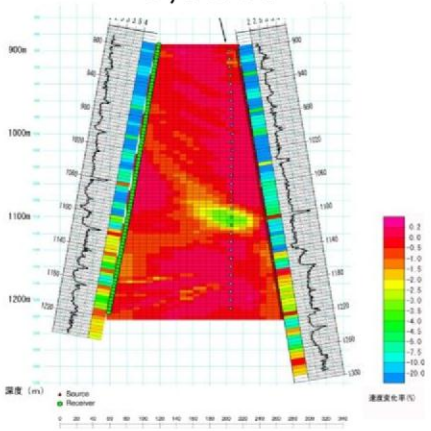


MS2/BL
6,200t

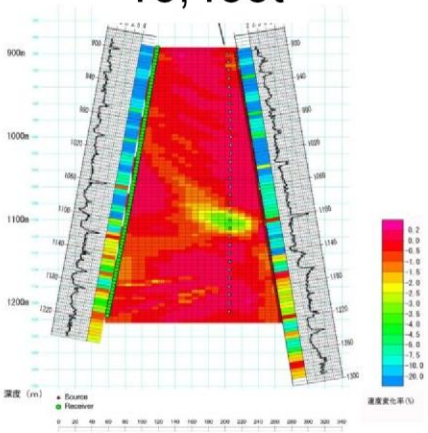


E2004

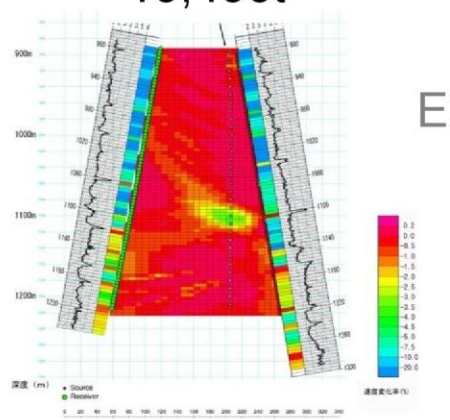
MS3/BL
8,900t



MS4/BL
10,400t

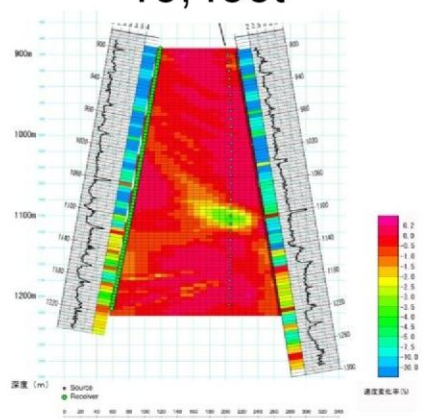


MS5/BL
10,400t



E2007

MS6/BL
10,400t



Nagaoka pilot test: targets and results

Primary targets

- ✓Investigation for the possibility of CO_2 geological storage in complex stratum, Japan
- ✓Study on the underground behavior of injected CO_2
- ✓Modeling of CO_2 behavior
- ✓Safety assessment of CO_2 injected underground

Major results

- ✓10,400 t-CO_2 was successfully injected at rate of 20-40t-CO_2/day into a saline aquifer of 1,100 m depth
- ✓Any CO_2 leakage sign by the earthquakes didn't be detected

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- ✓Measurement of temperature and pressure at top and bottom of the reservoir formation
- ✓Micro-seismicity measurement
- ✓Time-lapse Well logging and fluid sampling
- ✓Time-lapse Cross-well seismic tomography

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- ✓CO_2 behavior was simulated with history matching using monitoring results

Basic knowledge of aquifer storage in Japan is obtained.
Test results are utilized for the development of safety assessment and storage potential evaluation.

Acknowledgements

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