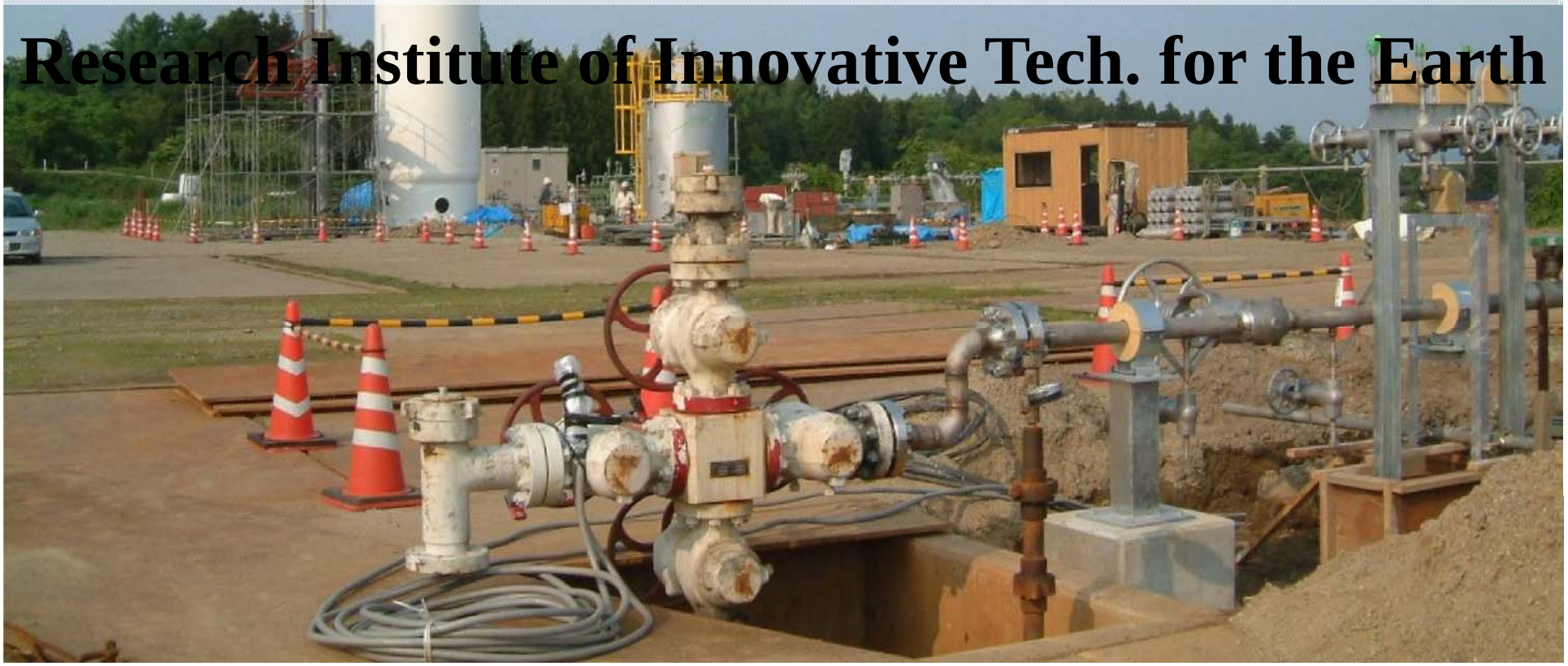
CO_2 Storage Experience in Japan including Impacts of Earthquakes

Ziqiu Xue (xue@rite.or.jp)

Research Institute of Innovative Tech. for the Earth



Purpose of Nagaoka Pilot Project

➢ **World CCS Projects（@2000）**

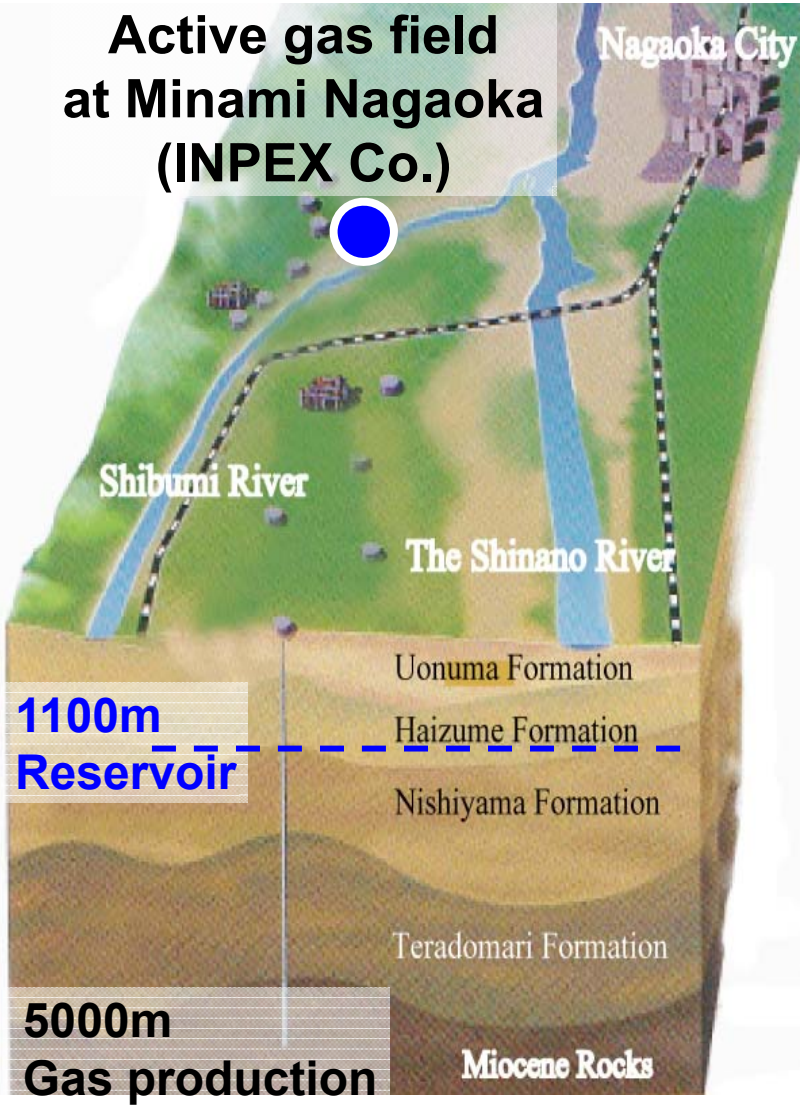
- **Sleipner（Norway, Aquifer, Associated CO_2）**
- **Weyburn（Canada, EOR, Coal Gasification）**

—Nagaoka Project—

1st on-shore aquifer CO_2 injection test

➡ **（Verification of CO_2 Storage in Complex Geology)**

Site Selection



Geological Factors

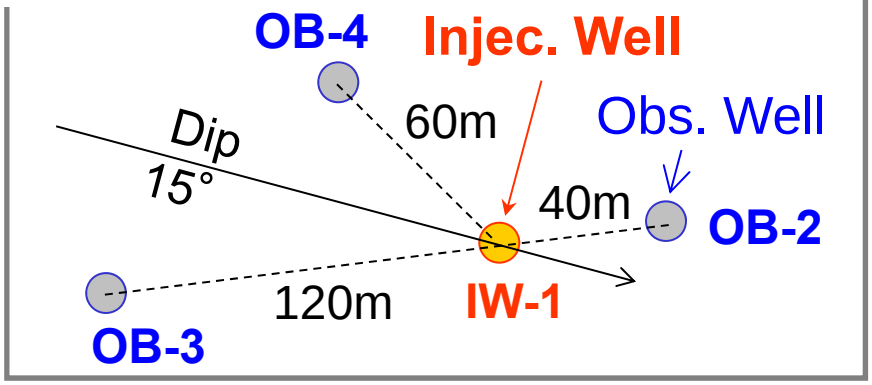
- Continuity of cap rock
- Gentle tilted reservoir
  - Depth（800-1200m），
  - Thickness（>10m）
- No faults within 1.5km^2
- Details data for subsurface

Operational Factors

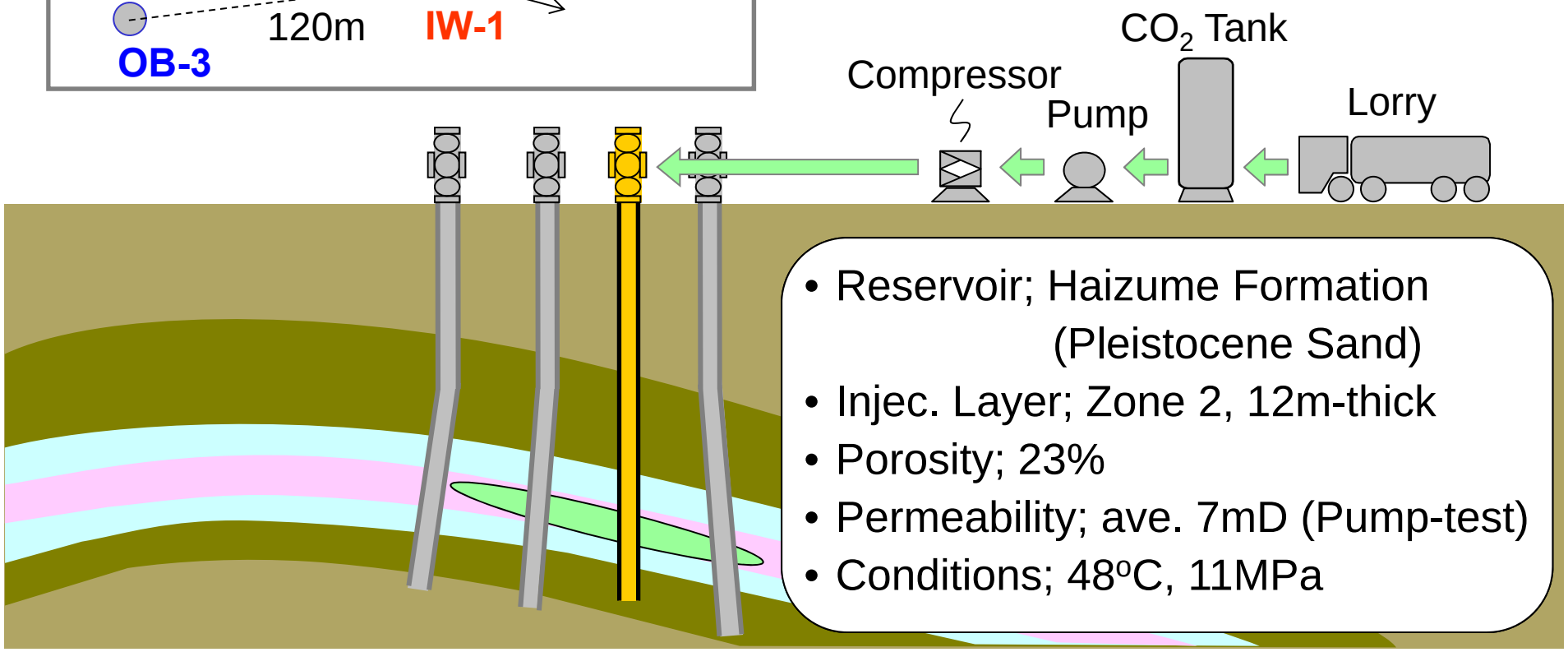
Social Acceptance, Well yard etc.

Overview of the Nagaoka Site

Well Configuration
at the Reservoir Depth

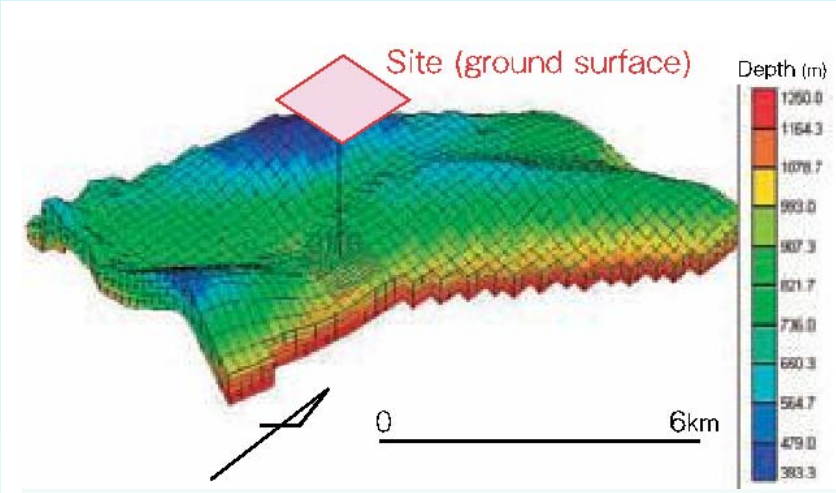


- Injec. Period; Jul. 2003~Jan. 2005
- Total amount; 10,400 ton CO_2
- Rate; 20~40 ton/day



- 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

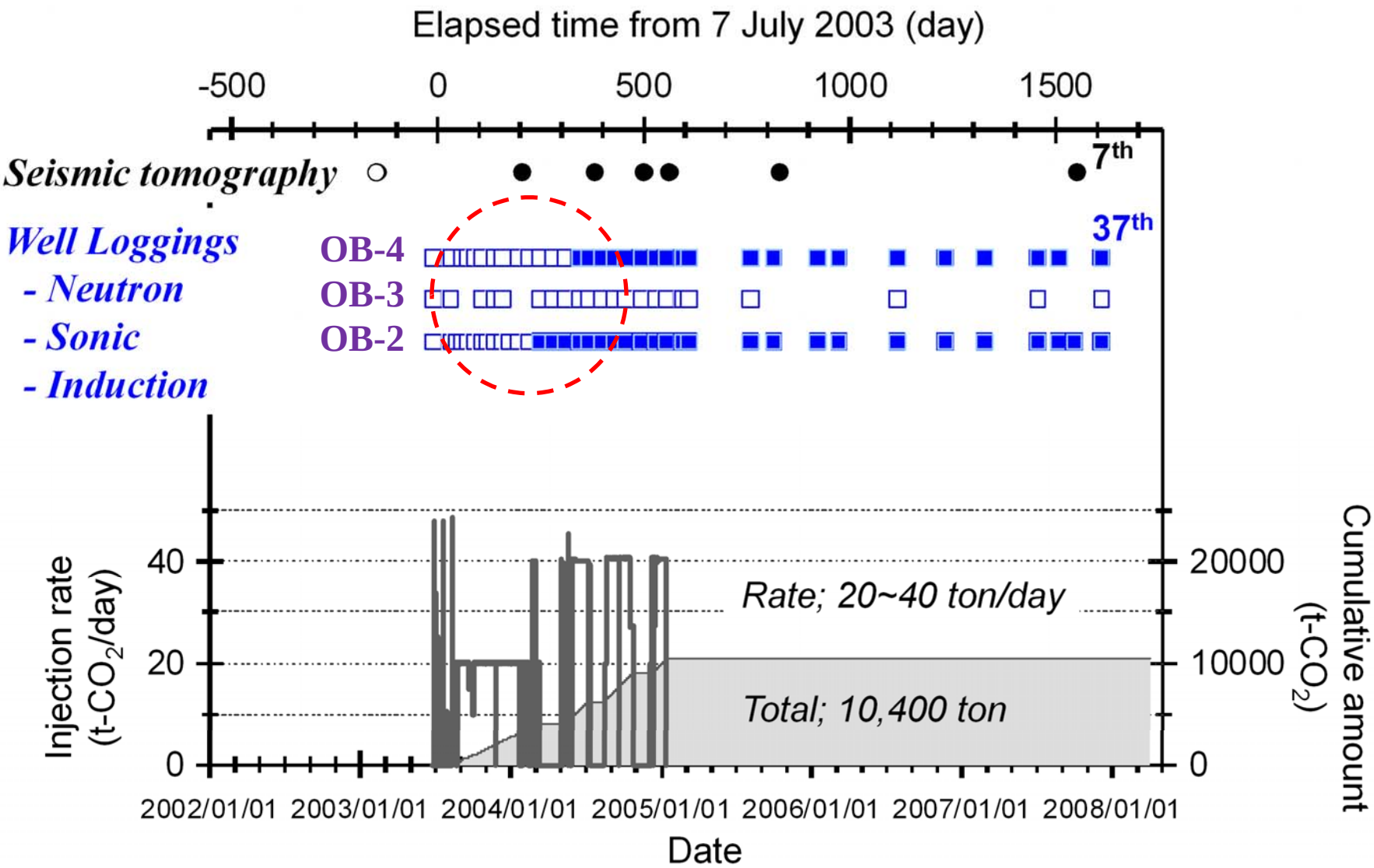
Reservoir (Haizume Formation)
✓Injection point is Edge of Anticline

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

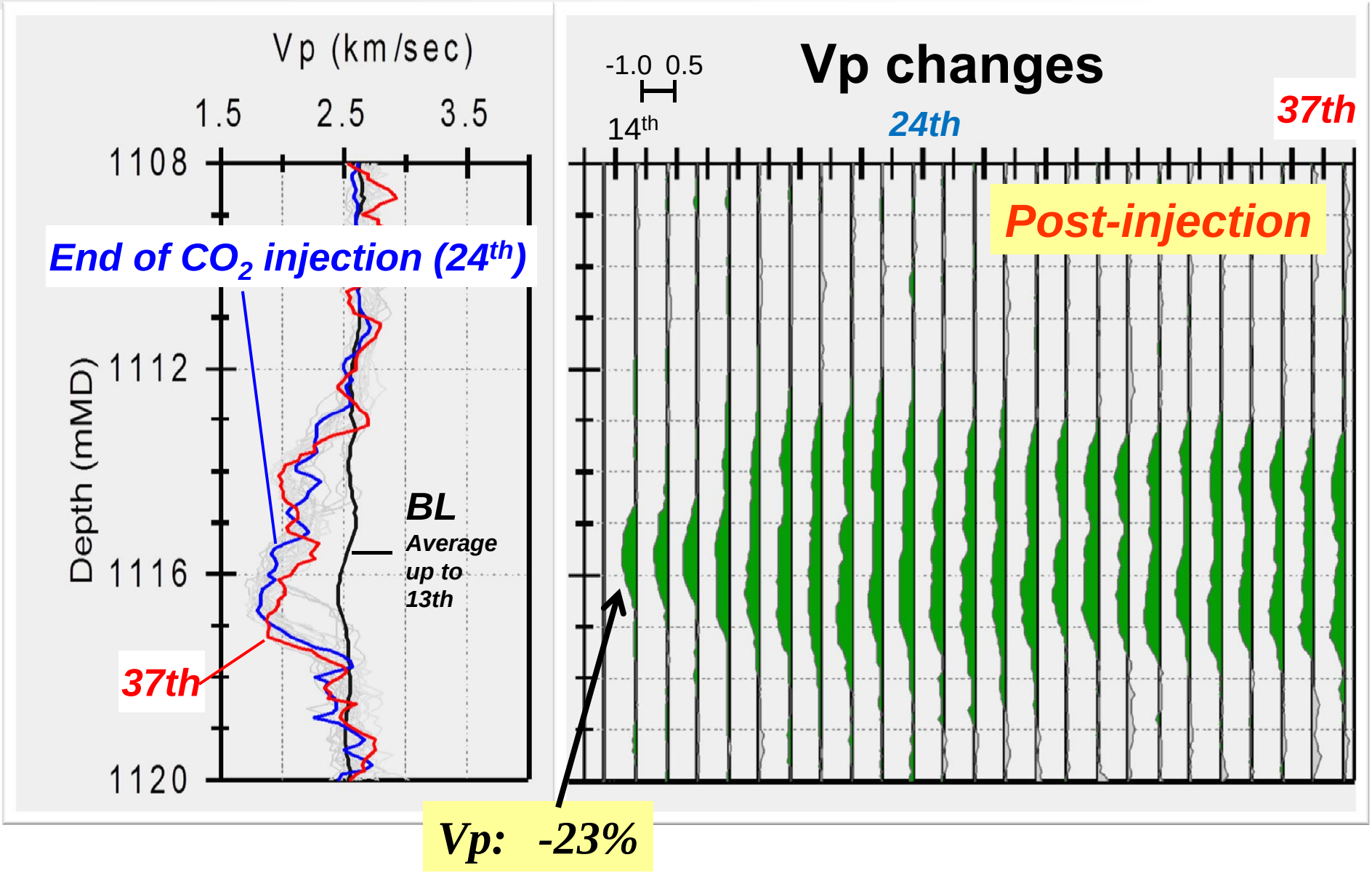
During Injection：History matching with pressure & logging data
（Reservoir model is updated by the monitoring data）

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

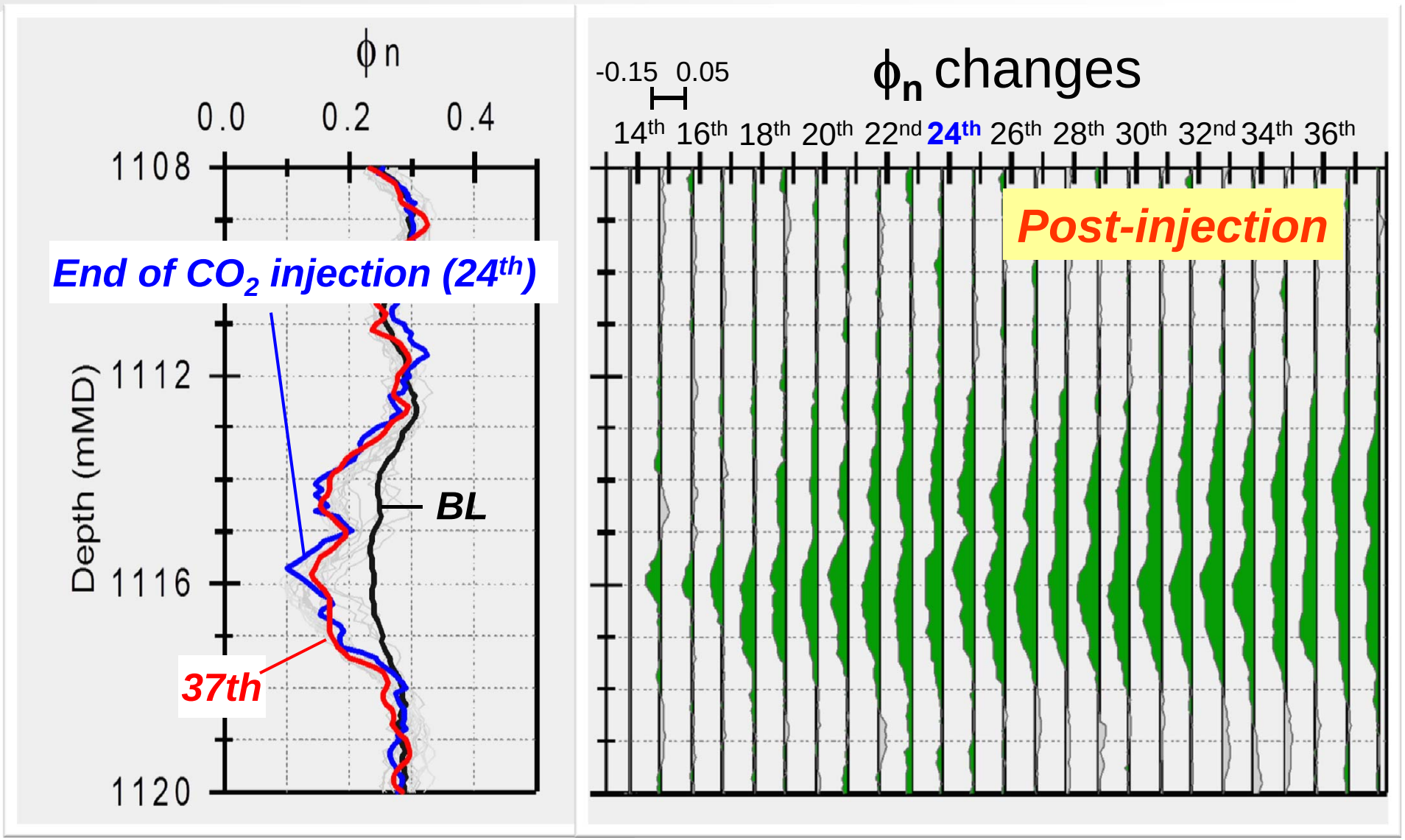
Detection of CO2 breakthrough by time-lapse logging



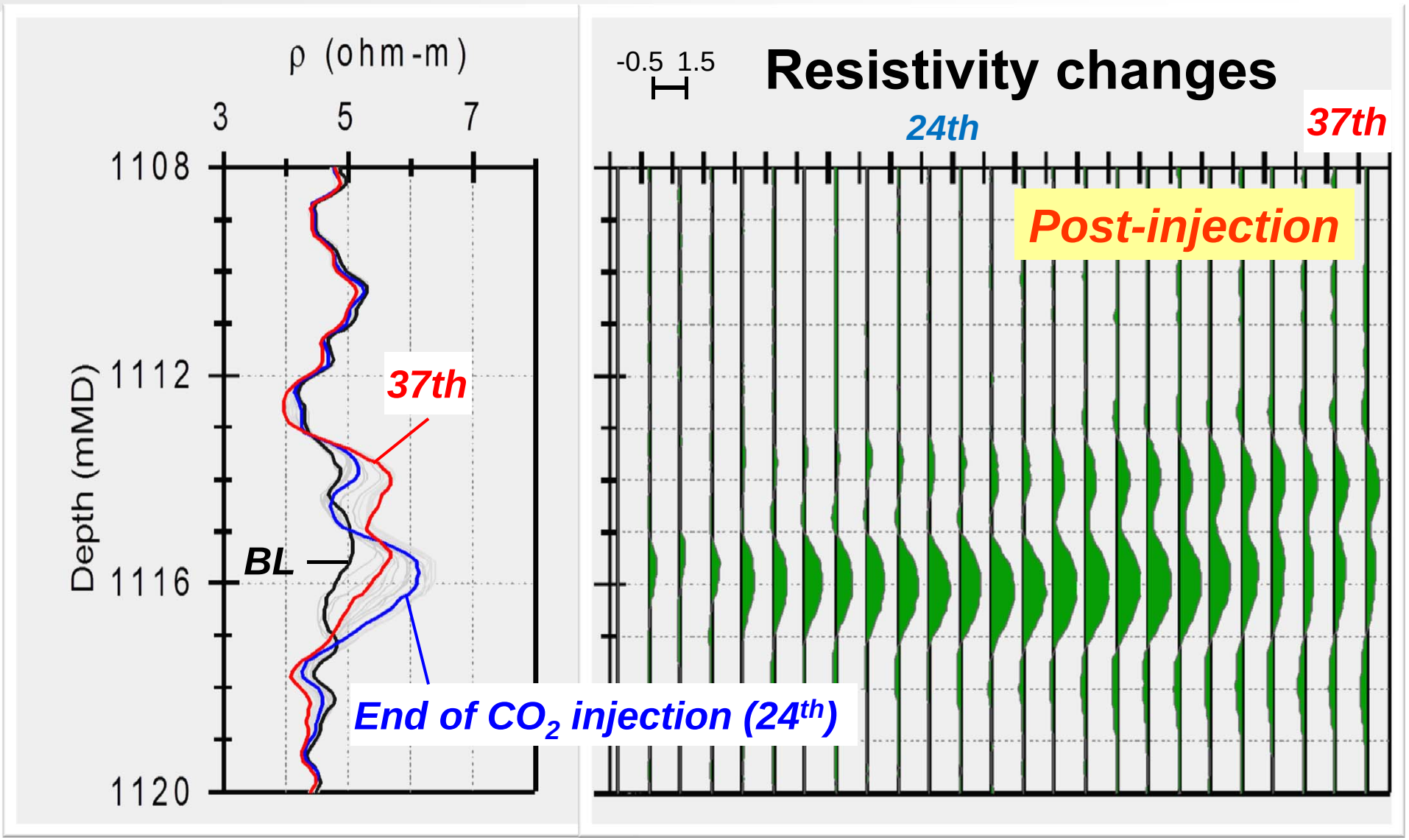
Sonic Logging @ OB-2



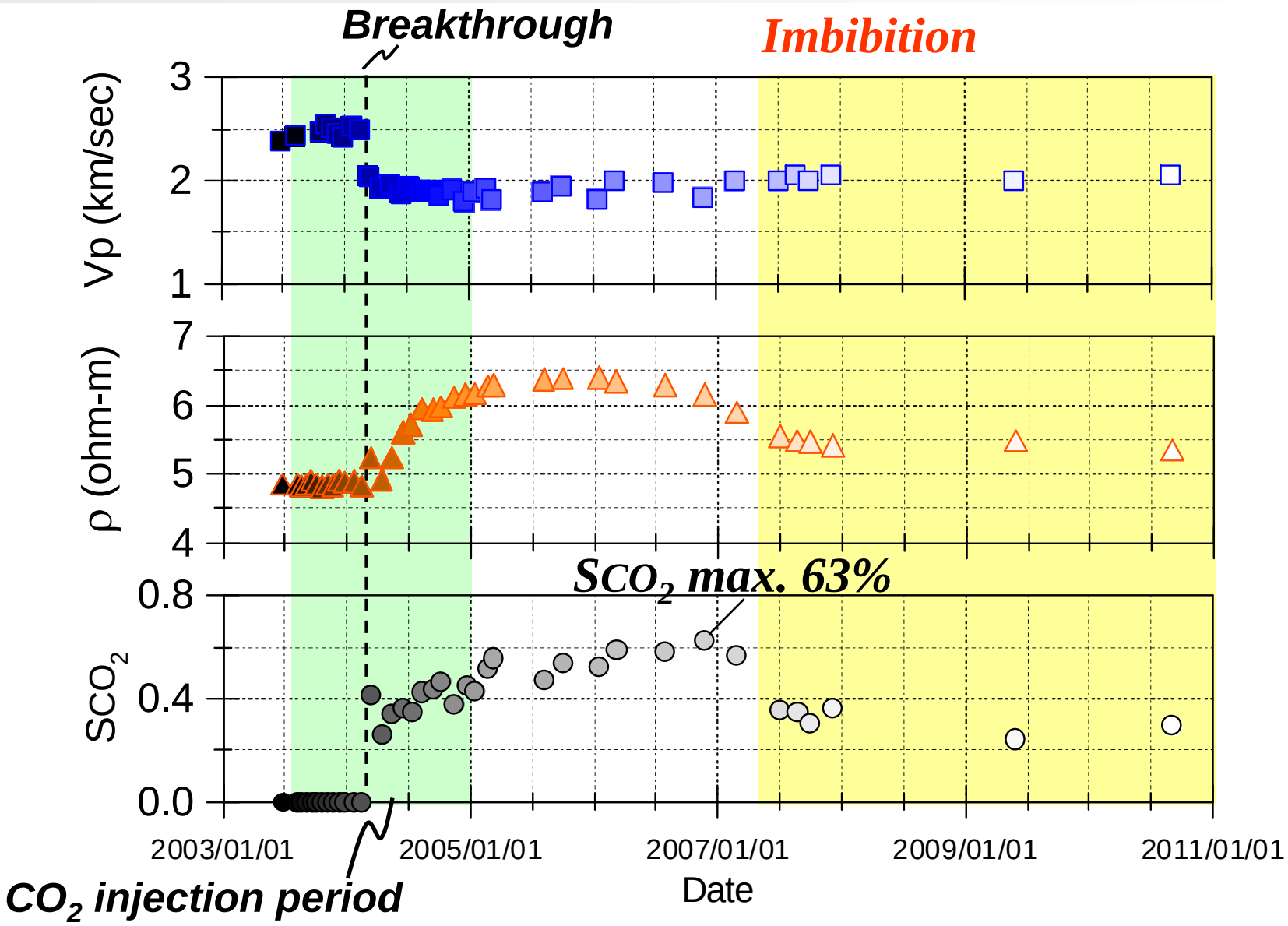
Neutron Logging @ OB-2



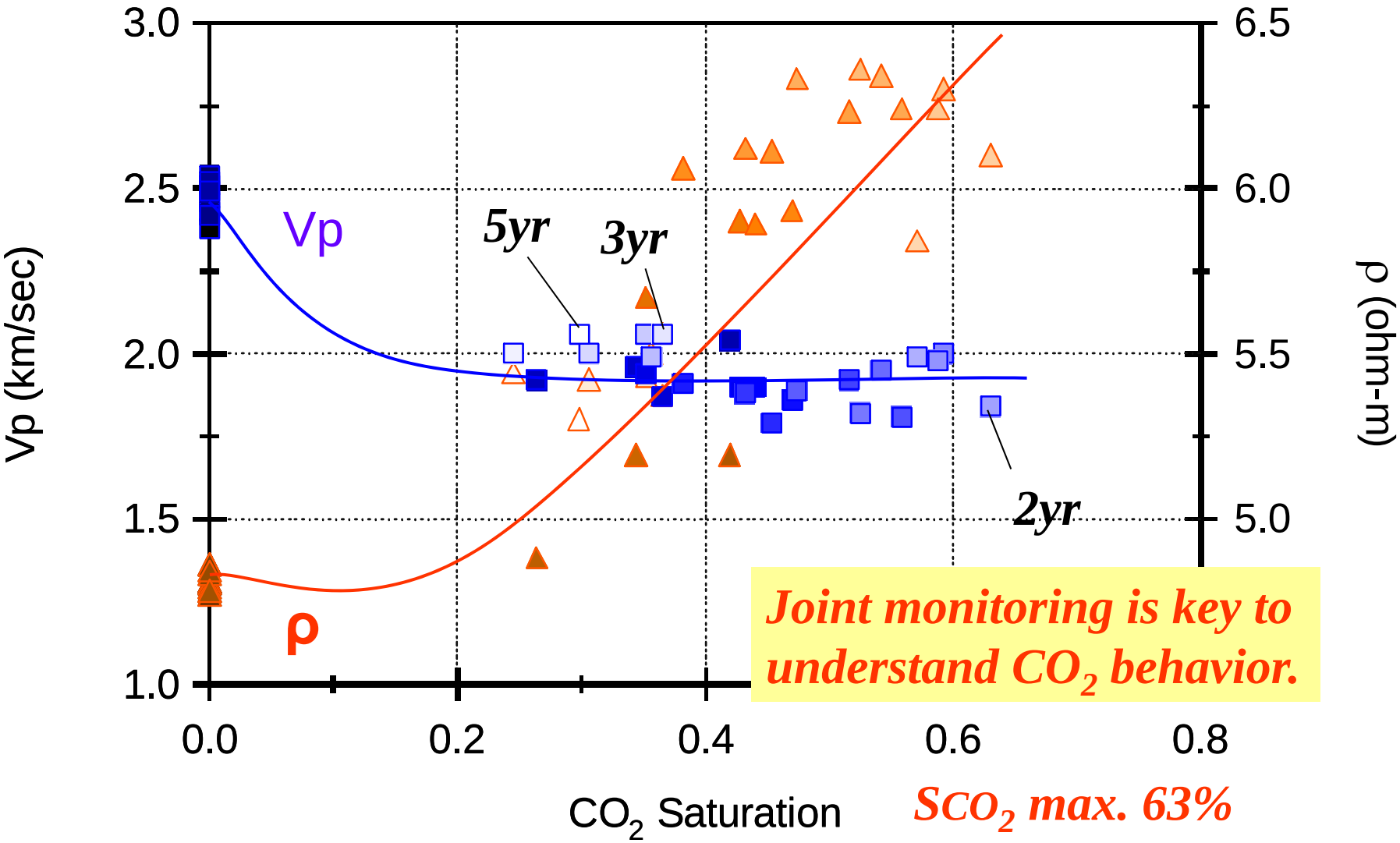
Induction Logging @ OB-2



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



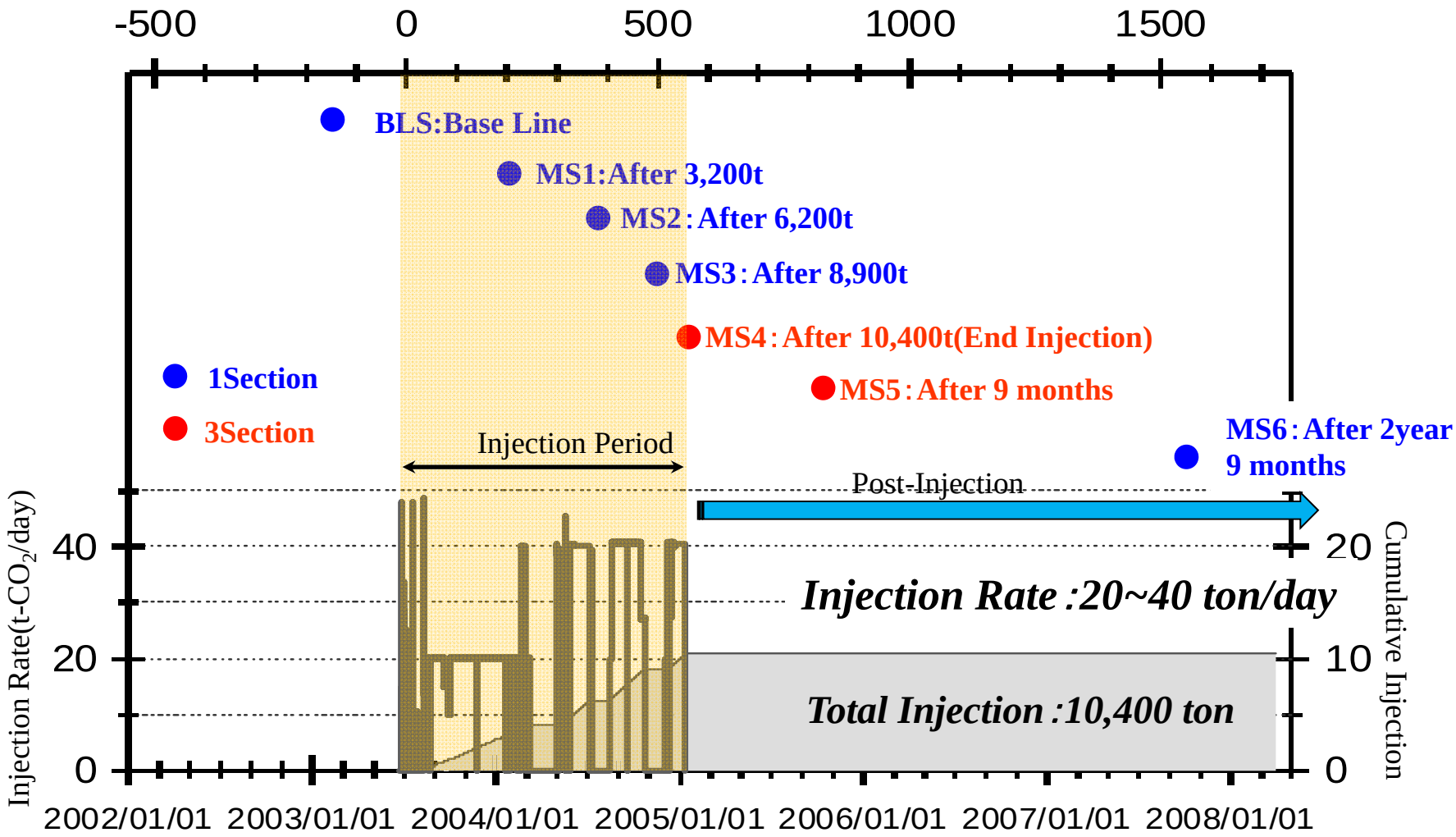
P-wave Velocity and Resistivity vs CO_2 saturation (1116.0m @ OB-2)



Joint monitoring is key to understand CO_2 behavior.

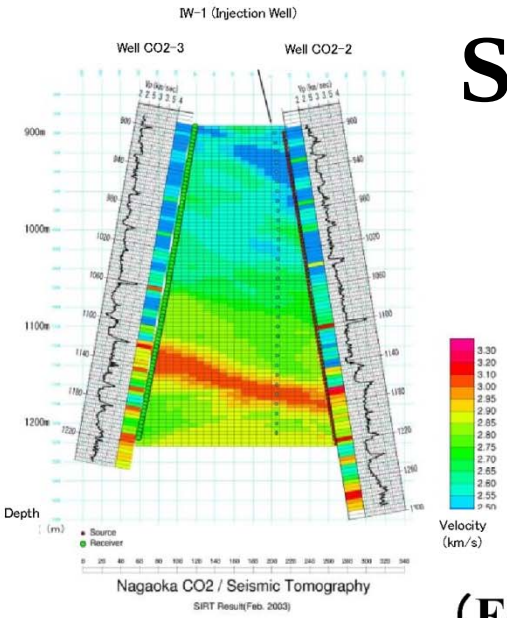
S_{CO_2} max. 63%

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

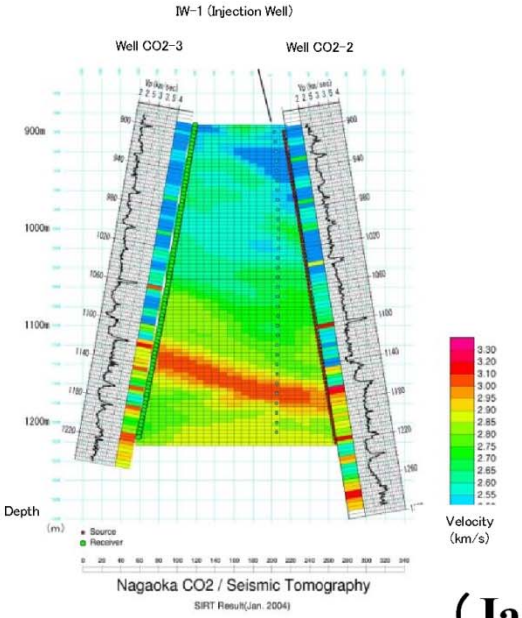


Seismic Tomography

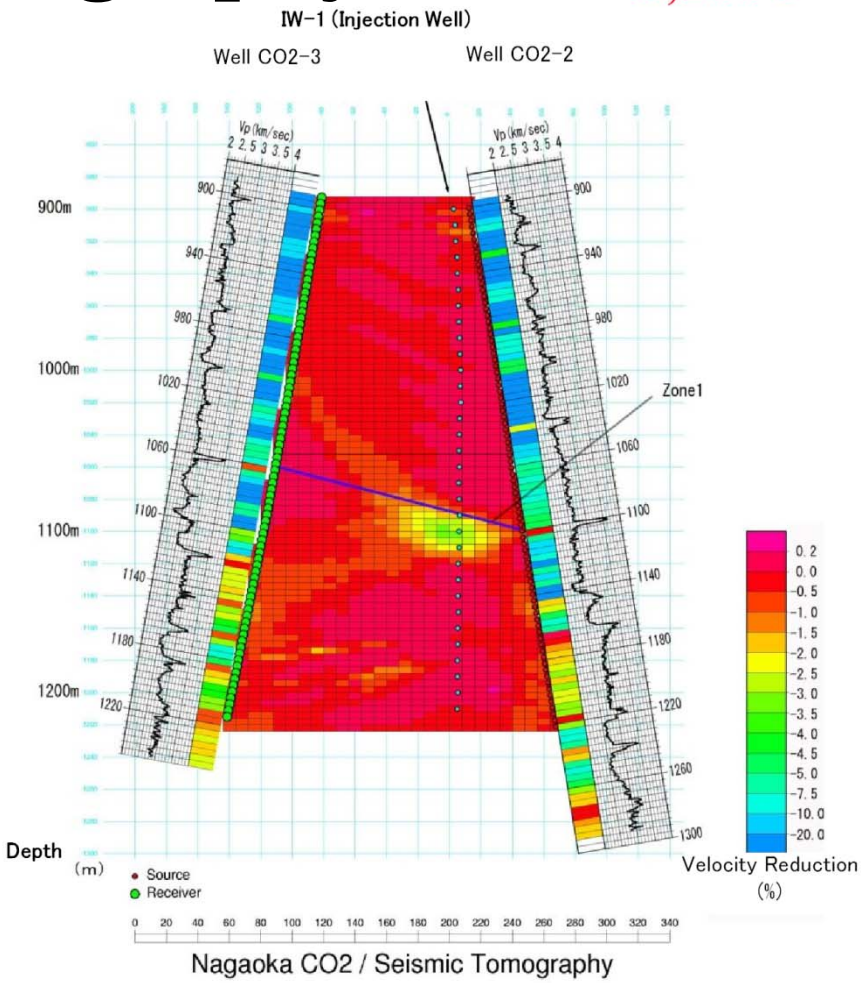
3,200 t



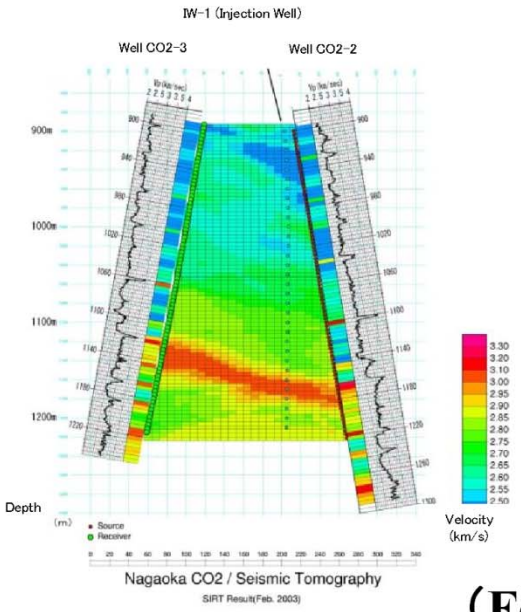
(Feb. 2003 :BLS)



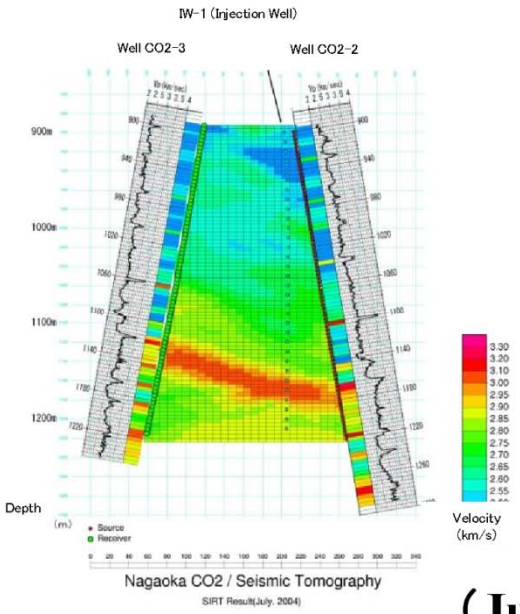
(Jan. 2004 :MS1)



Max: - 3. 0%

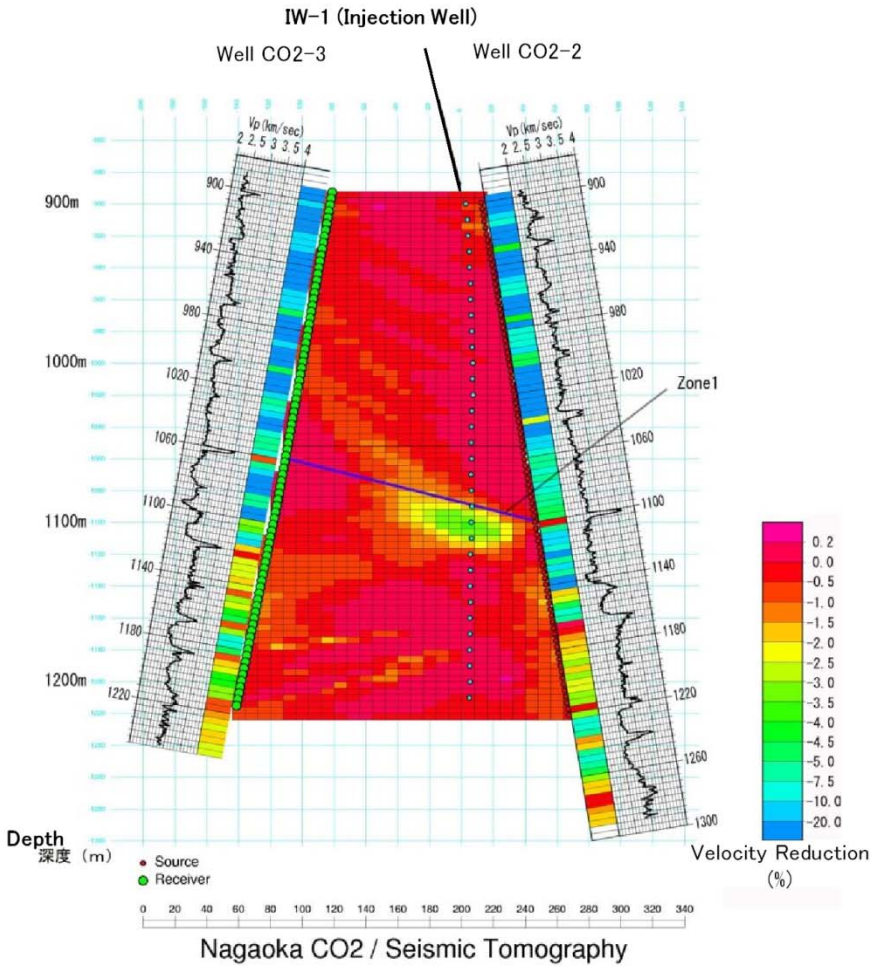


（Feb. 2003 :BLS）

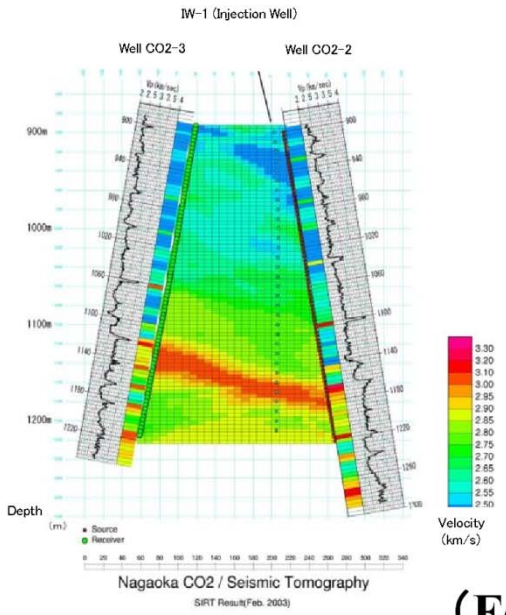


（July. 2004 :MS2）

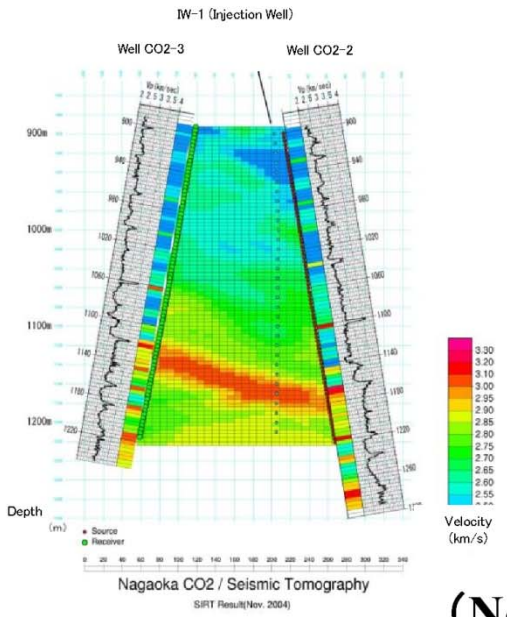
6,200 t



Max: －3. 5%

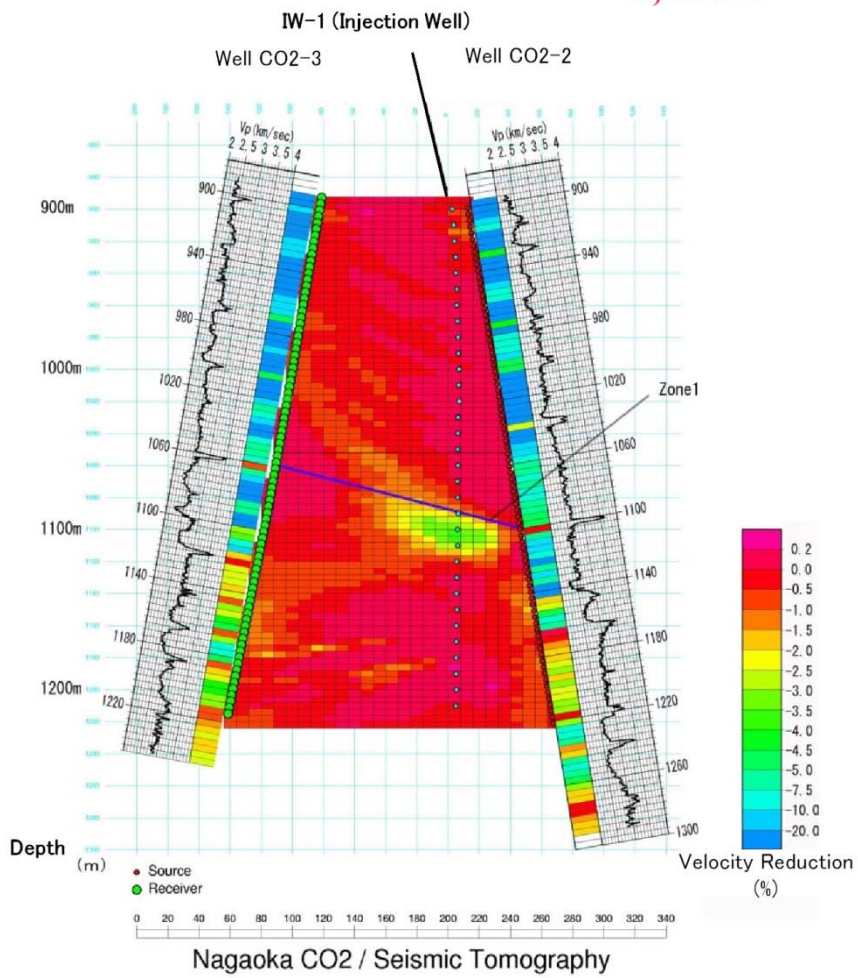


（Feb. 2003 :BLS）



（Nov. 2004 :MS3）

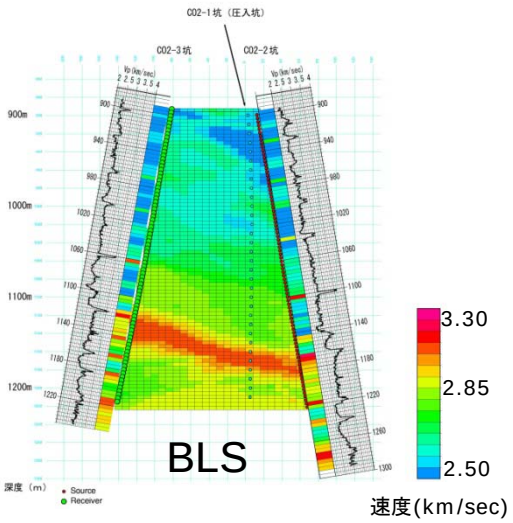
8,900 t

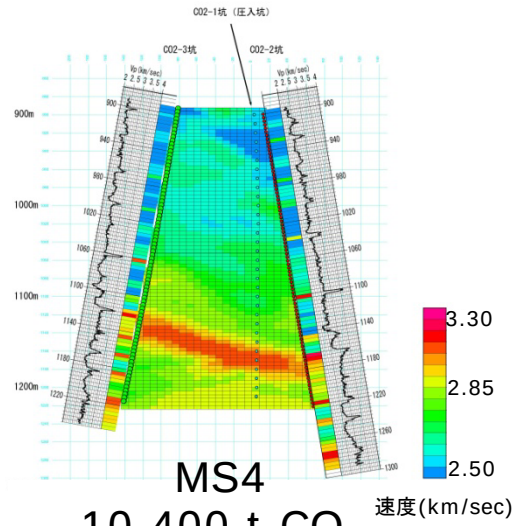


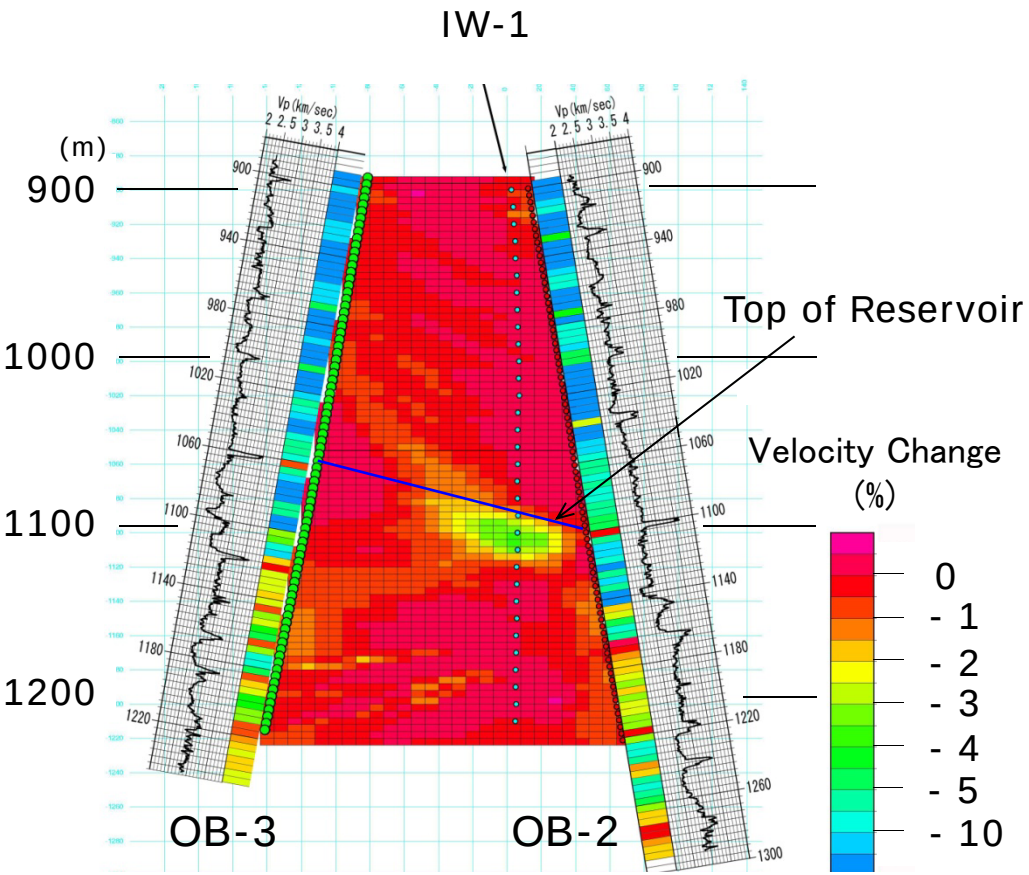
Max: －3. 5%

Time –lapse seismic tomography

Post-Injection: 10,400 t-CO_2



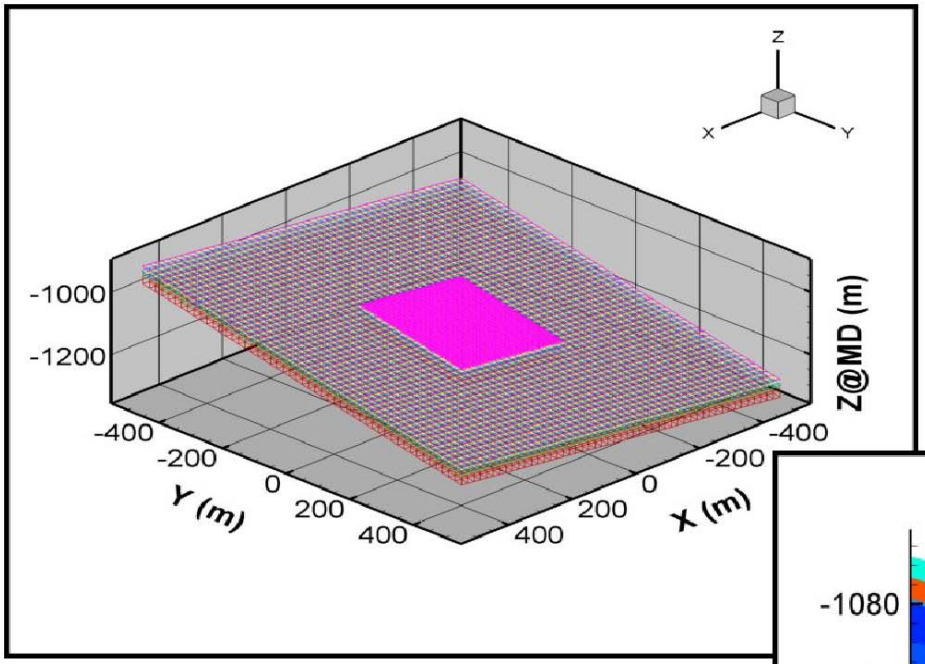




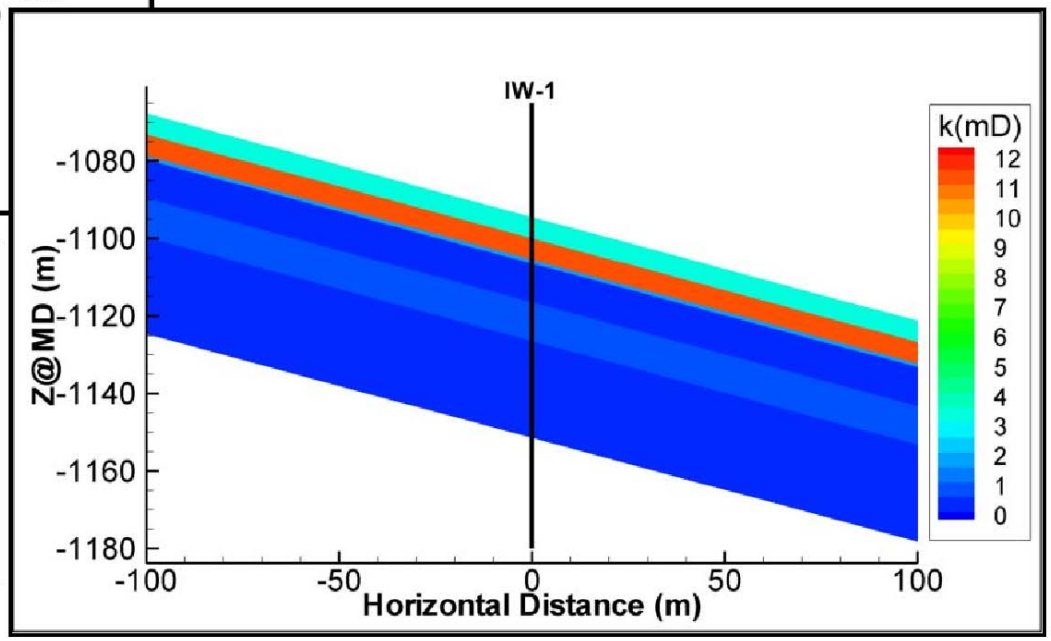
Max. Velocity Change= -3.5%

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



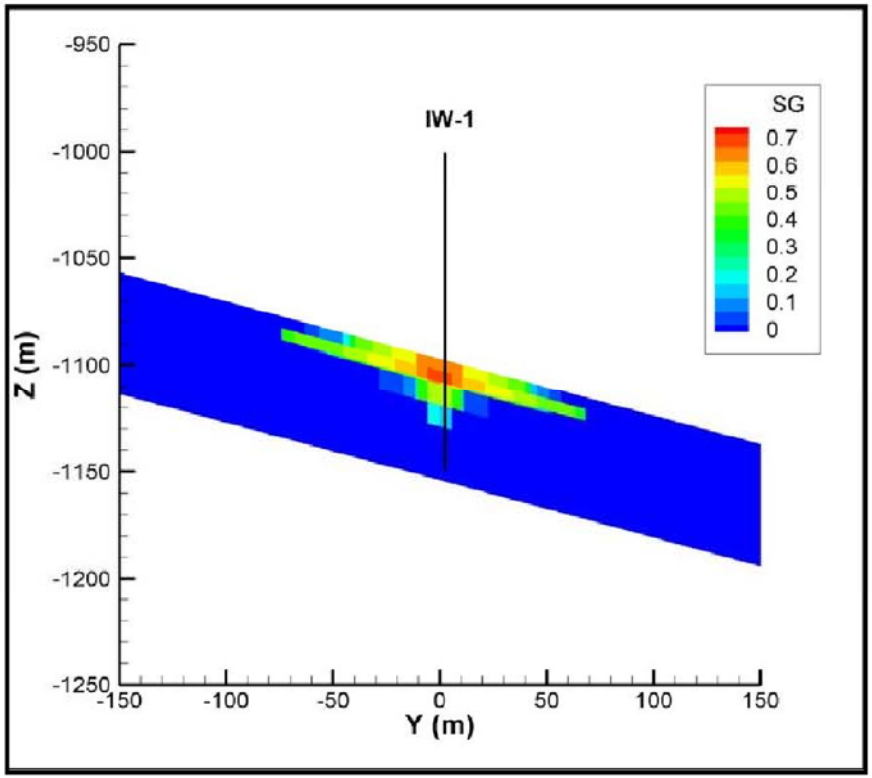
Layer	ϕ	Thick. (m)	Kh (mD)	kv/kh	β (1/Mpa)
Zone 2 U.	0.225	5.5	3.19	0.25	2.9×10^{-3}
Zone 2 M.	0.225	5.5	11.15	0.25	2.9×10^{-3}
Zone 2 L.	0.225	1.0	1.59	0.25	2.9×10^{-3}
Zone 3 U.	0.204	10.0	0.330	0.25	2.9×10^{-3}
Zone 3 L.	0.204	10.0	0.660	0.25	2.9×10^{-3}
Zone 4&5	0.234	25.0	0.460	0.25	2.9×10^{-3}

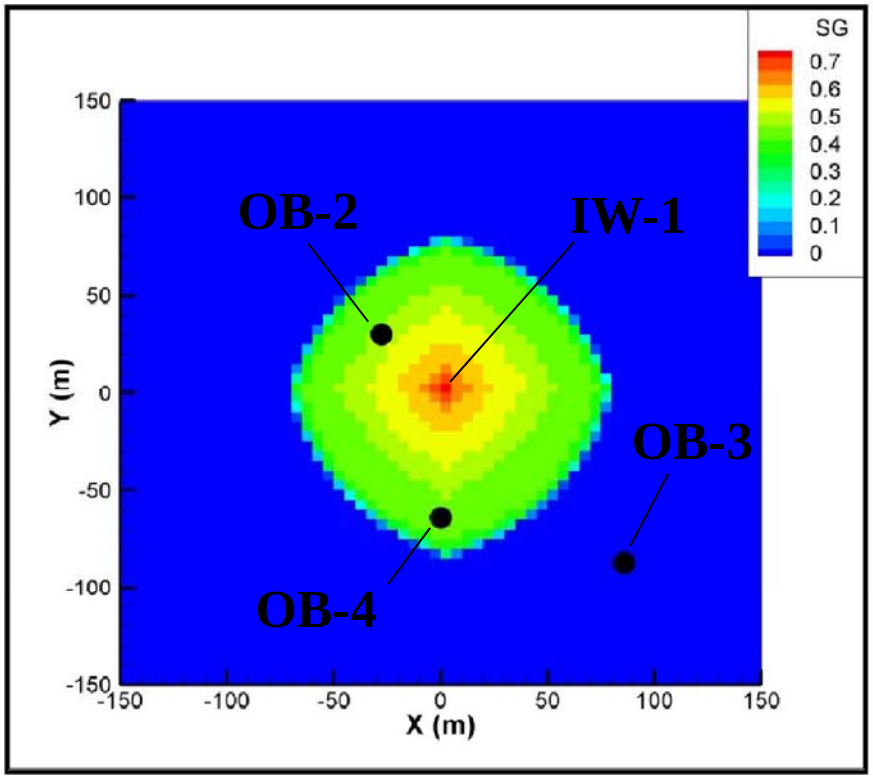
Ohkuma, H. (2008)

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

Results of Reservoir Simulation

CO2 Distribution at Terminating Injection



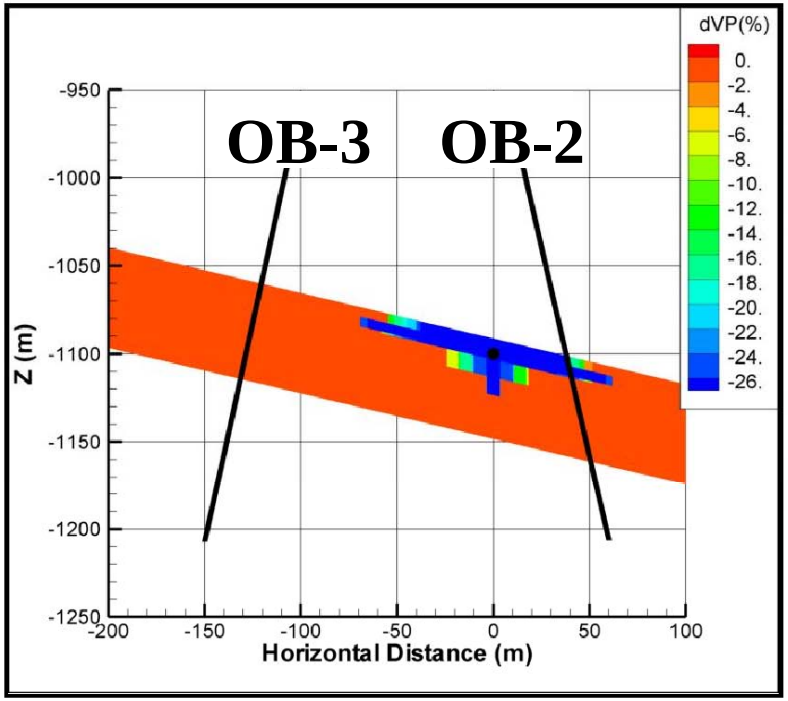


Distribution of Injected CO2

（Comparison Reservoir simulation and Tomography）

Simulation Results

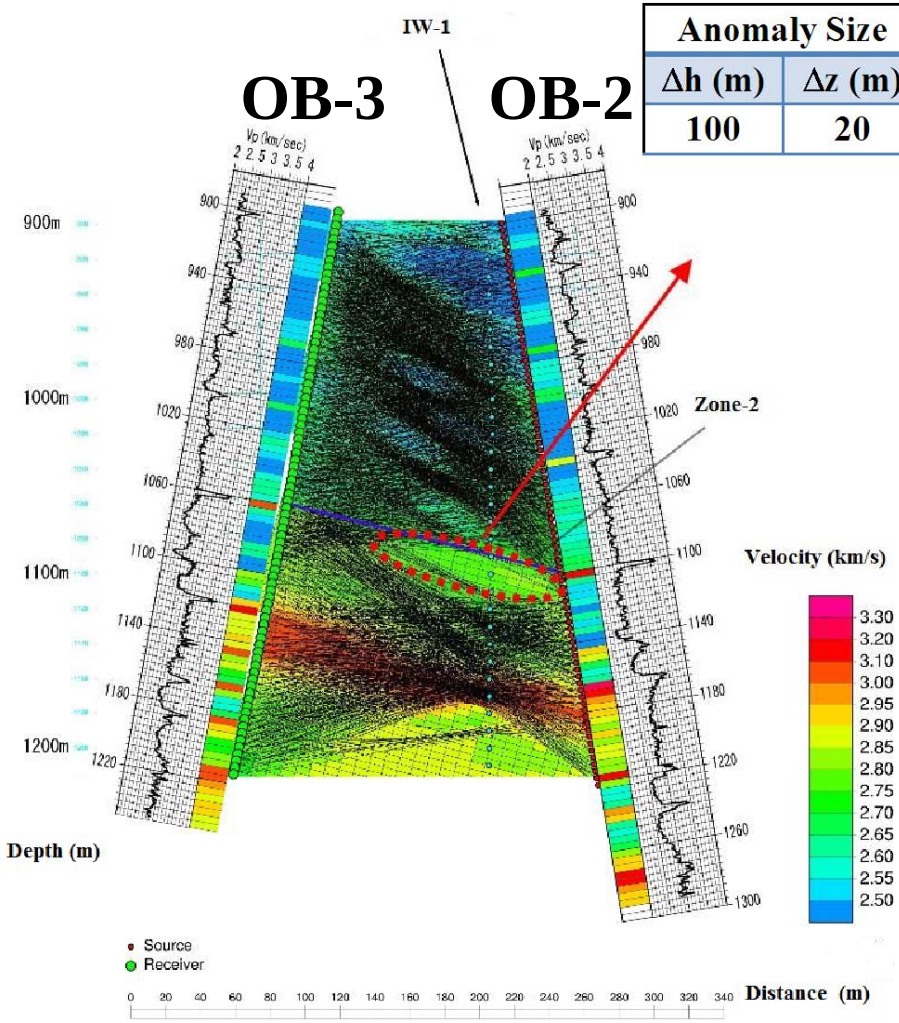
Anomaly Size	
Δh (m)	Δz (m)
105	22



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**

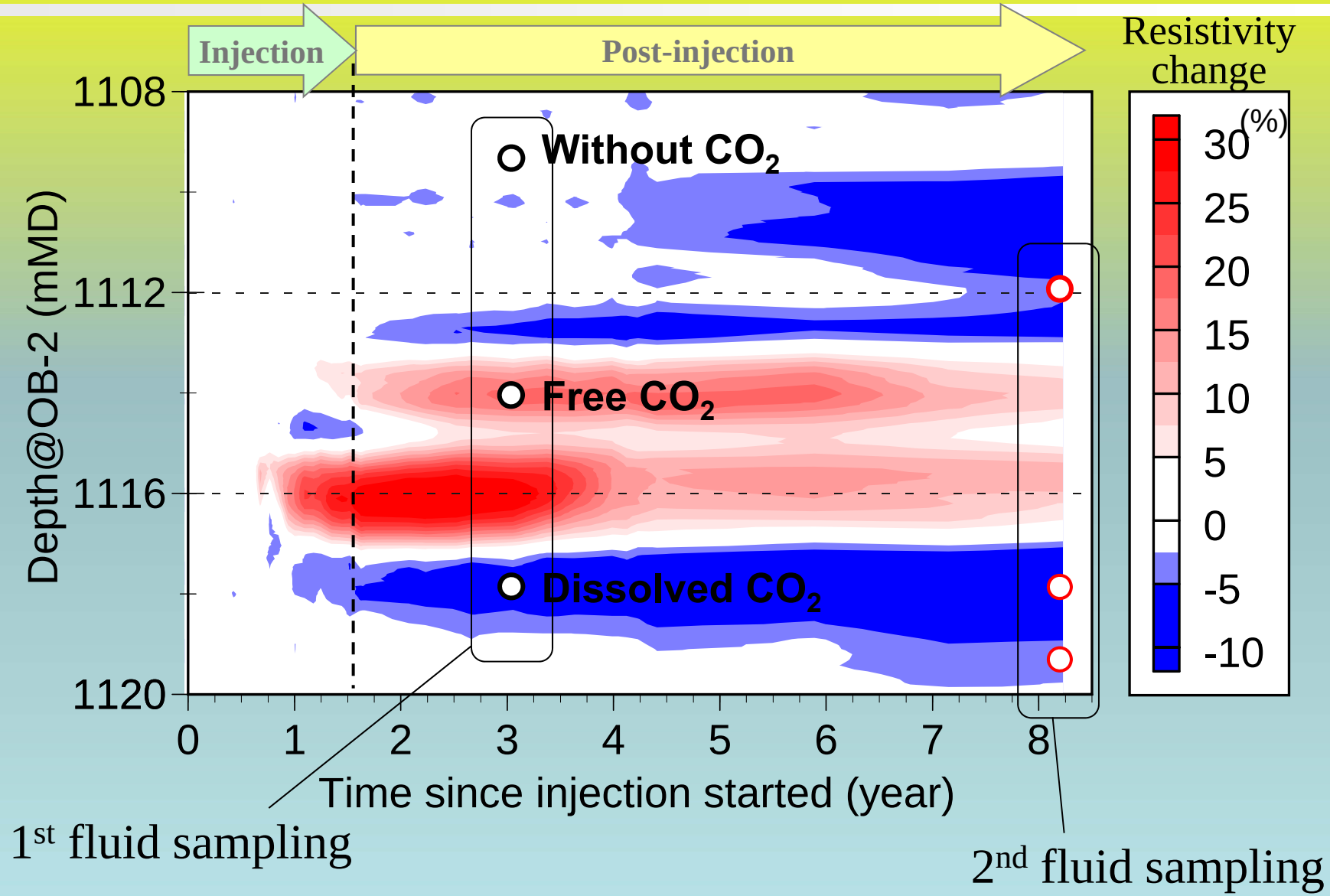
Evolution of Reservoir Model

CHDT*(Cased Hole Dynamic Tester)

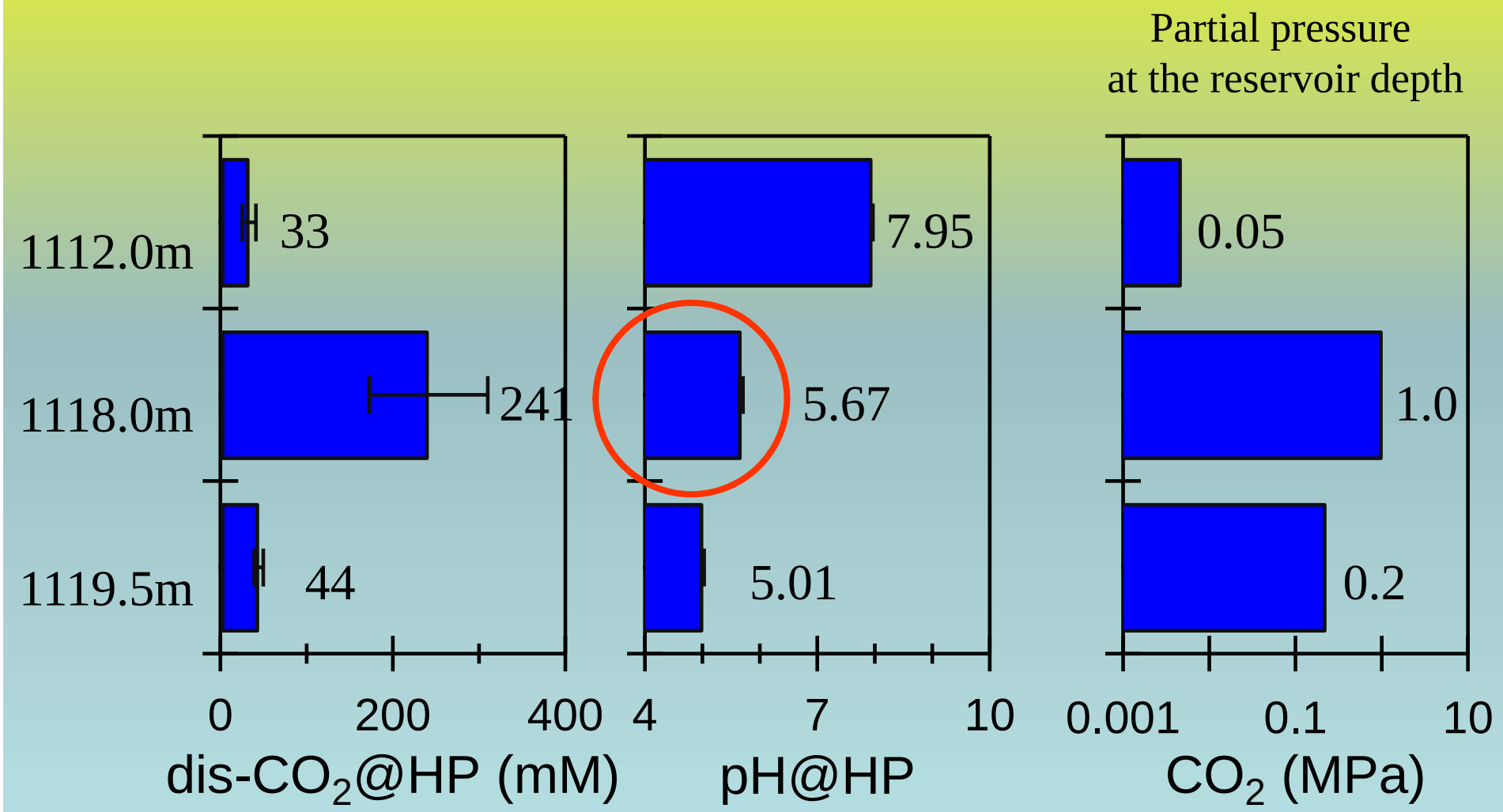
Drill

Fluid sampling from reservoir ➔➔➔ Geochemical Reactions

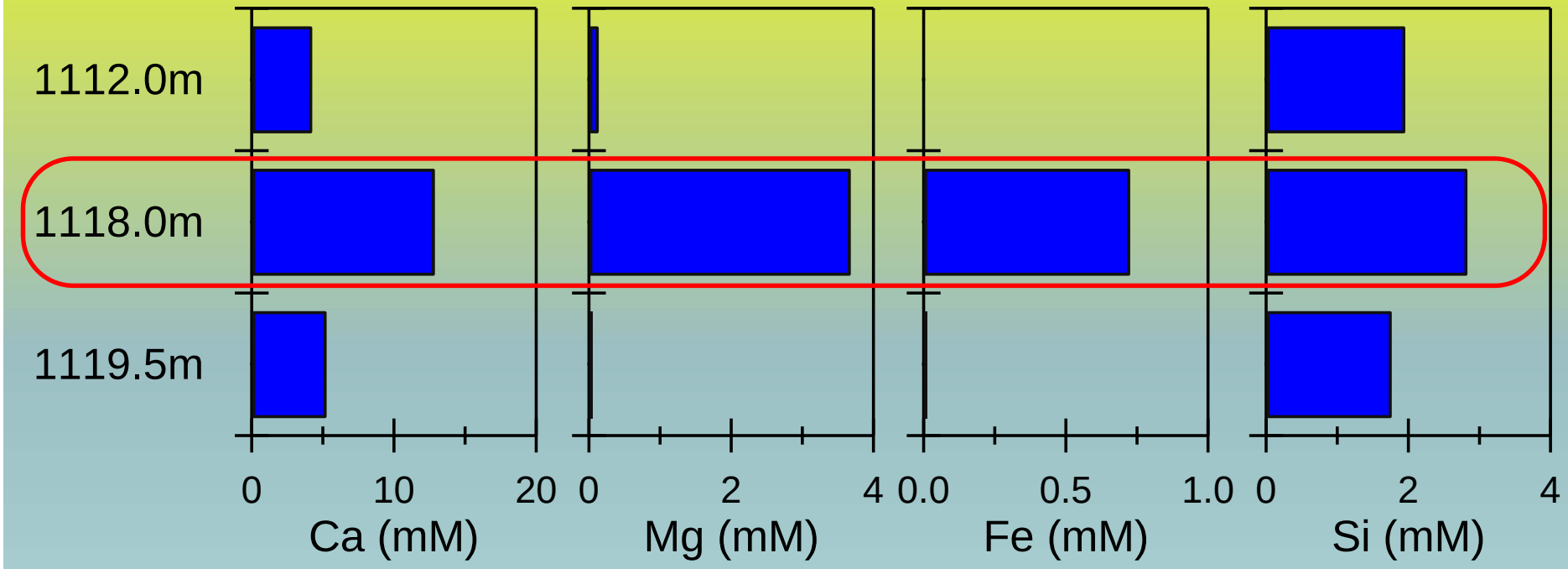
Formation Fluid Sampling at OB-2



Successful measurement of dis-CO_2 & pH under in-situ pressure condition



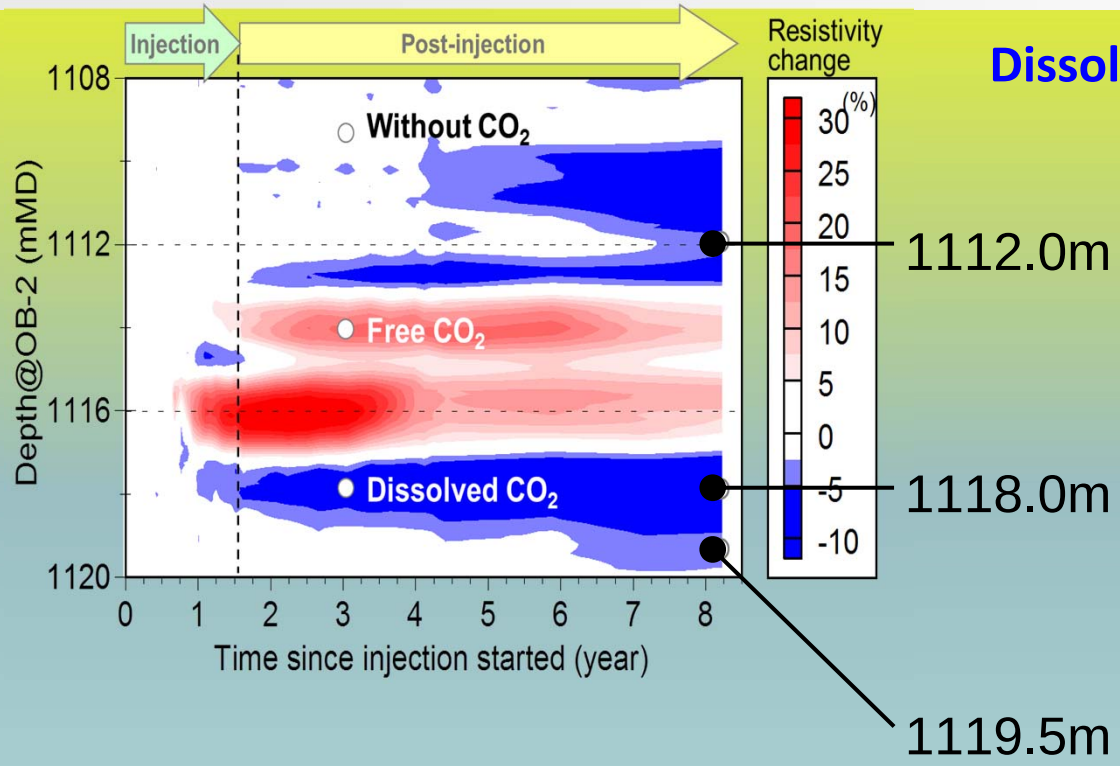
Dissolution of Minerals

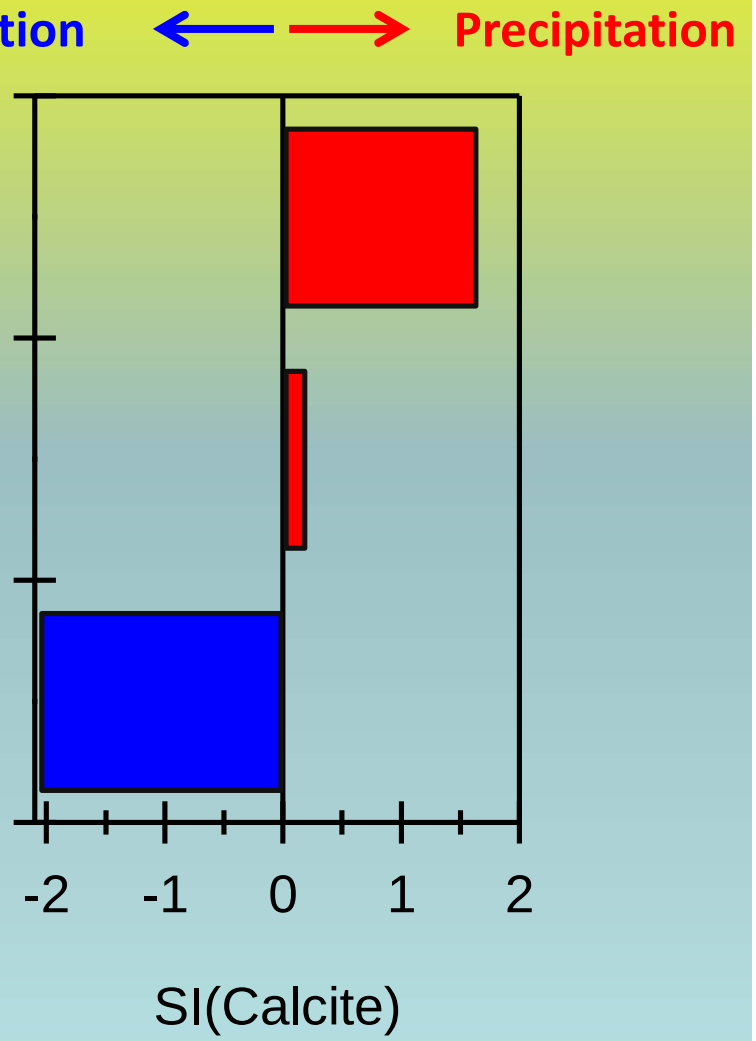


Concentrations of Ca, Mg, Fe and Si in fluid sampled at 1118.0m are much higher than other two depths.

→ ***Neutralization of pH by mineral dissolution***

Saturation Index (SI) of Calcite ($CaCO_3$)





Calcite shows a tendency of re-precipitate at 1118.0m.

→ ***Mineral trapping of CO2?***

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

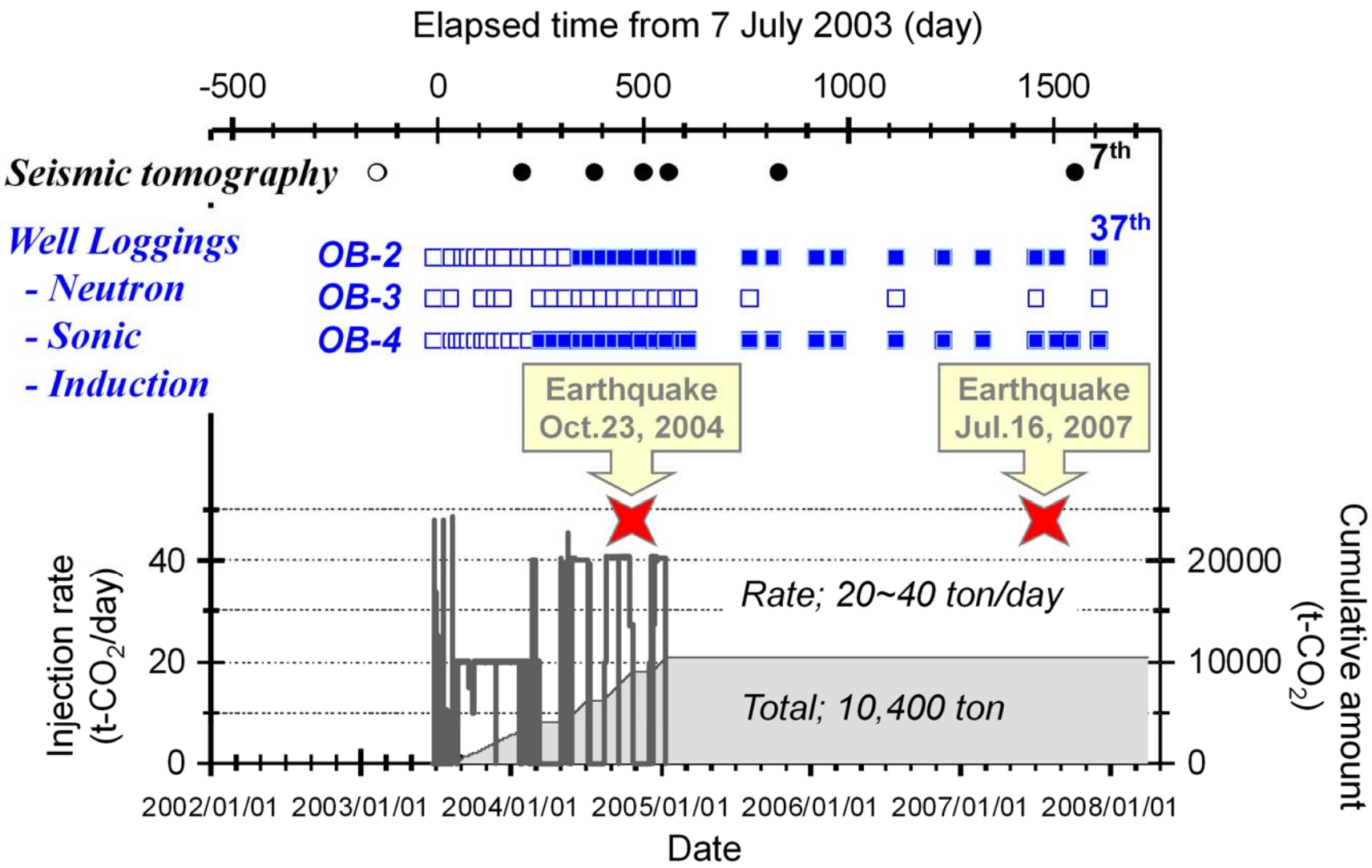
2005.1

(10 years)

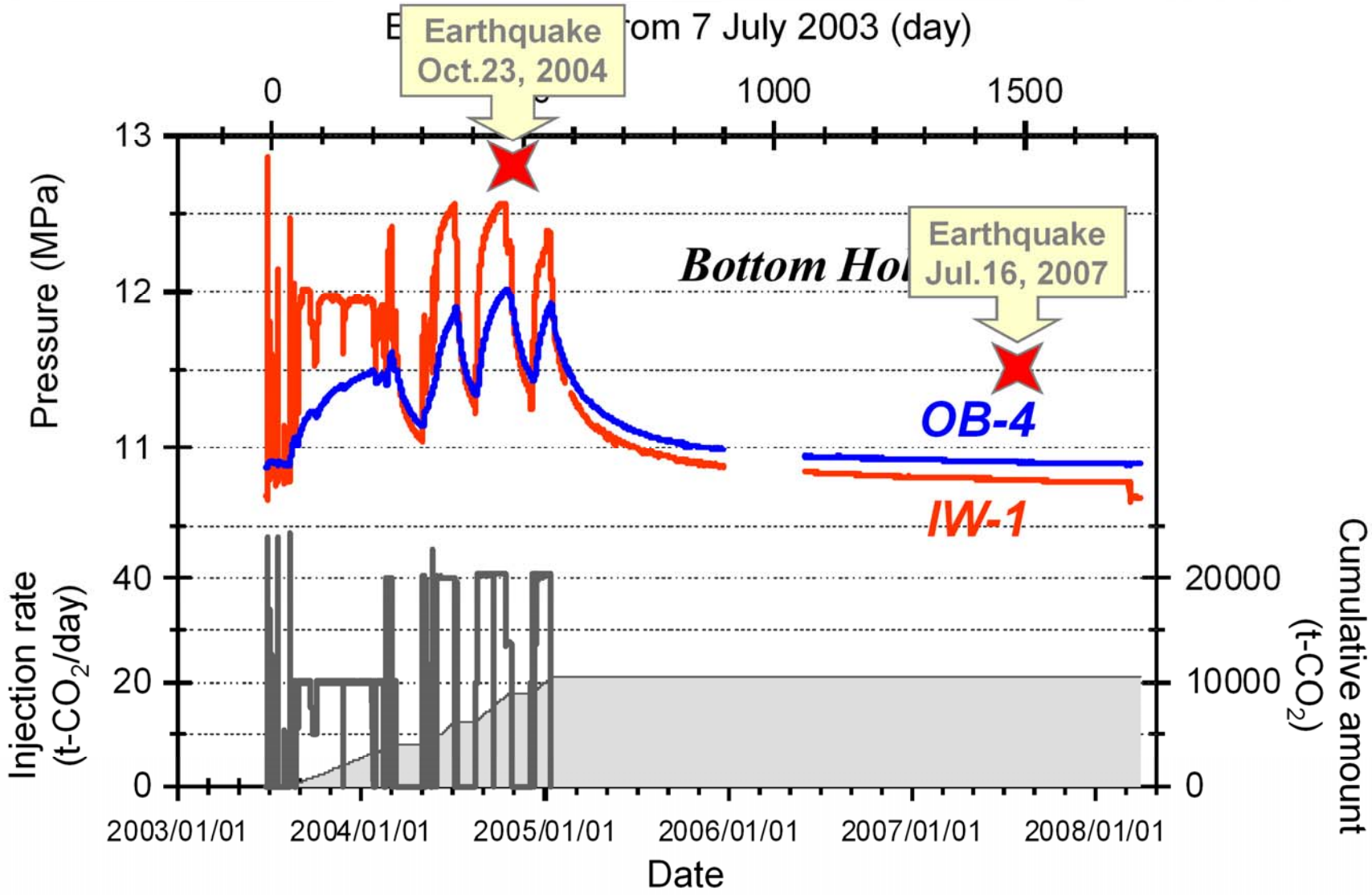
2015.3

The First Case on Post-Injection Monitoring

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



Changes in Bottom Hole Pressure



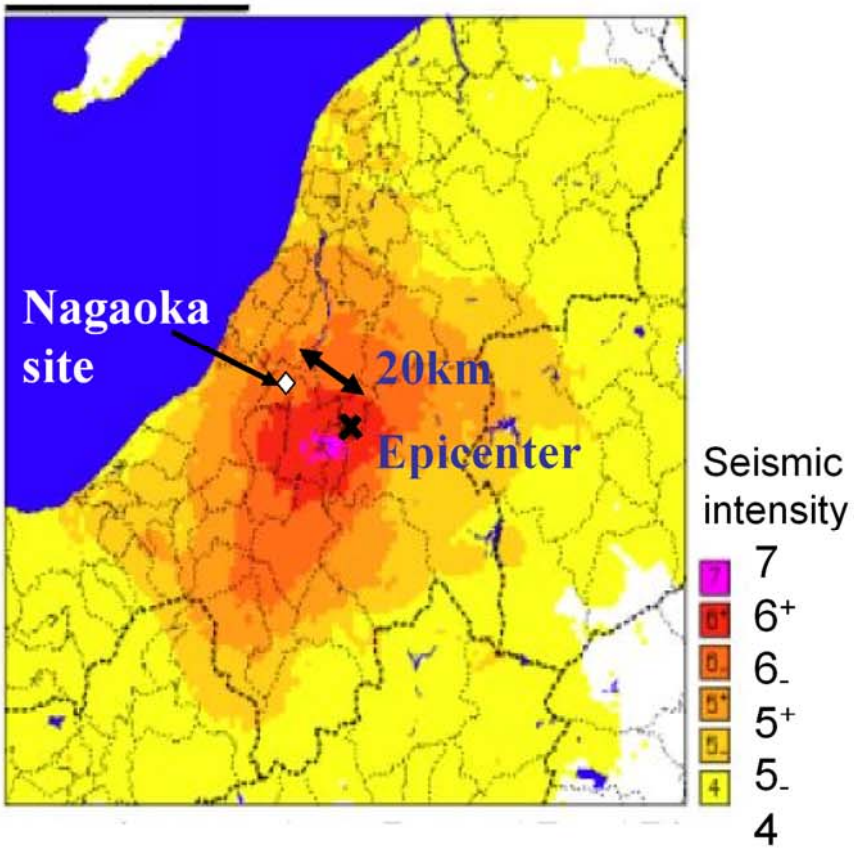
The Mid Niigata Prefecture Earthquake in 2004

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)

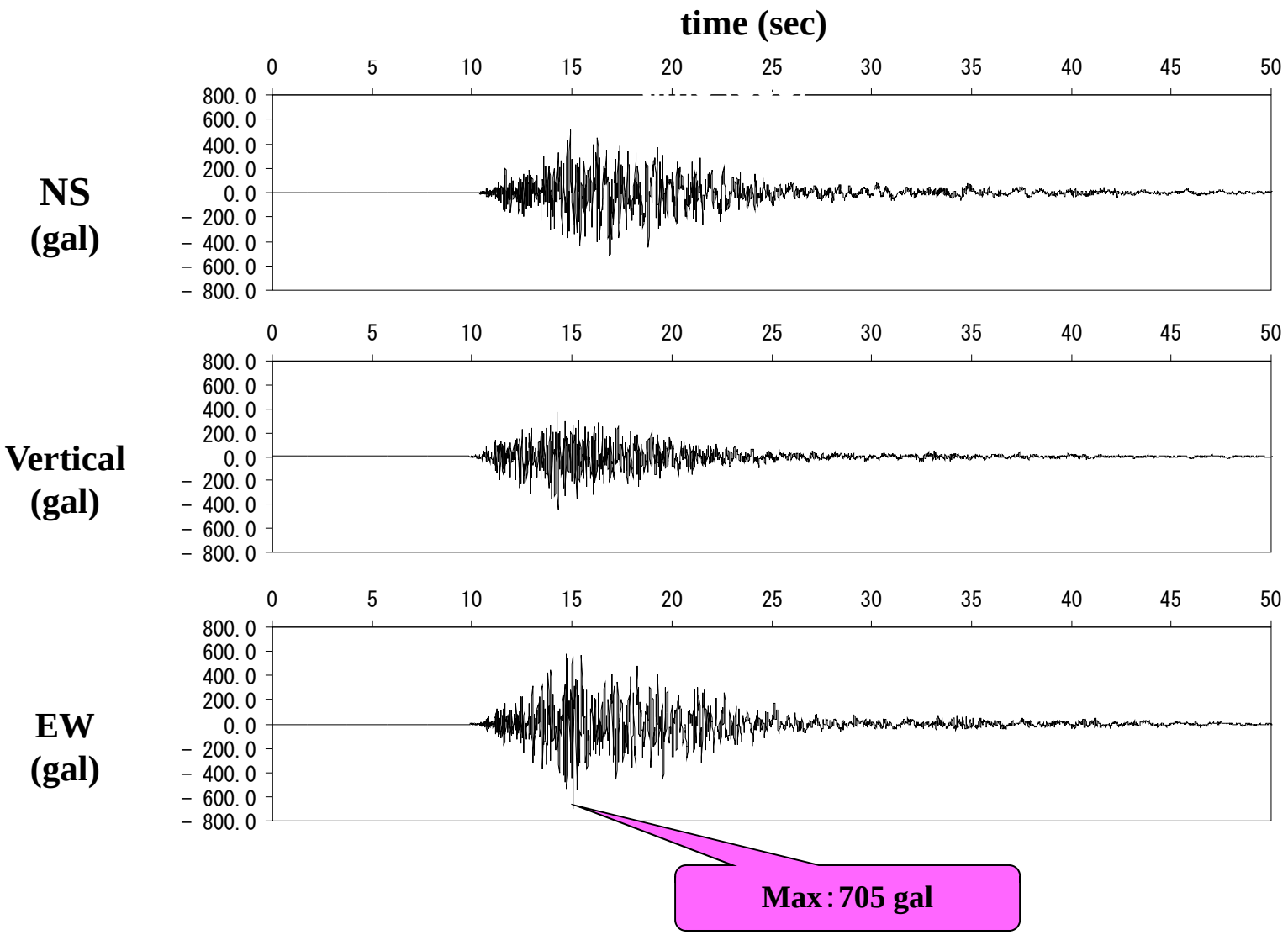
Injection was carefully resumed after confirming safety (6 Dec 2004)
injection rate: 40t-CO_2/day



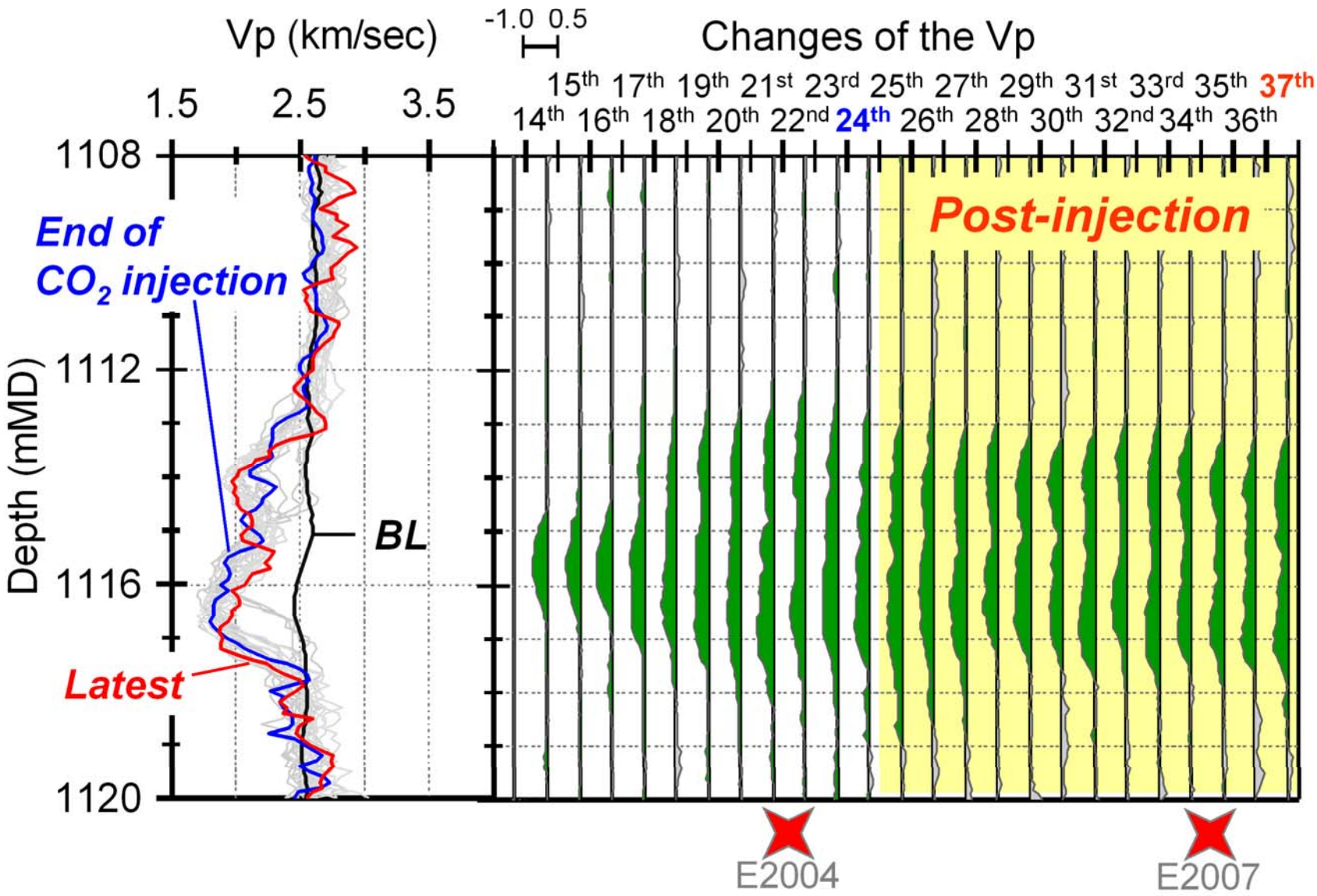
(GSJ, 2004 http://www.gsj.jp/jishin/chuetsu_1023/)

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

Main Shock:　2004/10/23 17:56 M6.8

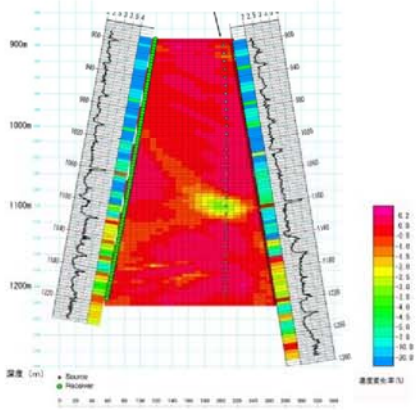


Sonic Logging (Vp) @ OB-2

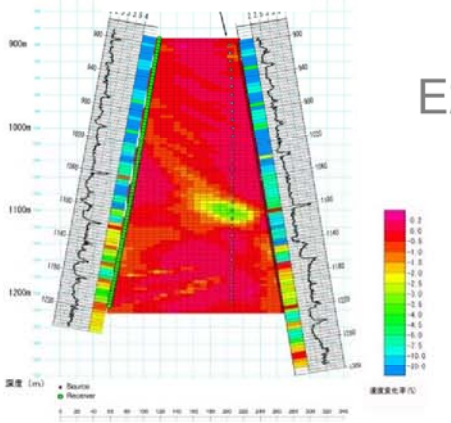


Results of Crosswell Seismic Tomography

MS1/BL
3,200t

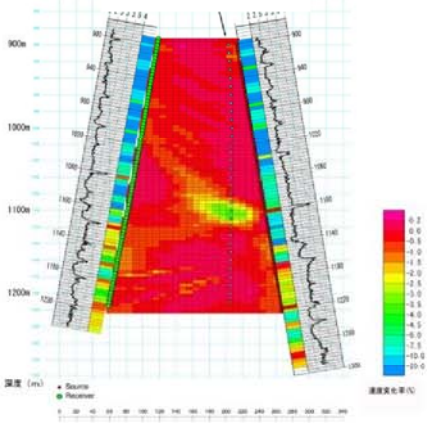


MS2/BL
6,200t

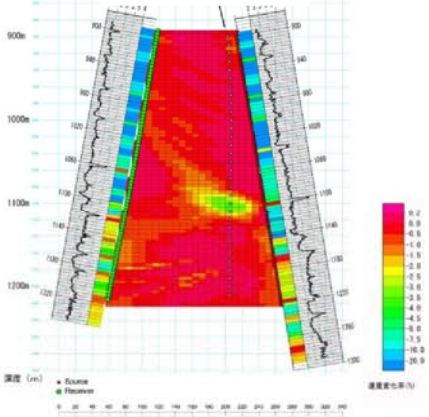


E2004

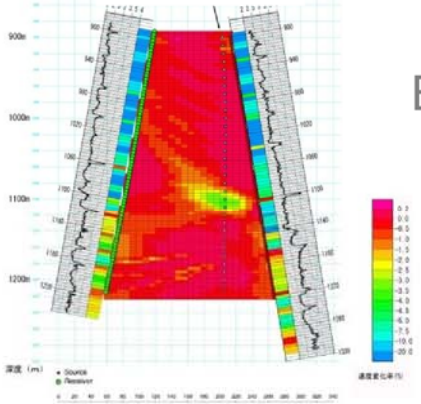
MS3/BL
8,900t



MS4/BL
10,400t

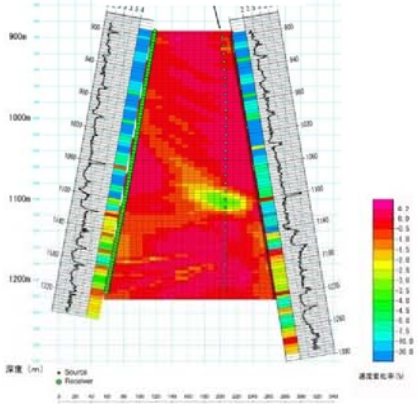


MS5/BL
10,400t



E2007

MS6/BL
10,400t



➢Pilot scale, Large scale, Commercial scale (1)

- **CO_2 plume size**

  （the reservoir scale vs CO_2 plume size, reservoir heterogeneity, permeability anisotropy）

- **formation pressure buildup**

  （fracture pressure, micro-seismicity, geo-mechanical deformation, controlled injection）

➔➔ *Alarm system according to magnitude and number of microseismic events.*

➢Pilot scale, Large scale, Commercial scale (2)

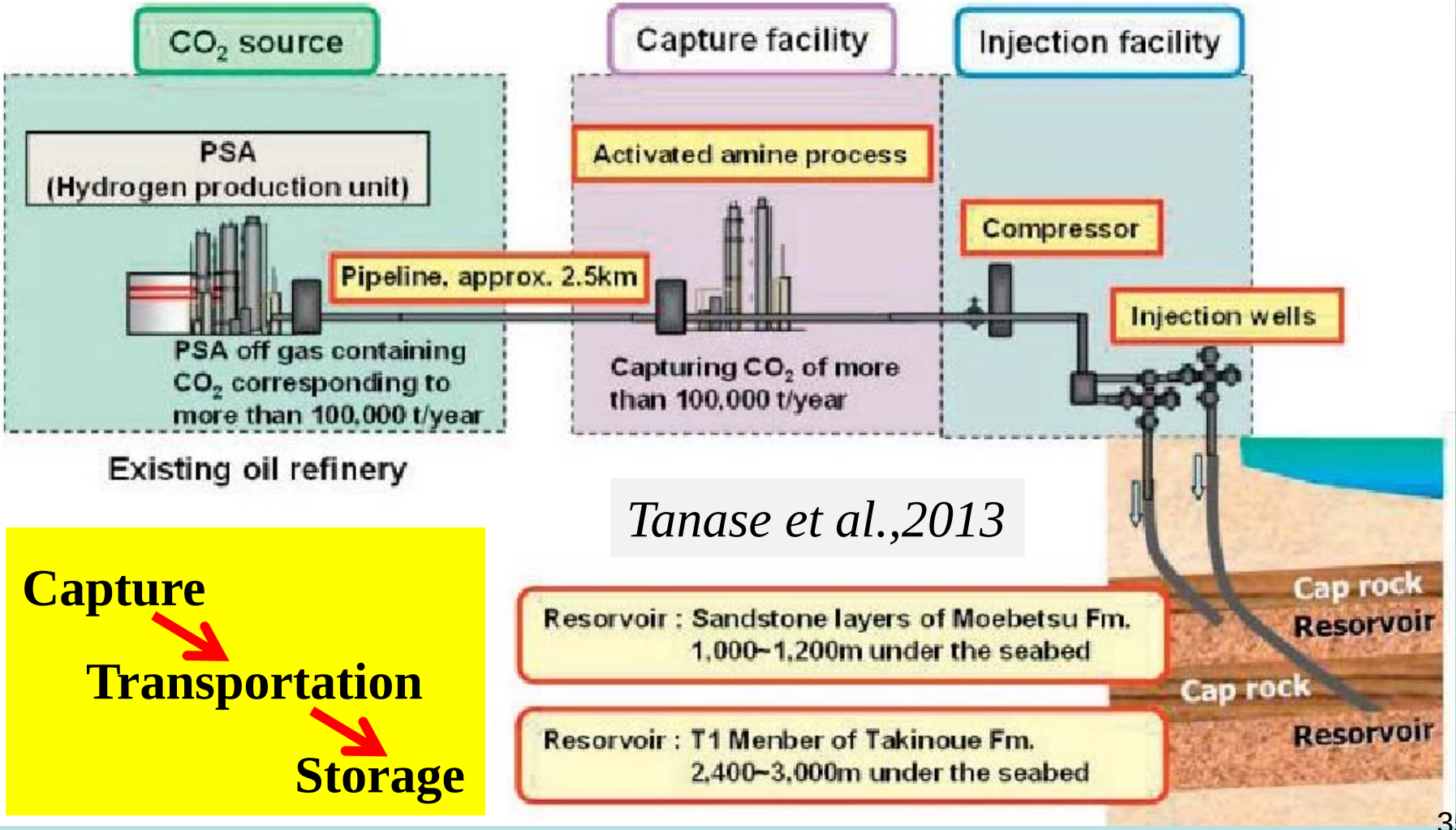
- **CO_2 trap mechanism**
  （field or lab data of residual CO_2 saturation, CO_2 dissolution, geo-chemical reaction）

- **technical feasibility of CO_2 monitoring**
  （geo-physical and -chemical monitoring, quantitative evaluation of CO_2）

➔➔ ***Same technology but Different geology, Different interpretation.*** ***No Silver Bullet!***

Large-scale Demonstration: 2012 -

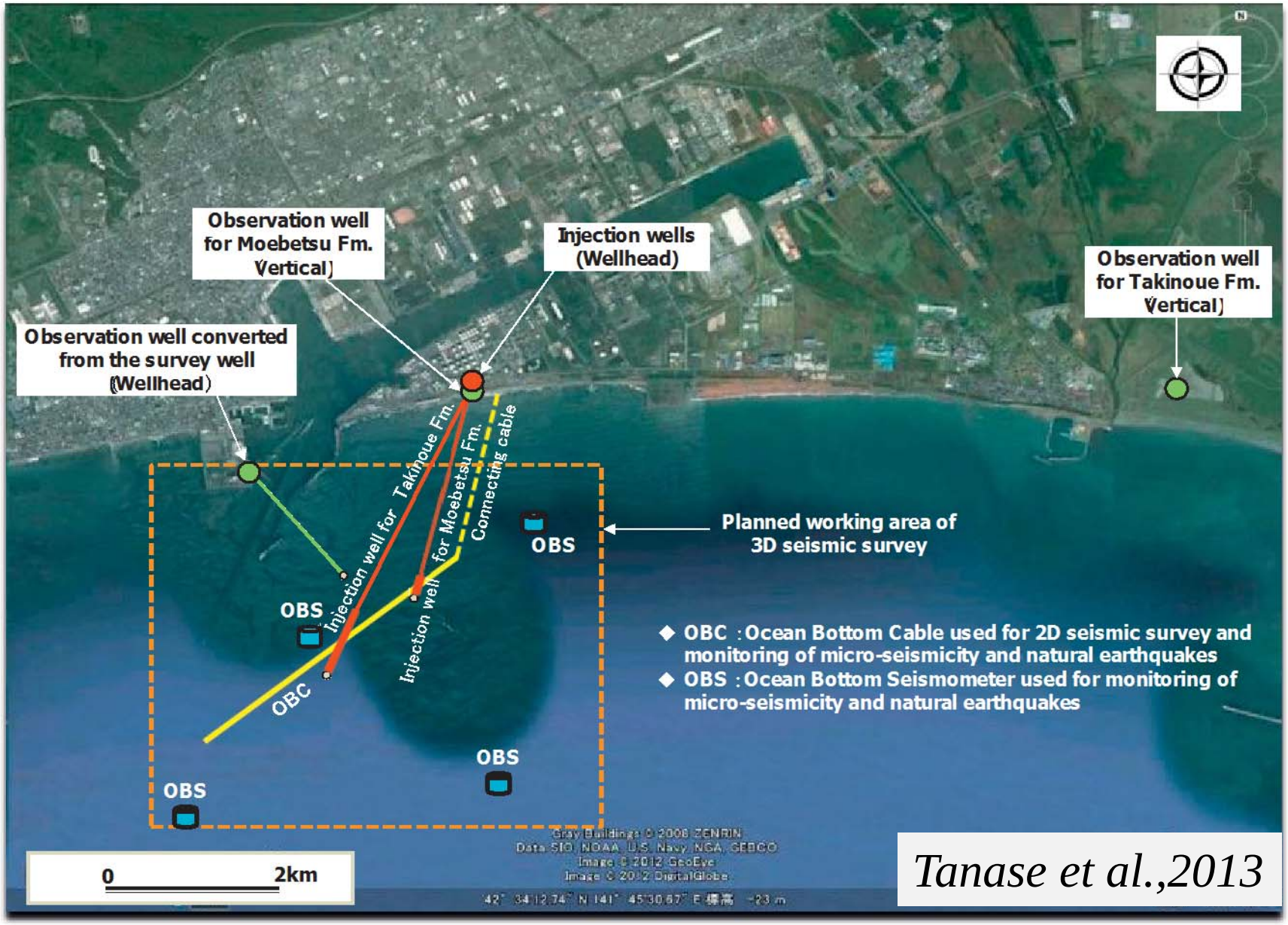
Offshore Tomakomai



Tanase et al.,2013

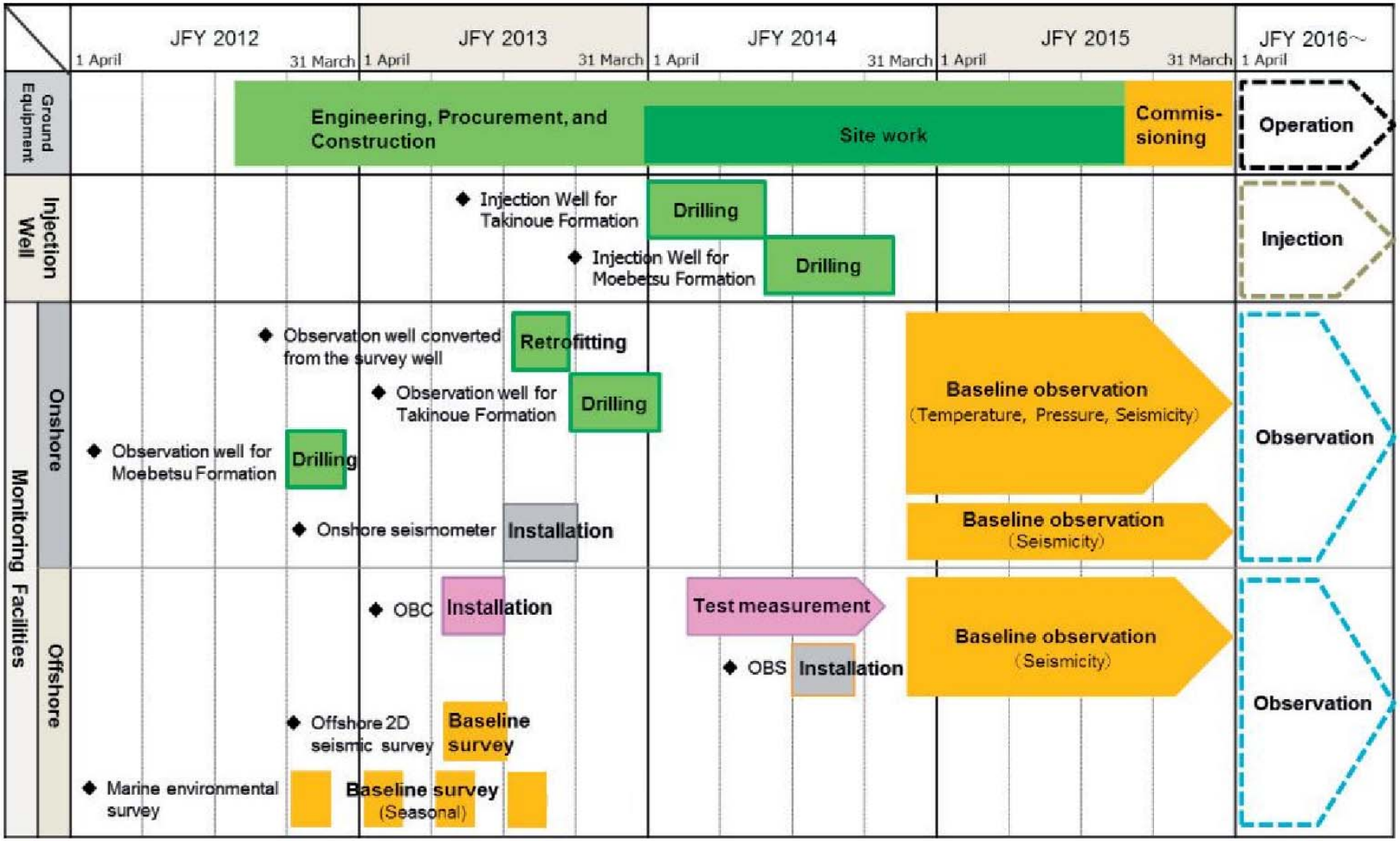
Capture
Transportation
Storage

Overview of the Tomakomai Project



Tanase et al.,2013

Time Schedule for the Tomakomai Project



Tanase et al.,2013

ACKNOWLEDGEMENTS

- This project is funded by Ministry of Economy, Trade and Industry (METI) of Japan under the research contract "Development of Safety Assessment Technology for Carbone Dioxide Capture and Storage".

- We thank staff of ENAA, Teikoku Oil Co.(INPEX), Geophysical Surveying Co. OYO Co., and RITE involved in Nagaoka pilot CO_2 injection project.