RITE CCS Workshop, 15 Feb. 2007

地中貯留におけるCO_2挙動モニタリングについて
― 長岡実証試験サイトの実例紹介 ―

Geophysical Monitoring of CO_2 Sequestration in Saline Aquifers

-- Lessons from the Nagaoka pilot-scale project --

薛　自求 *(Xue@rite.or.jp)*

Research Institute of Innovative Technology for the Earth

財団法人　地球環境産業技術研究機構

Why CO_2 Monitoring ?

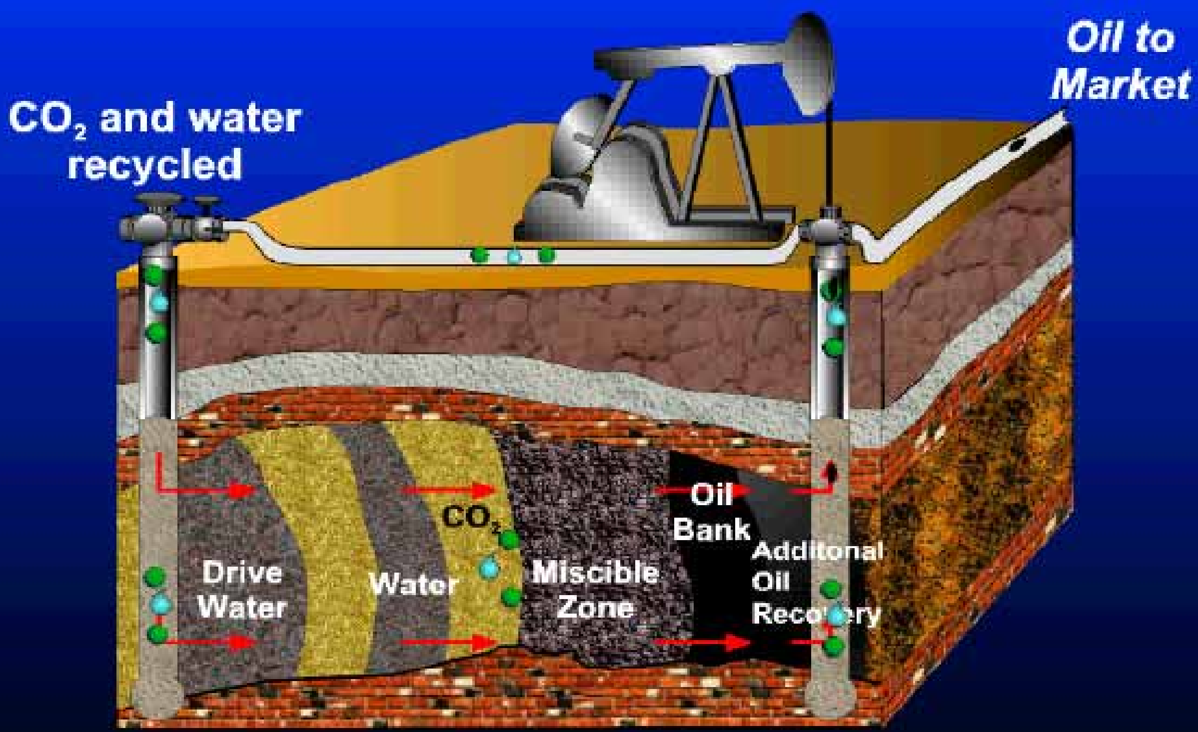
Map the movement of CO_2 & the CO_2 is being safely contained within the reservoir.

↓

CO_2 sequestration is a safe and verifiable mitigation technology option

Monitoring, Evaluation, Reporting and Verification (MERV)

Carbon Dioxide Flooding / CO_2-EOR



- 40-70% of CO_2 injected stays in reservoir

Examples from CO_2-EOR & CO_2 storage projects

Cross Well Seismic and Electromagnetic (EM)

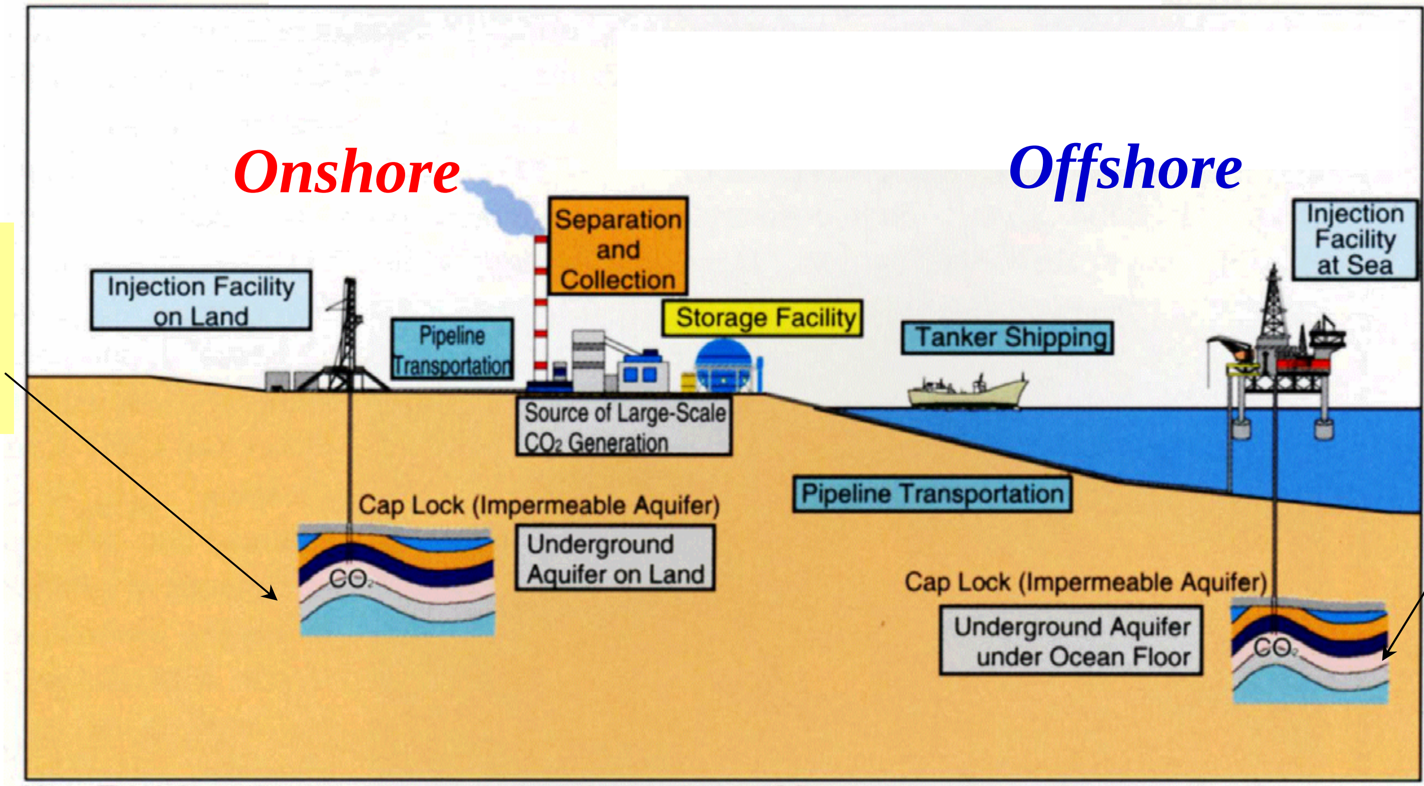
- McElroy oil field, West Texas, USA (Harris et al.,1995)
- Lost Hills oil field, South California, USA (Hoversten et al., 2003)

Time-lapse 3D Seismic Survey (4D Seismic)

- Weyburn oil field, South Saskatchewan, Canada (White, 2004)
- Sleipner, ***aquifer***, North Sea, Norway (Art et al., 2004)

Research & Commercial Projects of CO_2 Storage

Frio (1600 ton) 2 wells



Note: This information presents an overview of subterranean CO_2 storage at the application level, and is not intended to serve as a direct explanation of injection validation tests.

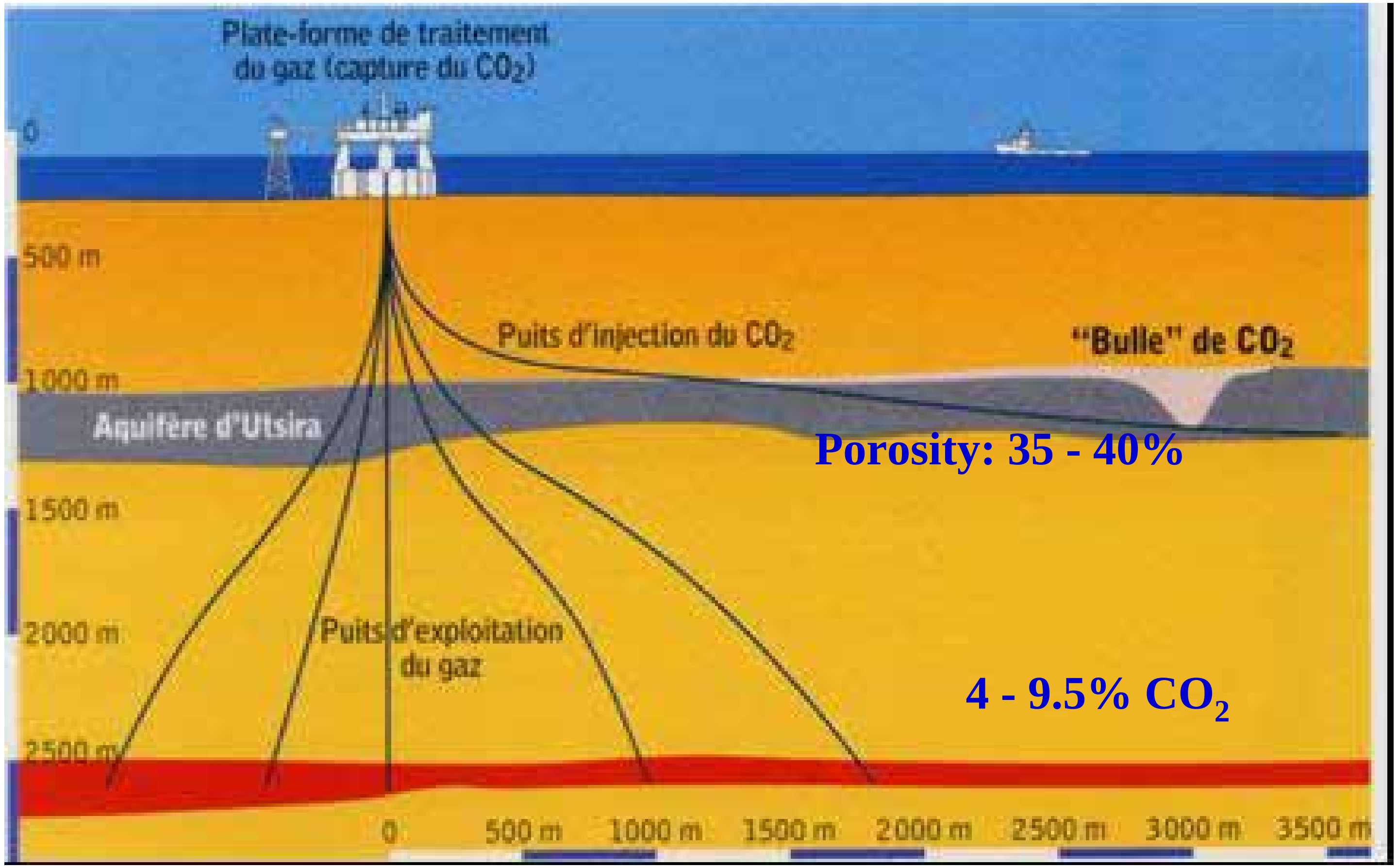
Sleipner Snovhit

Nagaoka, (10400 ton), 4 wells (one injection & three observation wells
A big research project of CO_2 storage at an onshore aquifer.

CO_2 Monitoring at Sleipner & Frio

SACS (Saline Aquifer CO_2 Storage)

North Sea, Norway (Statoil), Sleipner



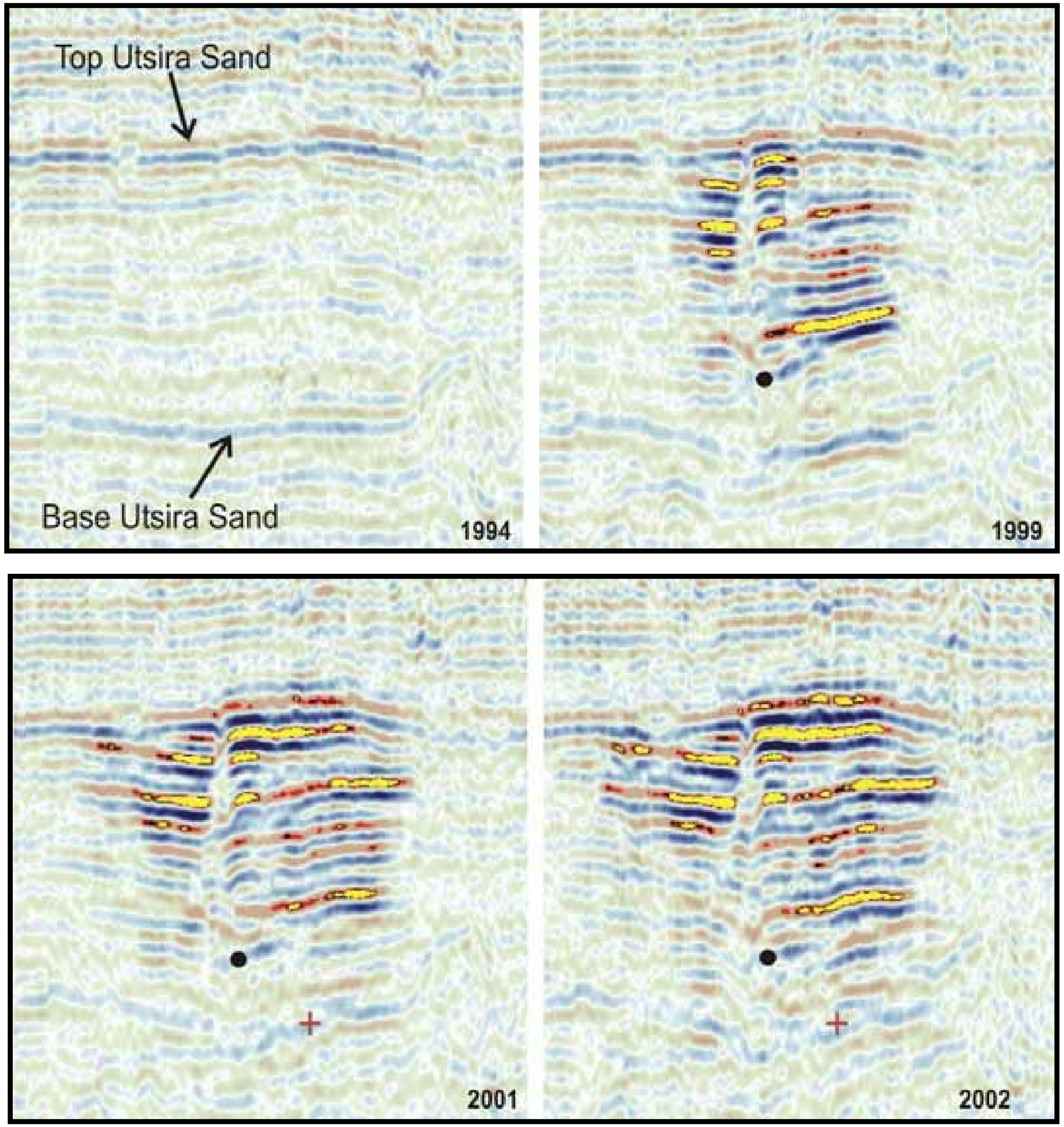
Porous Sand
(Net sand:80-100%)

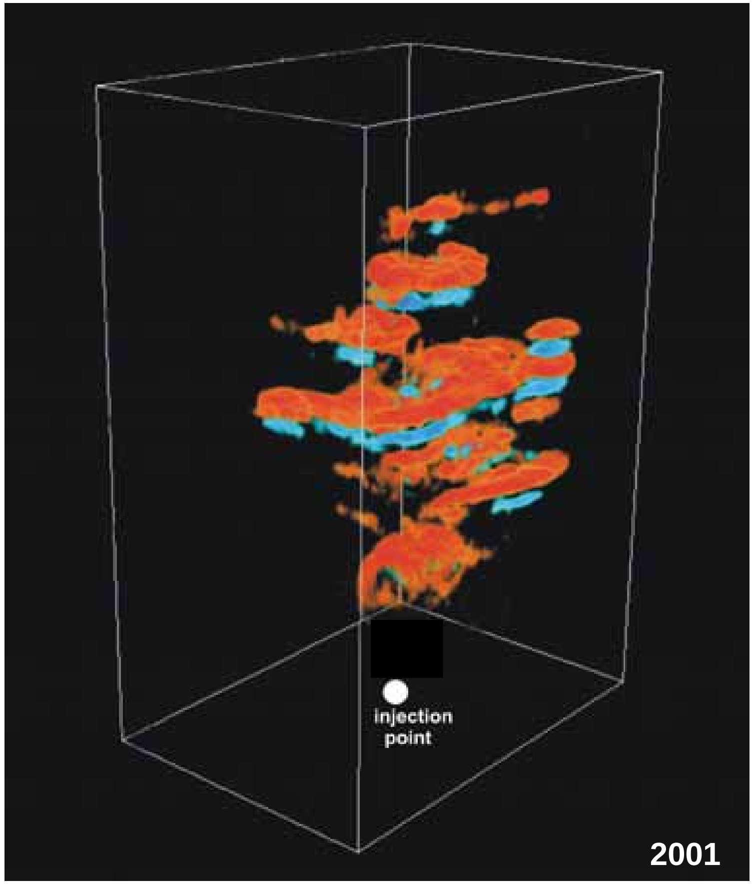
High Permeability
(1 - 3 darcy)

Temp: 37 °C
Pressure: 8 - 11MPa

1 million ton/year
(3% of Norway)

Seismic Survey at Sleipner

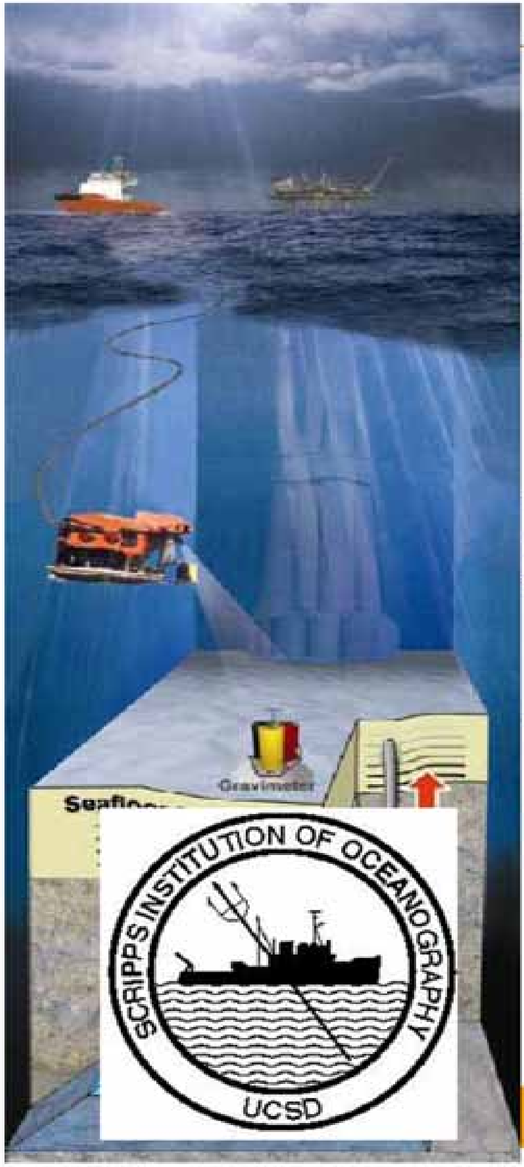




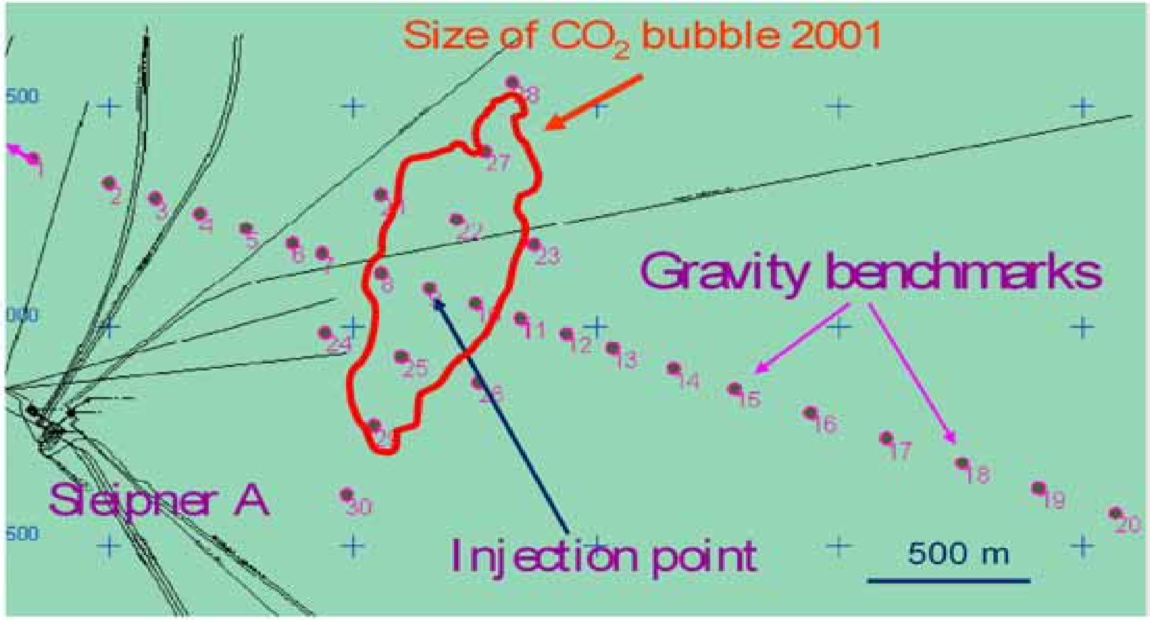
High reflectivity CO_2 plume

Chadwick (2004)

Microgravity Survey at Sleipner



Gravimetric monitoring



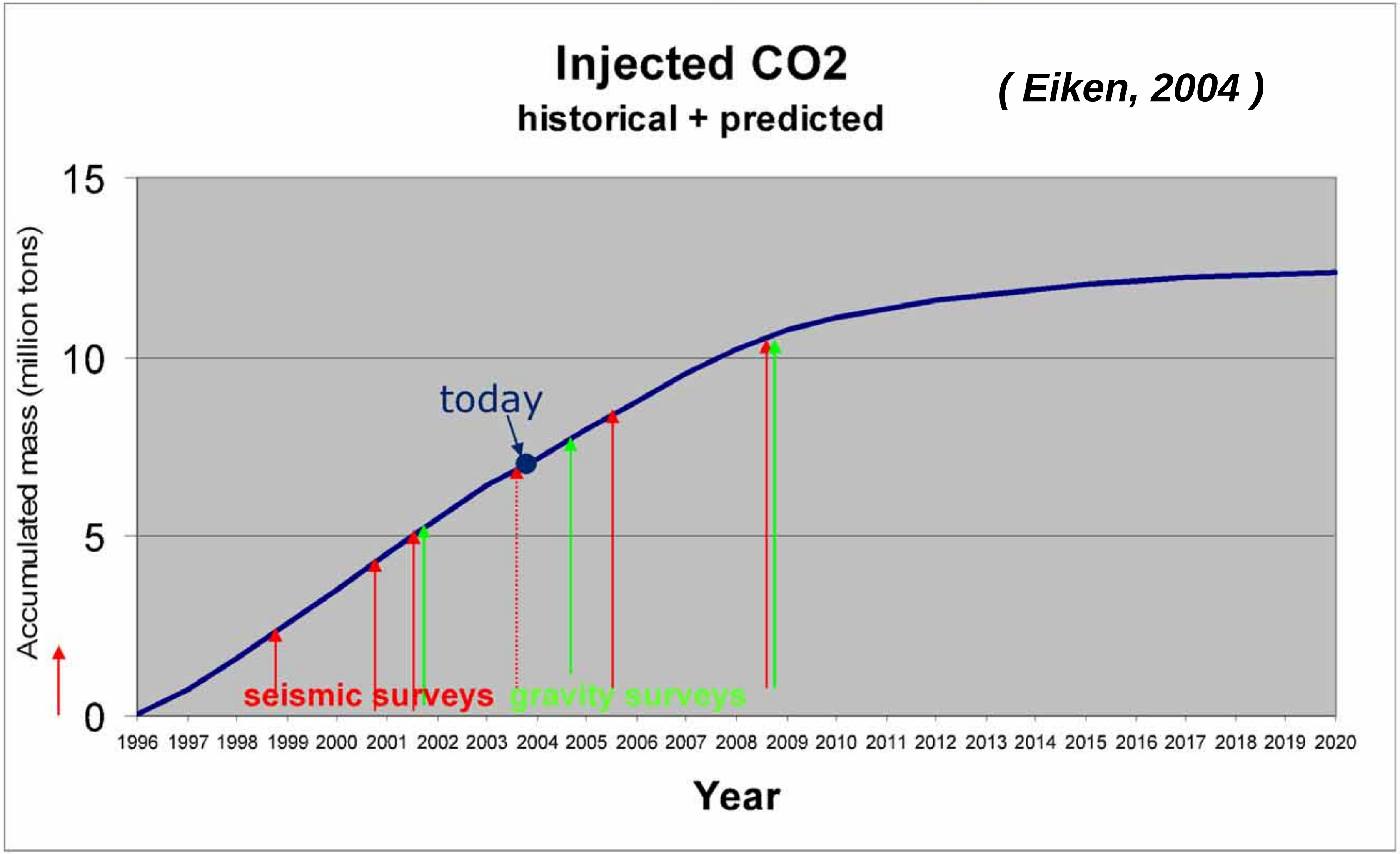
2002 base survey achievements:

- 3 Gal gravity repeatability (s.d.)
- 5 mm seafloor depth repeatability (s.d.)

Eiken, 2004

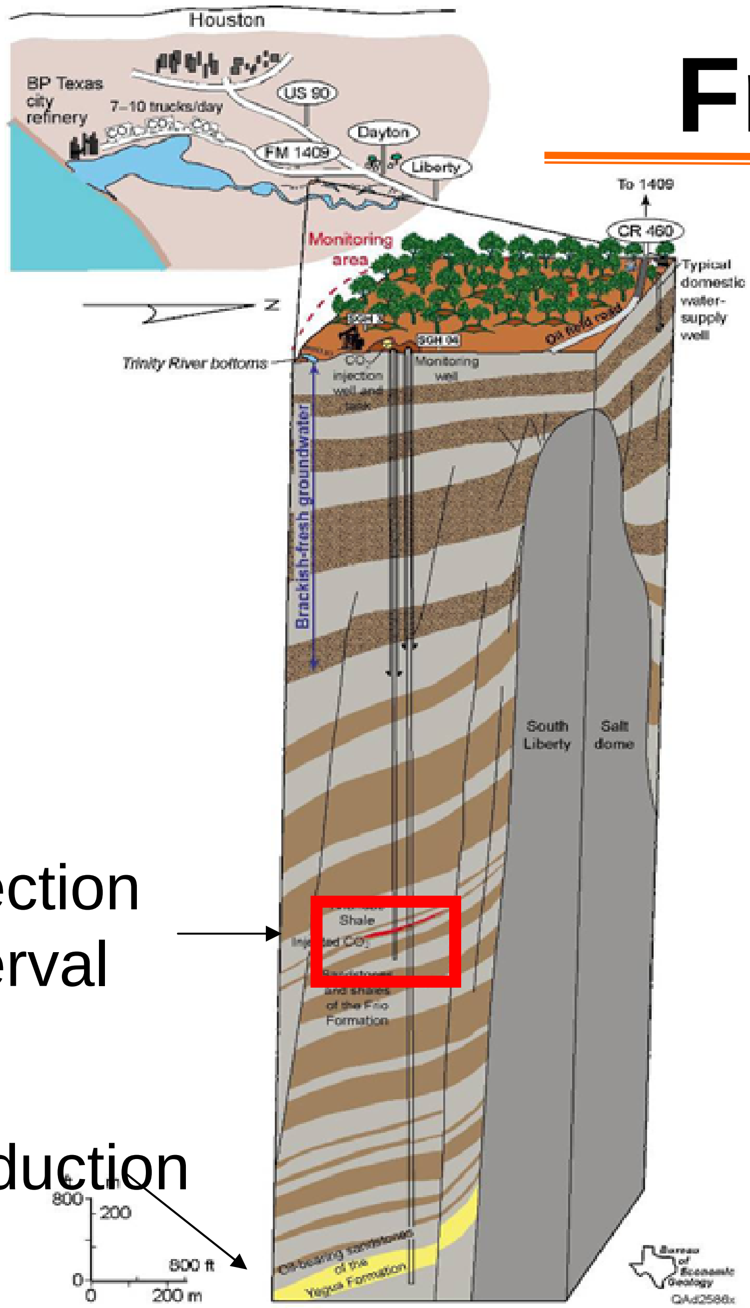
STATOIL

Accumulated CO_2 storage



Frio Brine Pilot Site

(Hovorka, 2006)



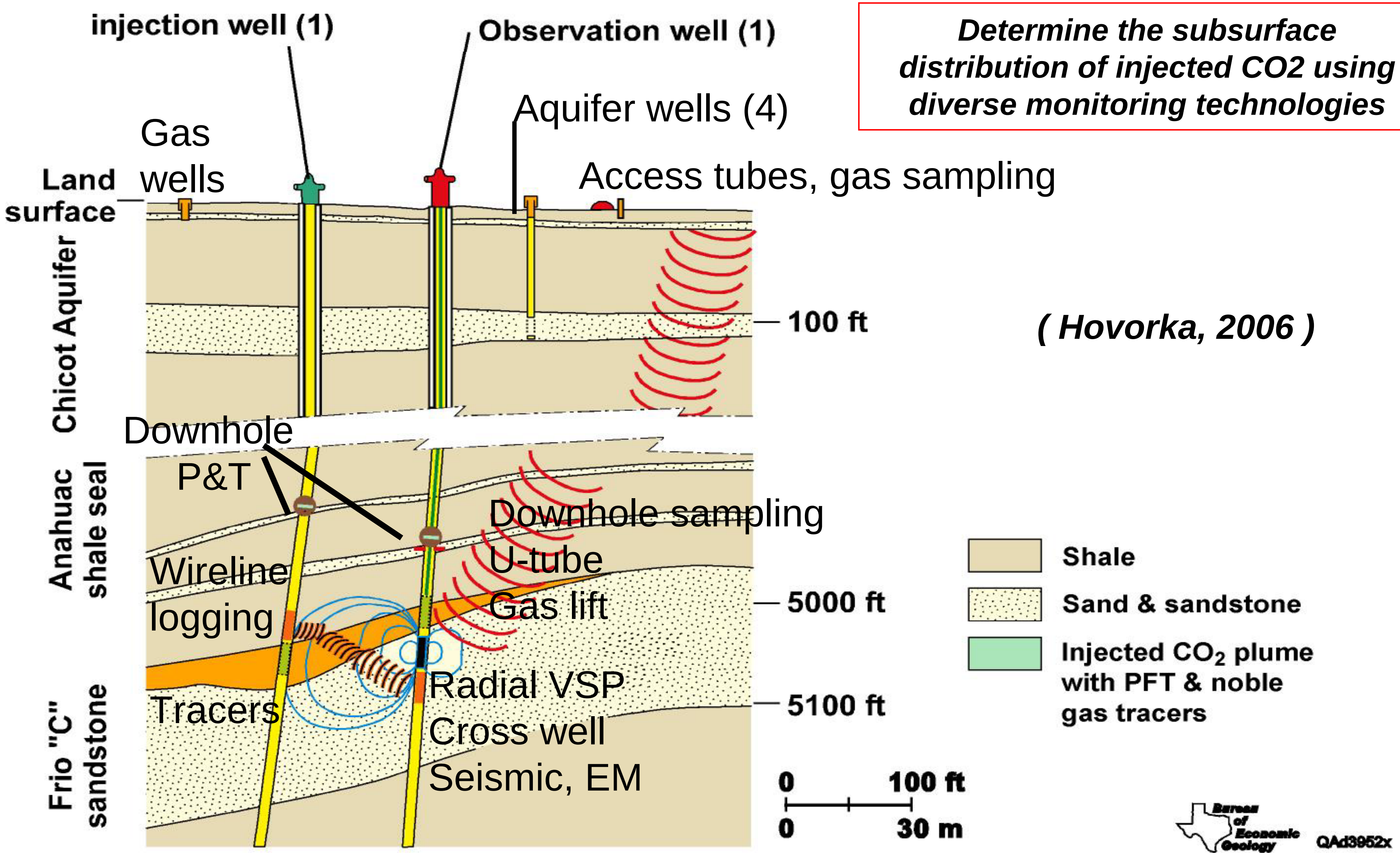
Injection interval

Oil production

- Injection interval: 24-m-thick, mineralogically complex Oligocene reworked fluvial sandstone, porosity 24%, Permeability **2.5 Darcys**
- Steeply dipping 18 degrees
- 7m perforated zone
- Seals – numerous thick shales, small fault block
- Depth **1,500 m**
- Brine-rock system, no hydrocarbons
- **150 bar, 53 degrees C**, supercritical CO_2

Monitoring at Frio Pilot

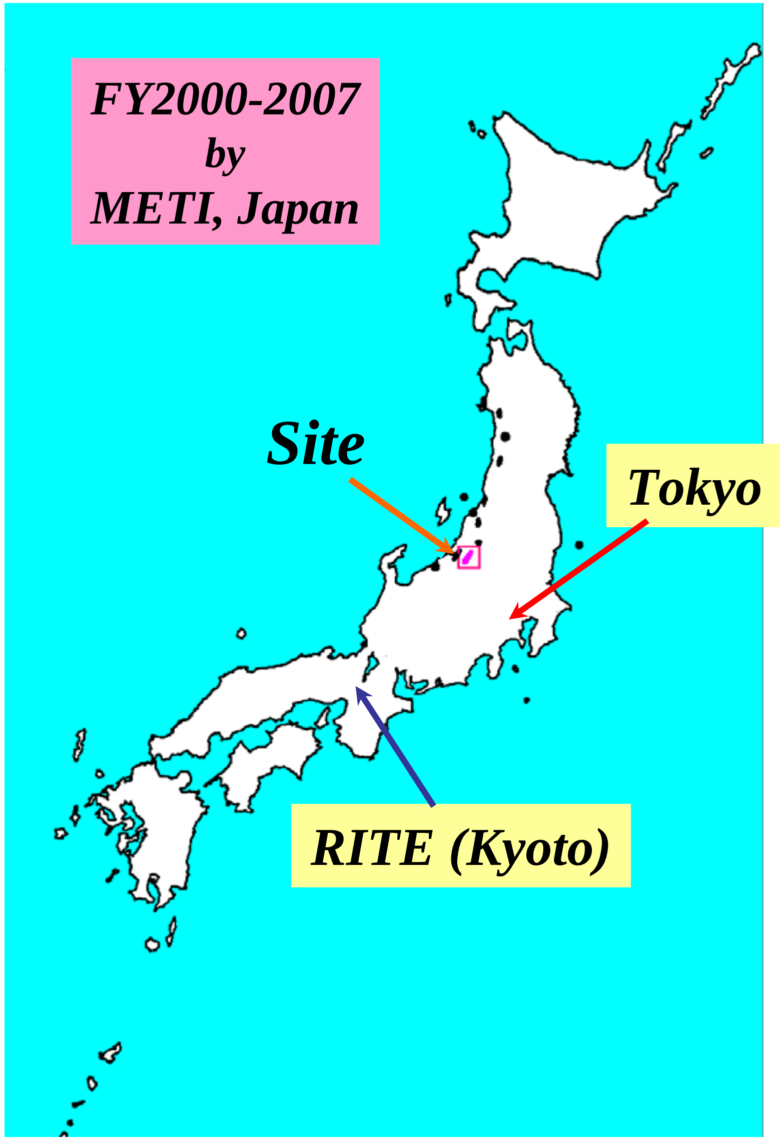
Determine the subsurface distribution of injected CO2 using diverse monitoring technologies



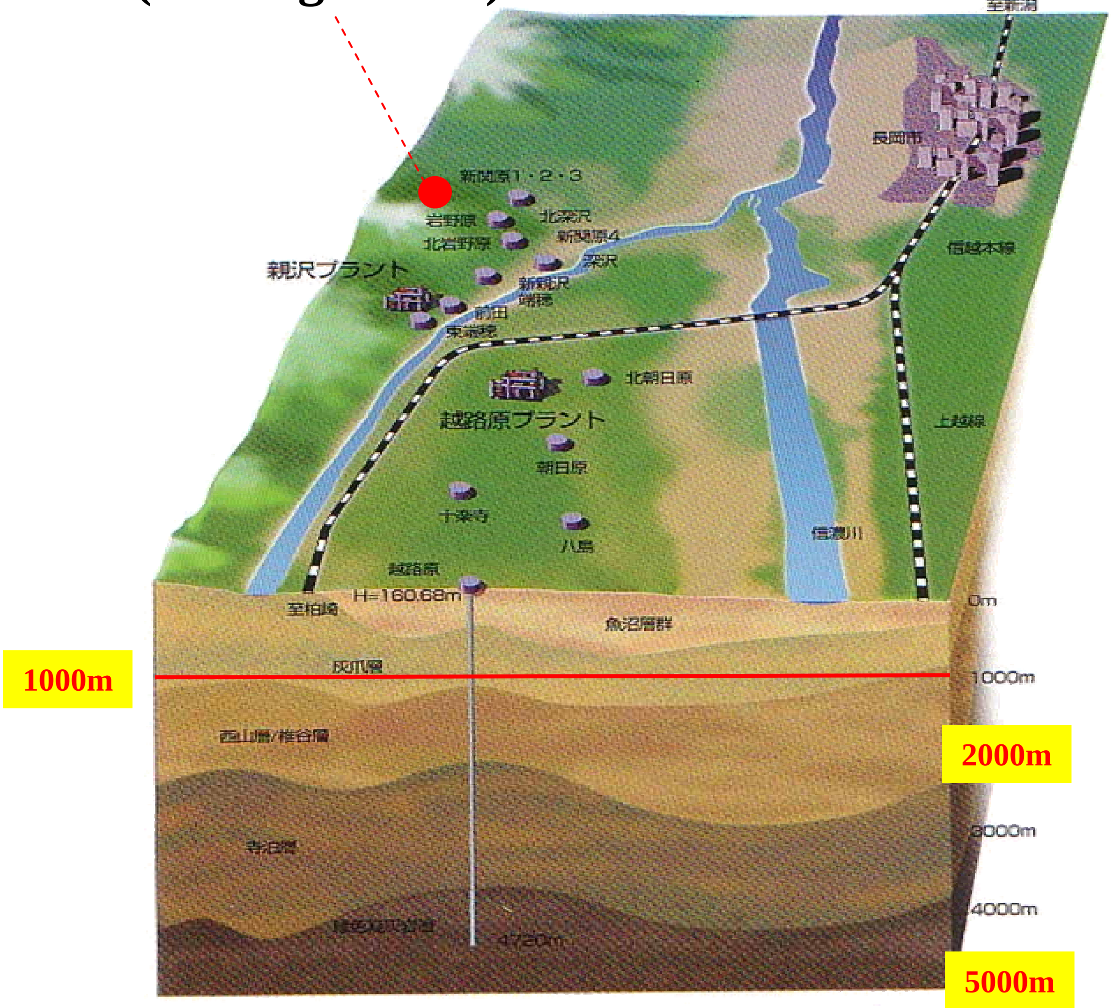
(Hovorka, 2006)


the Nagaoka project &
CO_2 Monitoring

Location of the Field Test Site for CO_2 Injection



Teikoku Oil, Niigata Prefecture
(active gas field)



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**

Objectives of time-lapse well logging and pressure measurement

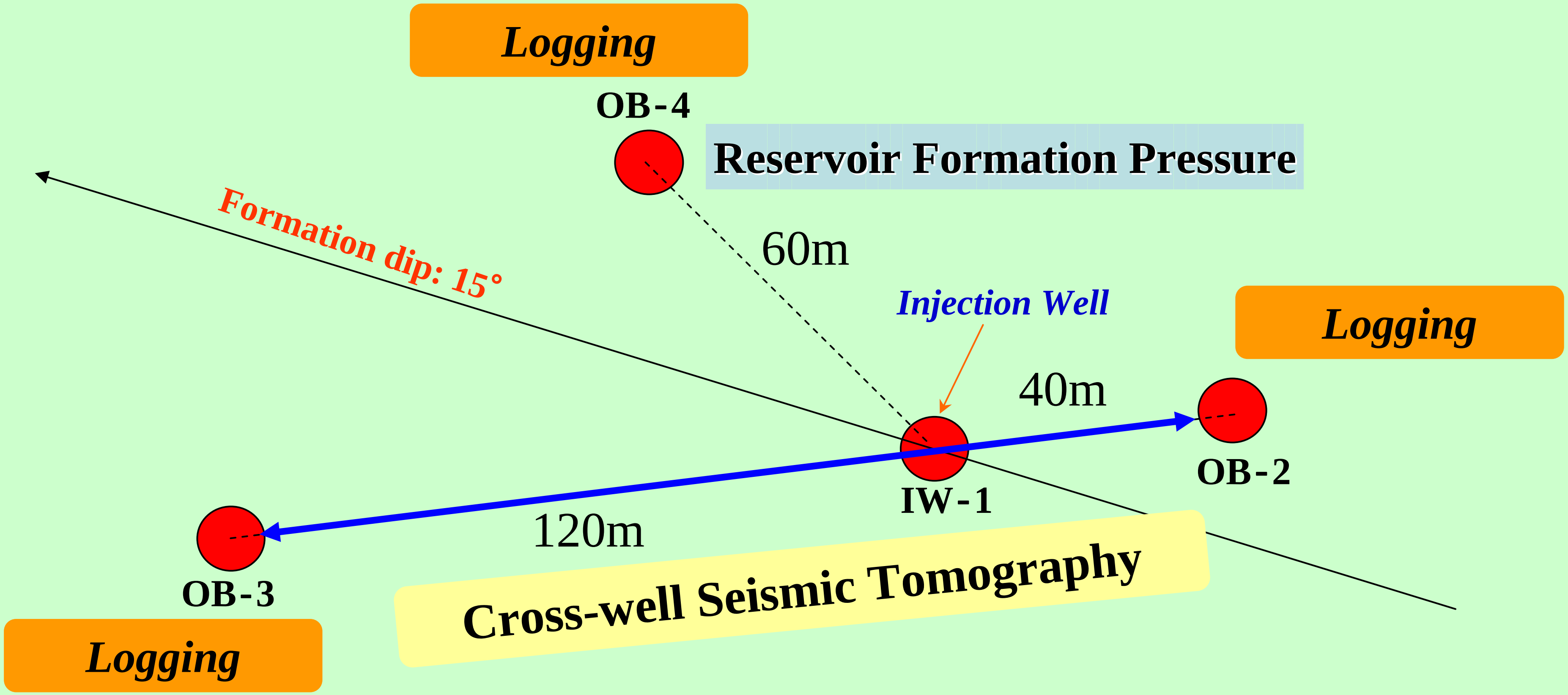
- **CO_2 breakthrough time** (*calibrating geological model*)
- **CO_2 movements after breakthrough & formation pressure buildup disappeared** (*driving force and long term behavior prediction*)

Trapping Mechanism

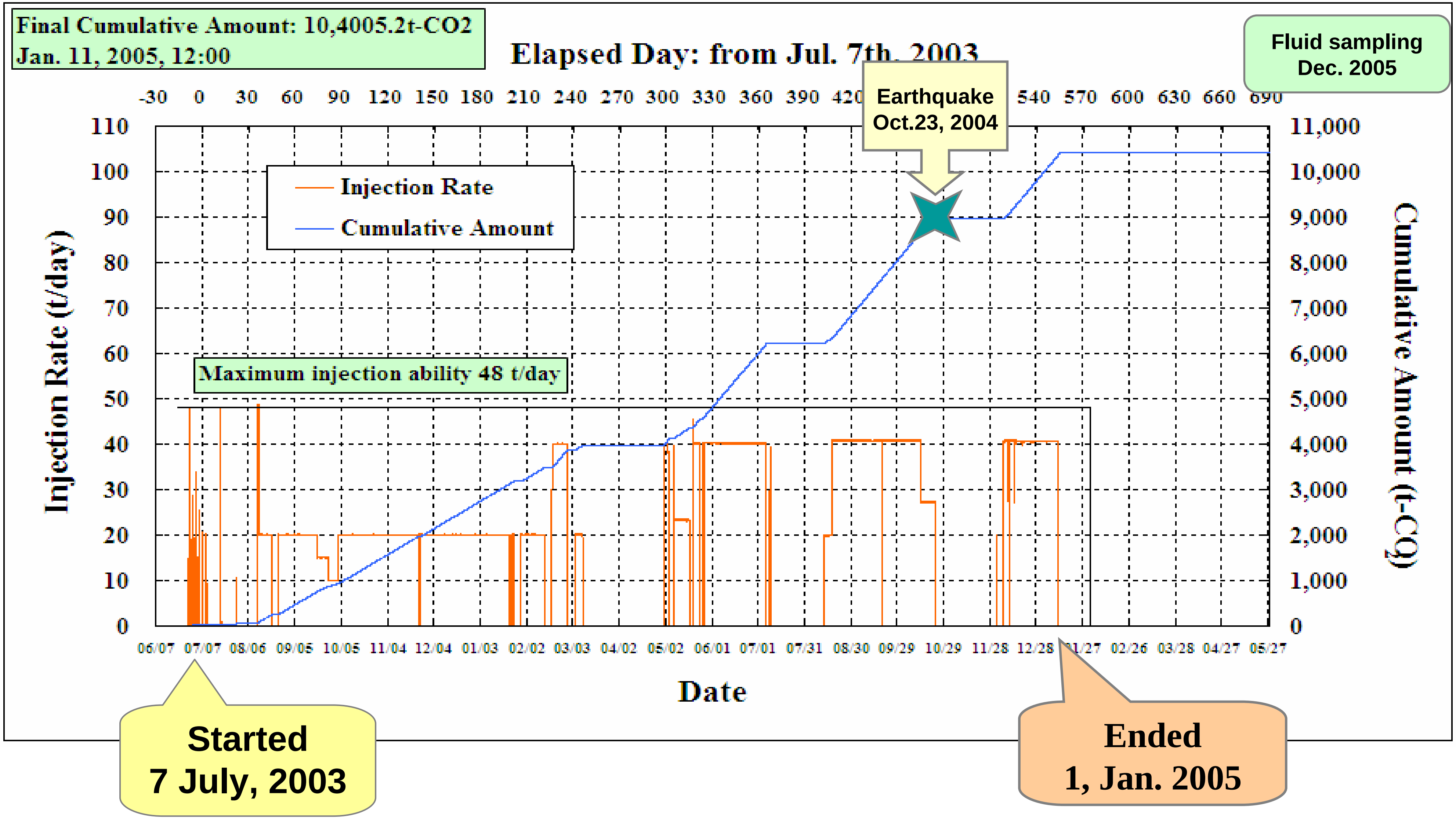
- **Formation pressure measurements at injection well and one of the three observation wells**

  (pressure buildup due to the low permeability, decay curves for permeability (single-phase) and relative permeability (two-phase) estimations)

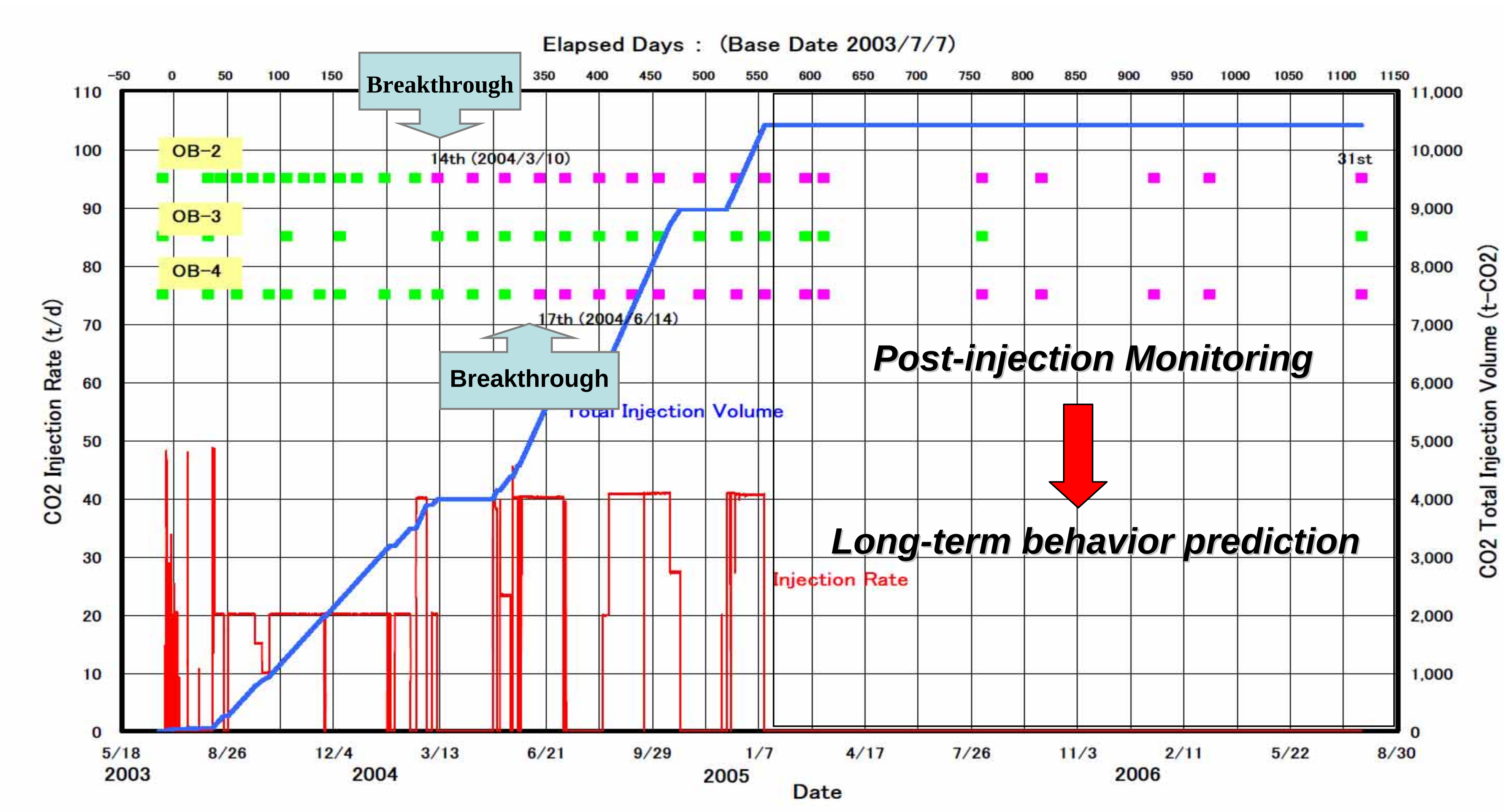
Geophysical Monitoring of CO_2 Sequestration



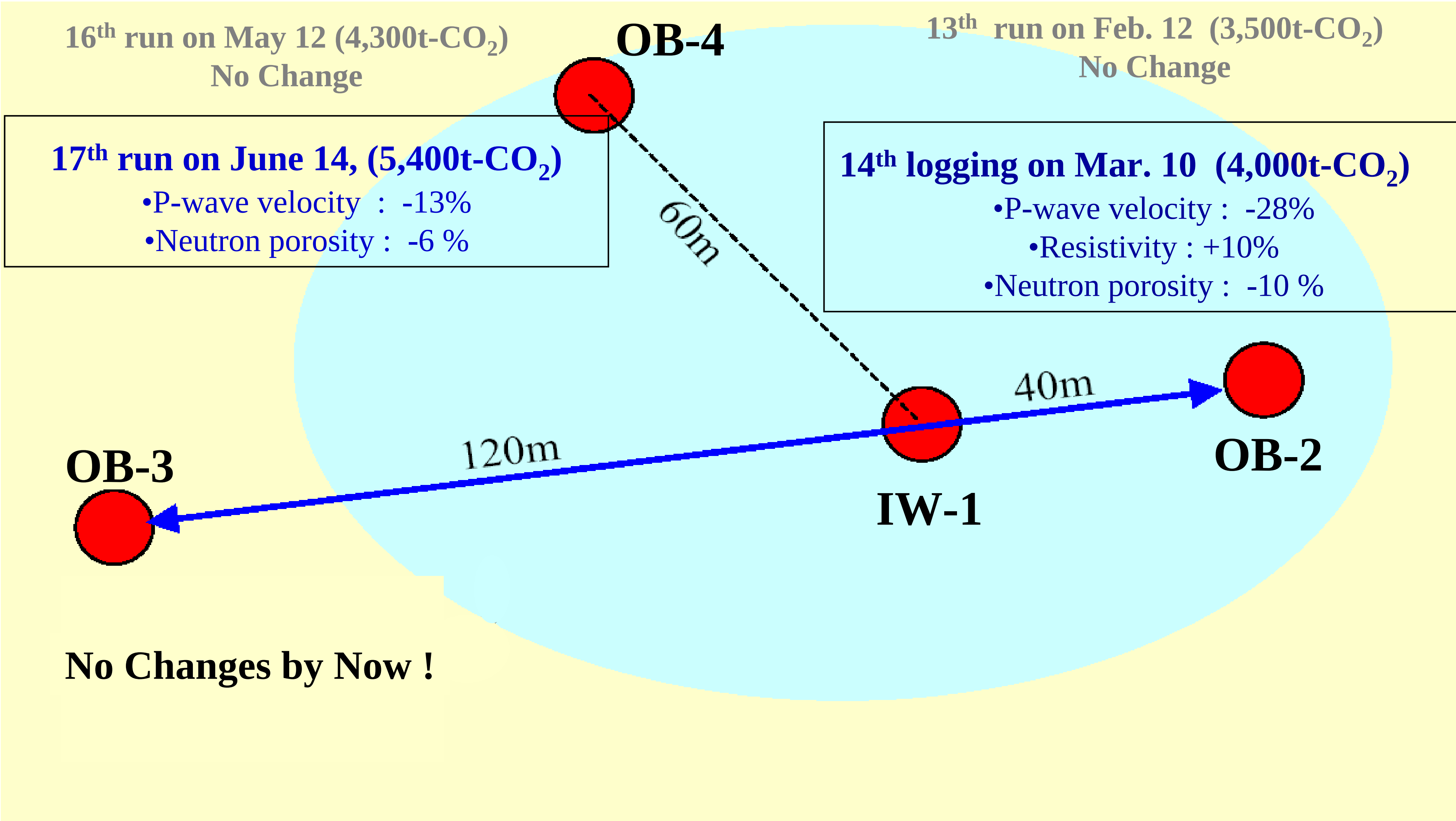
History of the CO_2 Injection at Nagaoka



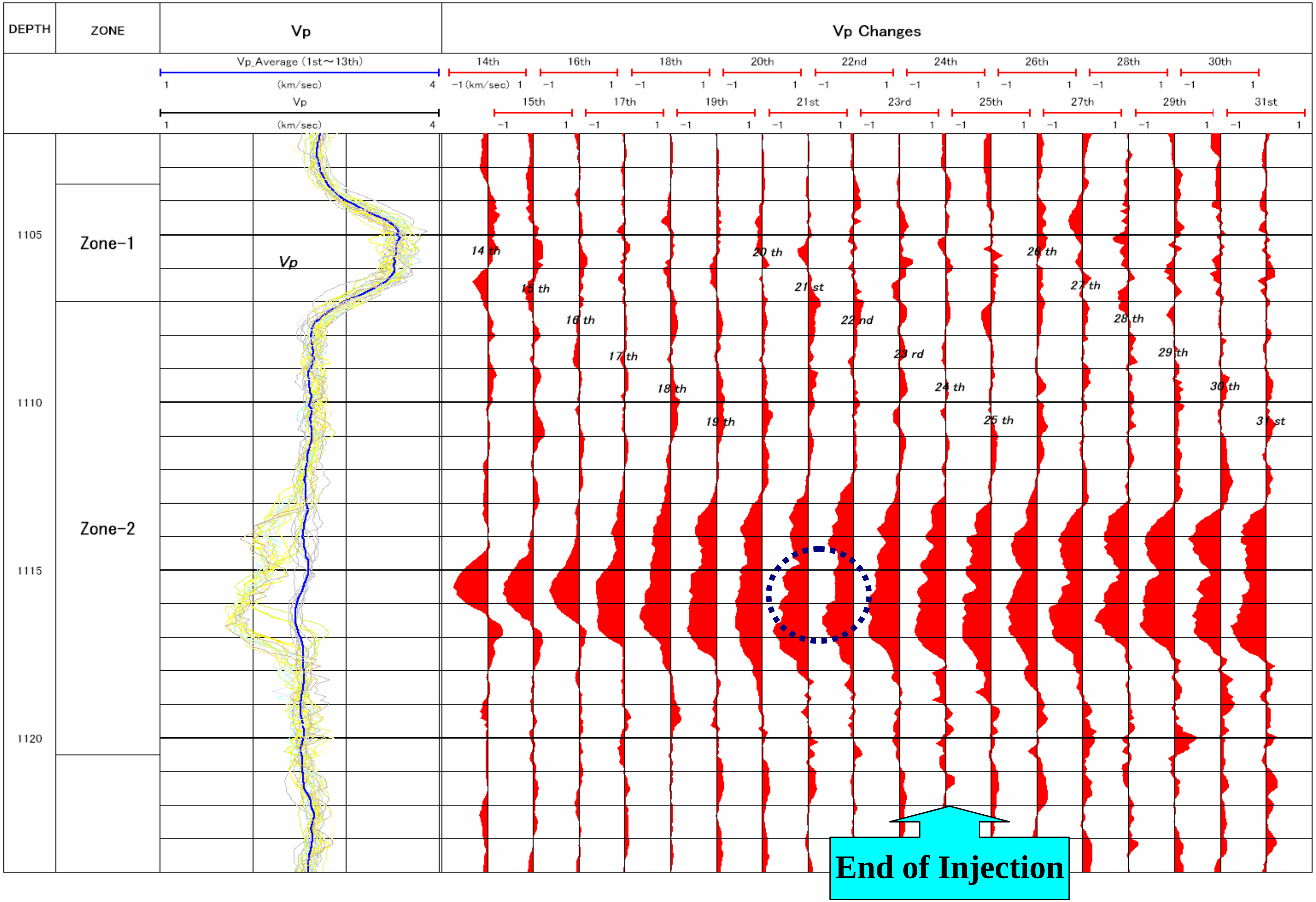
Time-lapse Well Logging



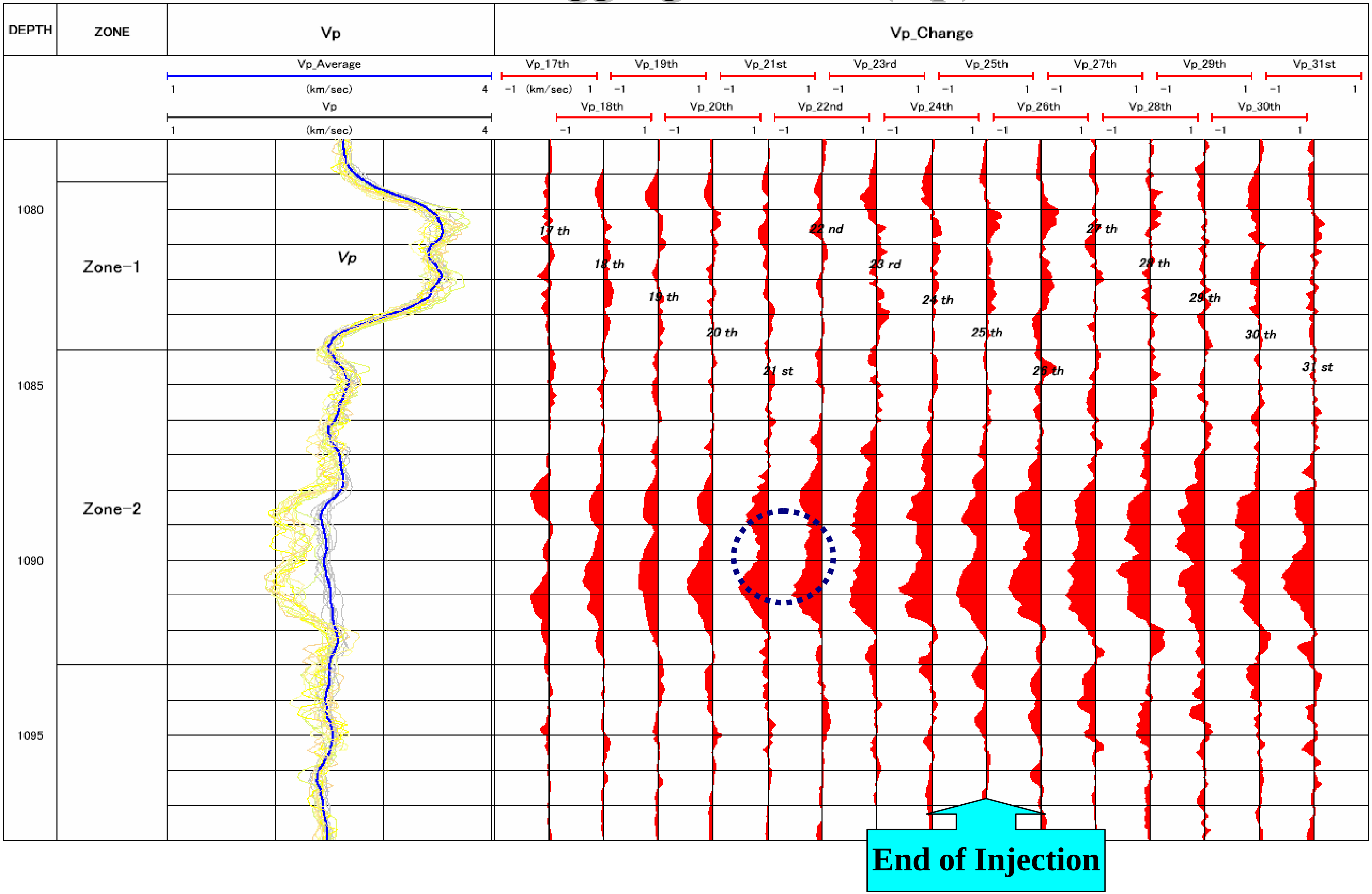
CO_2 Breakthrough time at OB-2 & -4



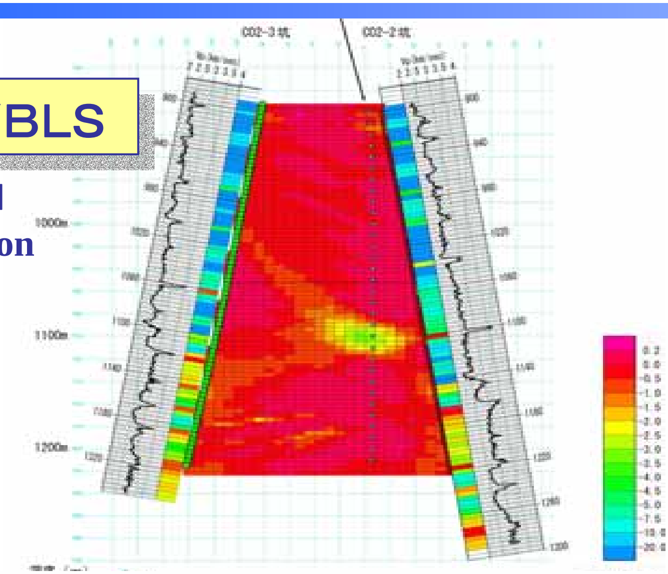
Sonic Logging @OB-2 (Vp)



Sonic Logging @OB-4 (Vp)

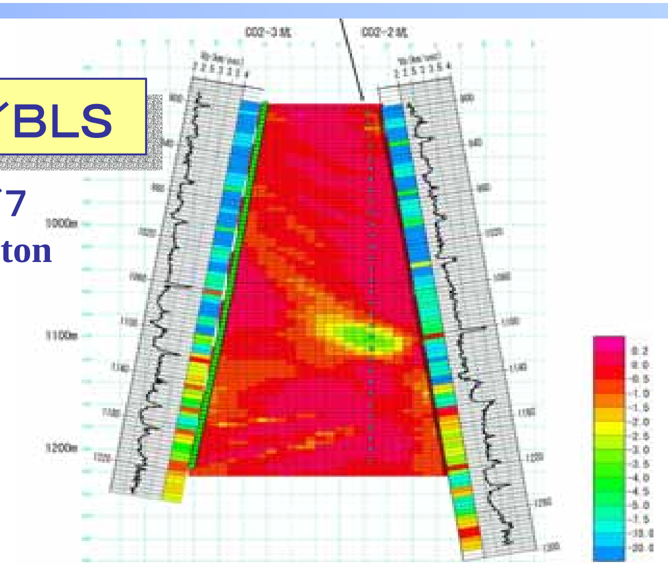


Results of Crosswell Seismic Tomography



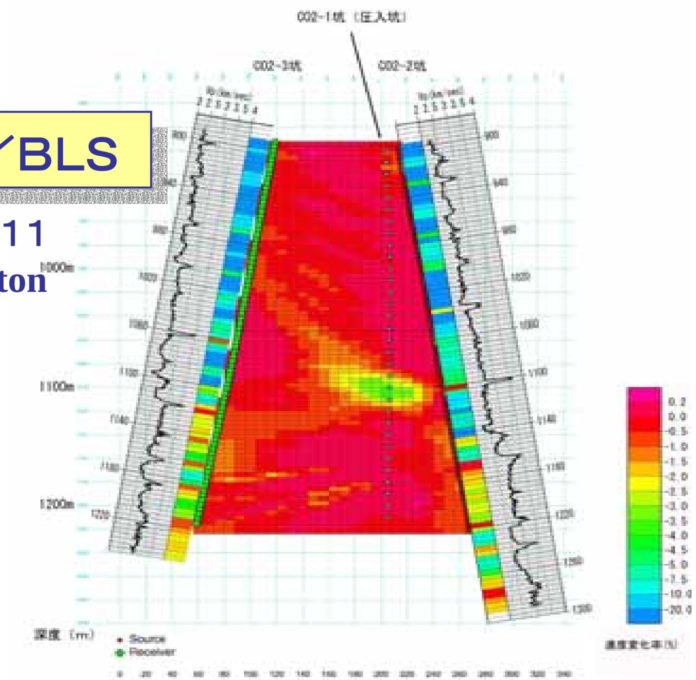
MS1／BLS

2004／1
3，200 ton



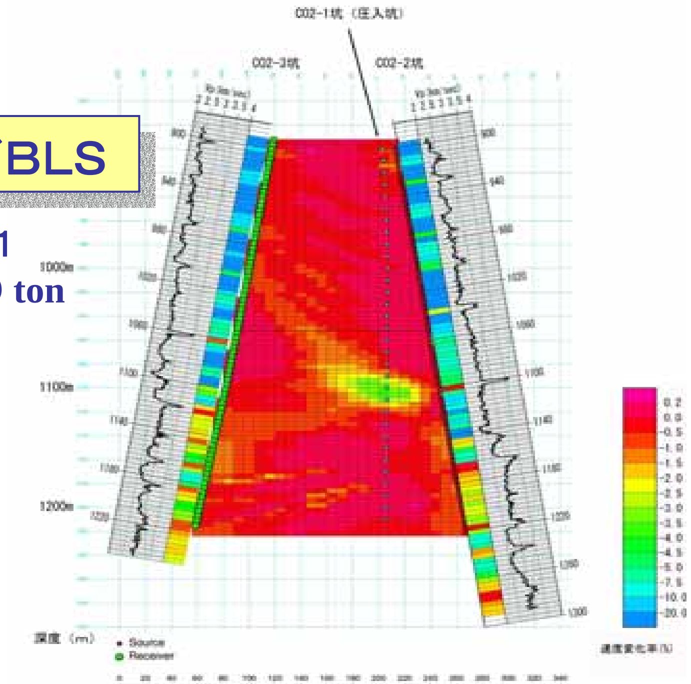
MS2／BLS

2004／7
6，200 ton



MS3／BLS

2004／11
8，900 ton



MS4／BLS

2005／1
10，400 ton

Geochemical Monitoring

— *fluid sampling from the reservoir* —

CO_2(sc or gas) → CO_2 (aq)
CO_2(aq)+H_2O → H_2CO_3

Solubility trapping

H_2CO_3 → H^+ + HCO_3^-
HCO_3^- → H^+ + CO_3^{2-}

Ionic trapping

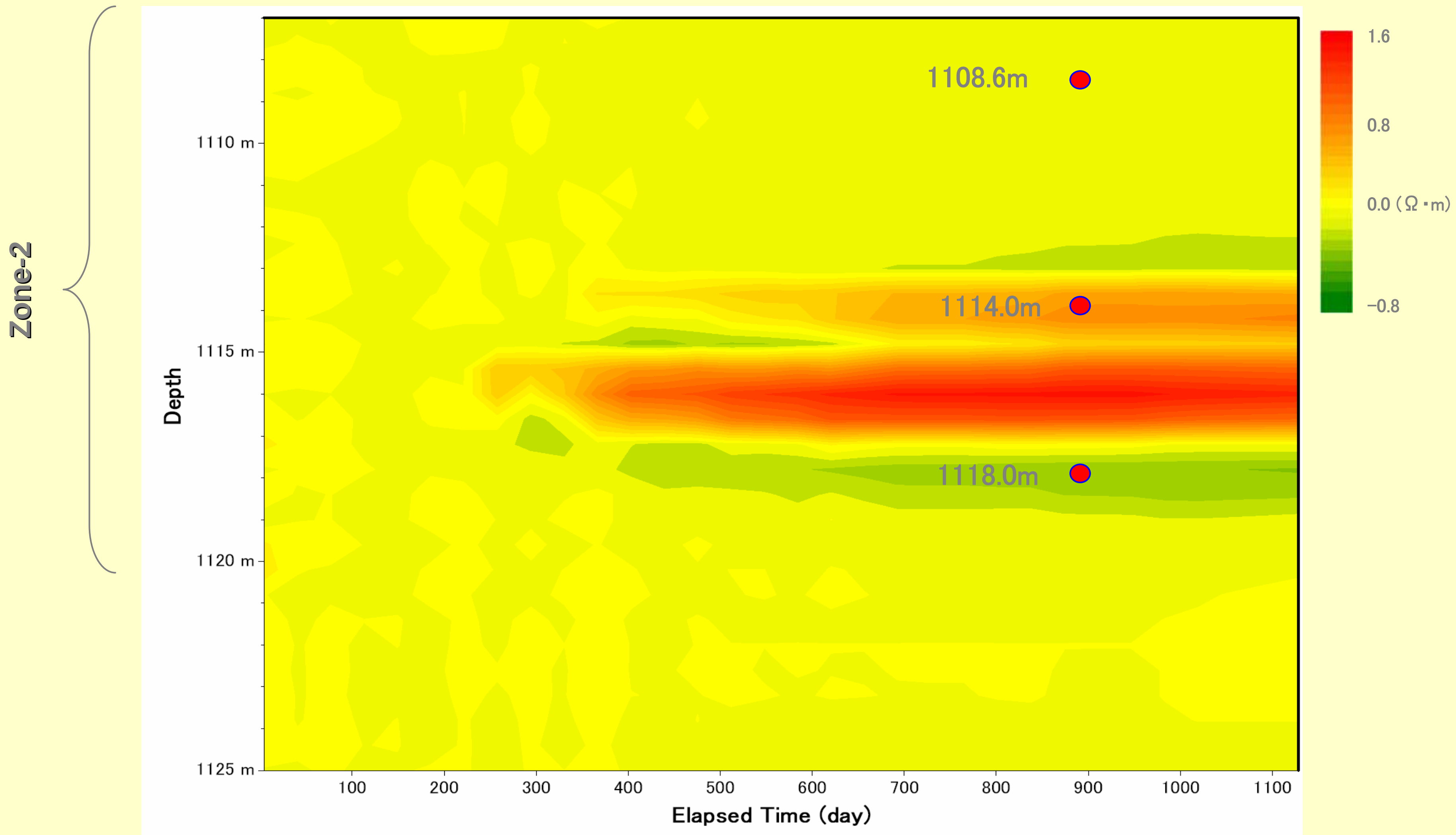
Ca^{2+} + HCO_3^- → $CaCO_3$ + H^+
Mg^{2+} + HCO_3^- → $MgCO_3$ + H^+

Mineral trapping

Fluid sampling

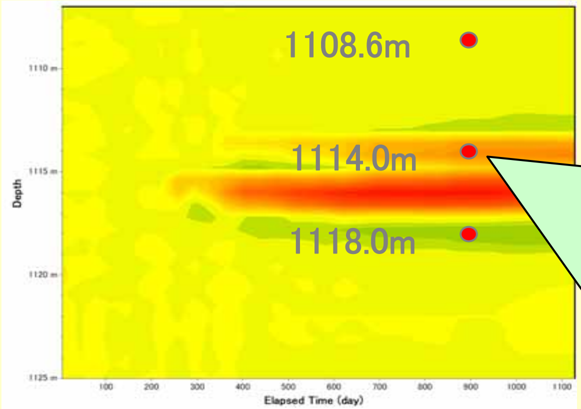
CHDT*(Cased Hole Dynamic Tester)

Fluid Sampling Points at OB-2



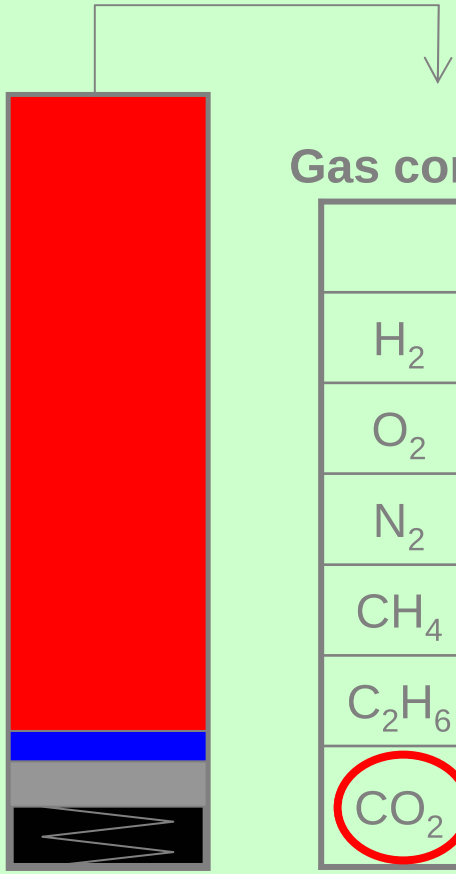
Fluid sampling

OB-2 1114m : Mostly free CO_2



Gas:
≒3,500ml

Water:
50ml - 280ml
(Contamination 96%)



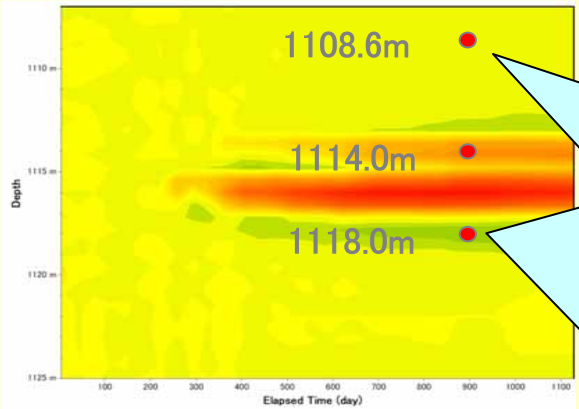
Sample Chamber
(volume 3,786ml)

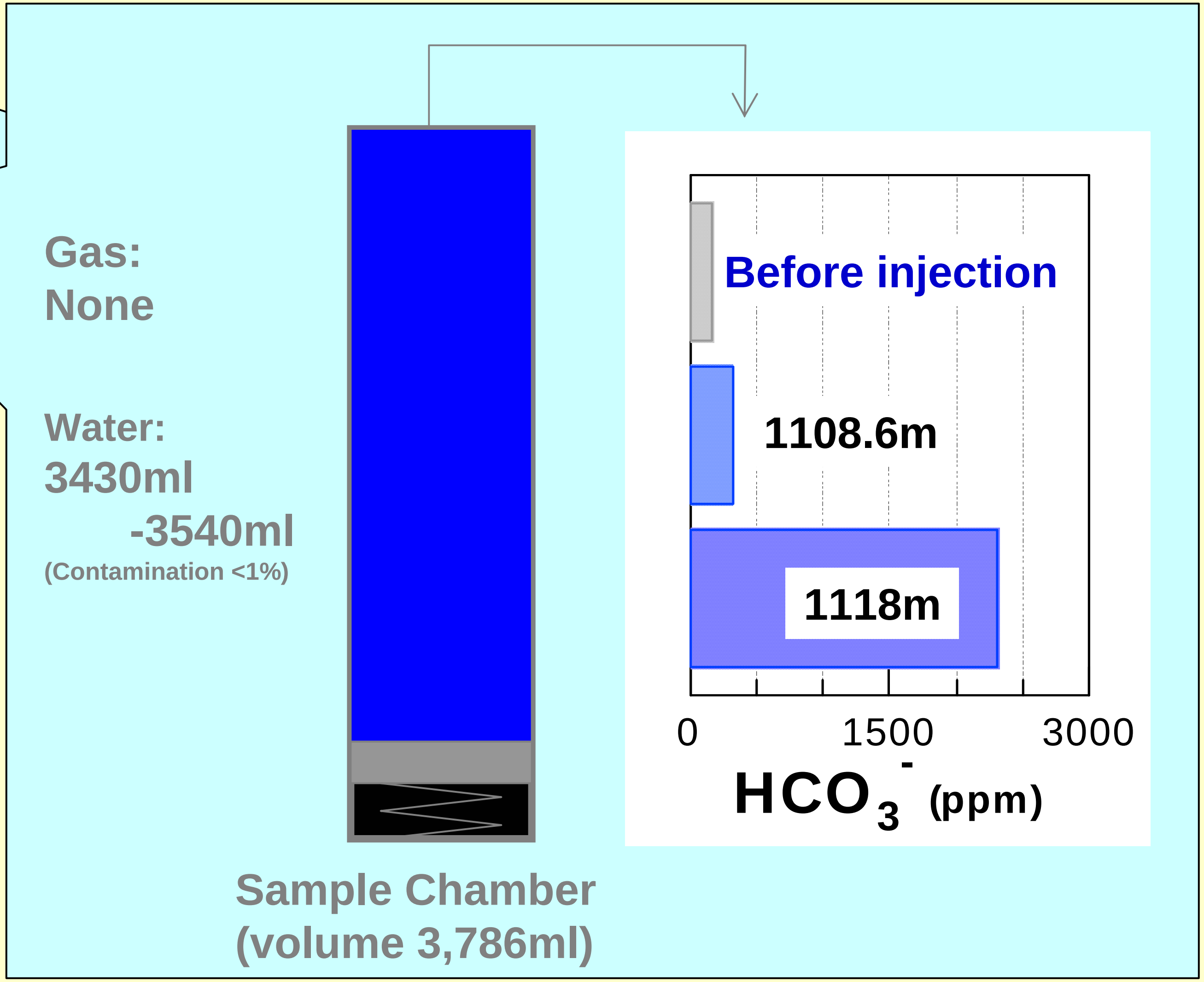
Gas composition

	mol%
H_2	0.00
O_2	0.20
N_2	0.75
CH_4	0.27
C_2H_6	0.00
CO_2	**98.78**

Fluid sampling

OB-2 1108.6m & 1118m：Water

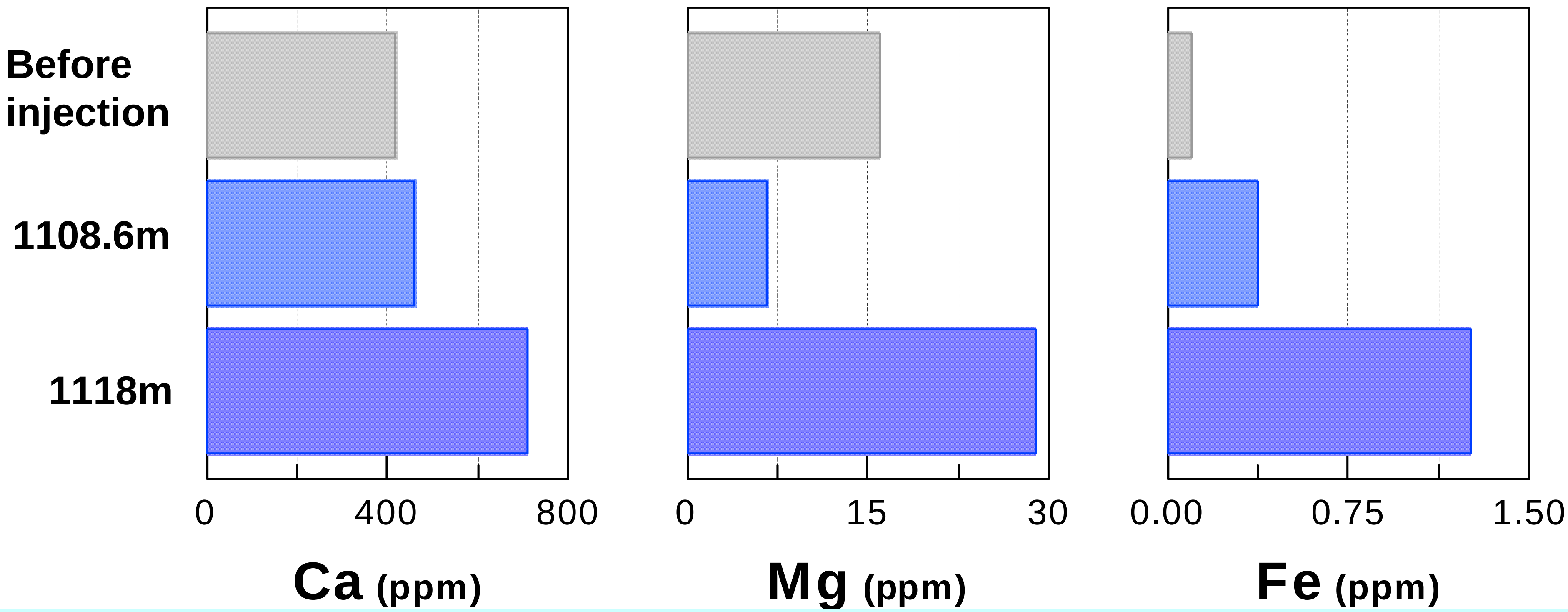




At 1118m, formation water rich in dissolved CO_2.

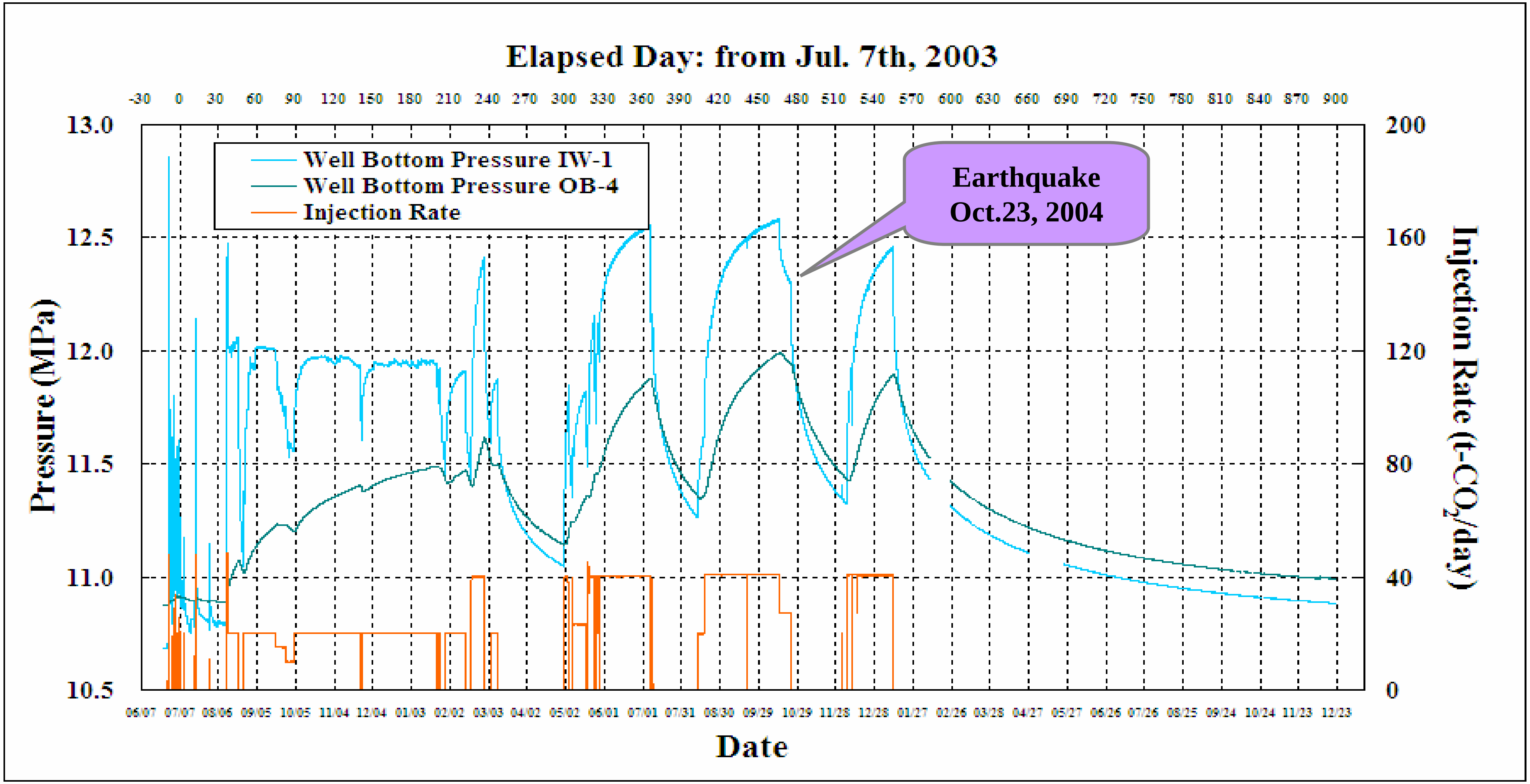
Fluid sampling

OB-2 1108.6m & 1118m ： Ca, Mg & Fe



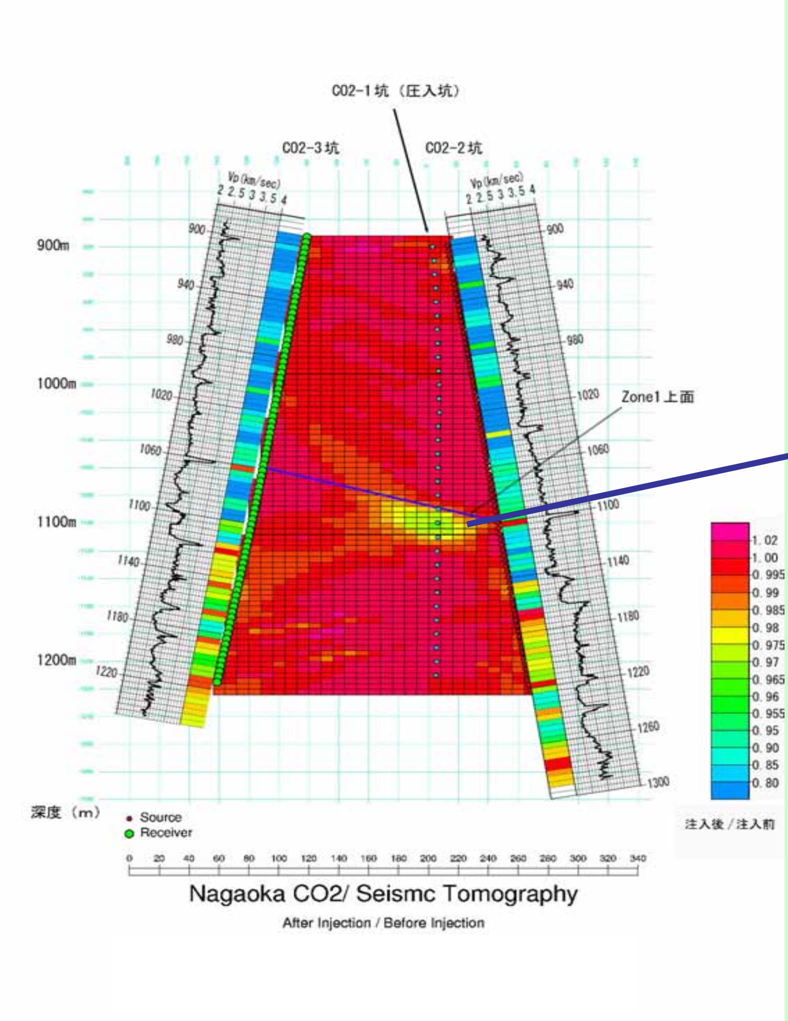
At the depth of 1118m (HCO_3^- conc. increased), concentrations of Ca, Mg and Fe also increased.

Formation Pressure Measurements



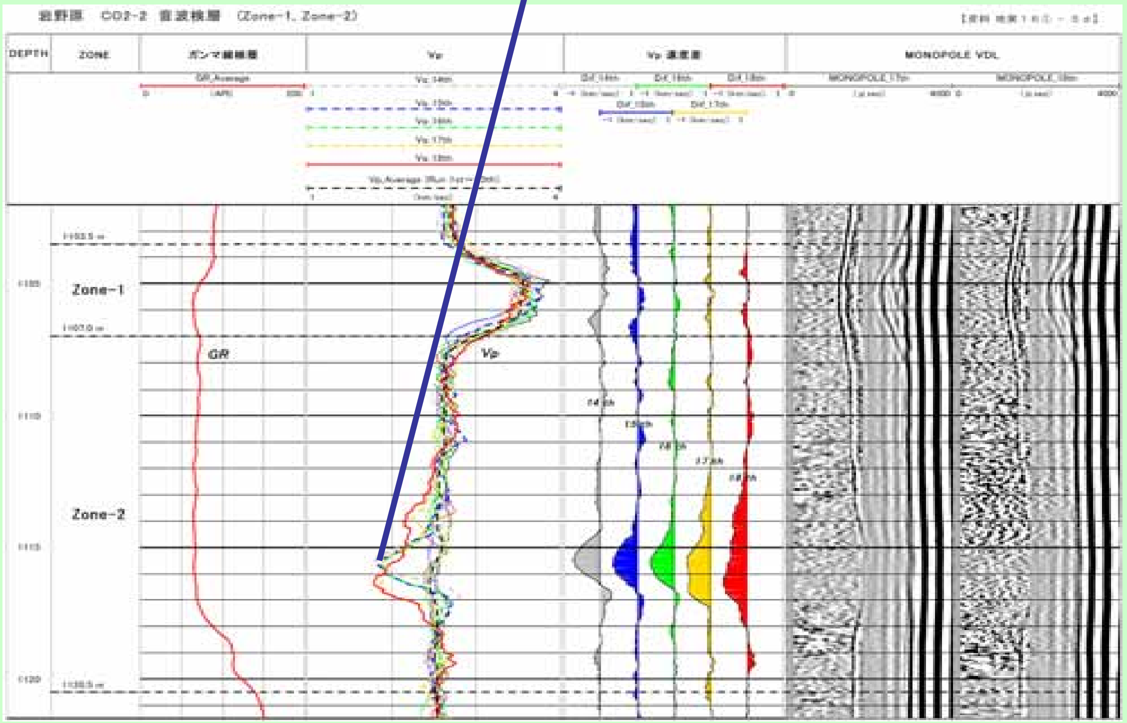
Interpretations on CO_2 Monitoring Results

Can we quantify in situ** CO_2 **?

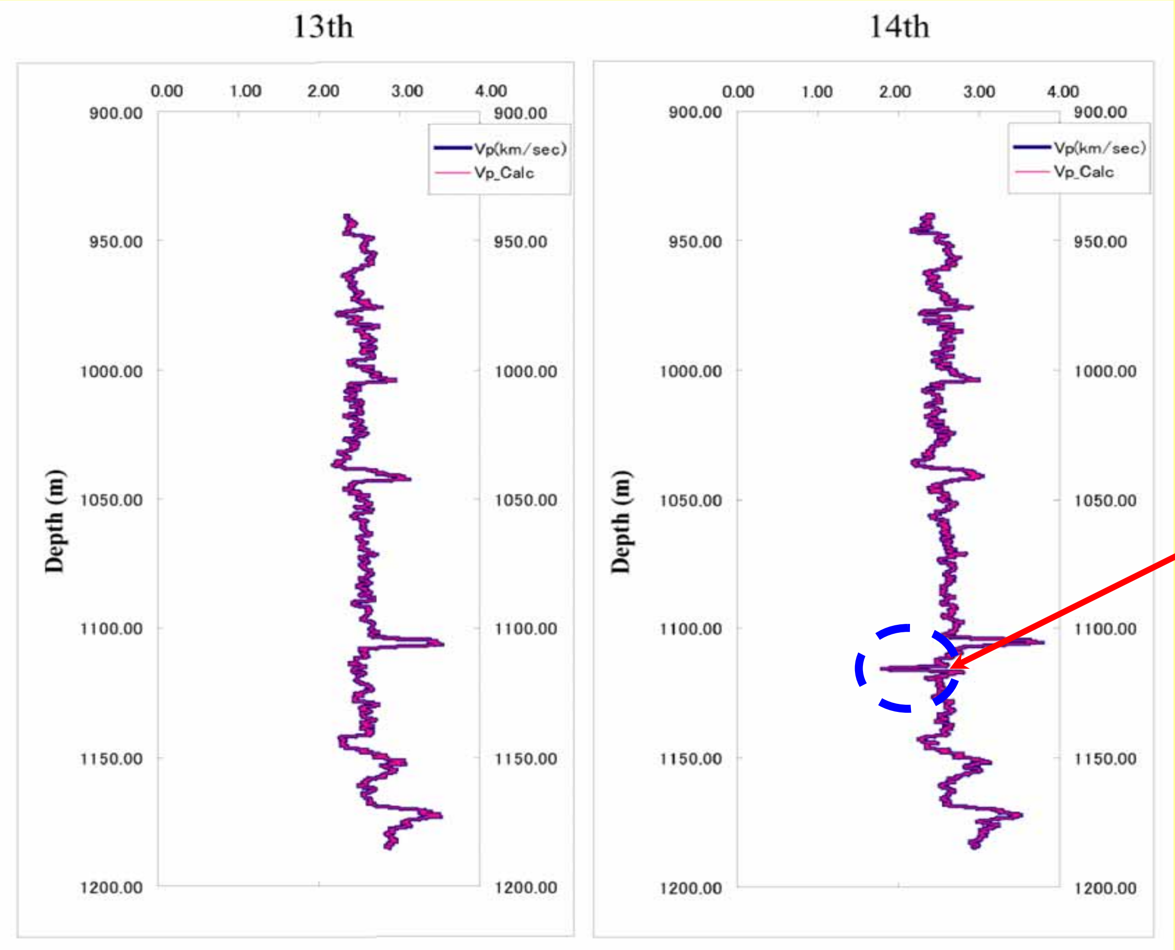


CO_2 saturation

?



History Matching on Sonic Vp



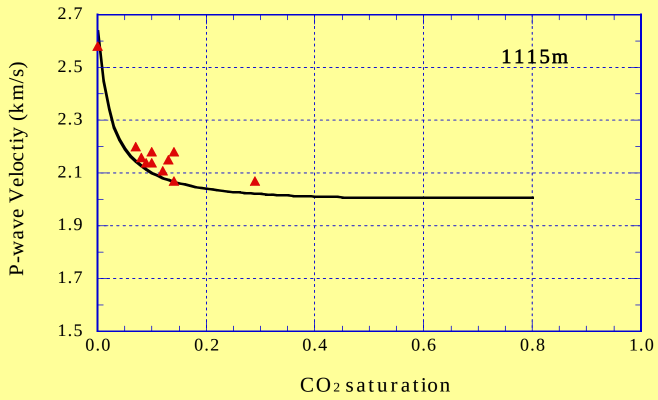
Estimation of CO_2 Saturation with Gassmann theory

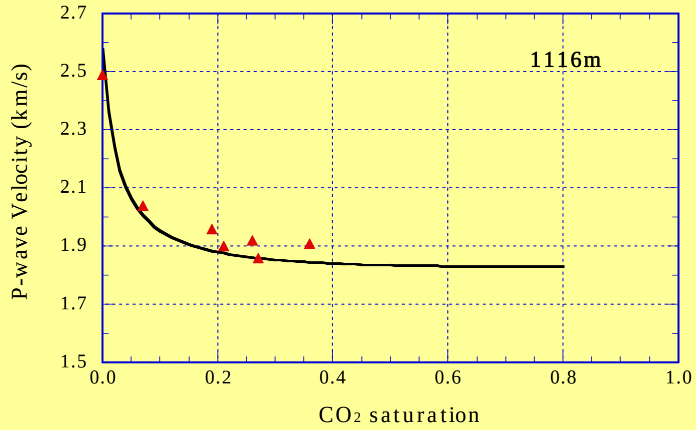
Velocity reduction due to breakthrough of CO_2

Xue et al.,2006

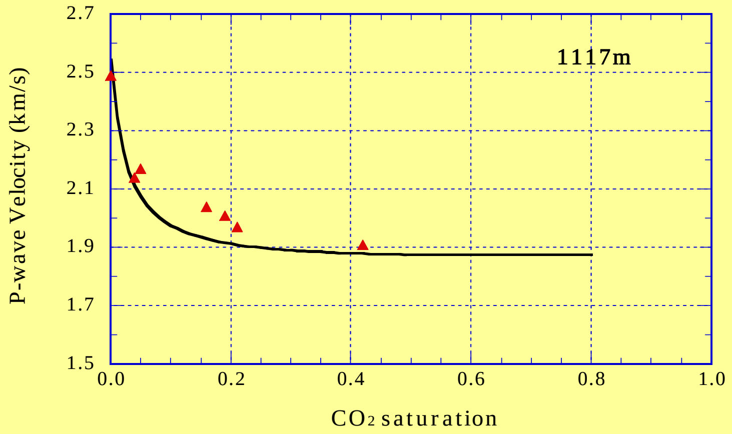
Sonic Vp in Observation Well OB-2 at Nagaoka CO_2 Injection Site

P-wave velocity vs CO_2 saturation

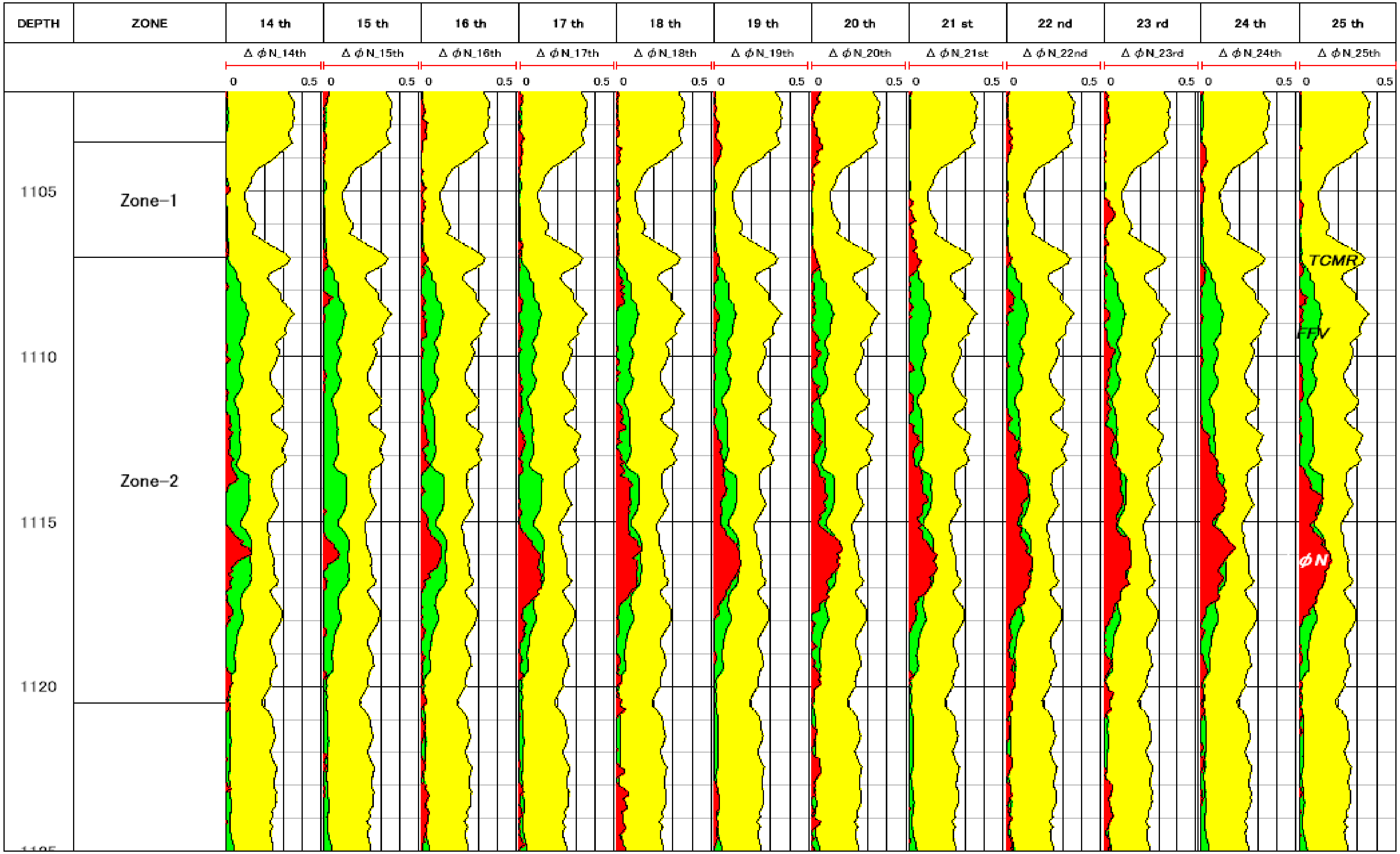




▲ : **estimated from sonic Vp @ OB-2**



CO_2 saturation in OB-2 (from NMR Log)



Conclusion Remarks

- **Time-lapse crosswell seismic tomography and well logging data image CO_2 clearly.**

- **CO_2 migration pattern depends strongly on the heterogeneity of the sandstone reservoir.**

- **Successfully applied Gassmann Theory to estimate CO_2 saturation from sonic P-wave velocity.**

- **Results of CO_2 monitoring improved understandings of CO_2 storage and show no evidence of leakage, even in the Mid-Niigata Earthquake (M6.8) on October 23, 2004.**

ACKNOWLEDGMENTS

•This project is funded by Ministry of Economy, Trade and Industry (METI) of Japan.

•We thank staffs of ENAA, Teikoku Oil Co., OYO Co., Geophysical Surveying Co. and RITE involved in Nagaoka pilot CO_2 injection project.