

地中貯留におけるCO₂挙動モニタリングについて

— 長岡実証試験サイトの事例紹介 —

Geophysical Monitoring of CO₂

Sequestration in Saline Aquifers

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

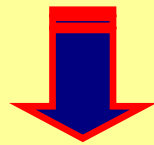
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Research Institute of Innovative Technology for the Earth

財団法人 地球環境産業技術研究機構

Why CO₂ Monitoring ?

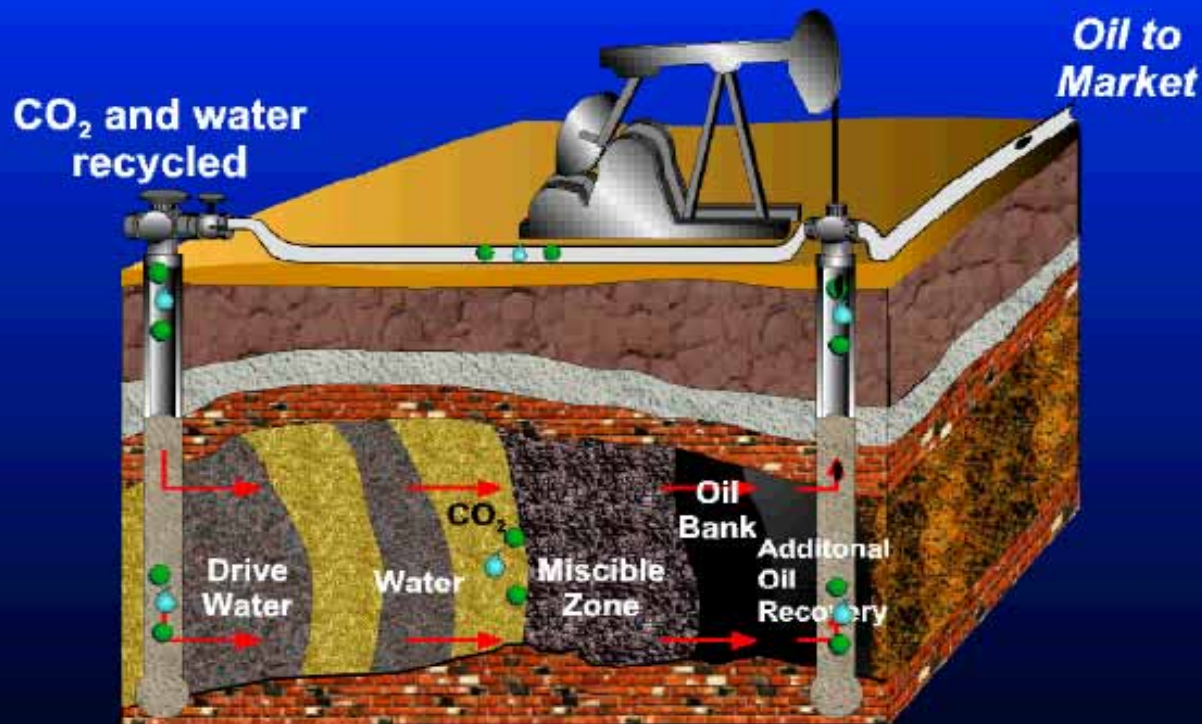
Map the movement of CO₂ & the CO₂ is being safely contained within the reservoir.



CO₂ sequestration is a safe and verifiable mitigation technology option

Monitoring, **E**valuation, **R**eporting and **V**erification (MERV)

Carbon Dioxide Flooding / CO₂-EOR



- ▶ 40-70% of CO₂ injected stays in reservoir

Examples from CO₂-EOR & CO₂ storage projects

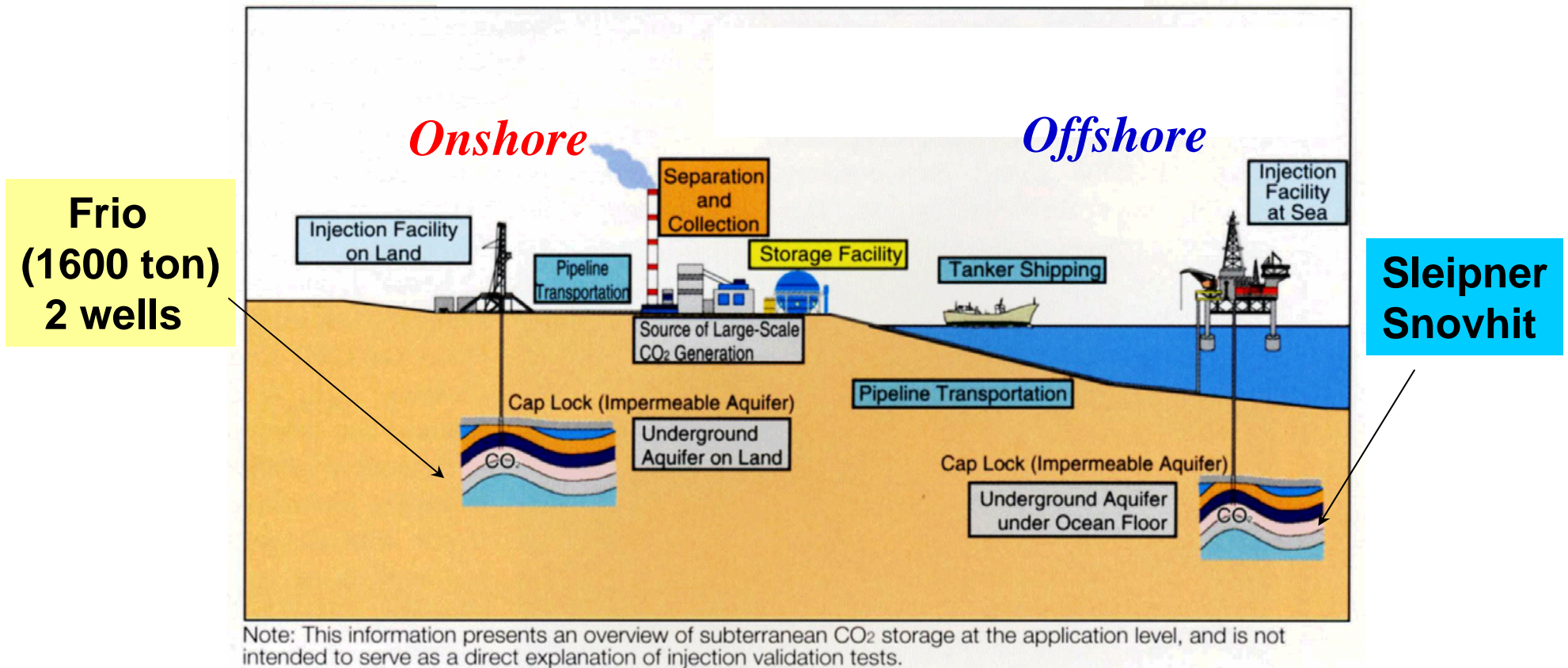
Cross Well **Seismic** and **Electromagnetic** (EM)

- 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 CO₂ Storage



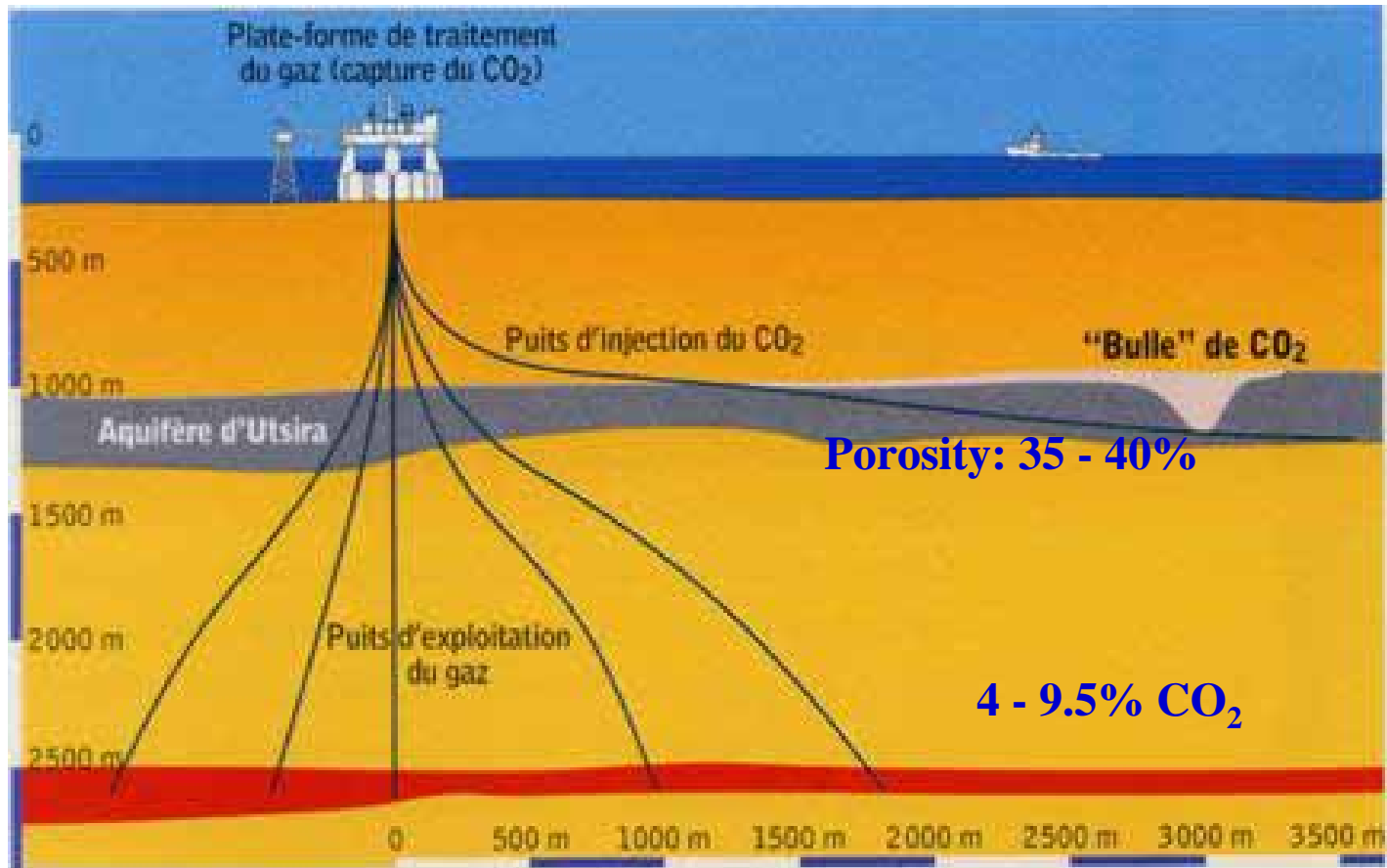
**Nagaoka, (10400 ton), 4 wells (one injection & three observation wells
A big research project of CO₂ storage at an onshore aquifer.**



CO₂ Monitoring at Sleipner & Frio

SACS (Saline Aquifer CO₂ Storage)

North Sea, Norway (Statoil), Sleipner



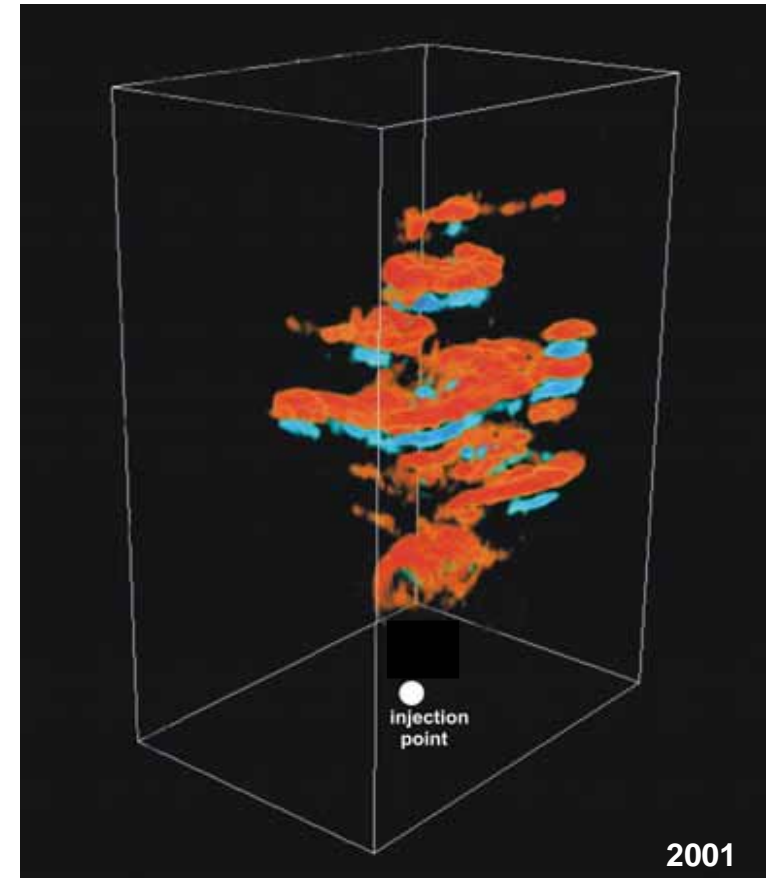
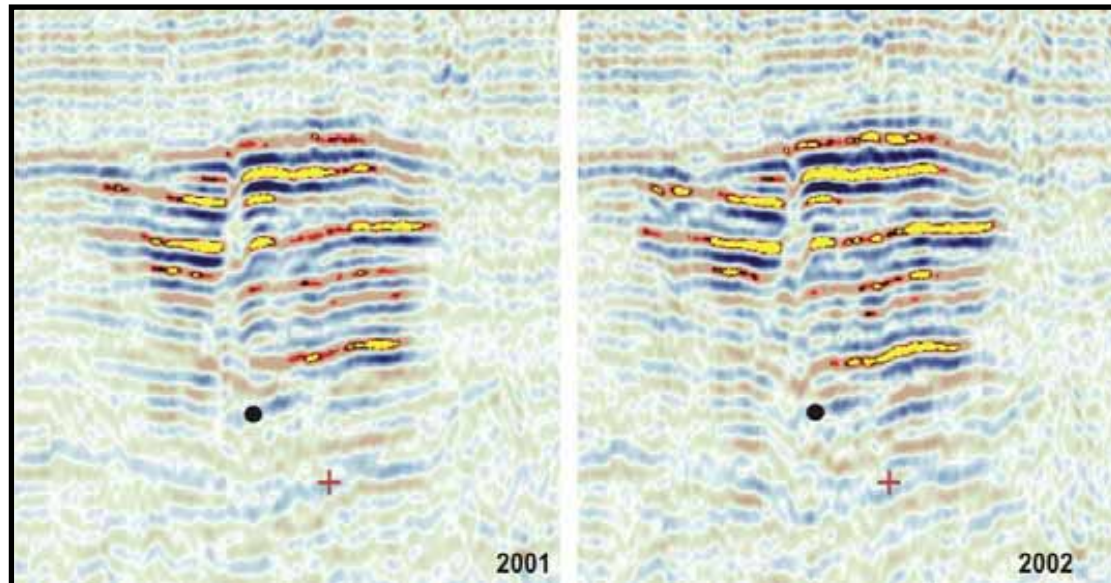
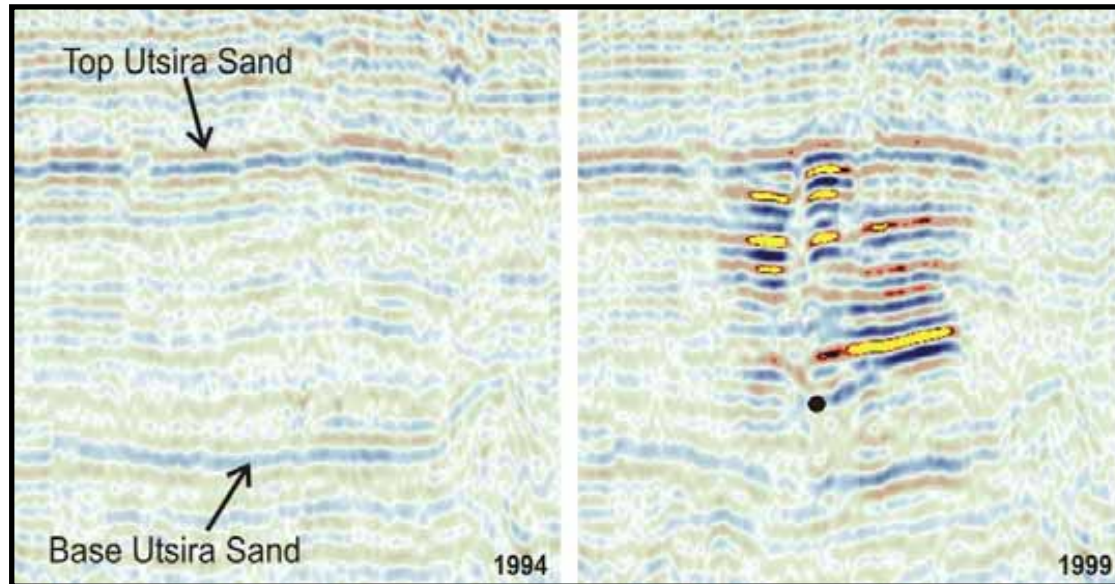
Porous Sand
(Net sand:80-100%)

High Permeability
(1 - 3 darcy)

Temp: 37 °C
Pressure: 8 - 11MPa

1 million ton/year
(3% of Norway)

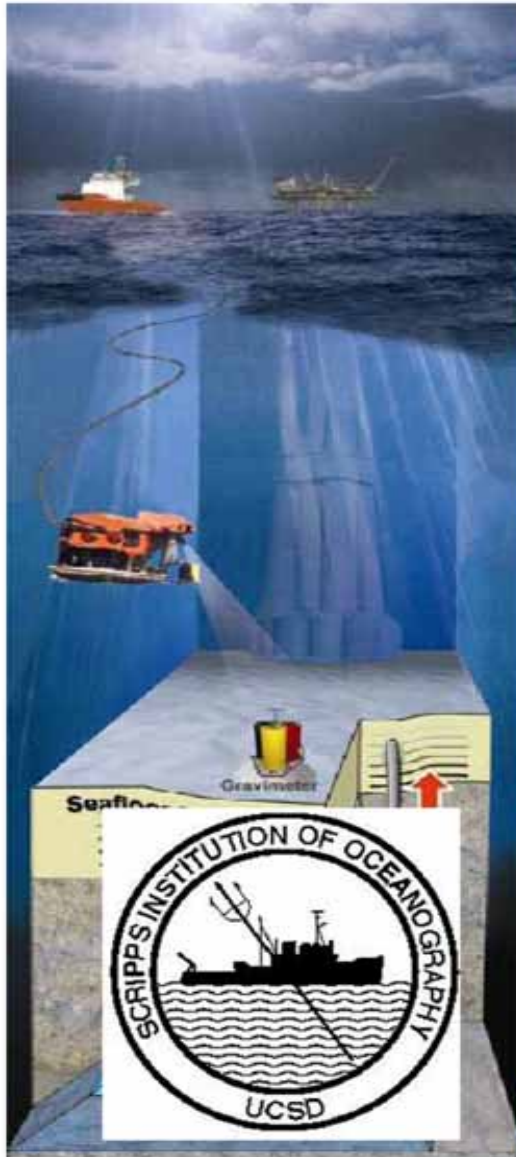
Seismic Survey at Sleipner



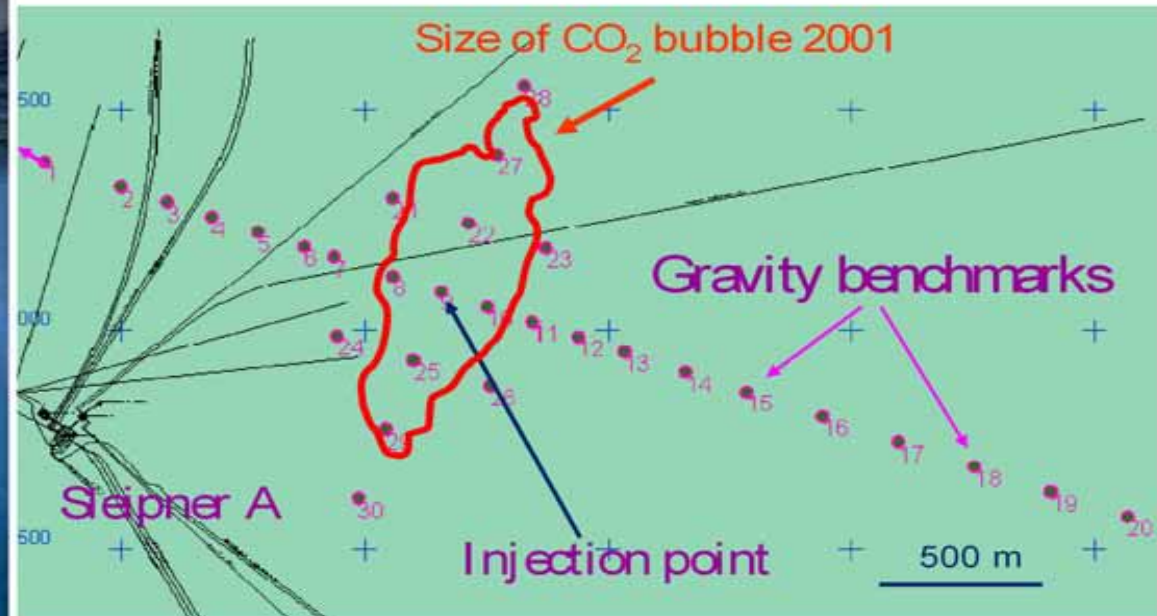
High reflectivity CO₂ plume

Chadwick (2004)

Microgravity Survey at Sleipner



Gravimetric monitoring



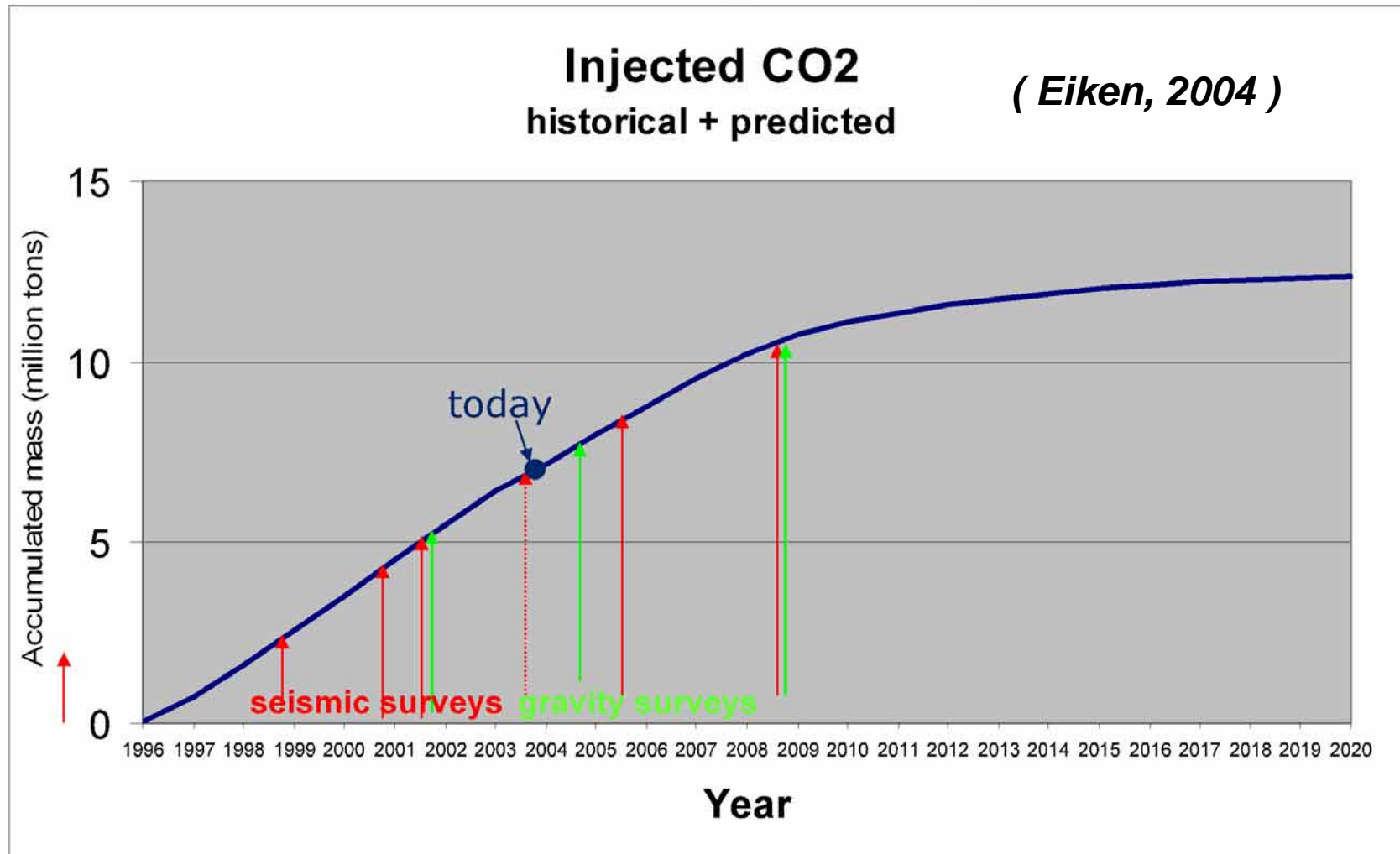
2002 base survey achievements:

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

Eiken, 2004

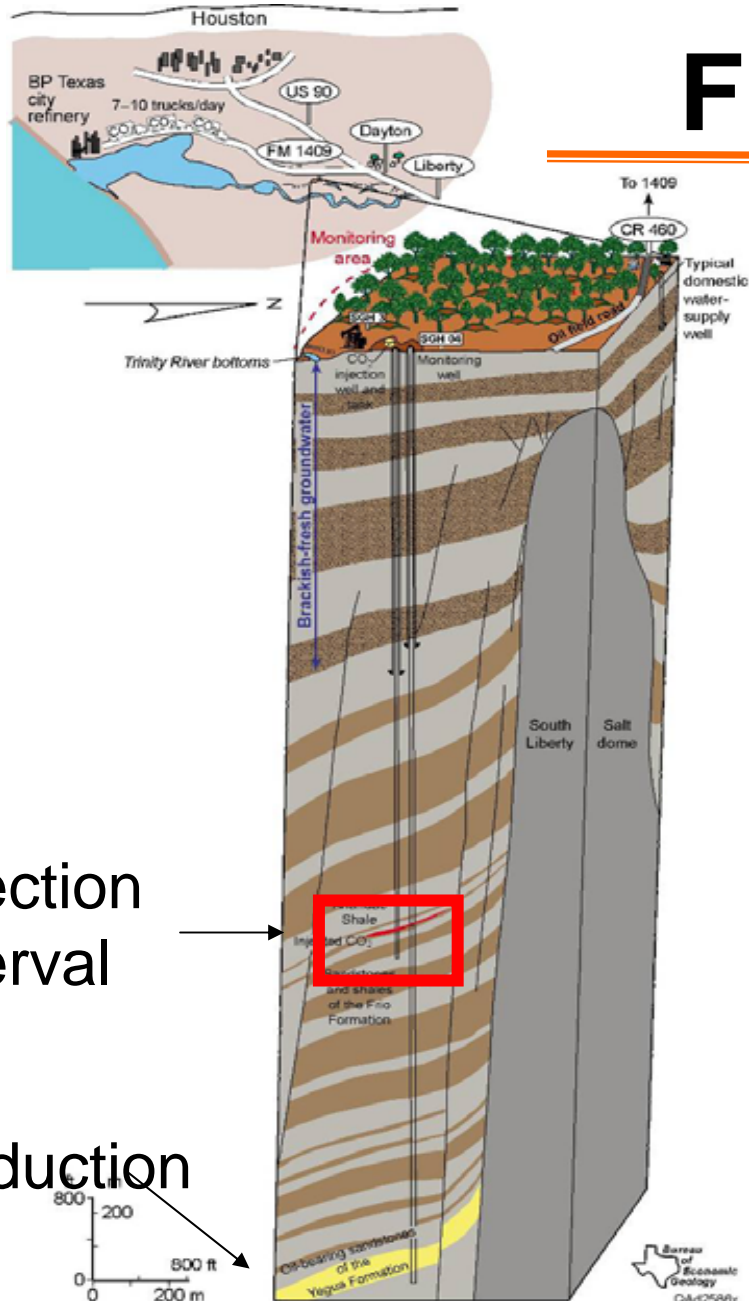


Accumulated CO₂ storage



Frio Brine Pilot Site

(Hovorka, 2006)

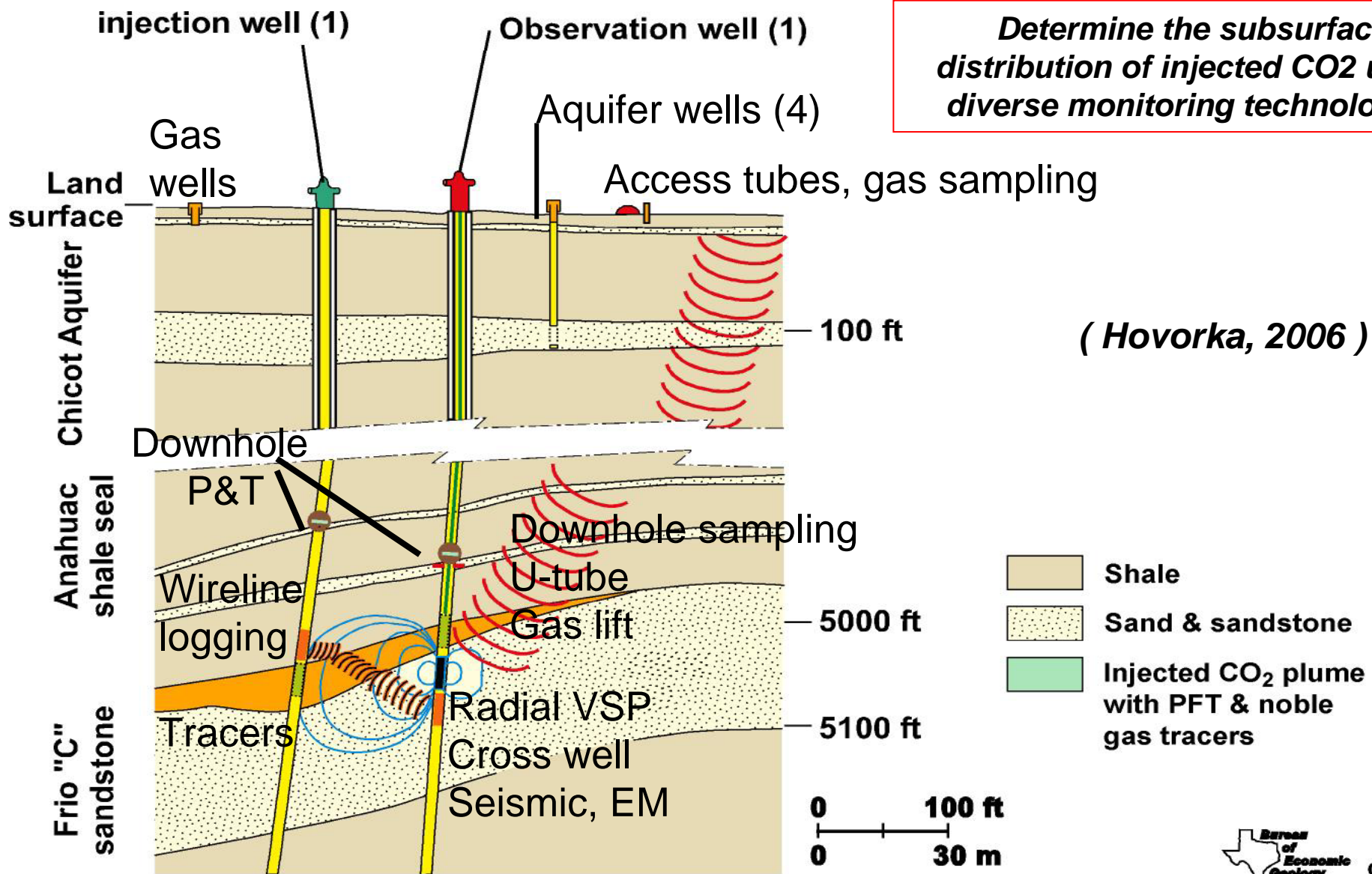


Injection interval

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 CO₂

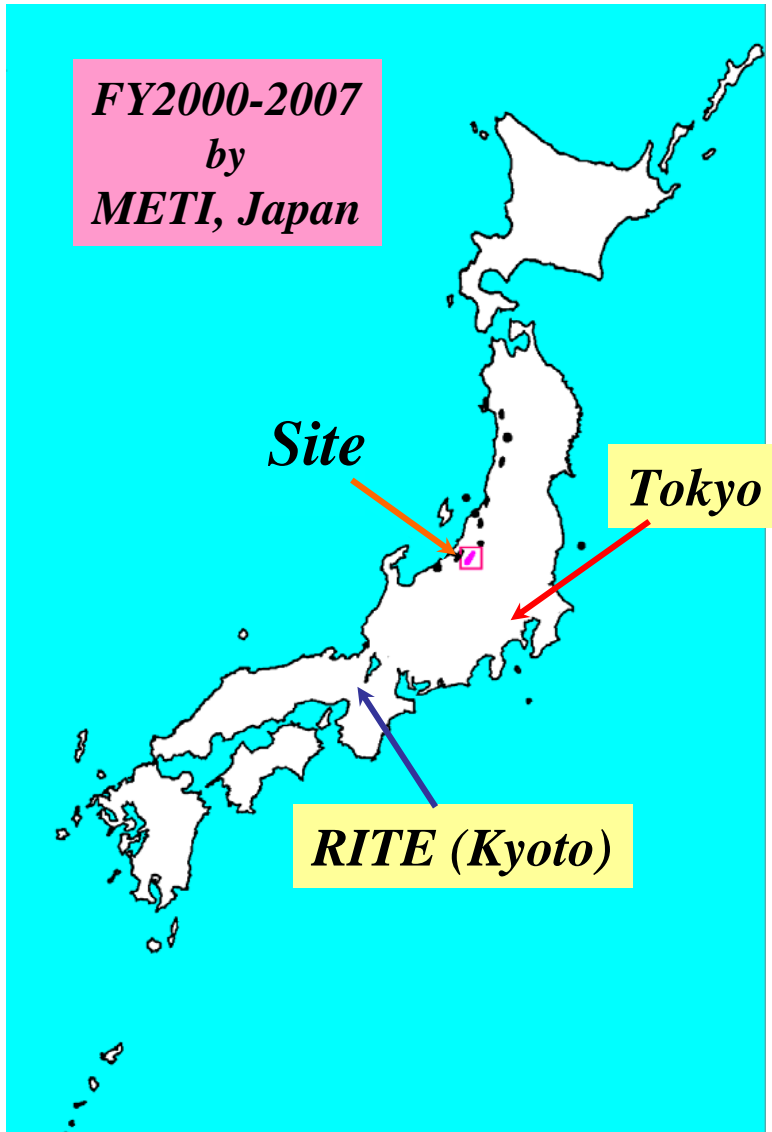
Monitoring at Frio Pilot



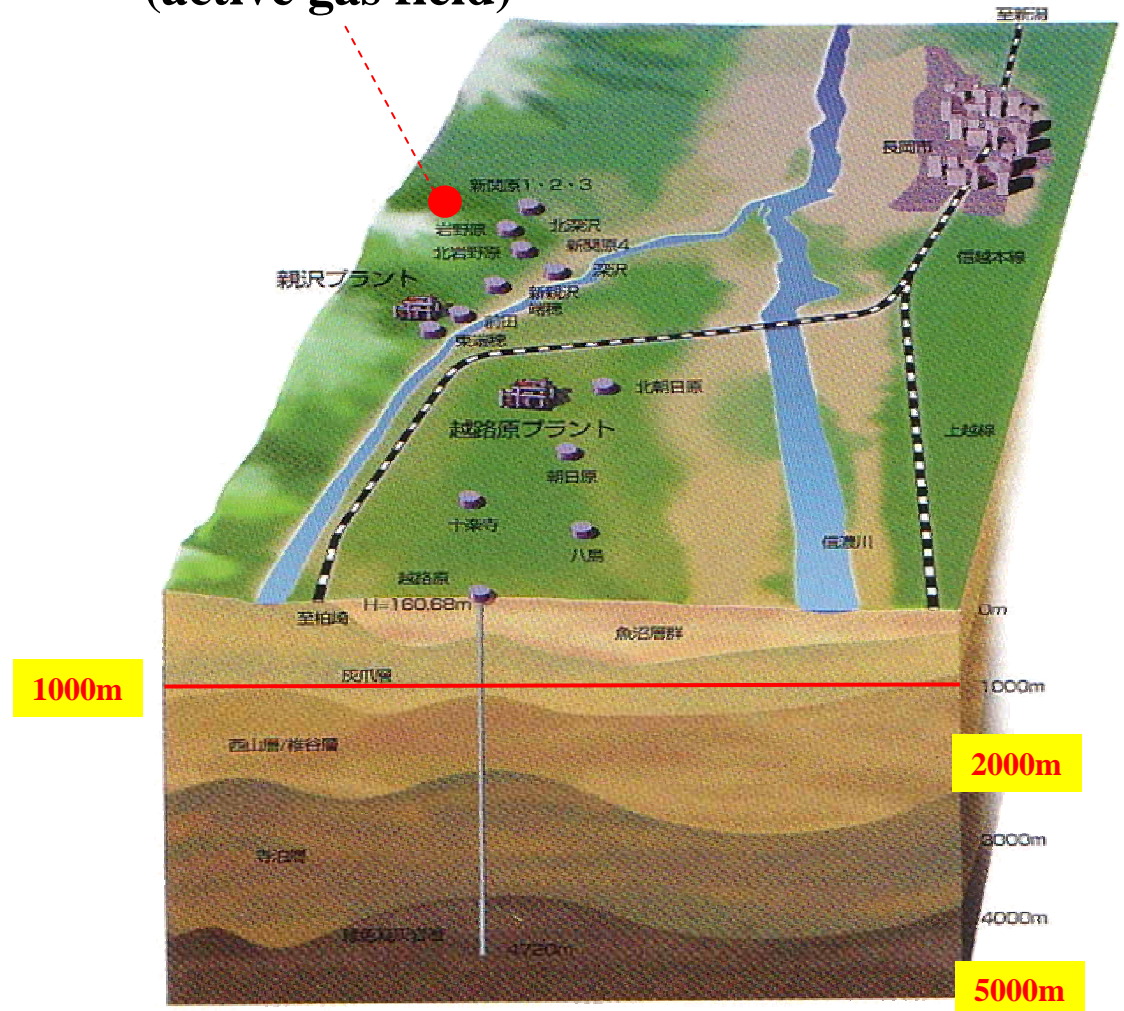


***the Nagaoka project &
CO₂ Monitoring***

Location of the Field Test Site for CO₂ Injection



Teikoku Oil, Niigata Prefecture (active gas field)



Overview and Objectives of the Project

- A Pilot-scale Demonstration -

- ◆ **Improved Understanding of the CO₂ Movement in the Porous Sandstone Reservoir**
 - ▶ **Seismic Wave Velocity Response to CO₂ Injection**
 - ▶ **Mechanism for the Injected CO₂ 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**

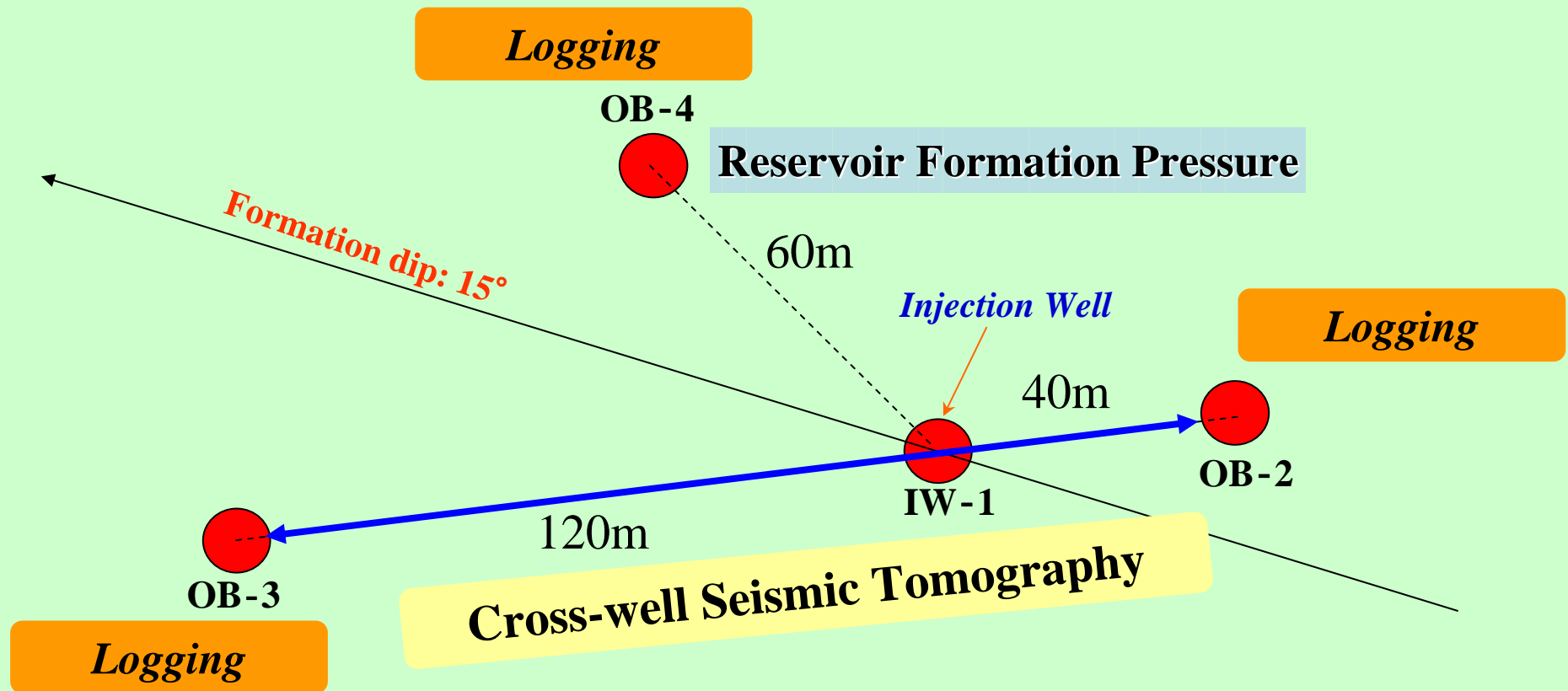
Objectives of time-lapse well logging and pressure measurement

- CO₂ breakthrough time (*calibrating geological model*)
- CO₂ movements after breakthrough & formation pressure buildup disappeared (*driving force and long term behavior prediction*)

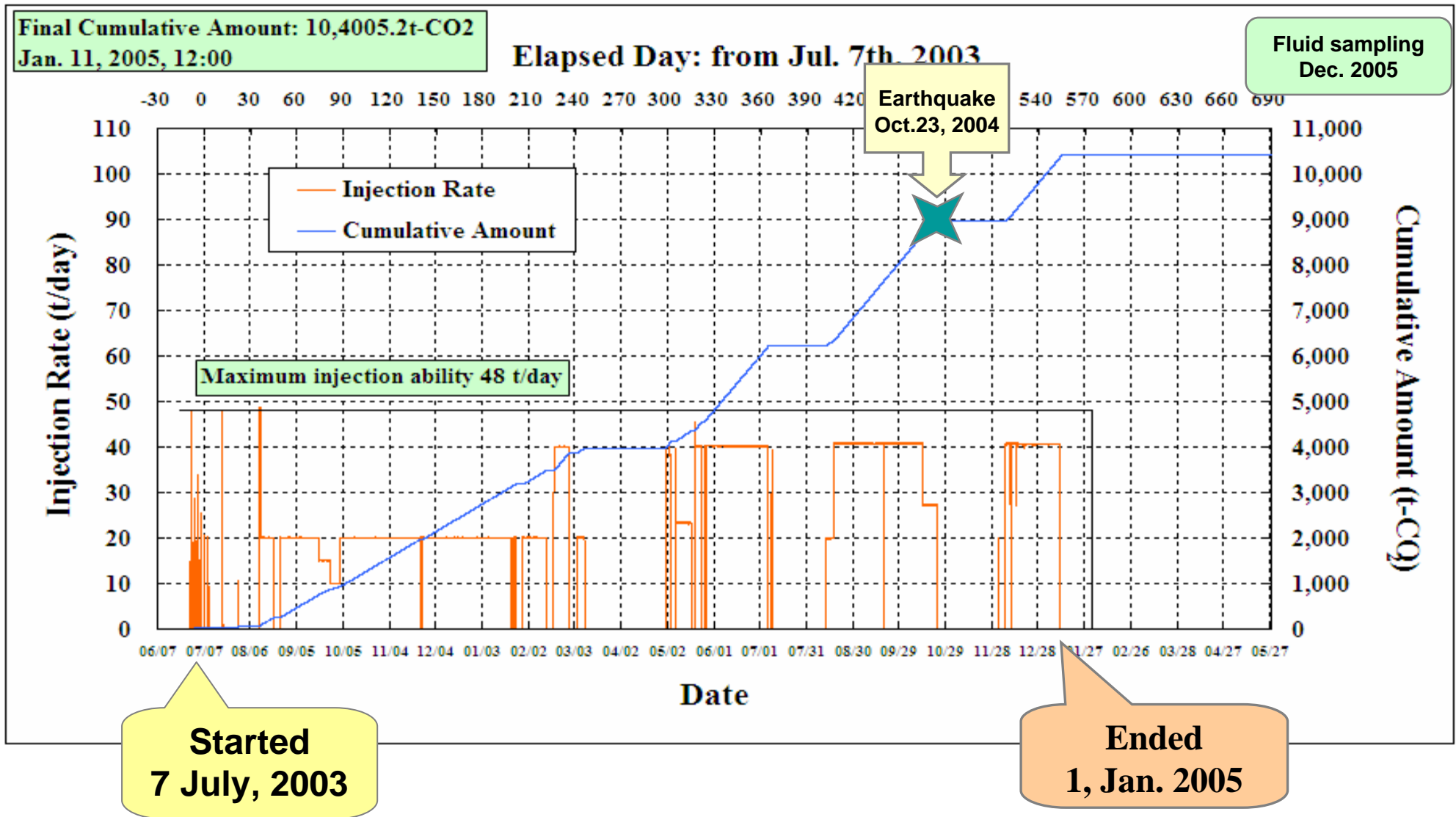
Trapping Mechanism

- 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)

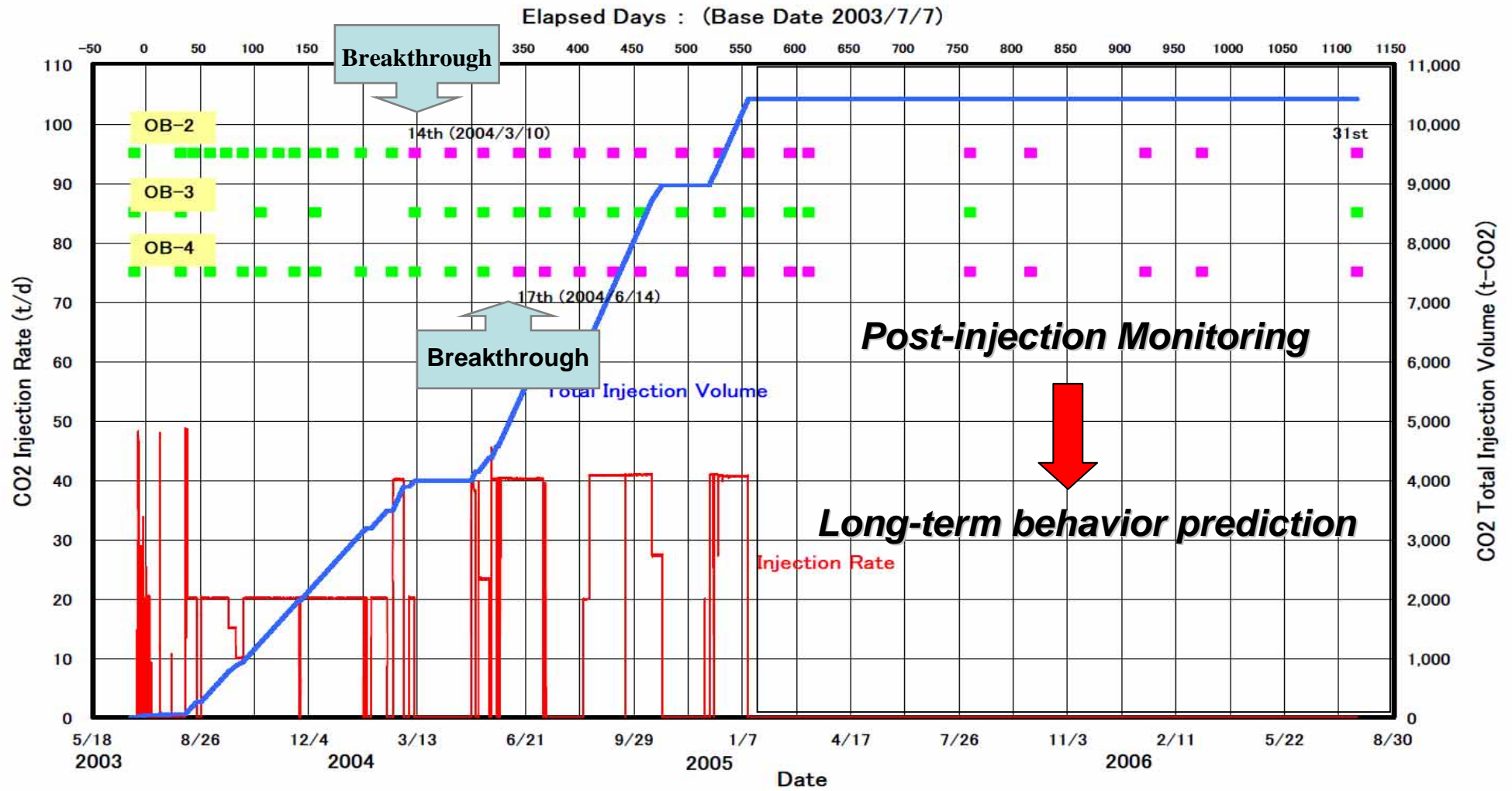
Geophysical Monitoring of CO₂ Sequestration



History of the CO₂ Injection at Nagaoka



Time-lapse Well Logging



CO₂ Breakthrough time at OB-2 & -4

16th run on May 12 (4,300t-CO₂)
No Change

13th run on Feb. 12 (3,500t-CO₂)
No Change

17th run on June 14, (5,400t-CO₂)

- P-wave velocity : -13%
- Neutron porosity : -6 %

14th logging on Mar. 10 (4,000t-CO₂)

- P-wave velocity : -28%
- Resistivity : +10%
- Neutron porosity : -10 %

OB-3



120m

OB-4



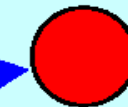
60m



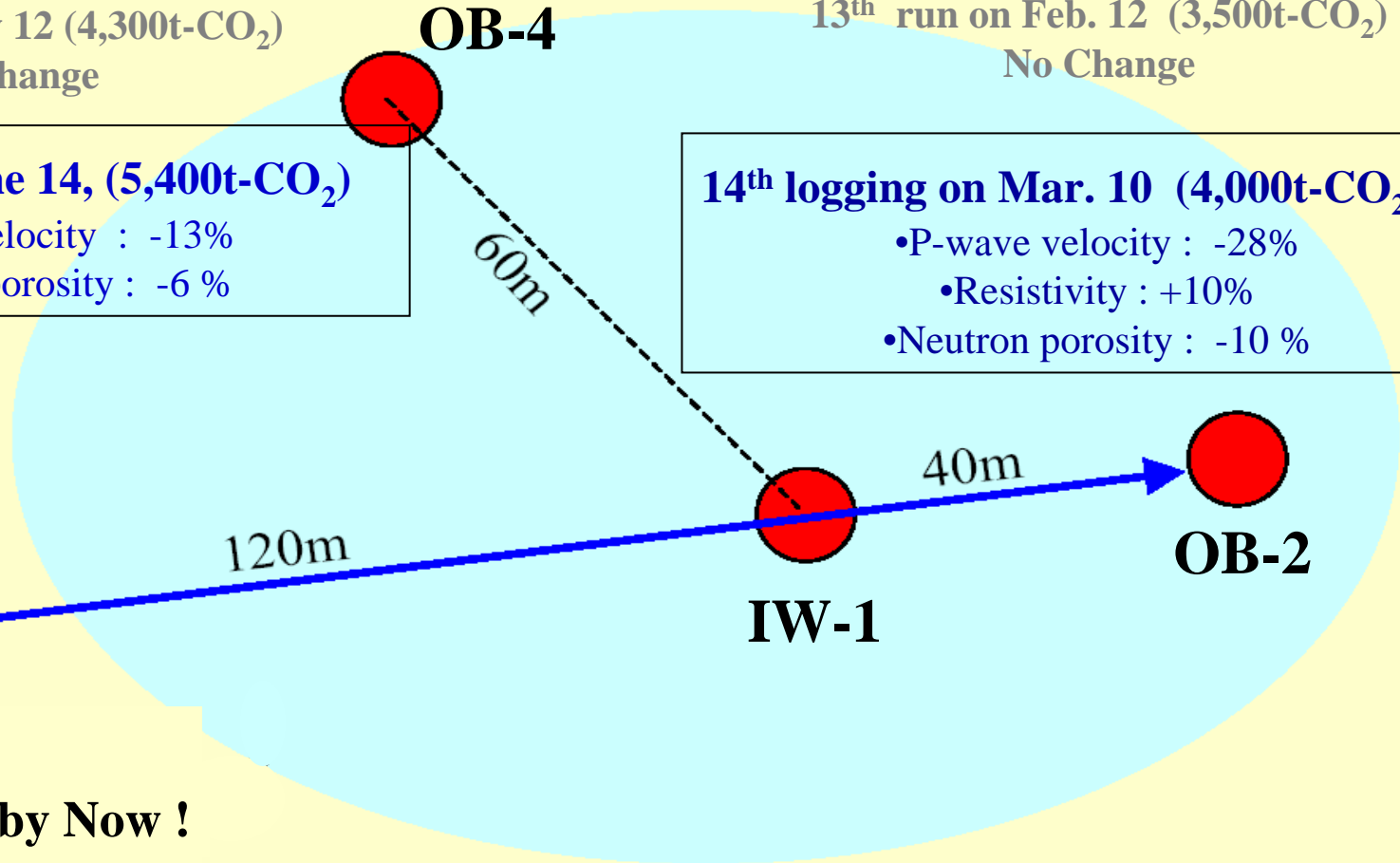
IW-1

40m

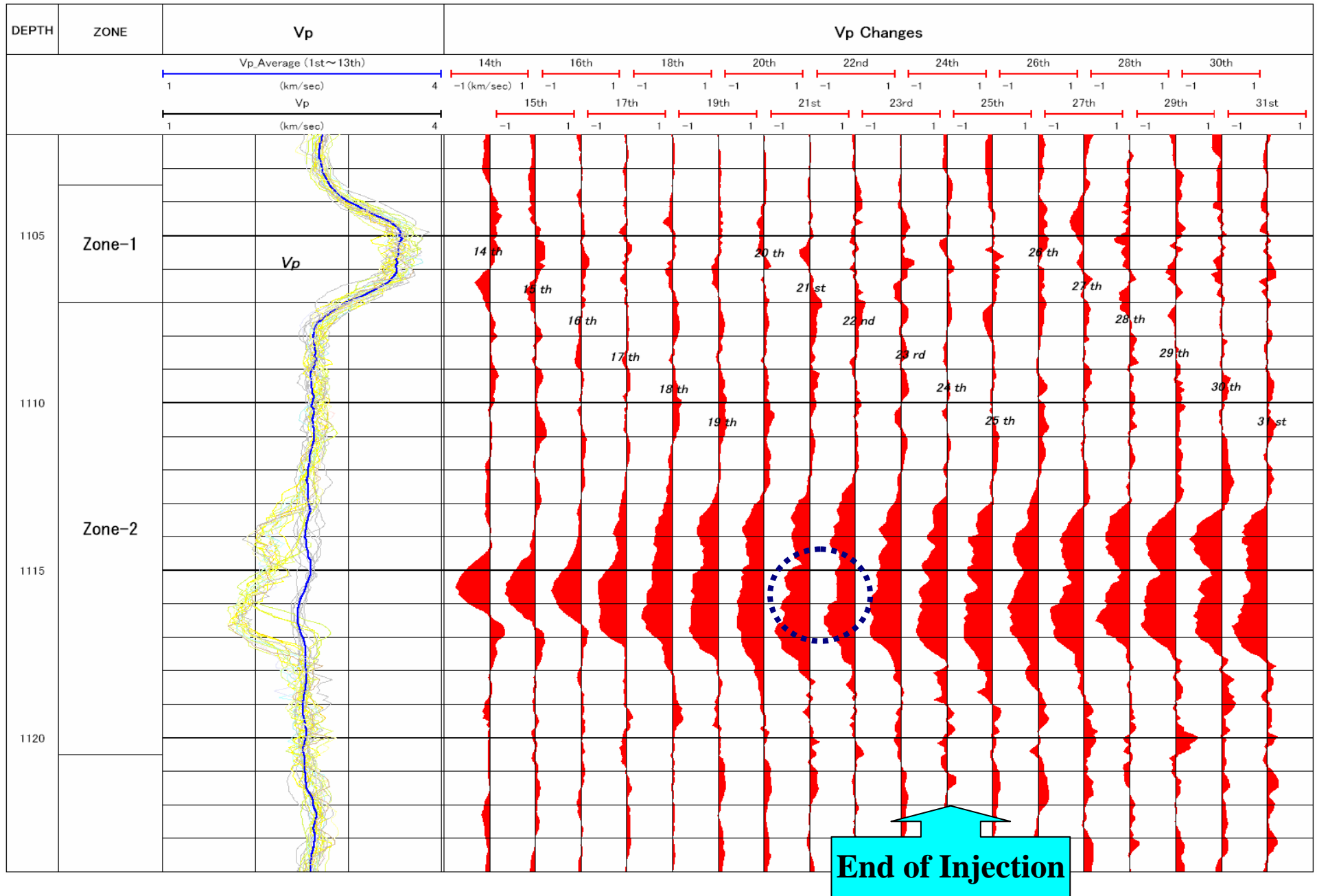
OB-2



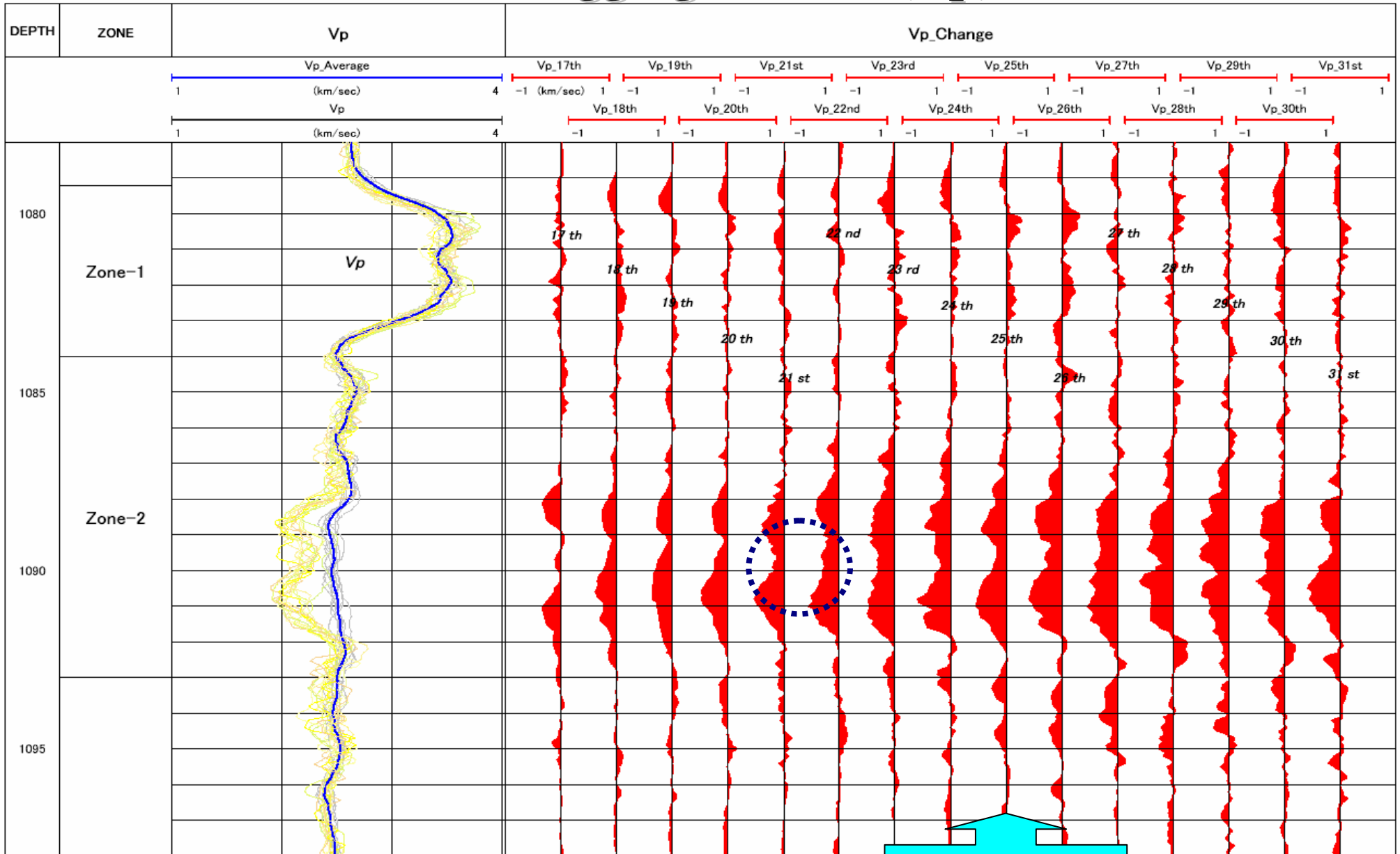
No Changes by Now !



Sonic Logging @OB-2 (Vp)



Sonic Logging @OB-4 (Vp)

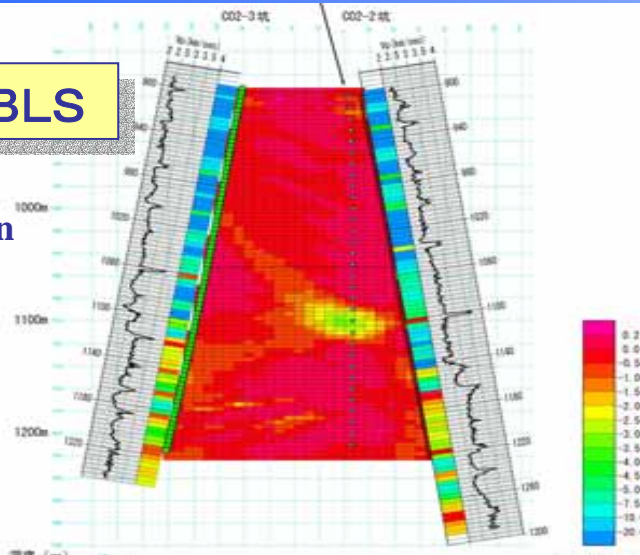


End of Injection

Results of Crosswell Seismic Tomography

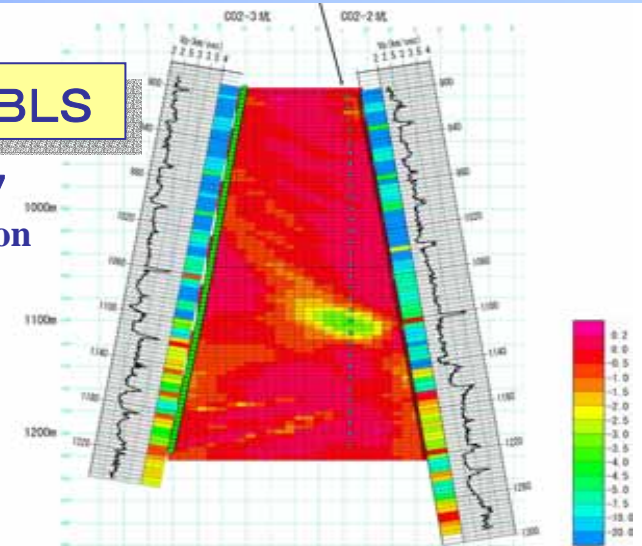
MS1/BLS

2004/1
3, 200 ton



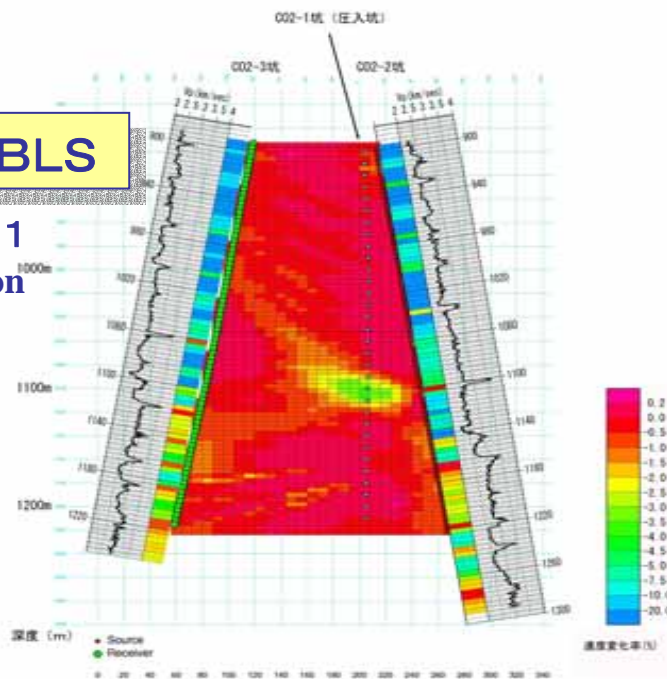
MS2/BLS

2004/7
6, 200 ton



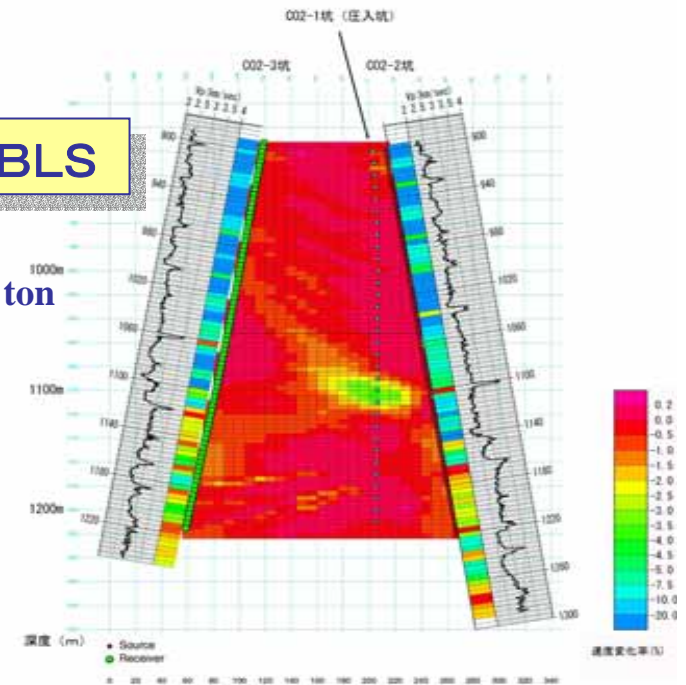
MS3/BLS

2004/11
8, 900 ton



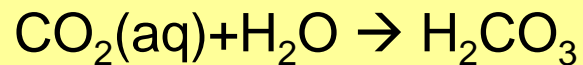
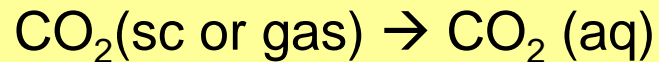
MS4/BLS

2005/1
10, 400 ton

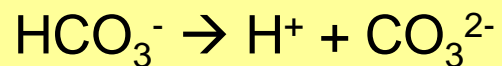
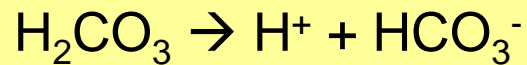


Geochemical Monitoring

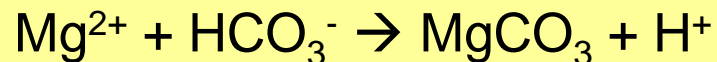
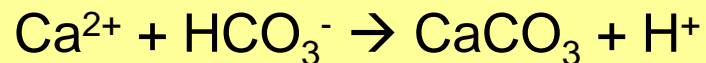
— *fluid sampling from the reservoir* —



Solubility trapping



Ionic trapping



Mineral trapping

Fluid sampling

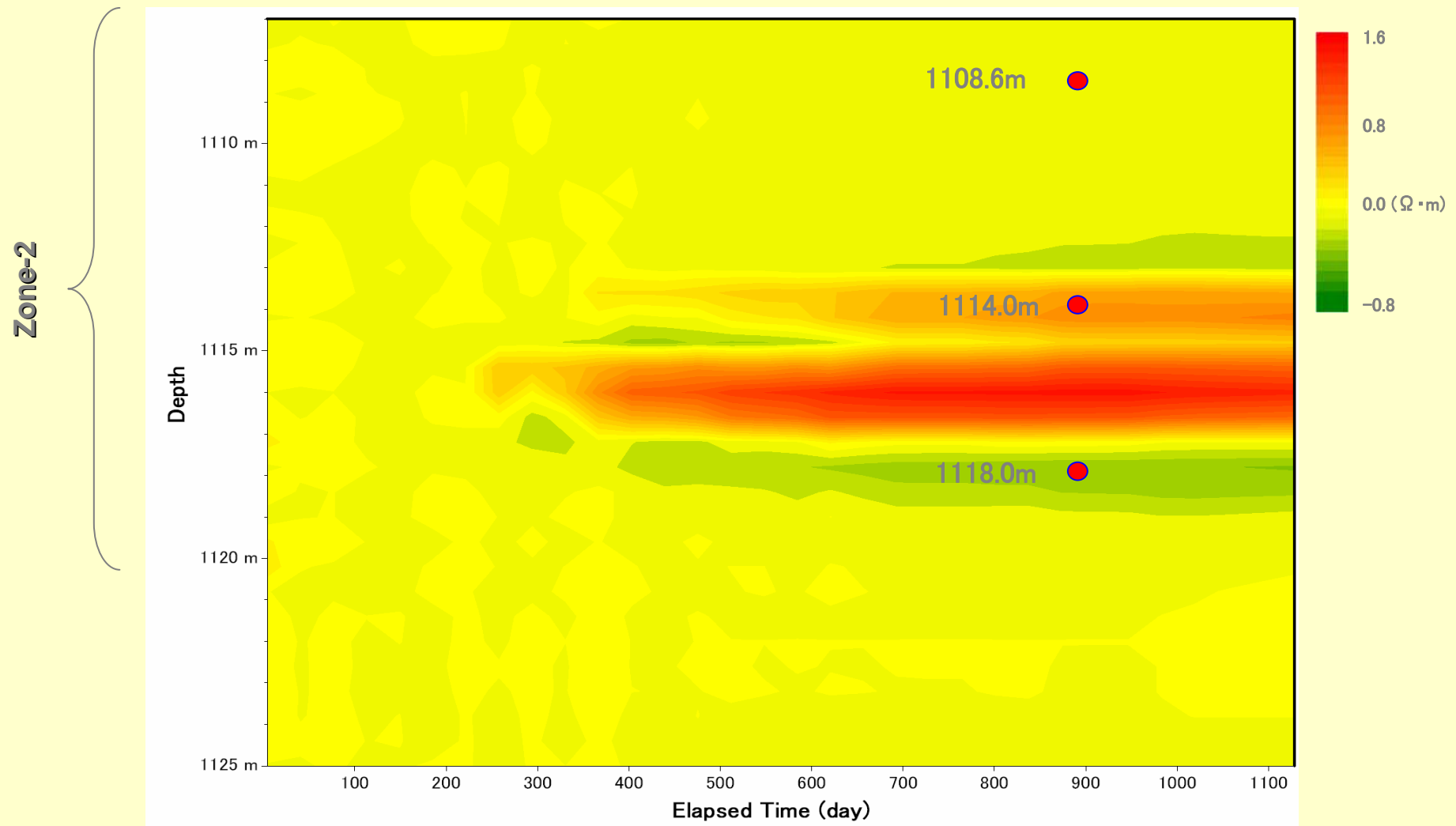
CHDT*(Cased Hole Dynamic Tester)



Drill

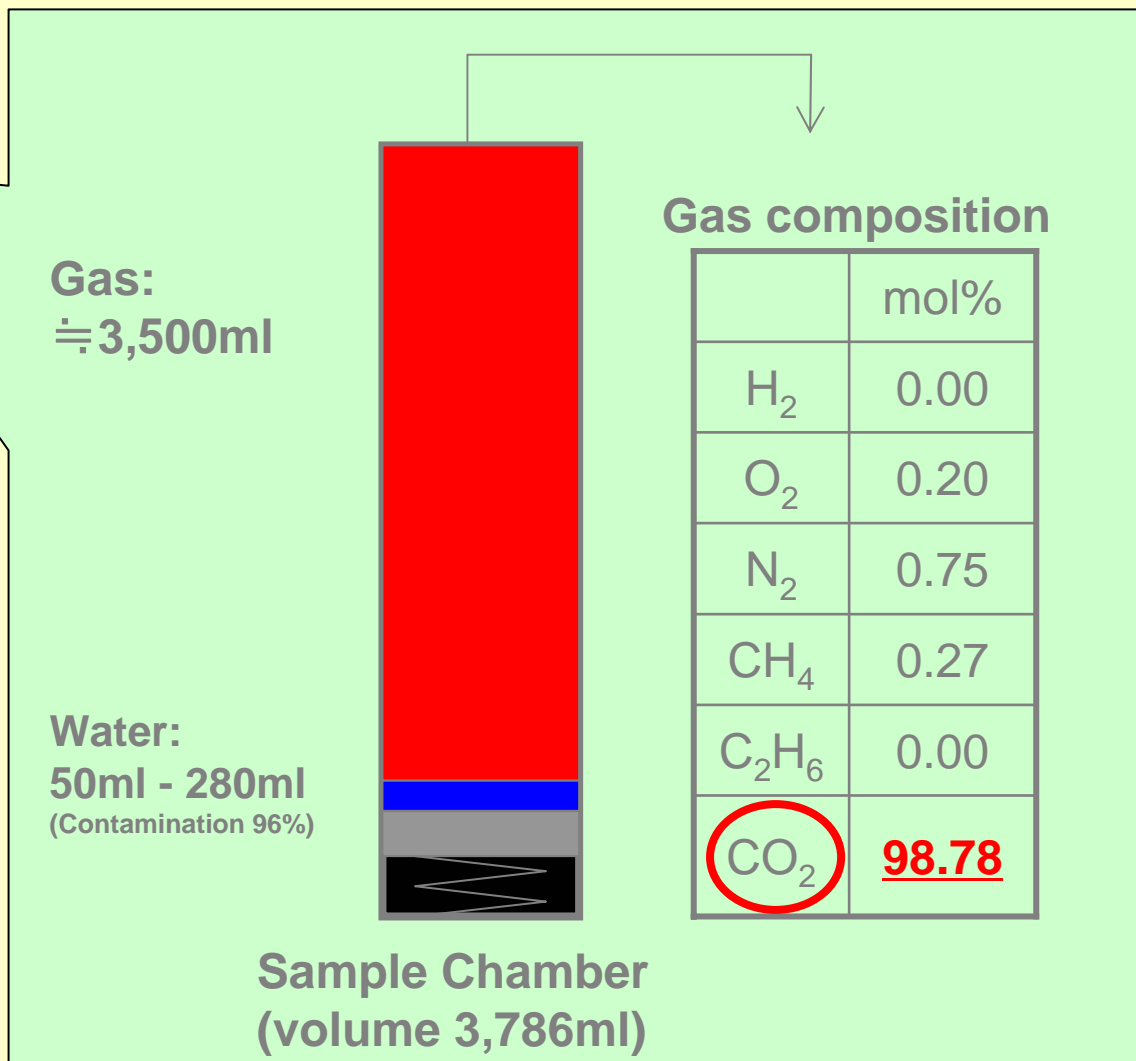
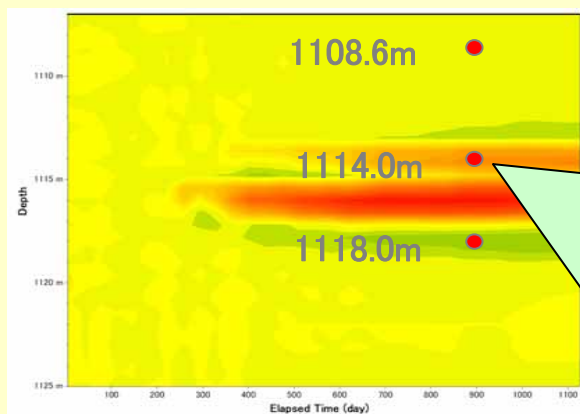


Fluid Sampling Points at OB-2



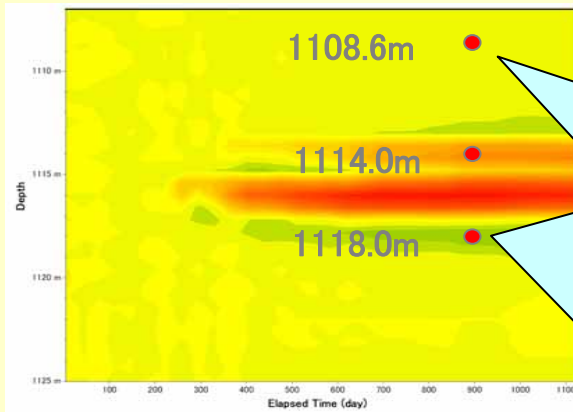
Fluid sampling

OB-2 1114m : Mostly free CO₂



Fluid sampling

OB-2 1108.6m & 1118m : Water



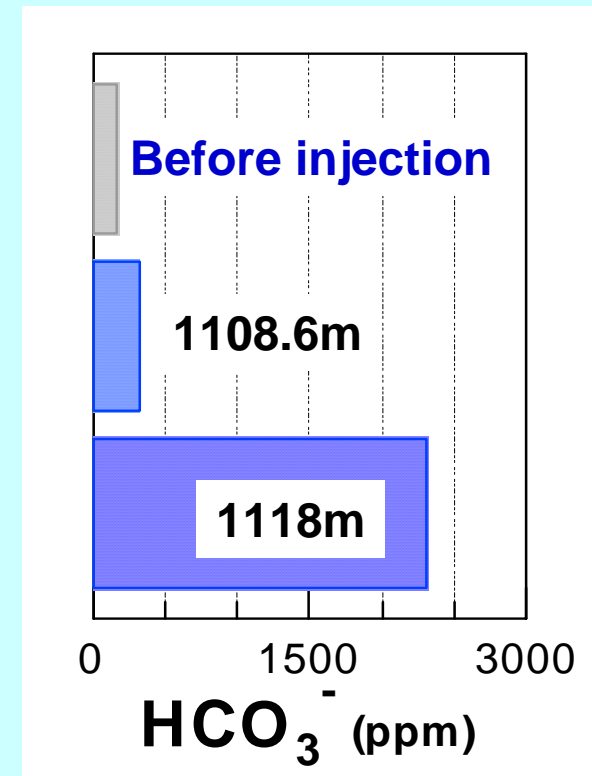
At 1118m,
formation water
rich in
dissolved CO₂.

Gas:
None

Water:
3430ml
-3540ml
(Contamination <1%)

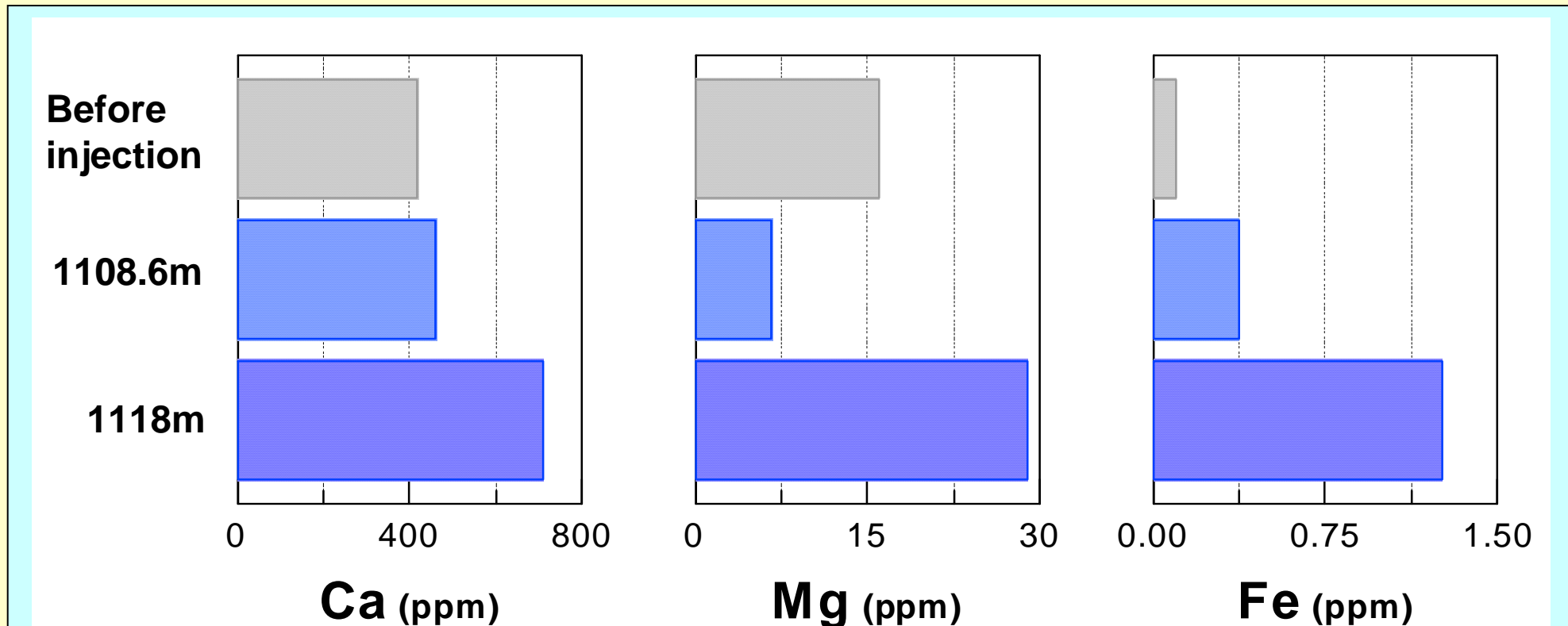


Sample Chamber
(volume 3,786ml)



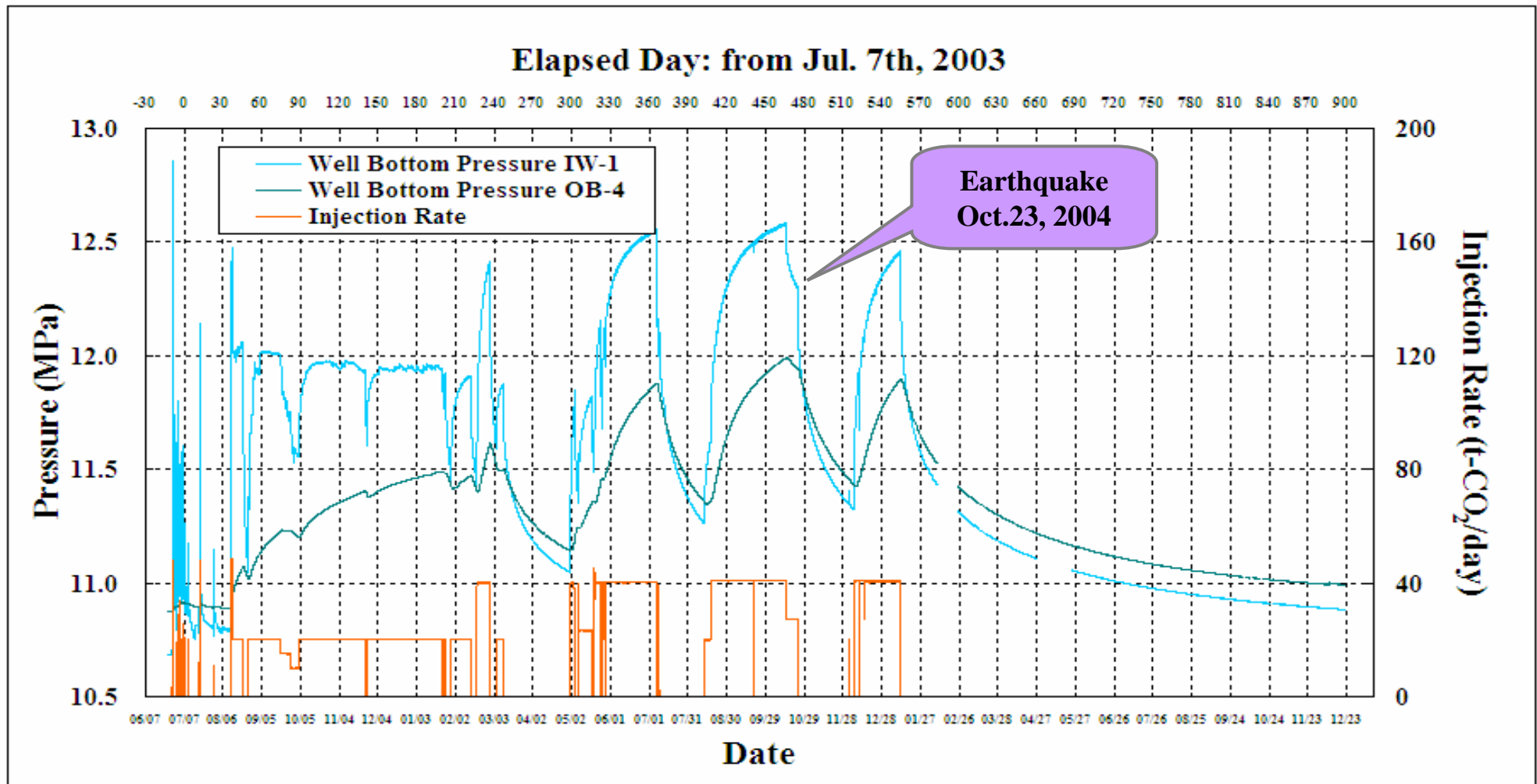
Fluid sampling

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.

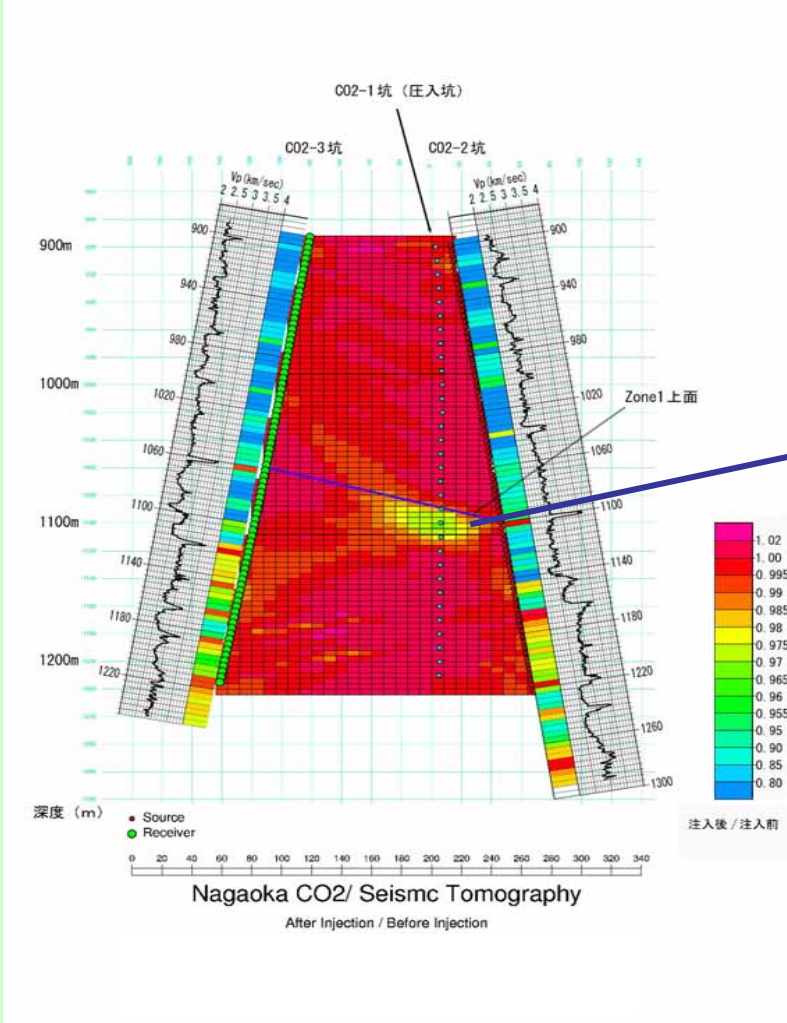
Formation Pressure Measurements



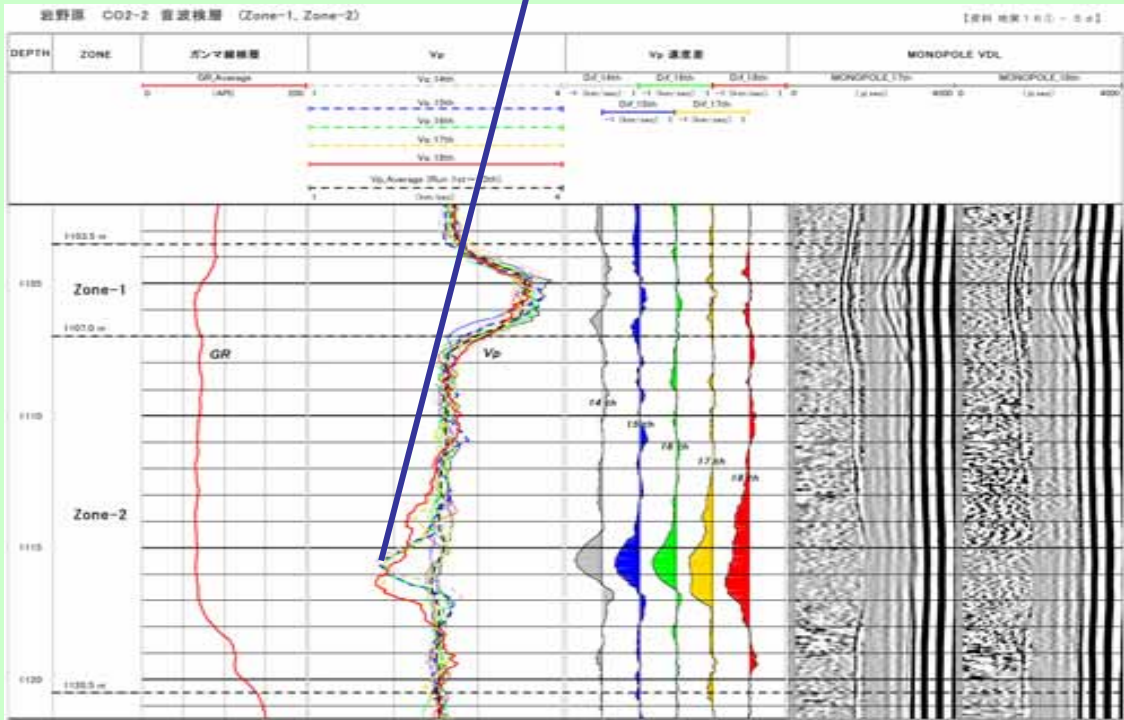
An aerial photograph of a forest with a yellow text box overlaid. The forest is dense with trees, and the colors are somewhat muted, suggesting a late autumn or winter scene. The text box is a solid yellow rectangle with black text inside.

Interpretations on CO₂ Monitoring Results

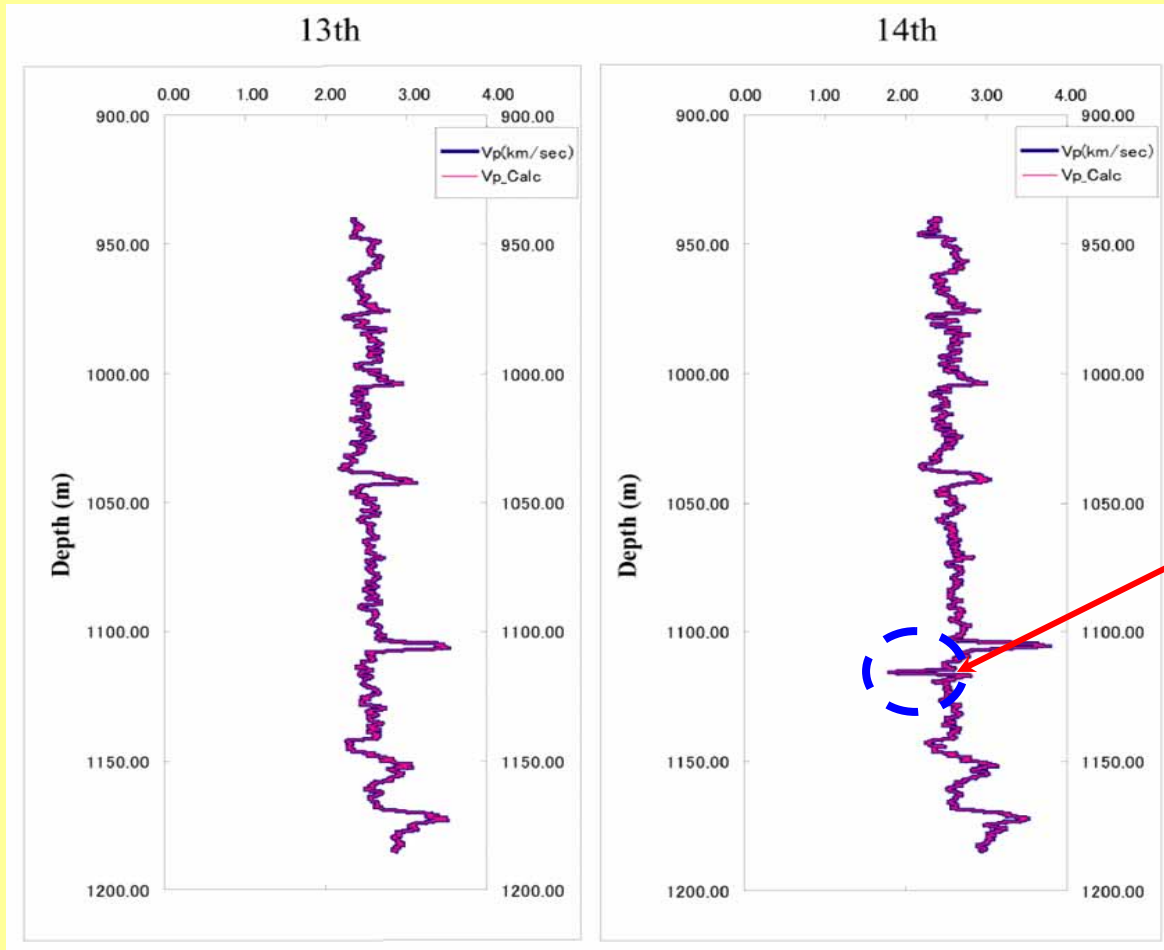
Can we quantify in situ CO₂ ?



CO₂ saturation ?



History Matching on Sonic Vp



Estimation of CO₂ Saturation
with Gassmann theory

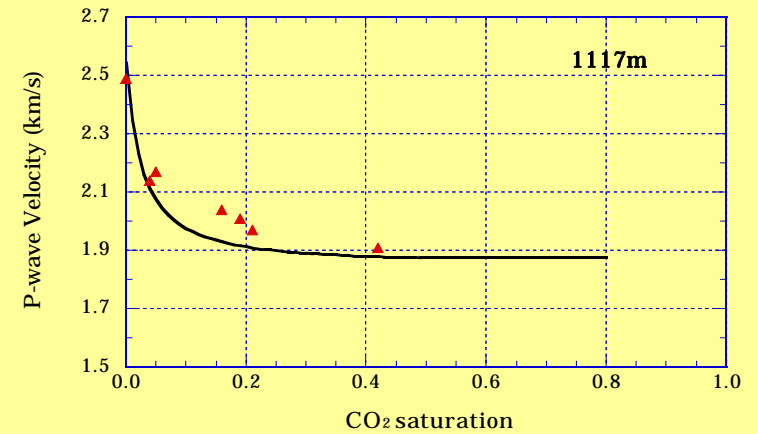
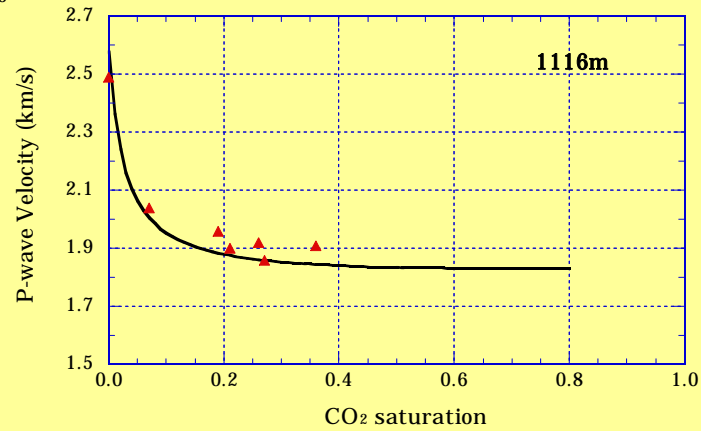
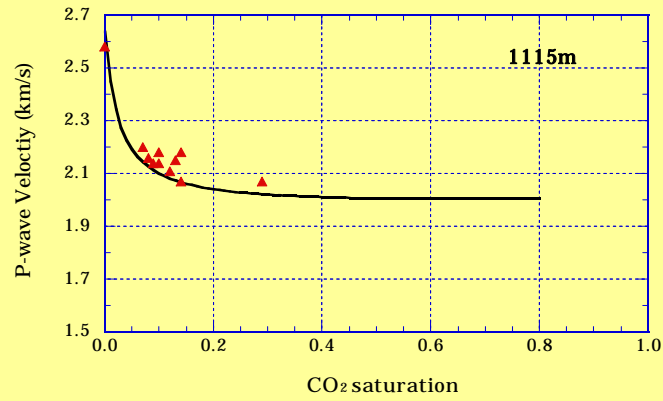


Velocity reduction due to
breakthrough of CO₂

Xue et al., 2006

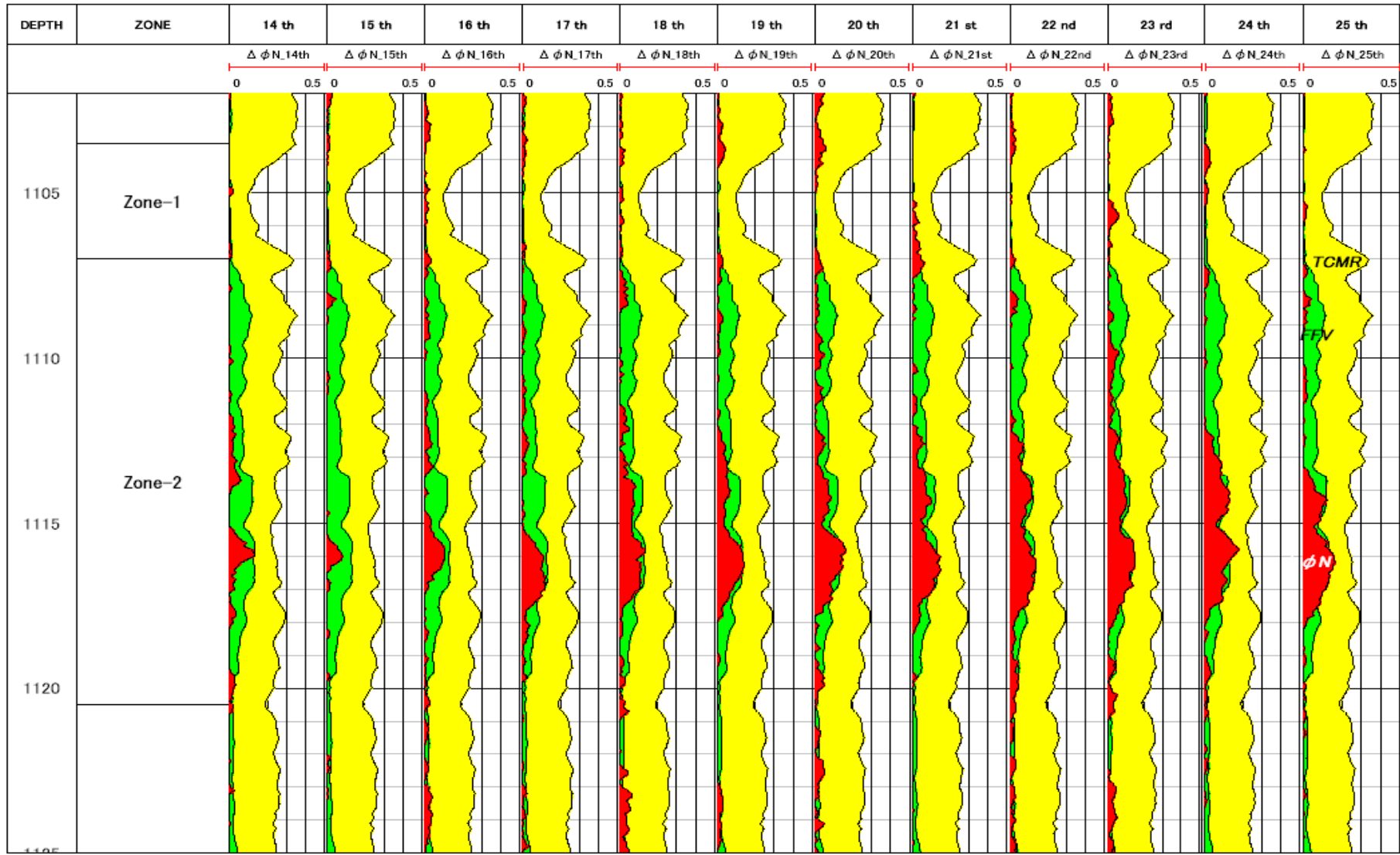
Sonic Vp in Observation Well OB-2 at Nagaoka CO₂ Injection Site

P-wave velocity vs CO₂ saturation



▲ : estimated from sonic Vp
@ OB-2

CO₂ saturation in OB-2 (from NMR Log)



Conclusion Remarks

- **Time-lapse crosswell seismic tomography and well logging data image CO₂ clearly.**
- **CO₂ migration pattern depends strongly on the heterogeneity of the sandstone reservoir.**
- **Successfully applied Gassmann Theory to estimate CO₂ saturation from sonic P-wave velocity.**
- **Results of CO₂ monitoring improved understandings of CO₂ 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 CO₂ injection project.**



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Launching in 2007, this journal will cover developments in greenhouse gas control in the power sectors and in the major manufacturing and production industries. It will cover all greenhouse gas emissions and the range of abatement options available, and comprise both technical and non-technical related literature in one volume.

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- Characterization of emission sources (current and future projections) including modelling analyses
- Matching emissions sources and storage opportunities

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- Design and technical issues
- Risk assessments and safety issues
- Permitting and regulatory issues

CO₂ Capture

- New research results and technical advances on chemical solvents, solid adsorbents, membranes and hybrid systems, PSA, FSA and cryogenics
- Results from demonstration activities
- Cost analyses and cost reduction strategies
- Environmental impacts/risk and safety

CO₂ Storage

- Geological and ocean (formation) capacity assessments, research results, demonstration projects, natural analogues, environmental impact, site selection, operational experiences, safety/risk assessments, monitoring and verification, inventories and accounting principles, legal issues, public acceptance, regulation and cost/market potential
- Mineral carbonates (research results, safety/risk assessments, legal issues, public acceptance, regulation and costs)

Alternative mitigation options

- Comparison of different GHG mitigation options such as energy efficiency, renewables and nuclear power and their potential to reduce CO₂ emissions

Non CO₂ GHGs

- Characterization of emission sources (current and future projections) including modeling analyses
- Assessment of mitigation options
- Comparison of non- CO₂ GHG options with CO₂ emissions reduction

Implementation

- Industry case studies on GHG mitigation technology implementation and financing options including the use of the Kyoto Mechanisms.

Economic instruments

- Discussion of policy options (national and international) to reduce GHG emissions including energy modeling studies and policy assessments on GHG mitigation.

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