Seismic Velocity and Resistivity Changes during CO_2 Injection into Water-saturated Sandstones

Application of Rock Physics to CO_2 Monitoring in Geological Sequestration

Ziqiu Xue

xue@rite.or.jp

Research Institute of Innovative Technology for the Earth

Monitoring of Injected CO_2

- ***Map the movement of CO_2 & the CO_2 is being safely contained within the reservoir.***
- ***Injection of CO_2 Causes Wave Velocity to Decrease and the Pore Pressure to Increase .***
- ***Lab Experiments are required to Convert Field Results of Wave Velocity to CO_2 Saturation.***

Laboratory Study and Field Survey in CO_2 Geological Sequestration

Field-scale

- 4D Seismic Survey
- Crosswell Tomography
- Well Logging
  (*sonic, induction, neutron*)

Lab-scale

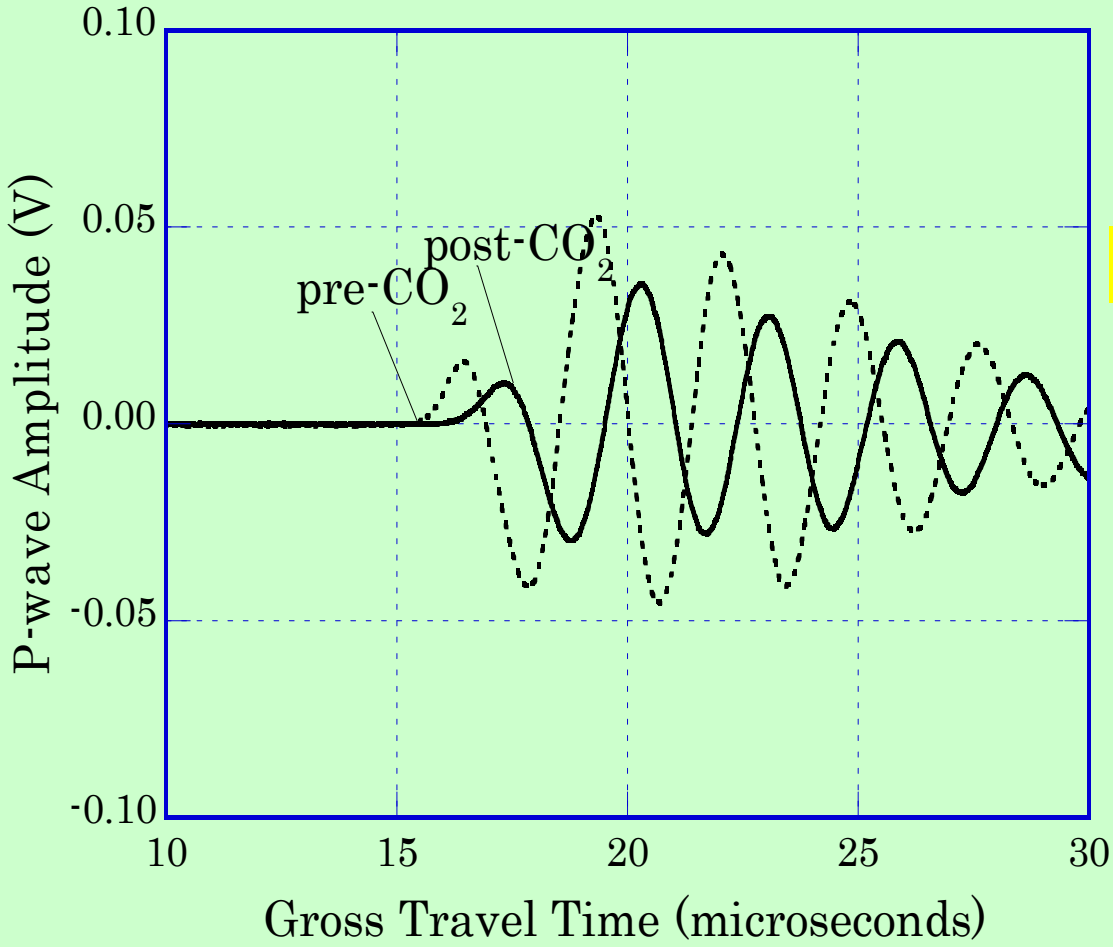
- Wave Velocity and Resistivity changes during CO_2 injection
- Sandstones with different ***porosity*** and ***permeability***
- Drilled Cores from CO_2 injection sites

Geophysical Parameter *velocity, resistivity* ⟺ **Reservoir Parameter** *fluid saturation*

Wave Velocity Response

due to

CO_2 Injection in Tako Sandstone



Supercritical CO_2

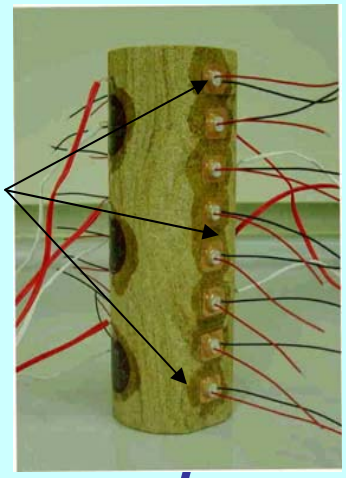
Vp: -10%

P-wave forms obtained from pre- and post- CO_2 flooding in Tako sandstone.

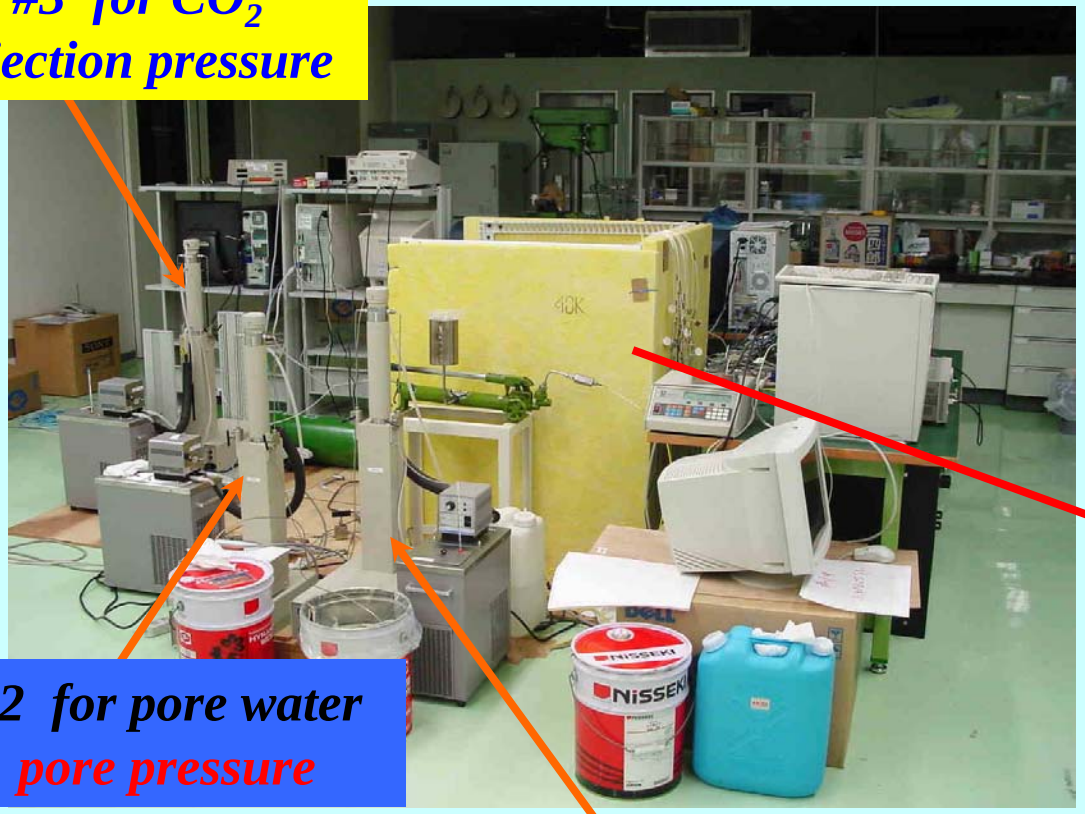
Experimental setup for P-wave velocity tomography

D=5, L=10cm

Array: 8 x 8



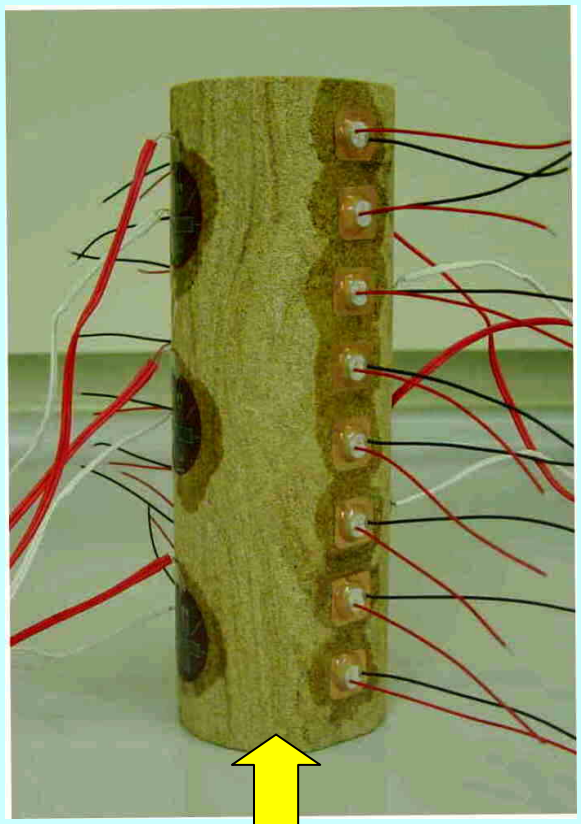
#3 for CO_2 injection pressure



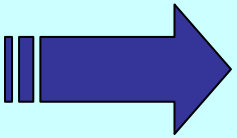
#2 for pore water pore pressure

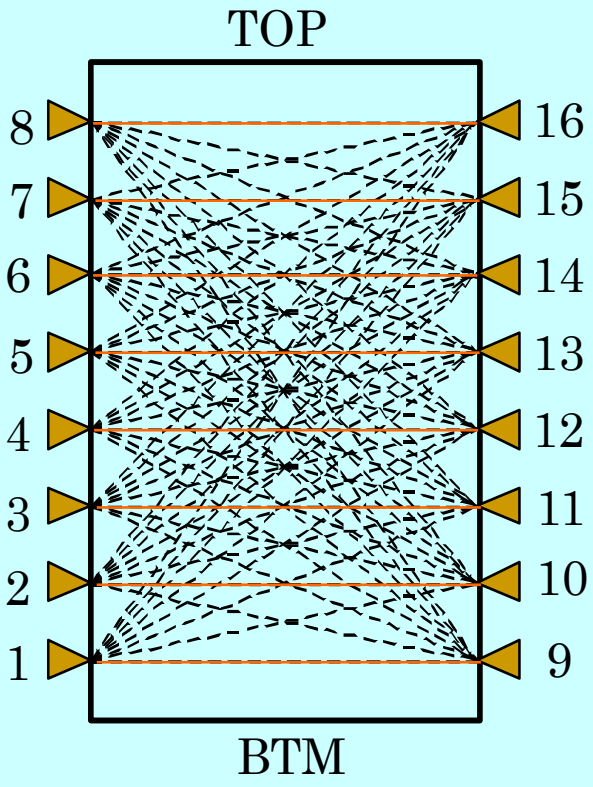
Syringe pump #1 for oil hydrostatic pressure

Experimental Study of Seismic Wave Tomography



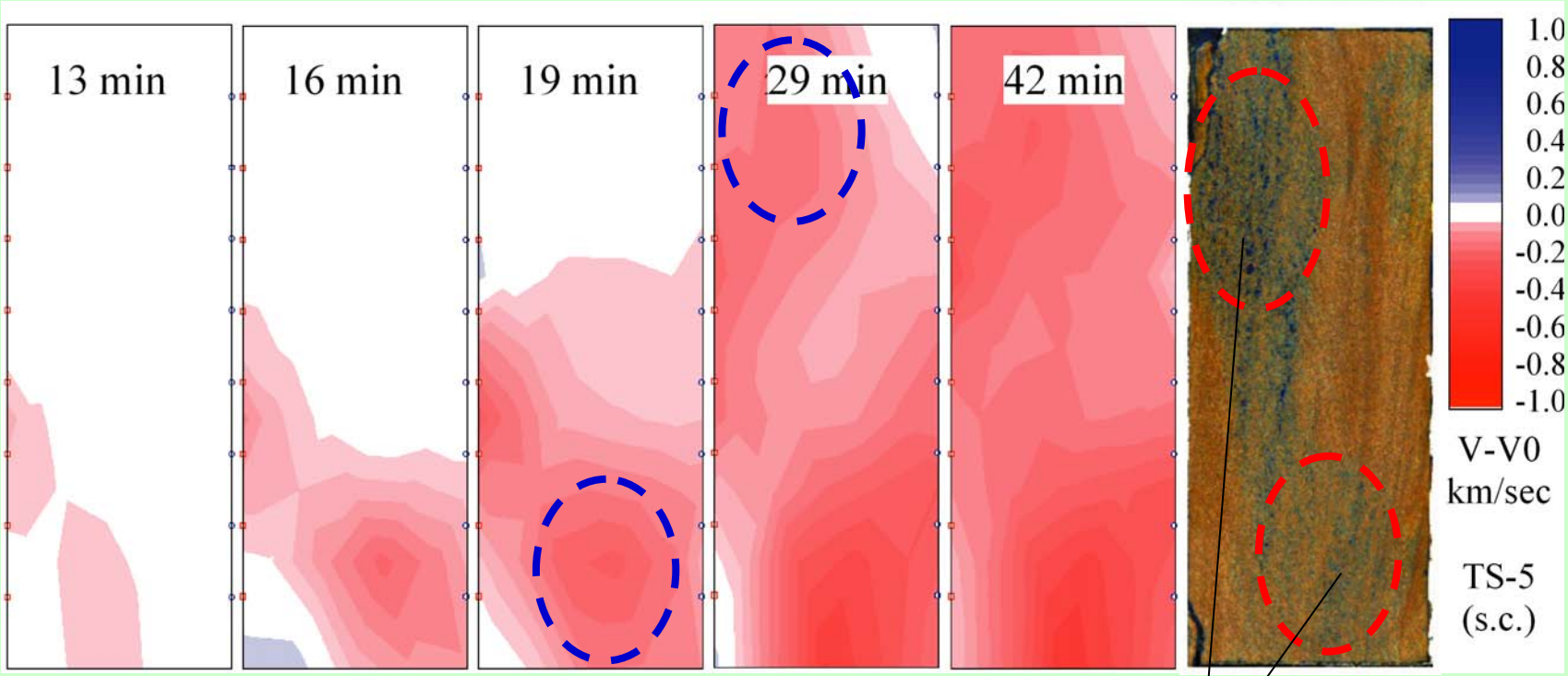
H_2O/CO_2





Sandstone: 23%, 3md

CO_2 migration in water-saturated sandstone



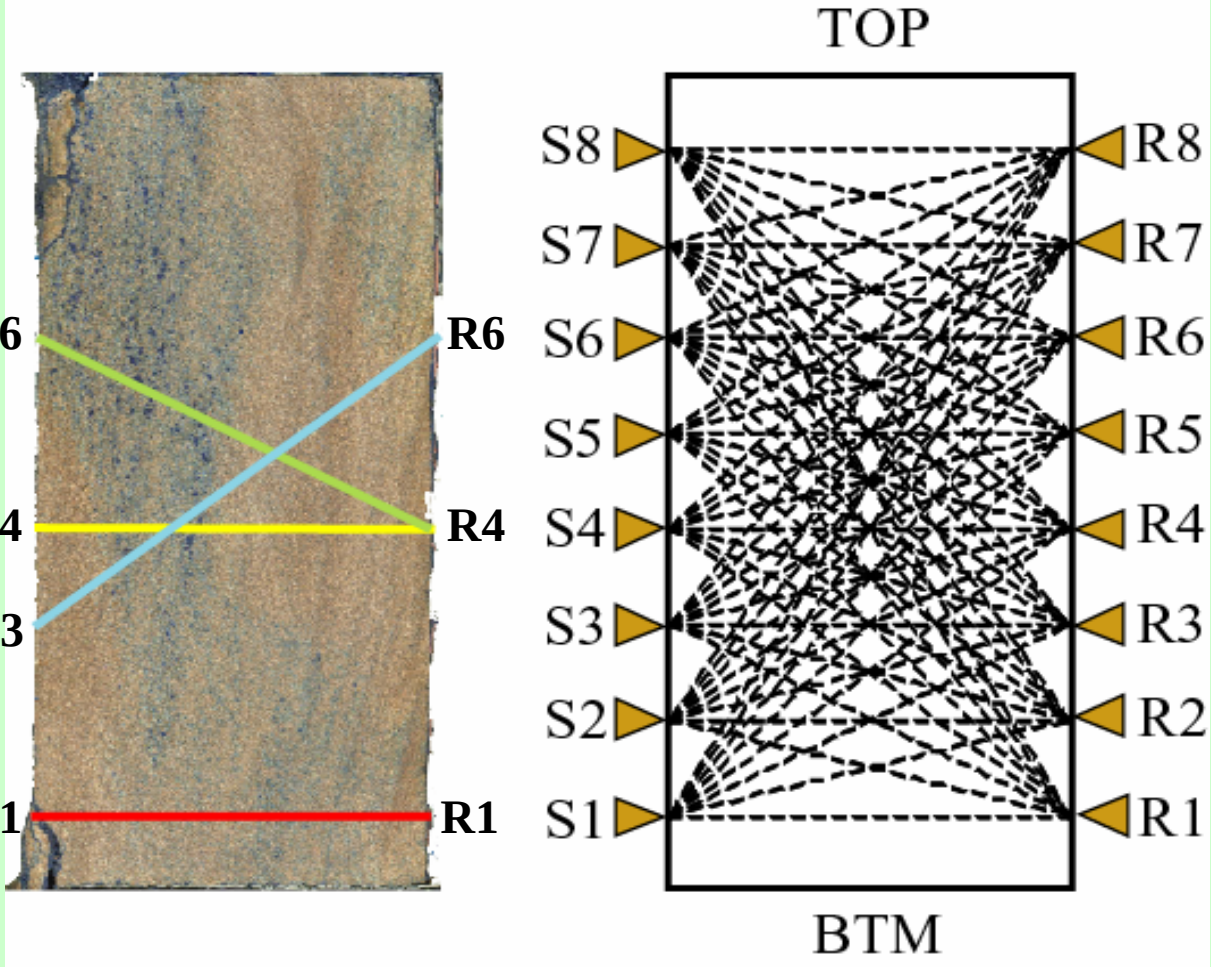
CO_2

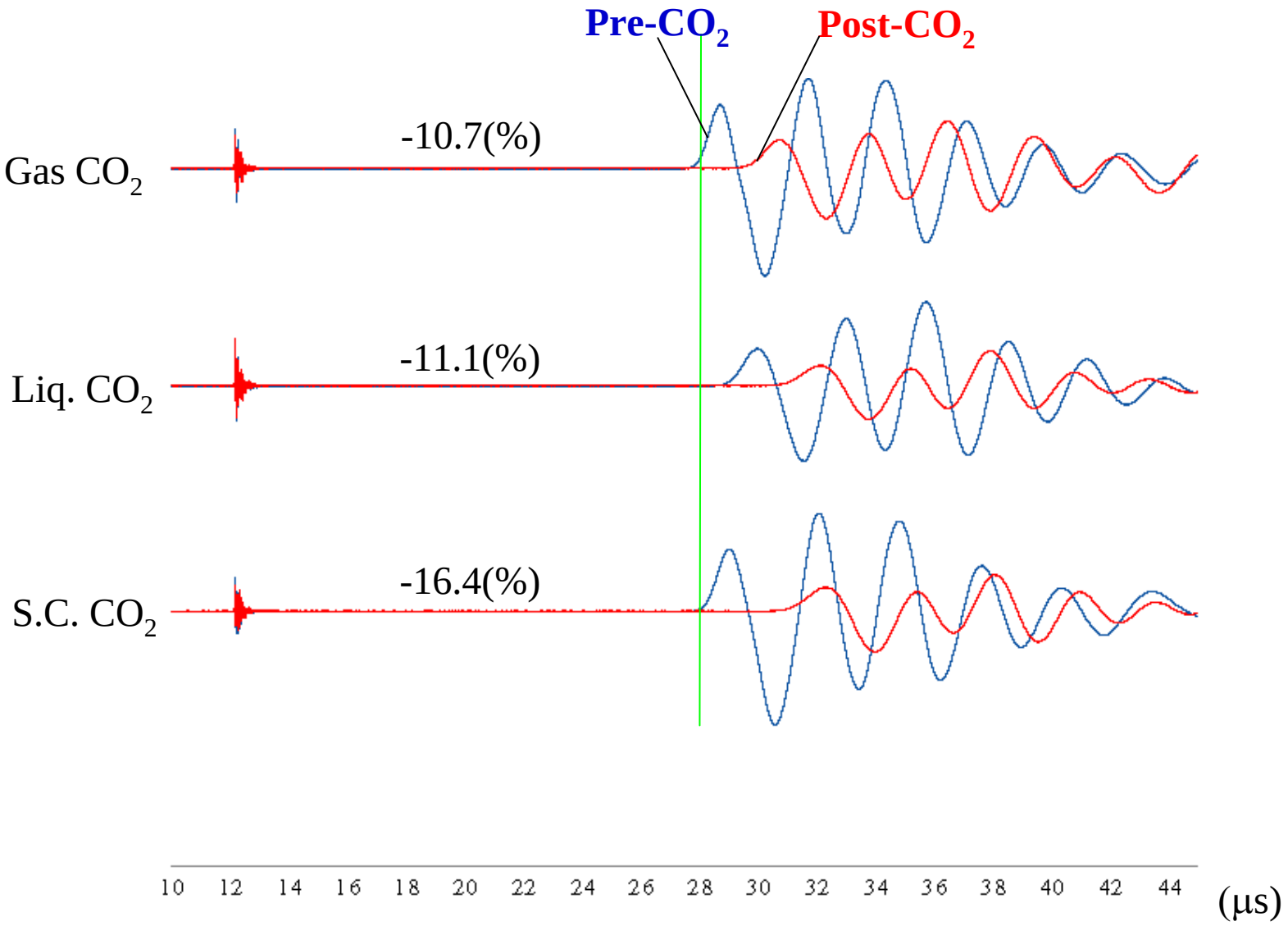
Xue and Lei, 2006

Pore space (blue resin)

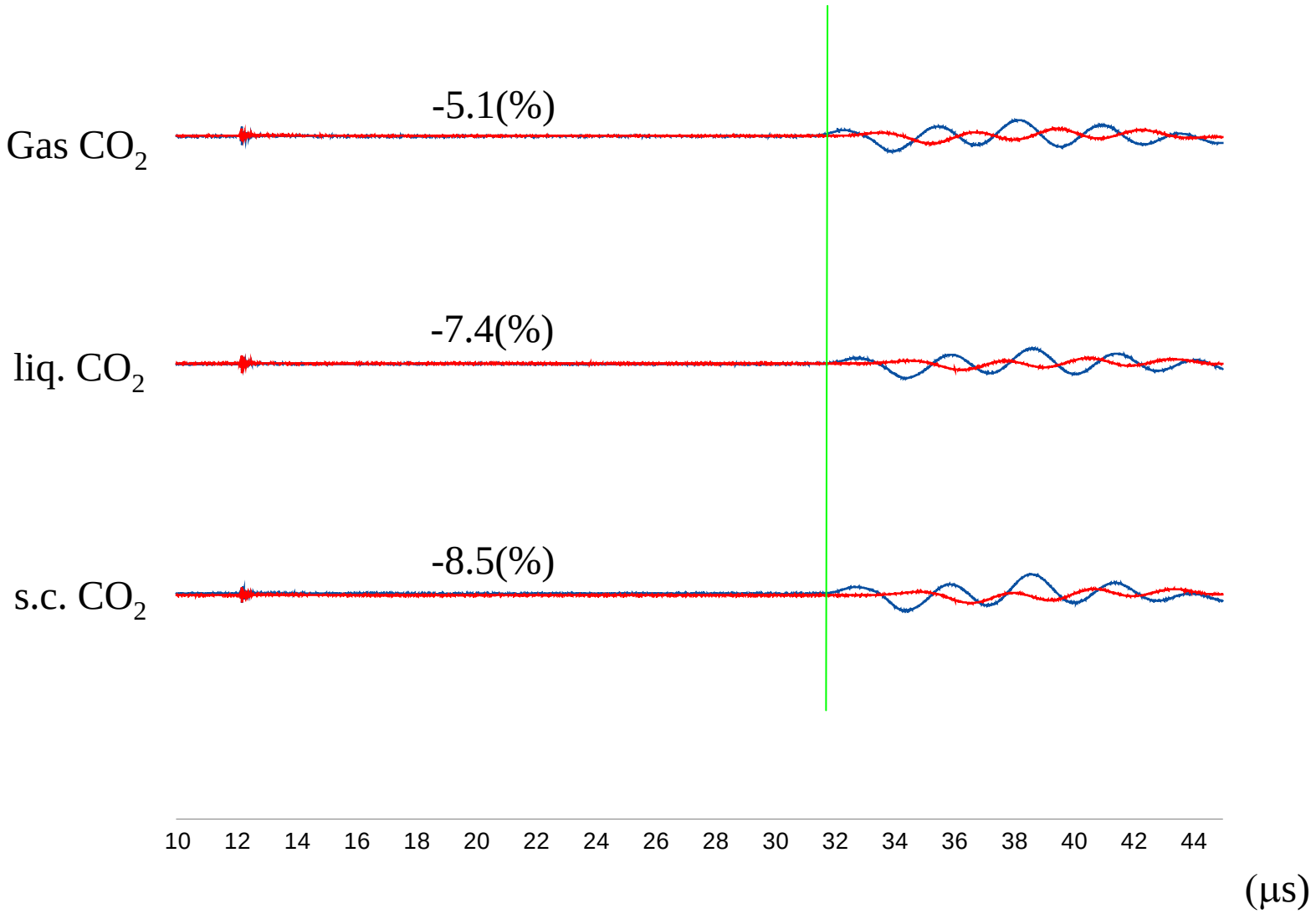
CO_2 flows parallel to bedding plane; Numeric numbers: Elapsed time

Velocity Reduction vs Pore Space





Ray path: S1-R1

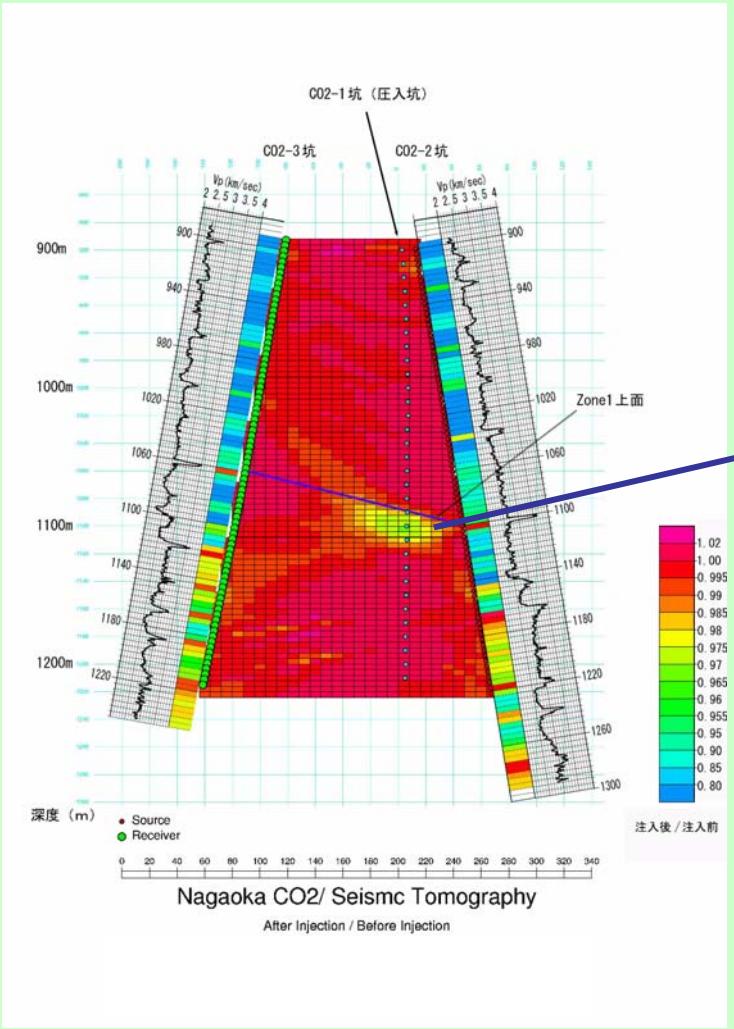


Ray path: S3-R6

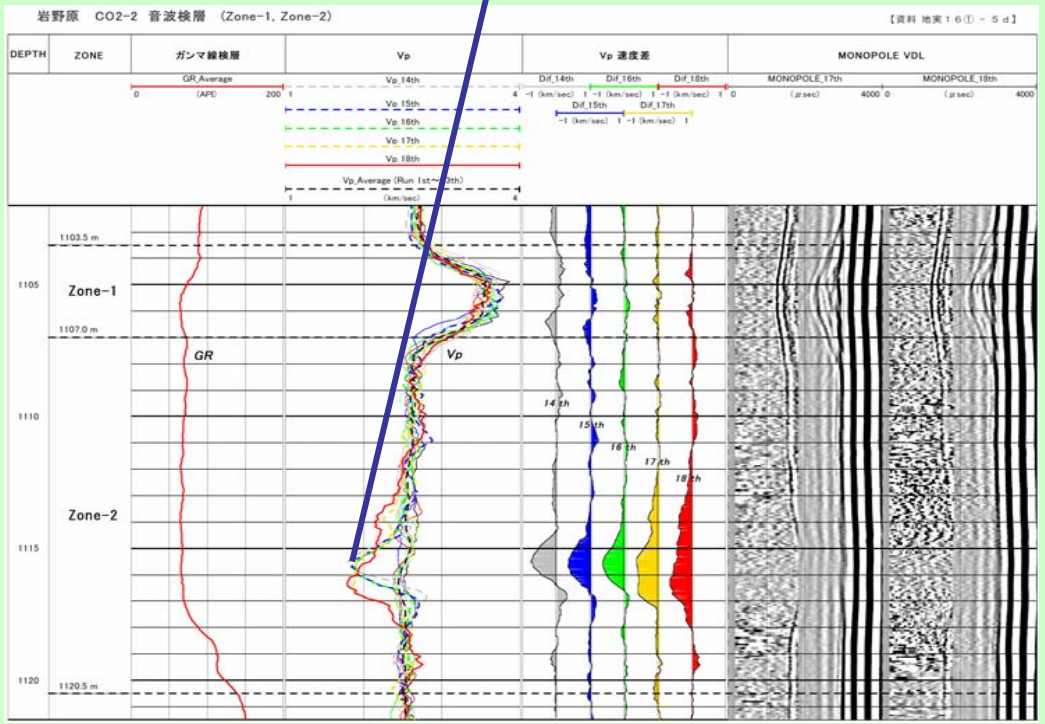
Estimation of CO_2 Saturation

from

Sonic P-wave Velocity

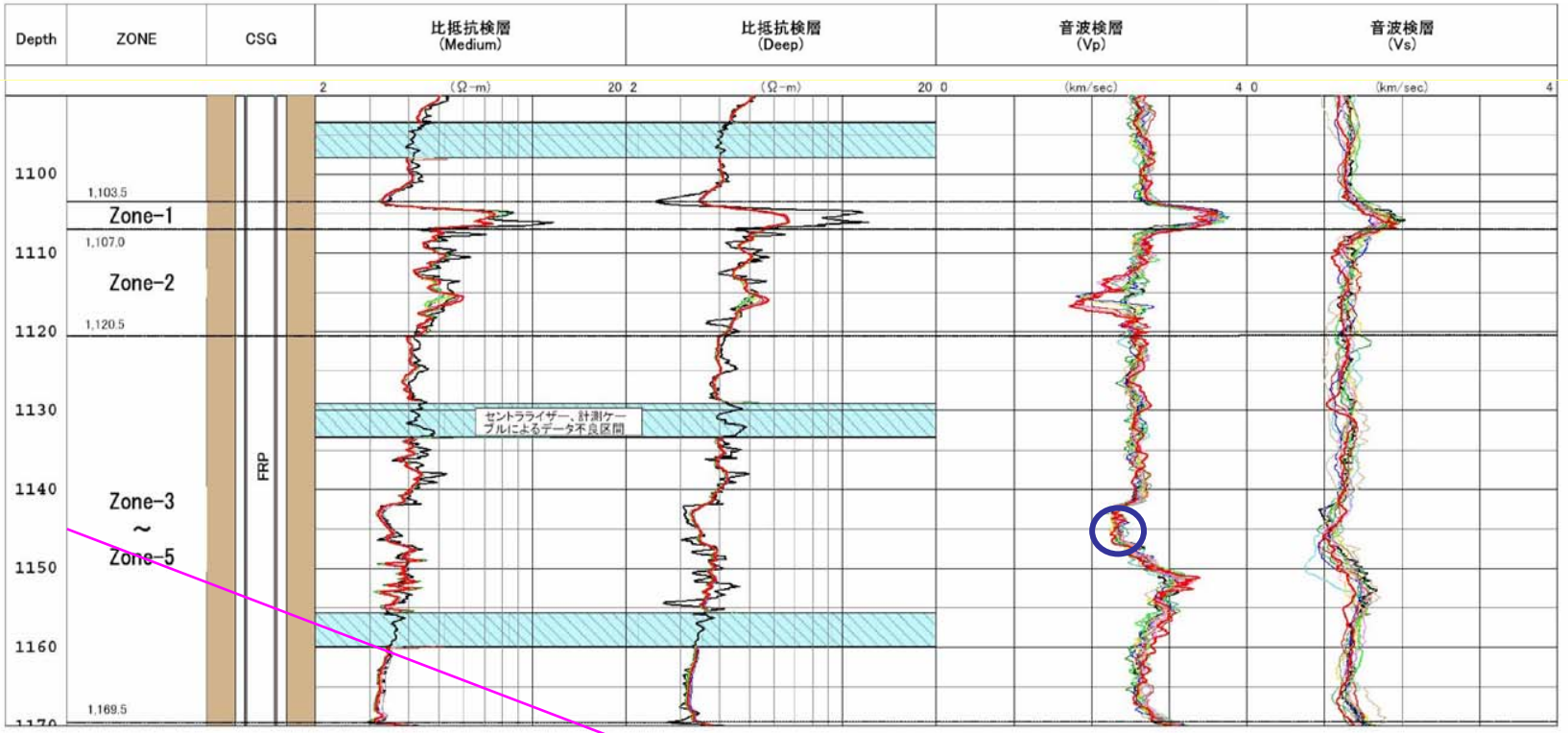


CO_2 saturation
?



Velocity reduction: -23%

Observation Well OB-2



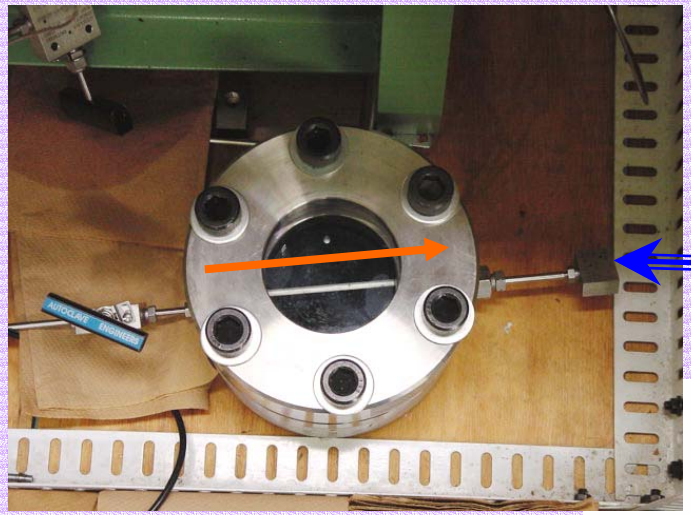
fine-grain sandstone

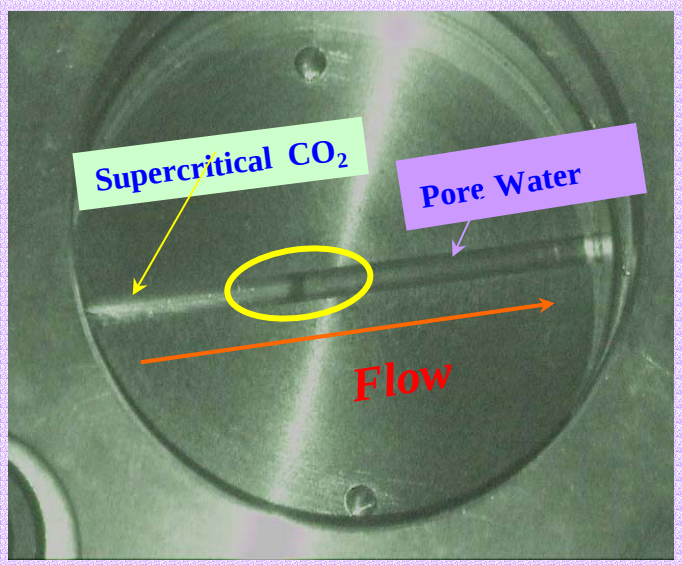
diameter: 5cm, length: 7cm

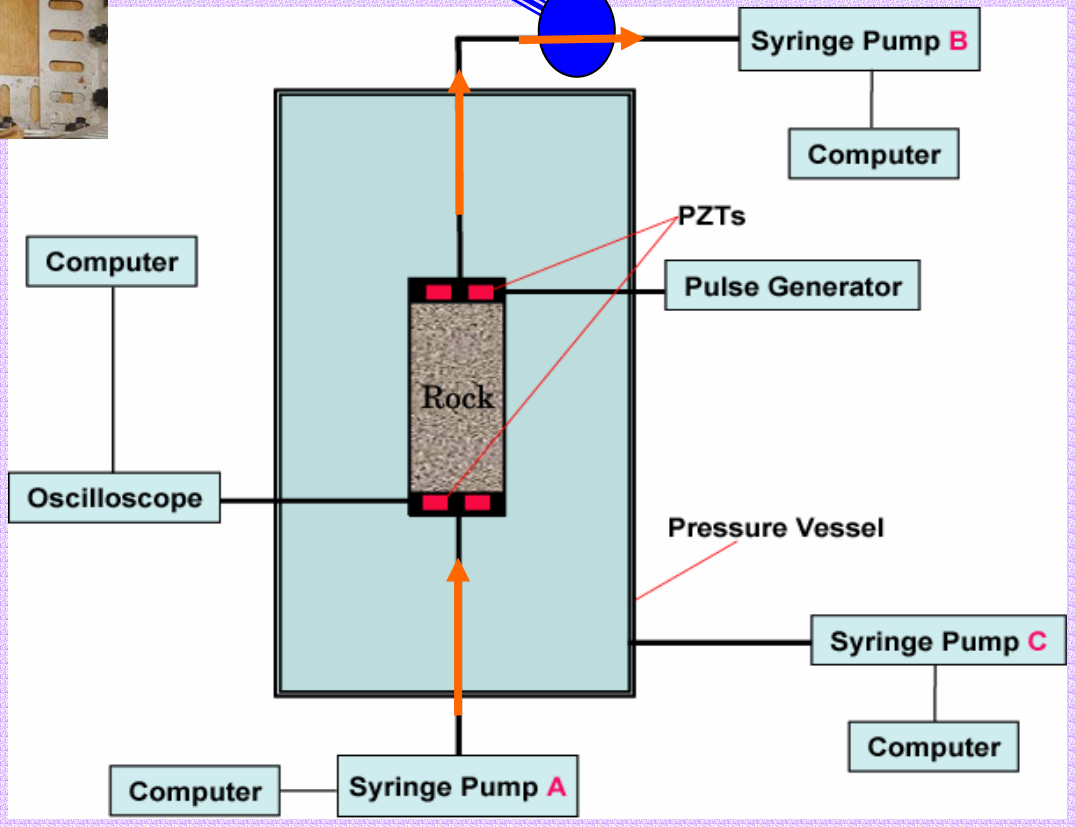
1145.49m - 1145.58m

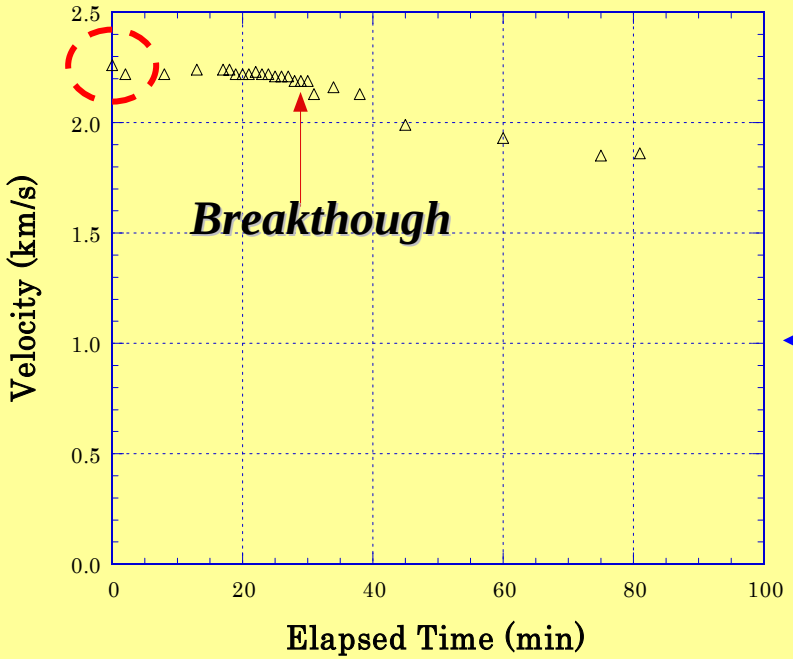
Experimental System Diagram

Measurements of Vp during injection of CO_2 under simulated in-situ P&T conditions.









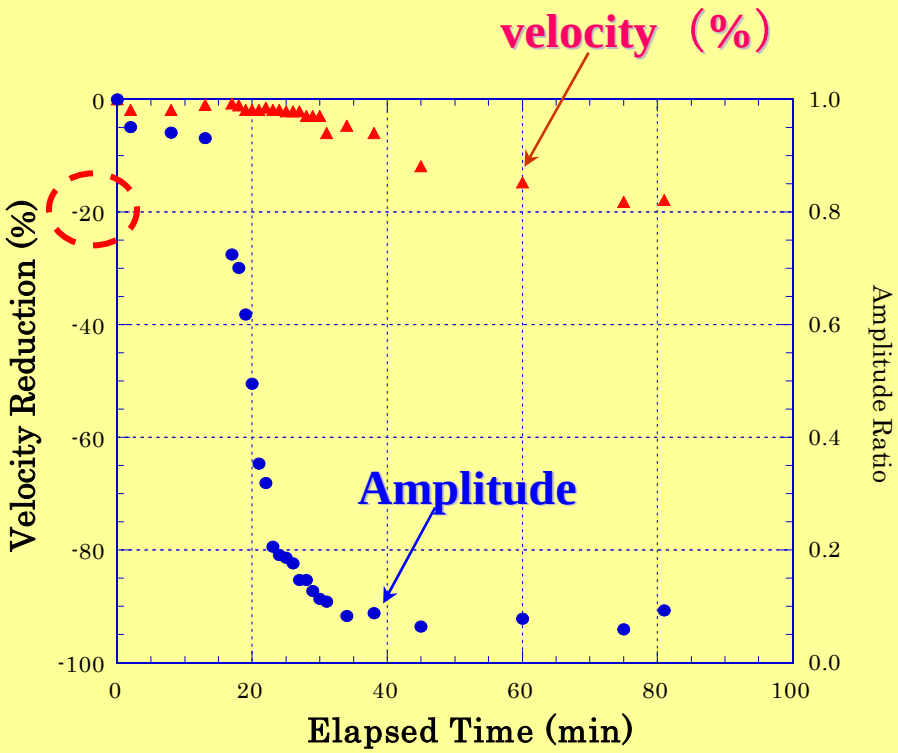
Pore Pressure : 10 MPa
CO_2 Inj.Pres. : 10.5 MPa
Temperature : 38℃

Sonic Vp （Zone 2）

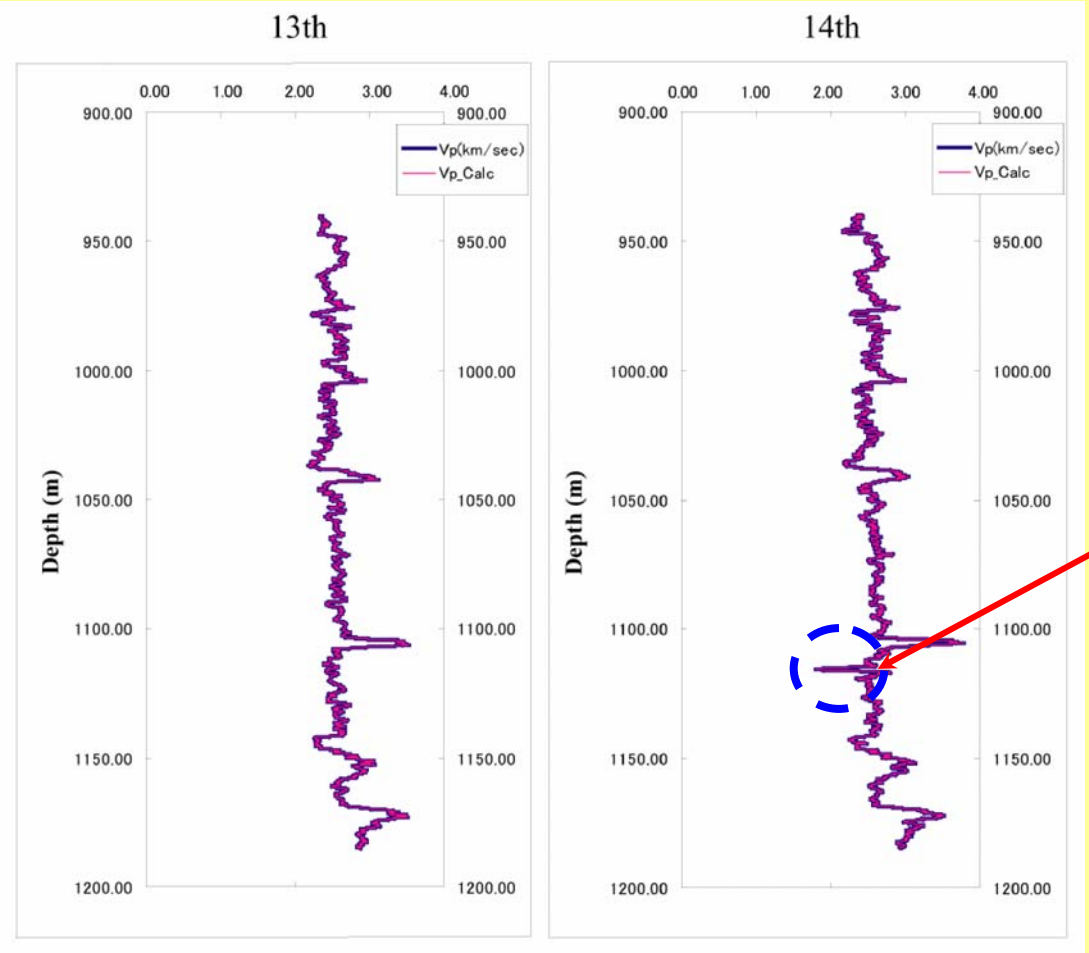
Pre-CO_2: 2.3 km/s

Post-CO_2: 1.8 km/s

- 21.7 %



History Matching on Sonic Vp



Estimation of CO_2 Saturation with Gassmann theory

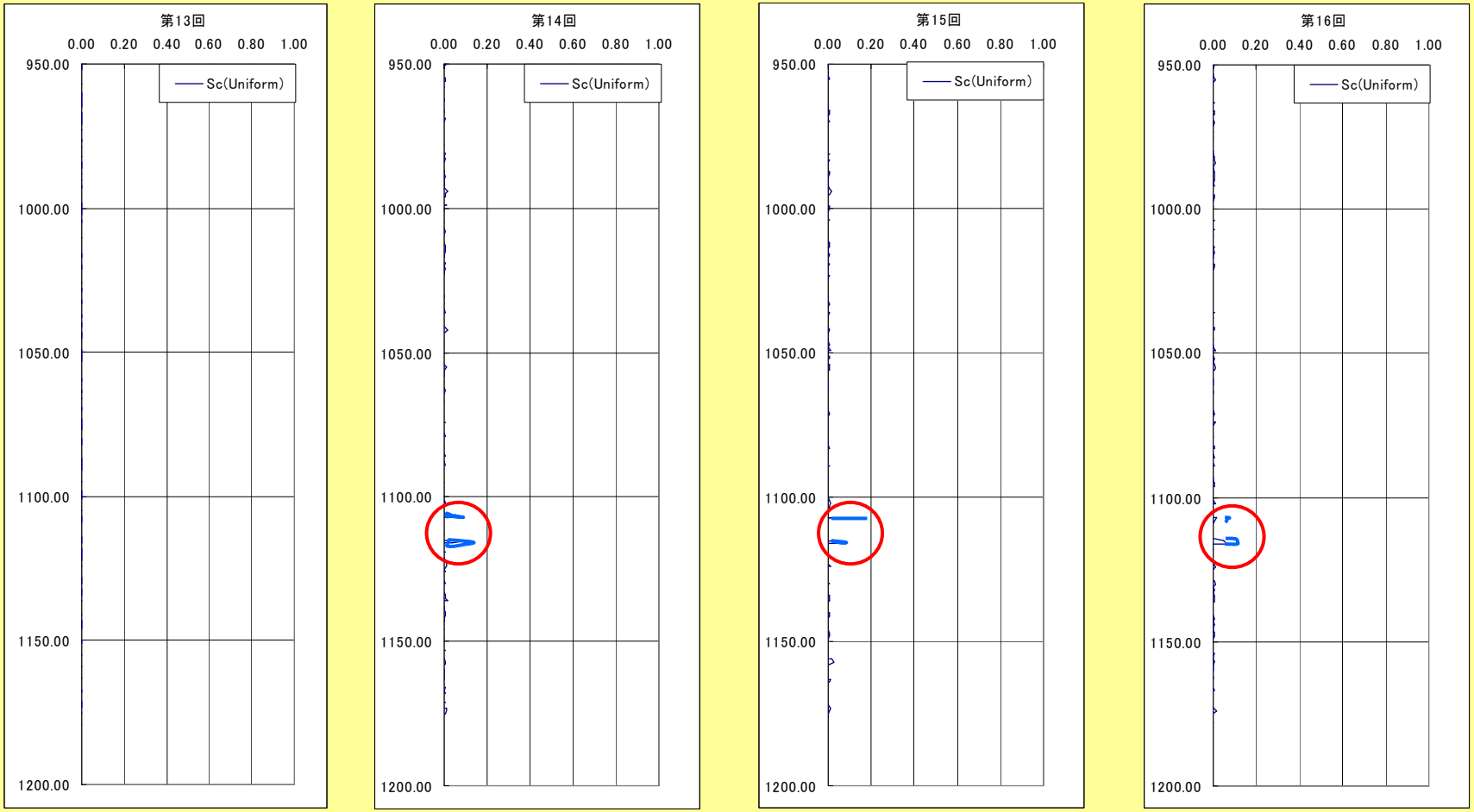
Velocity reduction due to breakthrough of CO_2

Xue et al.,2006

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

International Workshop on CO_2 Geological Storage , Japan '06

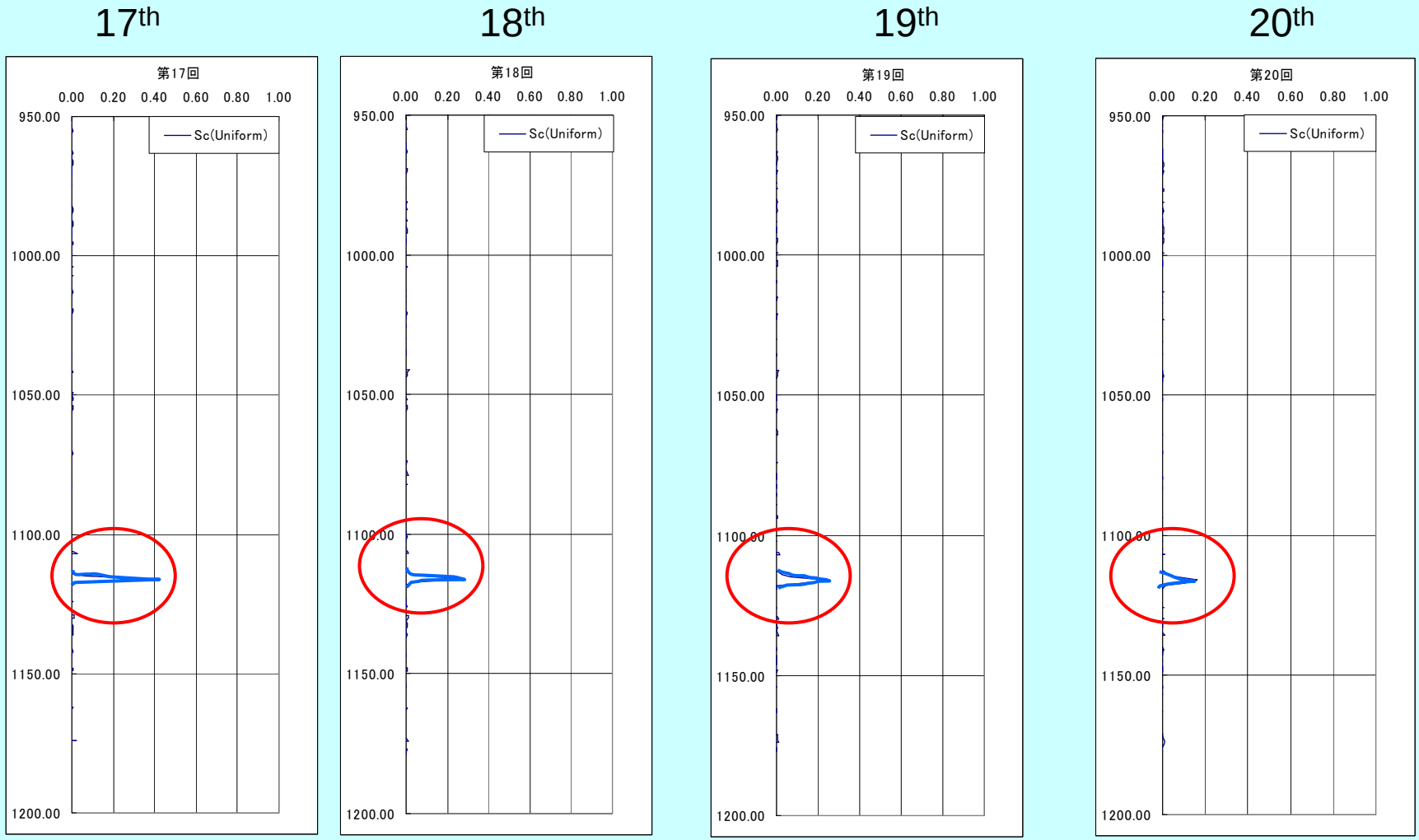
13th 14th 15th 16th



Depth (m)

CO_2 saturation (fraction)

International Workshop on CO_2 Geological Storage , Japan '06

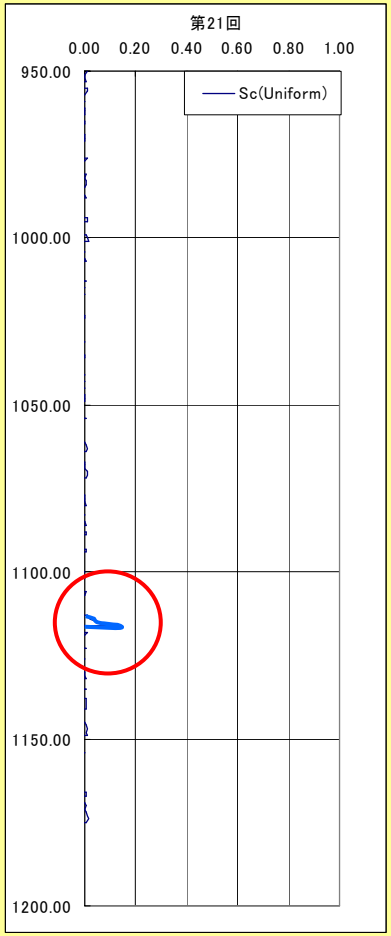


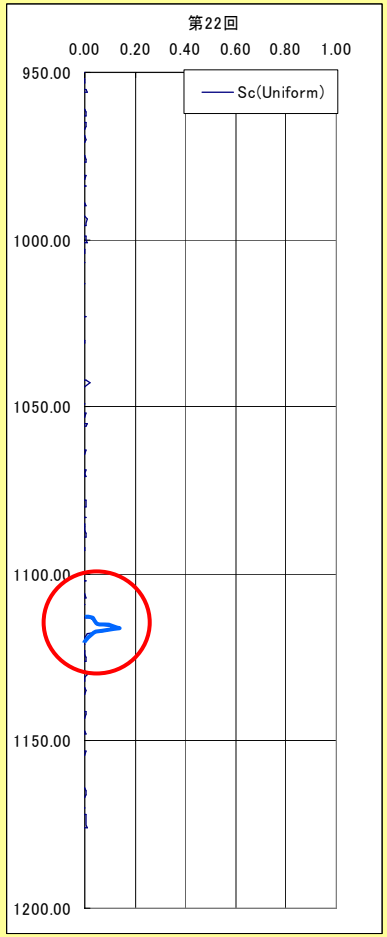
International Workshop on CO_2 Geological Storage , Japan '06

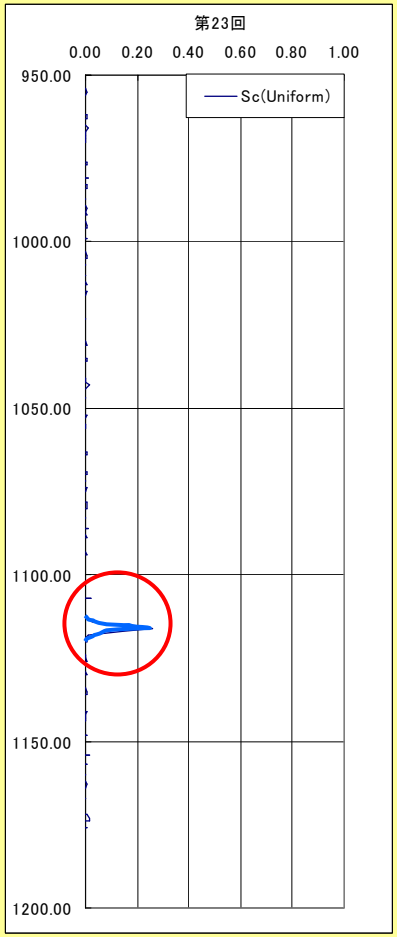
21st

22nd

23th



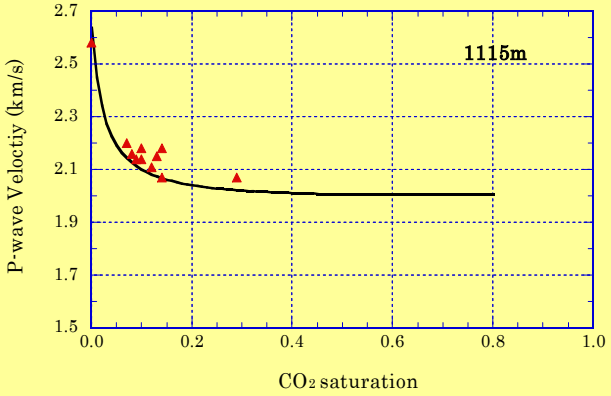


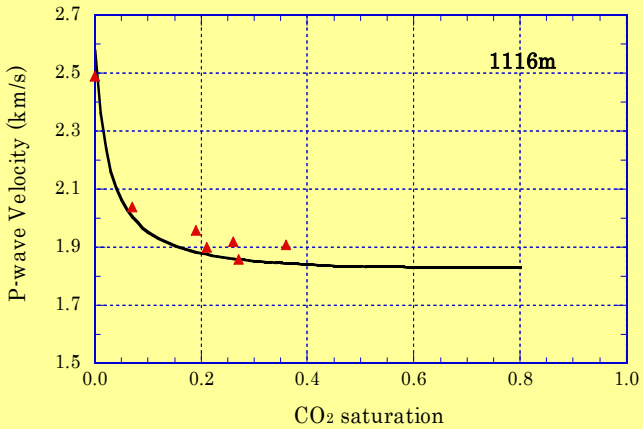


Depth (m)

CO_2 saturation

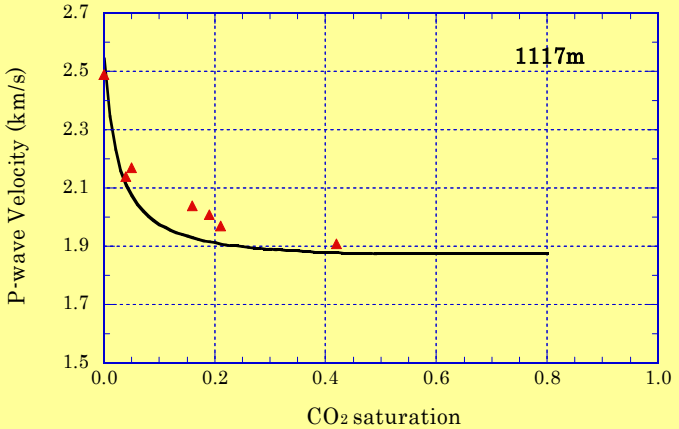
P-wave velocity vs CO_2 saturation





▲ : estimated from sonic Vp

—— : predicted with Gassmann theory

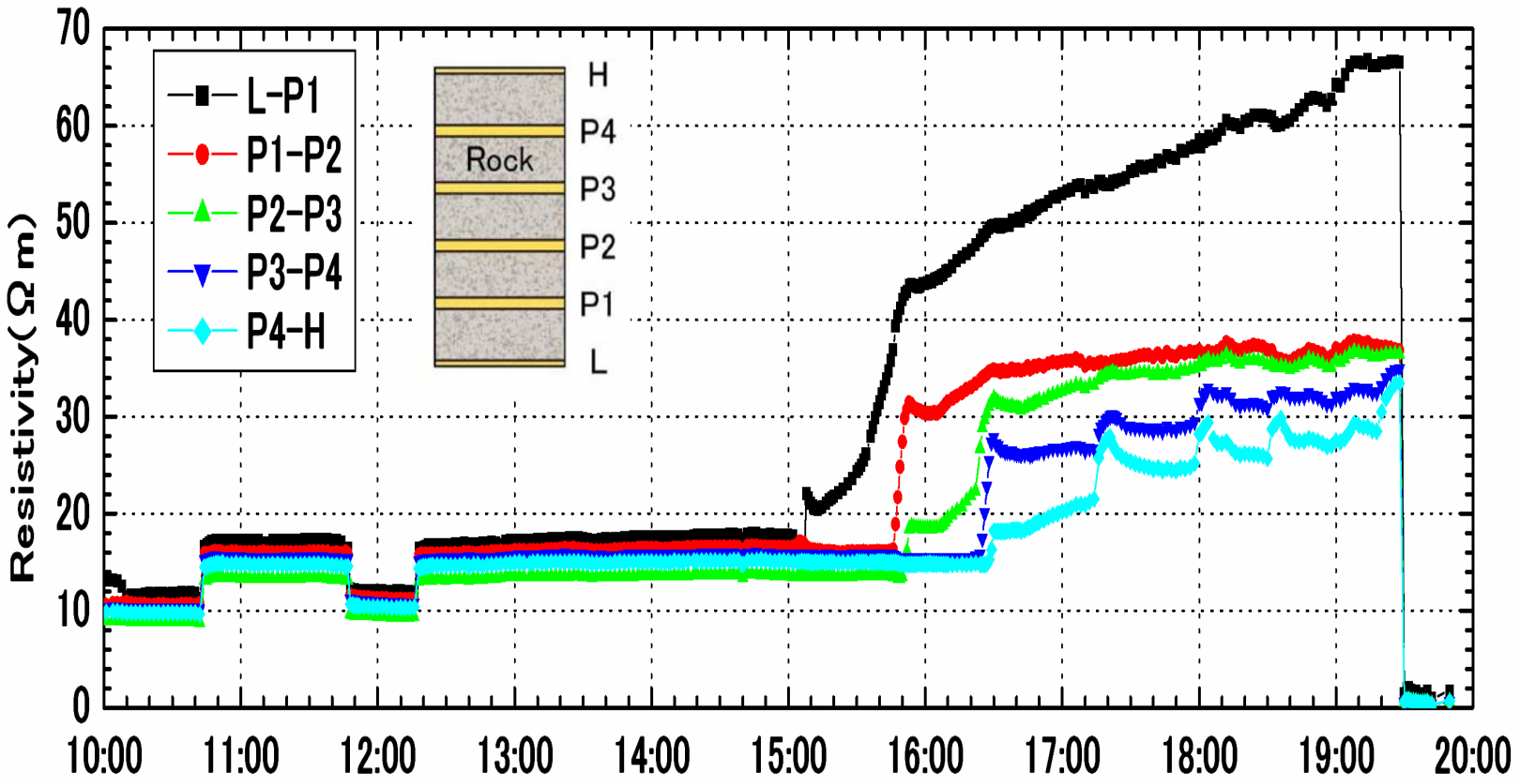


Resistivity Changes

caused by

CO_2 Injection in Berea Sandstone

Resistivity changes during injection of s.c. CO_2 into Berea sandstone saturated with artificial formation water



Kubota et al.,2006

CONCLUSIONS

- **P-wave velocity and resistivity clearly responded to CO_2 injection into water-saturated sandstones.**

  Vp: -10% (order); ρ: + 300% (Max)

- **CO_2 migration pattern depends strongly on heterogeneous pore structure and bedding plane in porous sandstones.**

- **Confirmed sonic Vp reduction (-20%) due to CO_2 breakthrough with drilled cores retrieved from the observation well OB-2.**

Conclusions (cont.)

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

  less Vp decrease: >20% CO_2 saturation

- **Resistivity increases are larger in sandstone sample (lab-scale) compared to induction logging (field-scale).**

- **Supporting developments of cost-effective methods for CO_2 monitoring in geological sequestration.**

ACKNOWLEDGMENTS

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

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