◆ 超臨界流体部会 第21回 サマースクール ◆

物理化学的視点から地下深部への超臨界CO_2圧入を考える

二酸化炭素地中貯留技術研究組合・技術部長

(公財)地球環境産業技術研究機構 (RITE)
CO_2貯留研究グループリーダー

せつ　じきゅう
薛　自求
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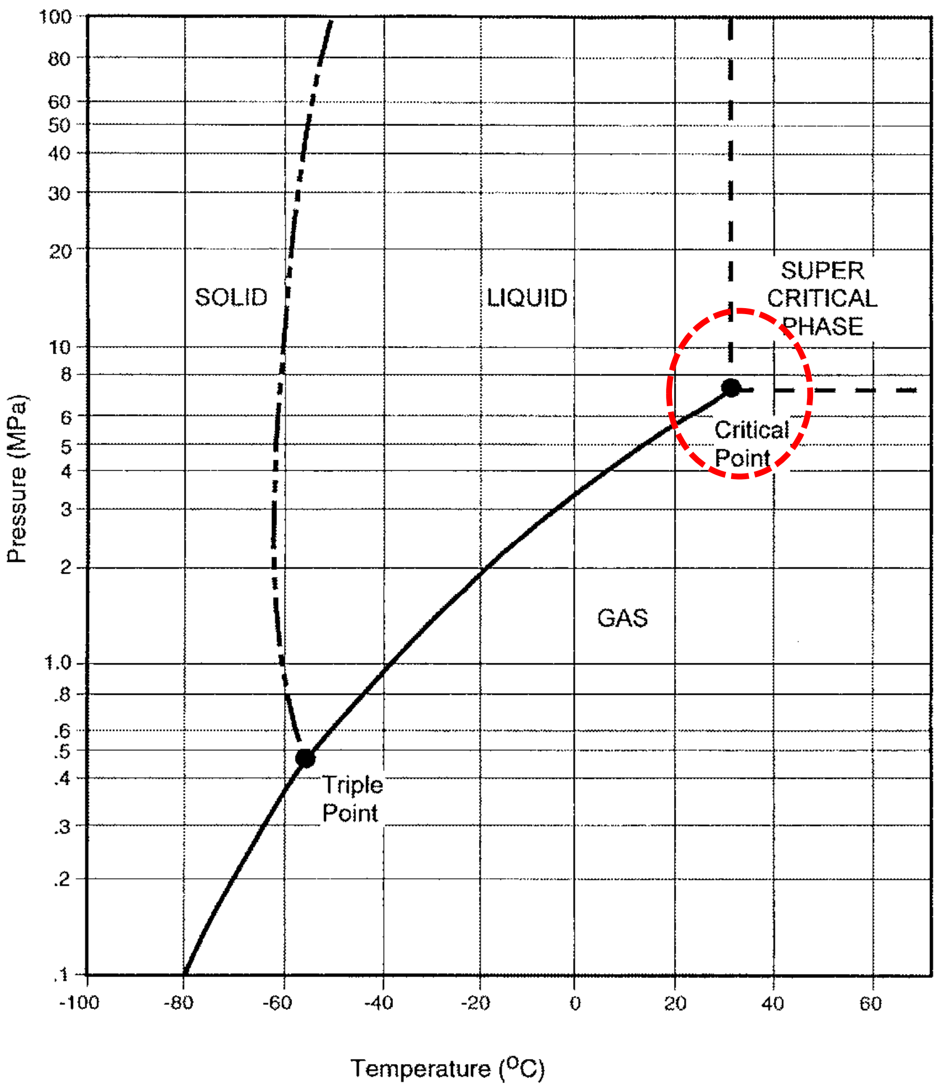
1. 超臨界CO_2 - CO_2地中貯留

Supercritical CO_2, Saline Aquifer CO_2 Storage



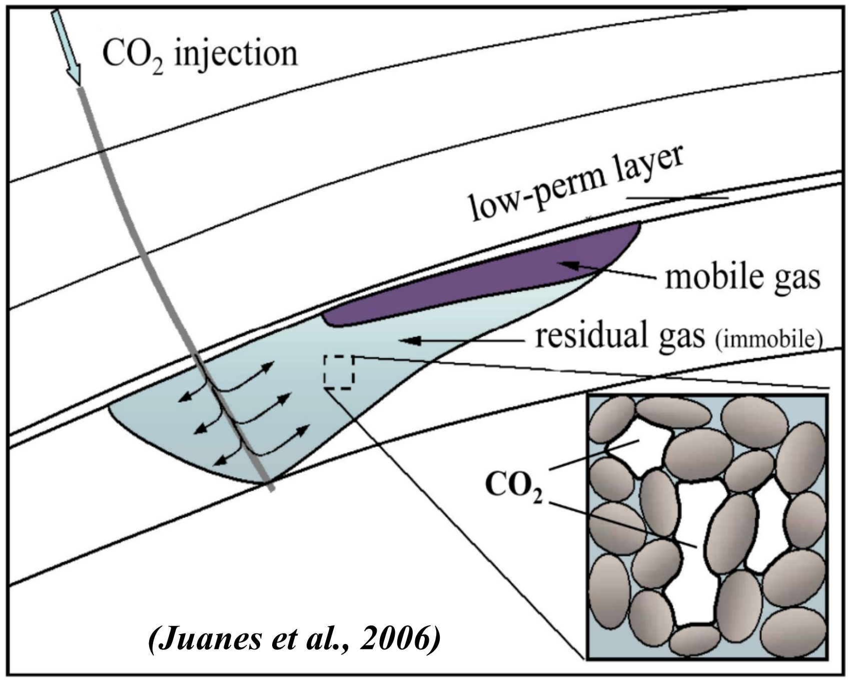
・常温大気圧下（25℃, 0.1 MPa）では、

CO_2（気体）密度が 1.8 kg/m^3 、

・帯水層条件下（12.5 MPa, 47℃）では、

CO_2（超臨界）密度が 656 kg/m^{3}となるが、

地層水よりは小さい。



どのような地層にCO₂圧入するか・塩水性帯水層

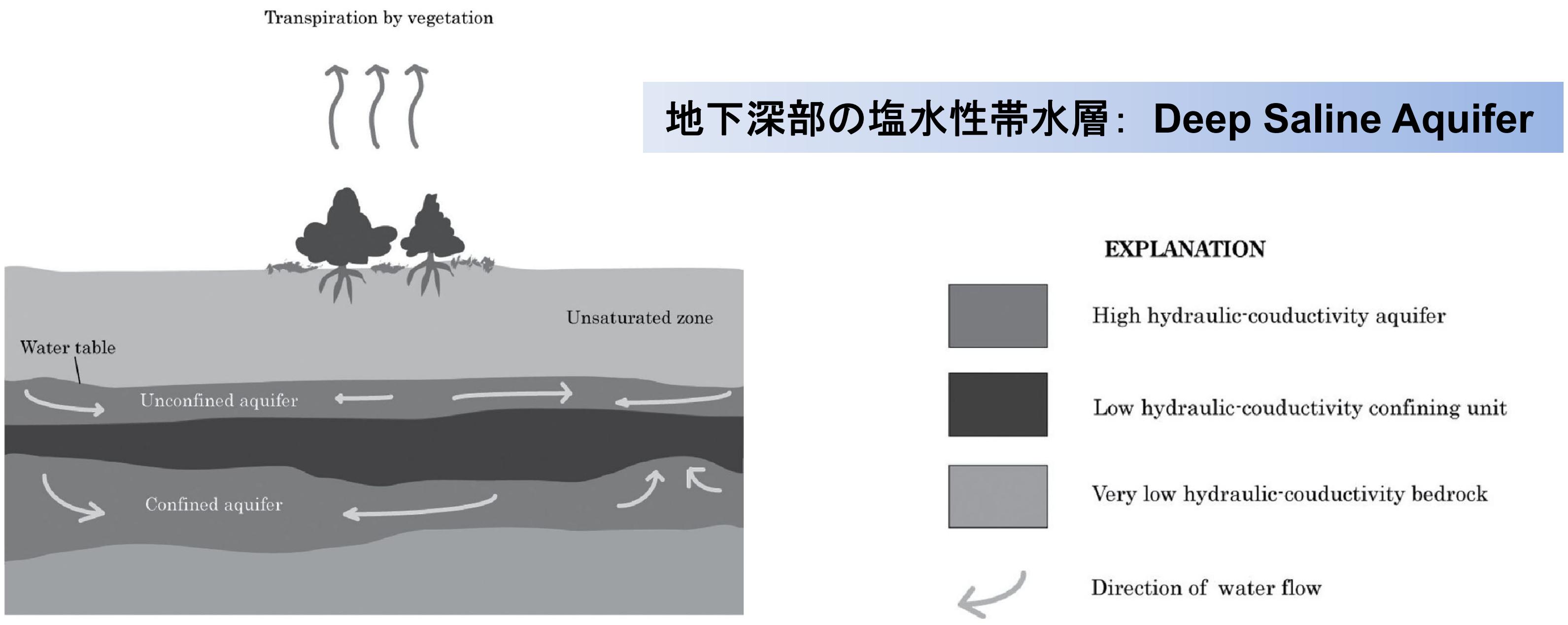
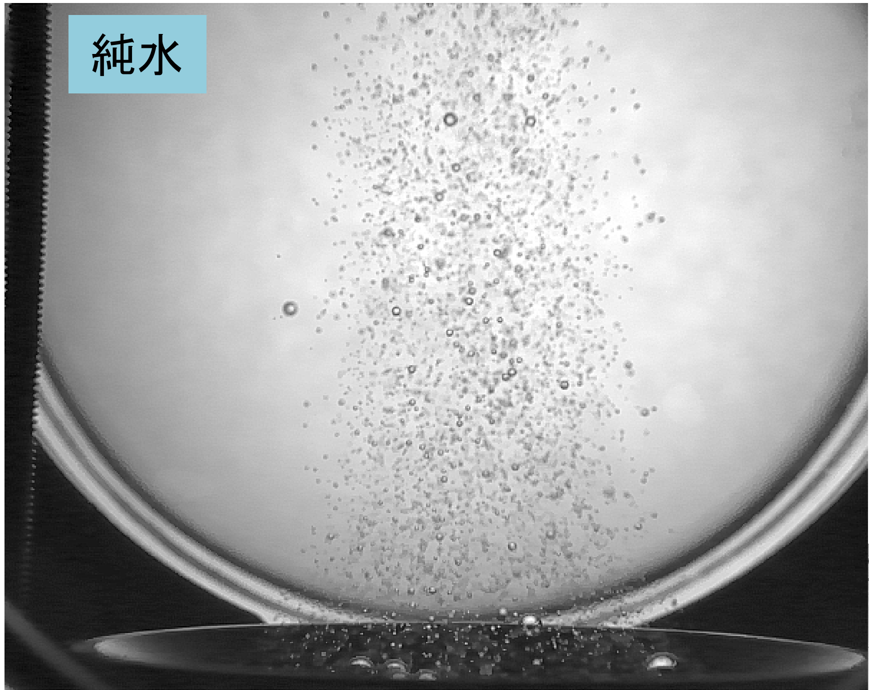
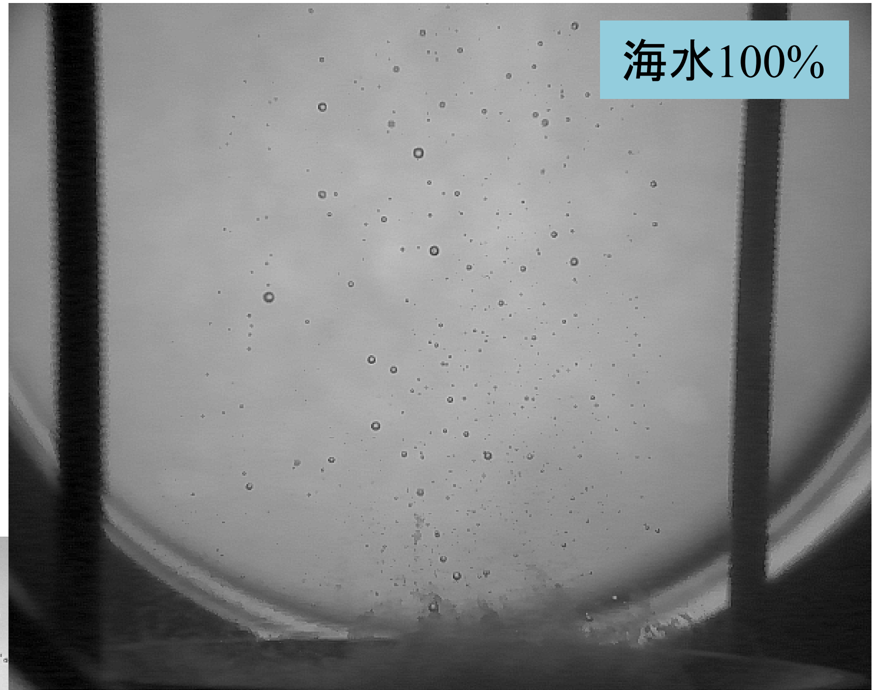


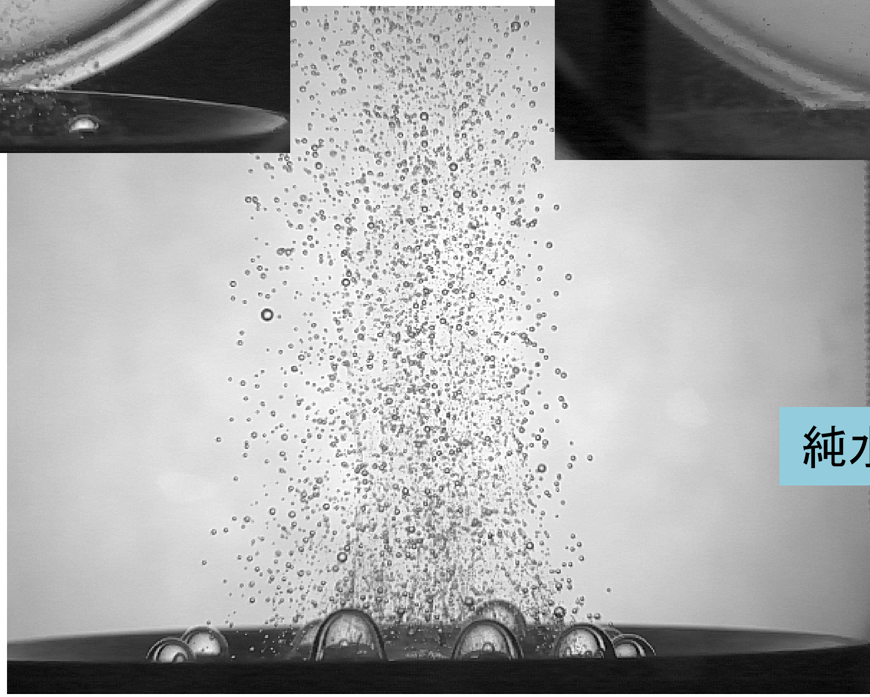
Table 1 Comparisons of pH and concentrations of chemical components in formation water, sea water and ground water (Mito, 2005).

	Formation Water	Sea Water	Ground Water	Unit
pH	7.9	8.1	7.1	–
Na	1,936	10,784	426	mg/L
K	385	399	11	mg/L
Ca	421	412	85	mg/L
Mg	16	1,284	31	mg/L
HCO_3	374	108	138	mg/L
SO_4	77	2,712	115	mg/L
Cl	3,852	19,352	615	mg/L

地層水塩分濃度 vs 超臨界CO_2気泡サイズ

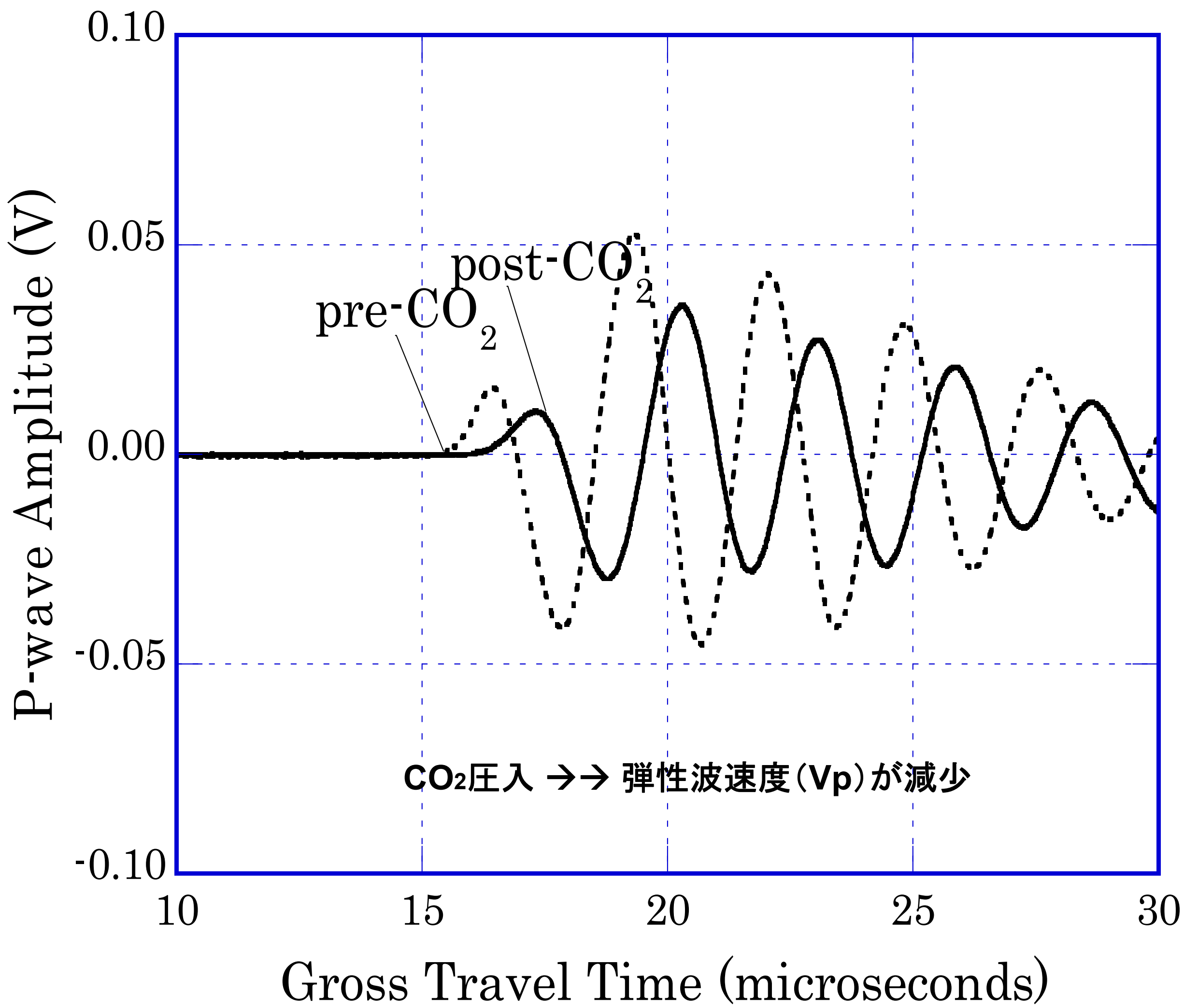






純水：海水＝50% : 50%

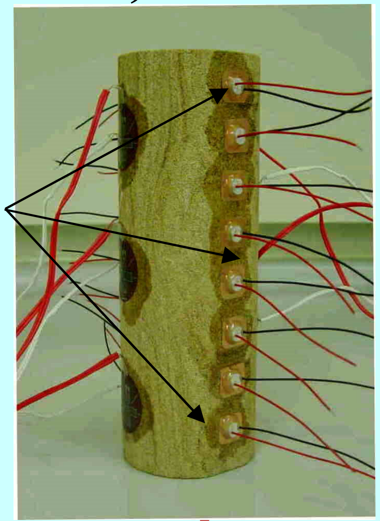
２．地球物理的視点：　地下に圧入されたCO_2挙動モニタリング



P-wave forms obtained from pre- and post- CO_2 flooding in a porous sandstone

Experimental setup for P-wave velocity tomography

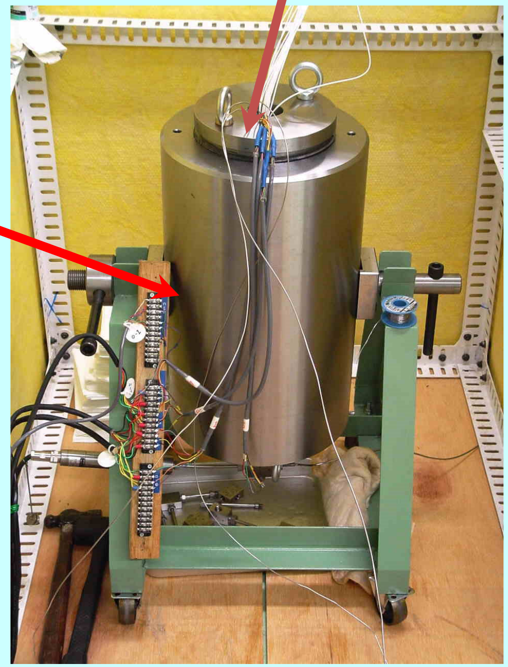
D=5, L=10cm



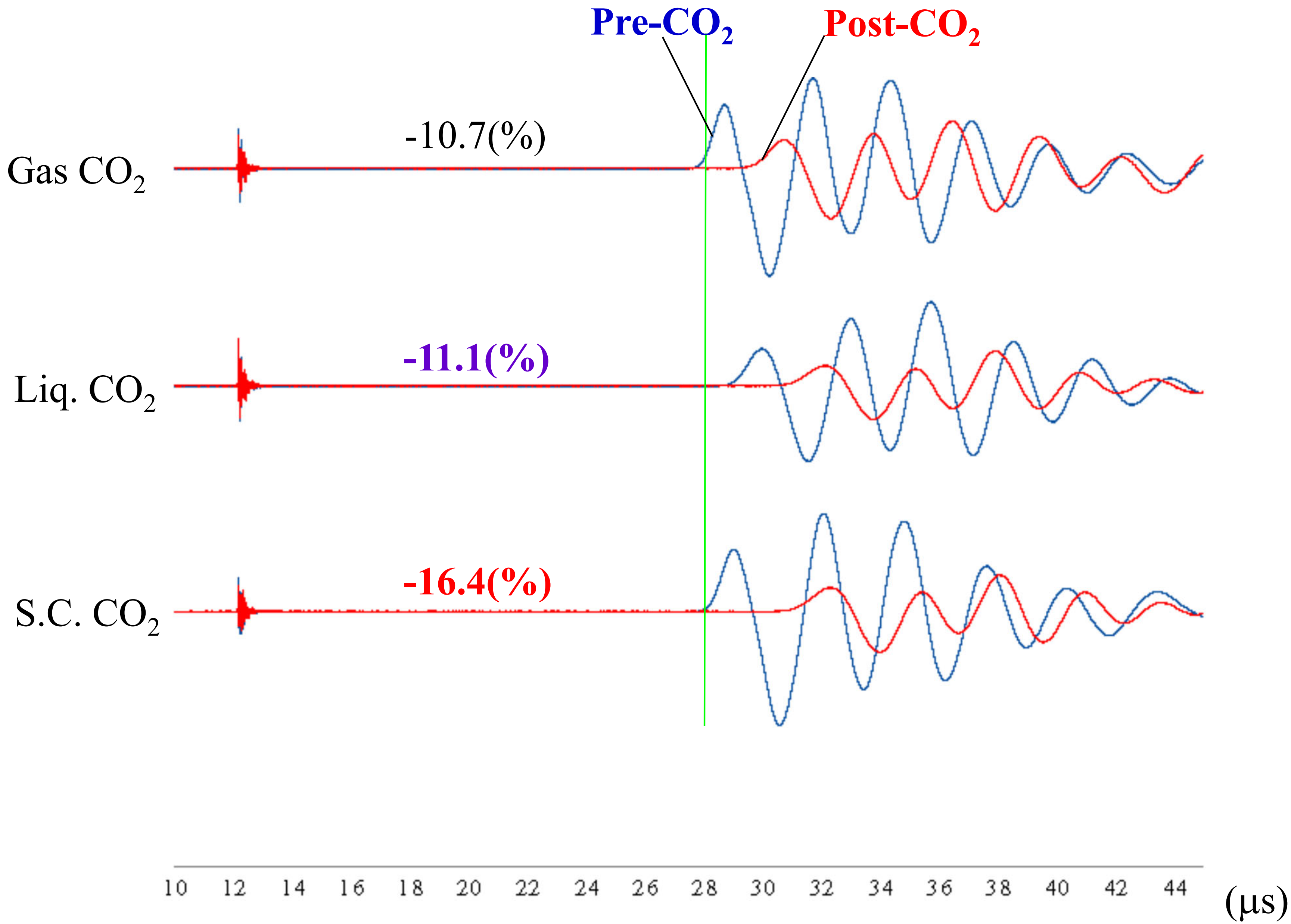
Array: 8 x 8

#3 for CO_2 injection pressure

#2 for pore water pore pressure

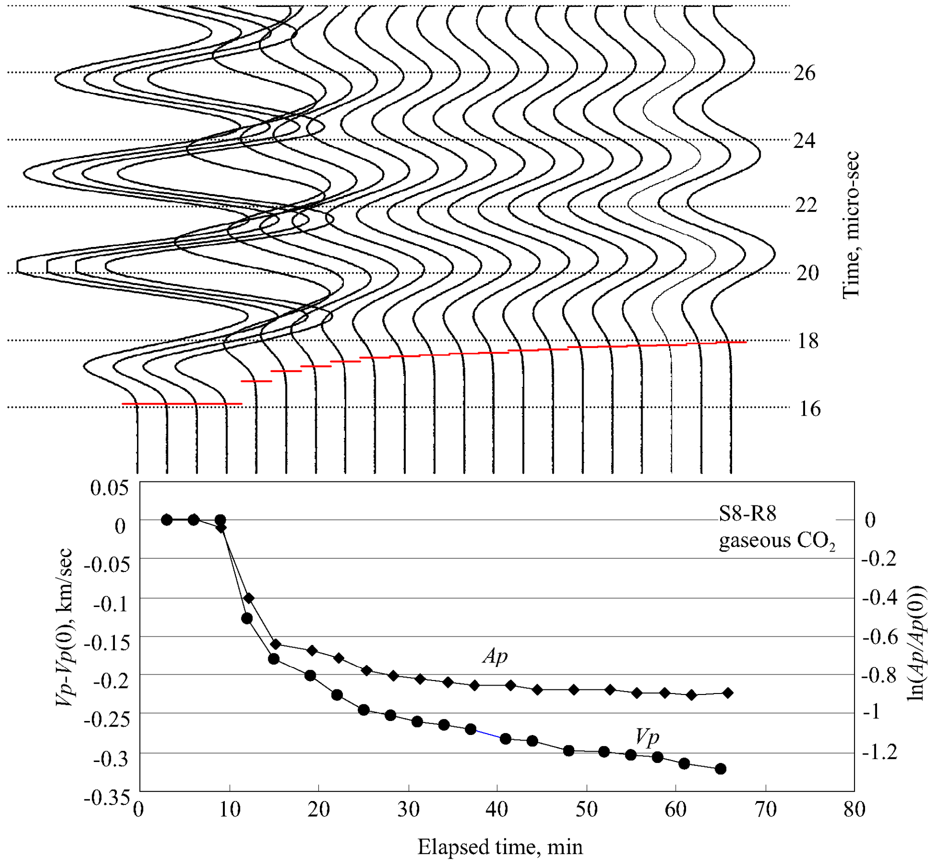


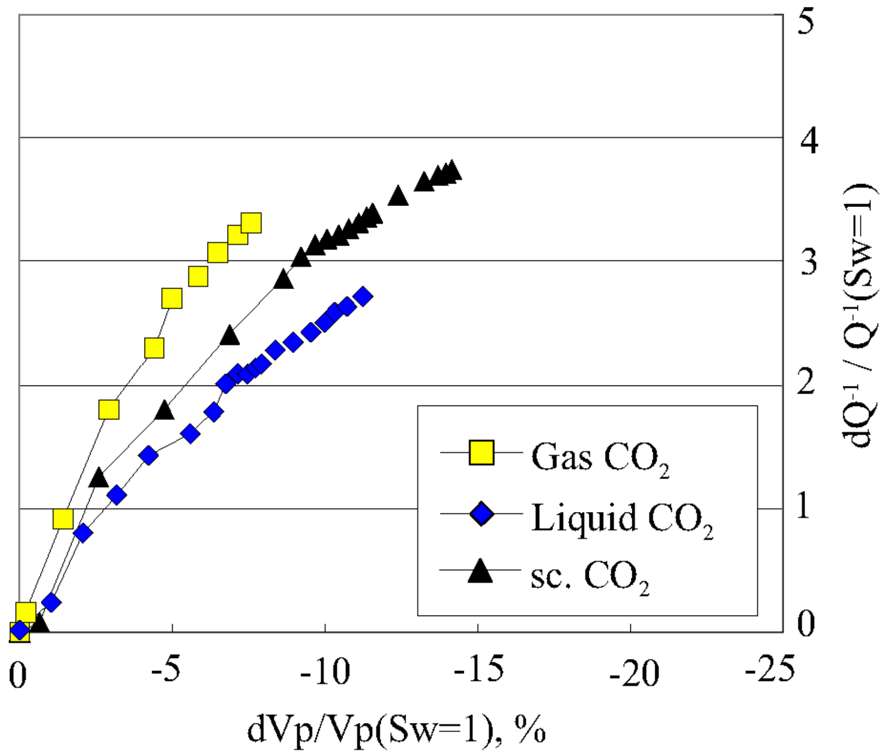
Syringe pump #1 for oil hydrostatic pressure



Velocity reductions resulting from injection of CO_2 in different phases

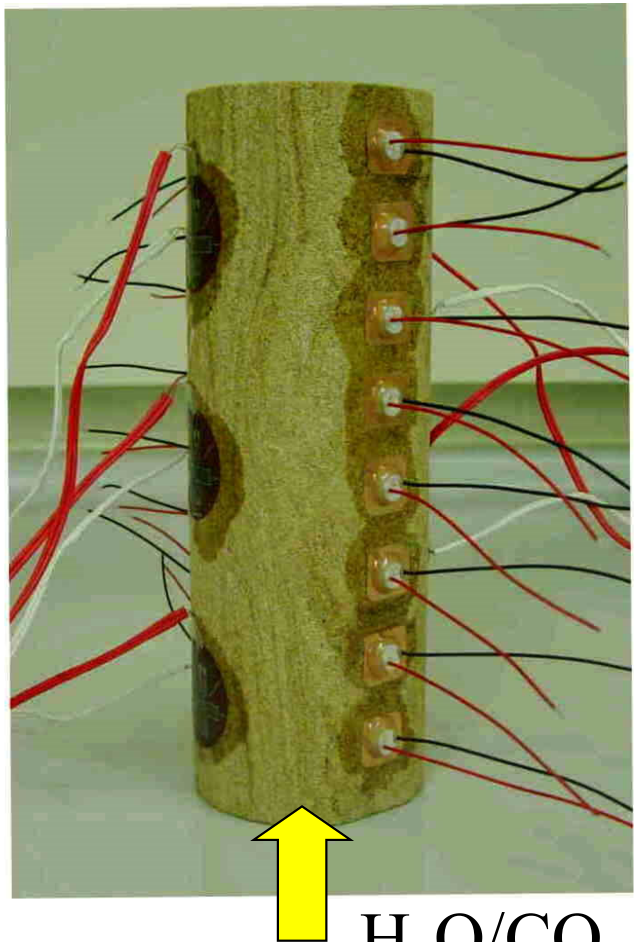
Changes in velocity and attenuation during injection of CO_2 in Tako sandstone



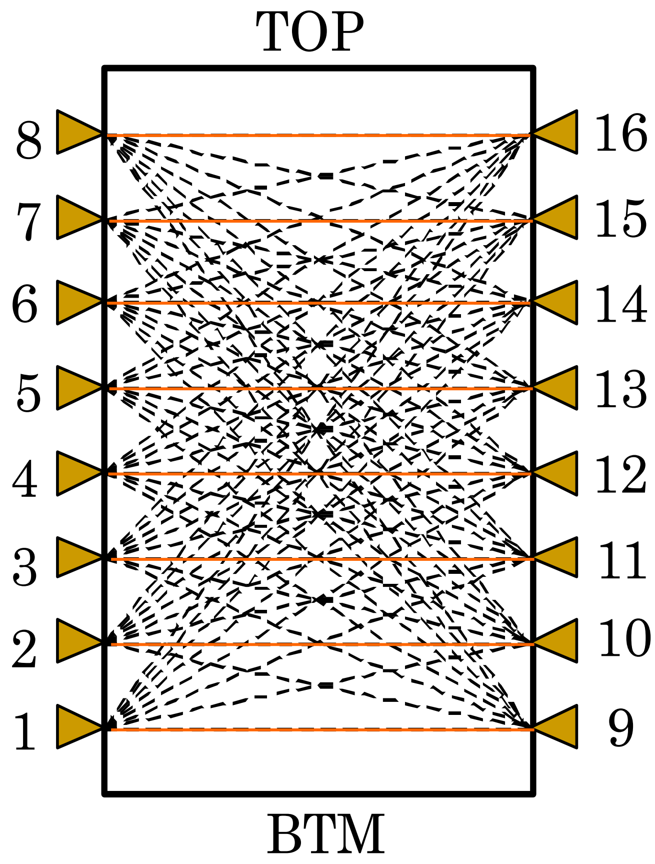


Lei and Xue: Physics of the Earth and Planetary Interiors 176, 224-234,2009

Experimental Study of Seismic Wave Tomography

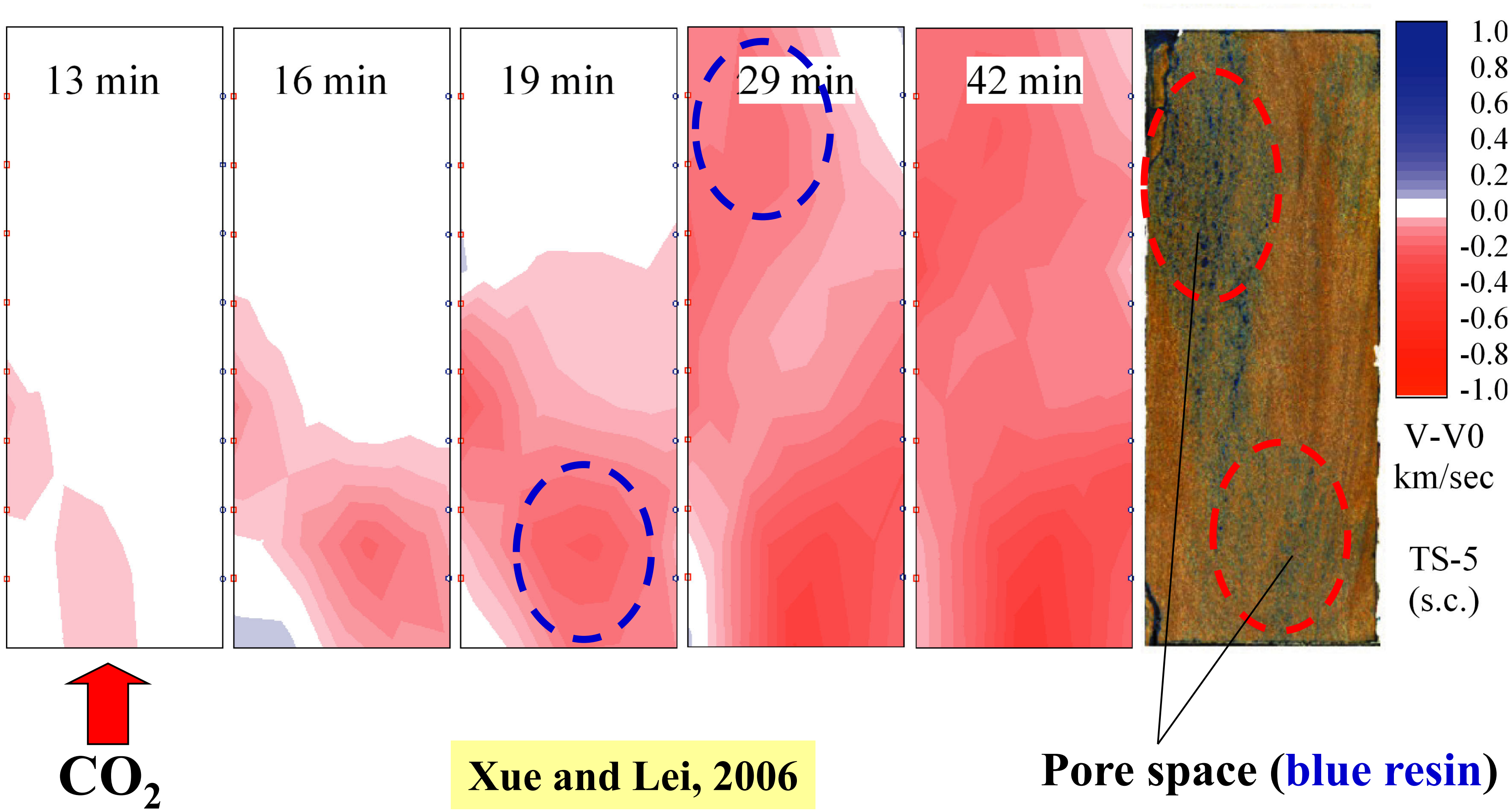


H_2O/CO_2



Sandstone: 23%, 3md

CO_2 migration in water-saturated sandstone

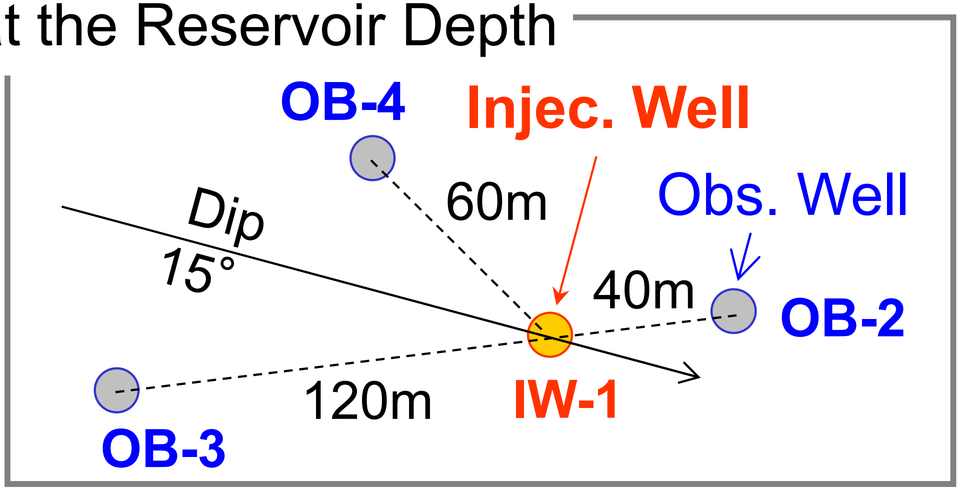


Xue and Lei, 2006

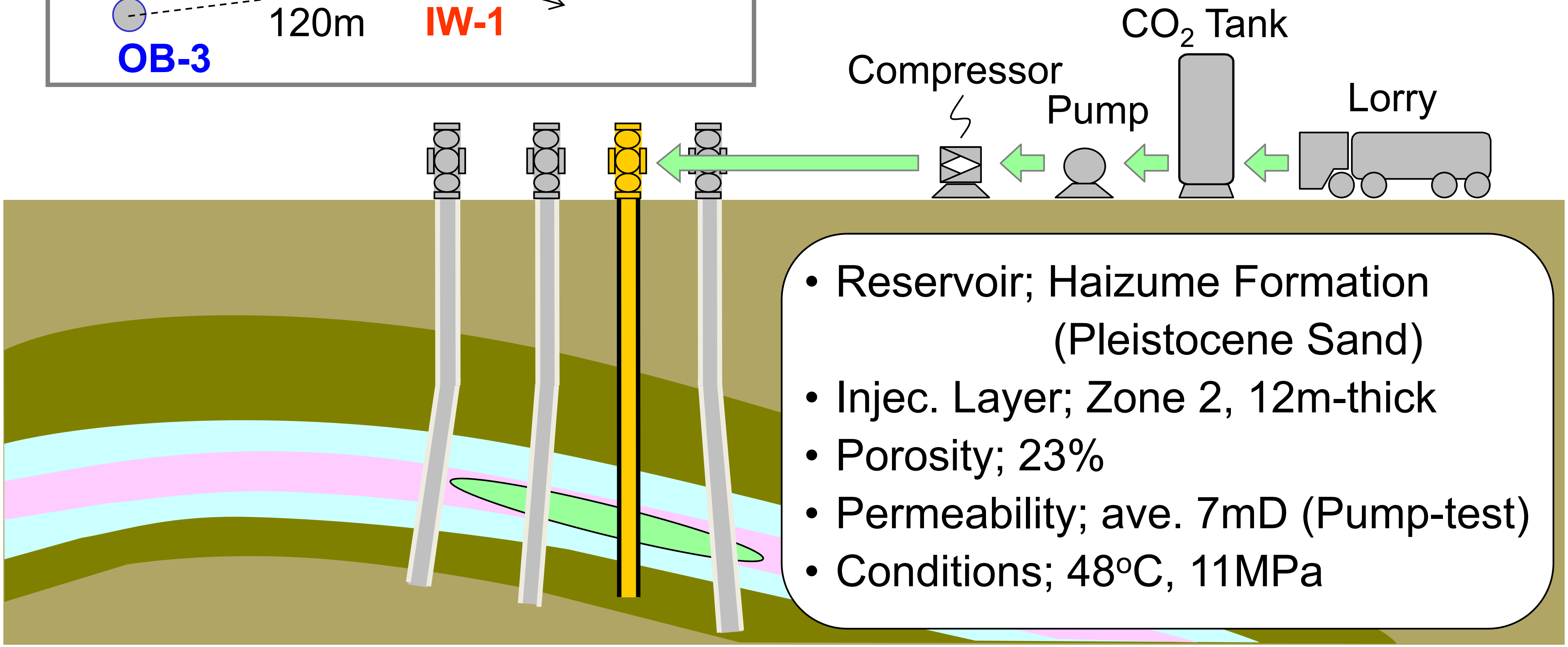
CO_2 flows parallel to bedding plane; Numeric numbers: Elapsed time

Overview of the Nagaoka Site

Well Configuration
at the Reservoir Depth

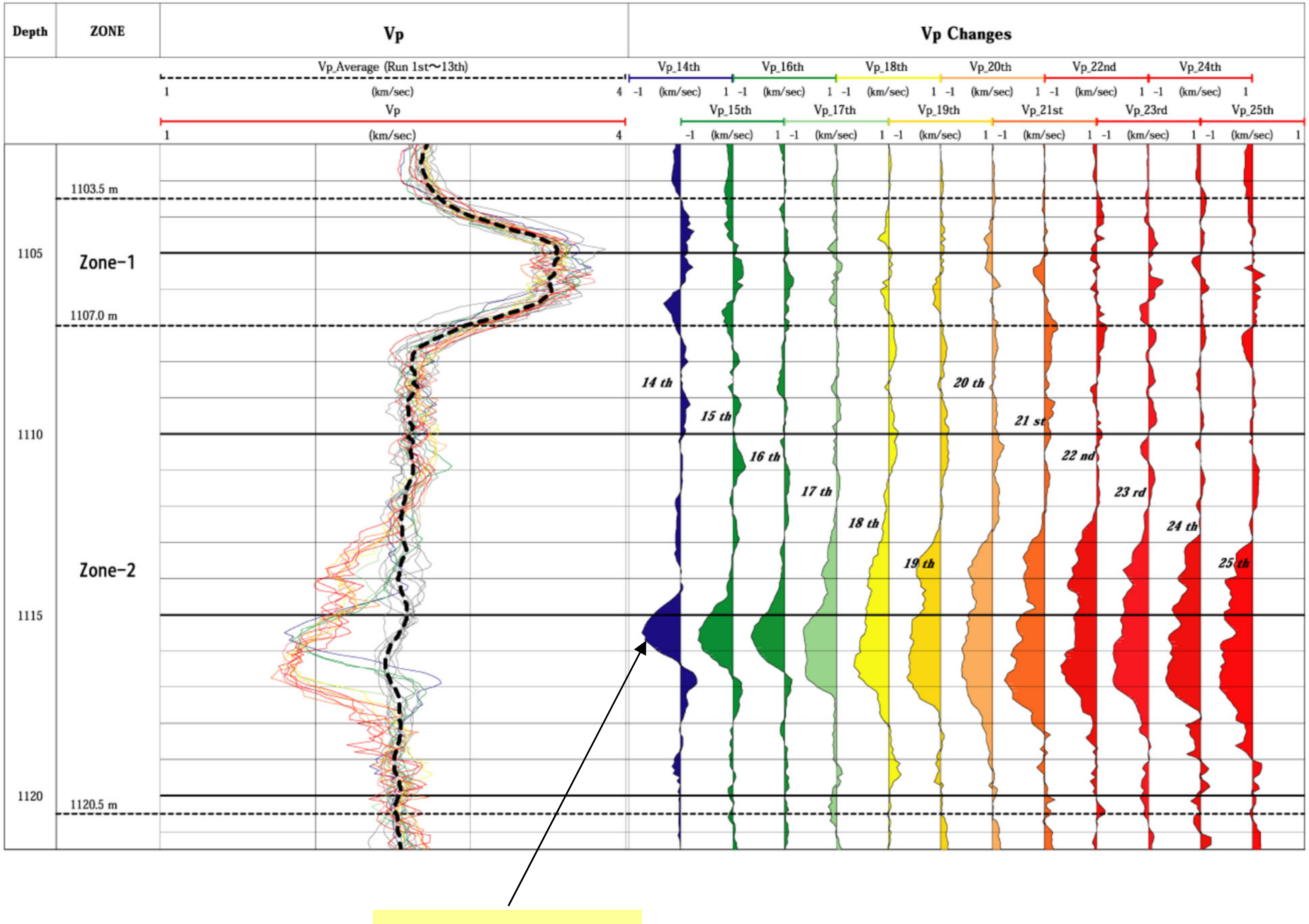


- Injec. Period; Jul. 2003~Jan. 2005
- Total amount; 10,400 ton CO_2
- Rate; 20~40 ton/day



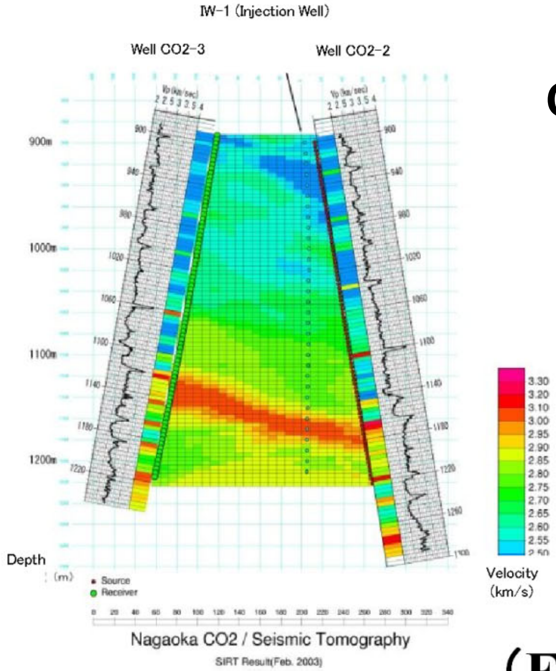
- Reservoir; Haizume Formation (Pleistocene Sand)
- Injec. Layer; Zone 2, 12m-thick
- Porosity; 23%
- Permeability; ave. 7mD (Pump-test)
- Conditions; 48°C, 11MPa

Sonic Log (Vp) from the Nagaoka pilot site

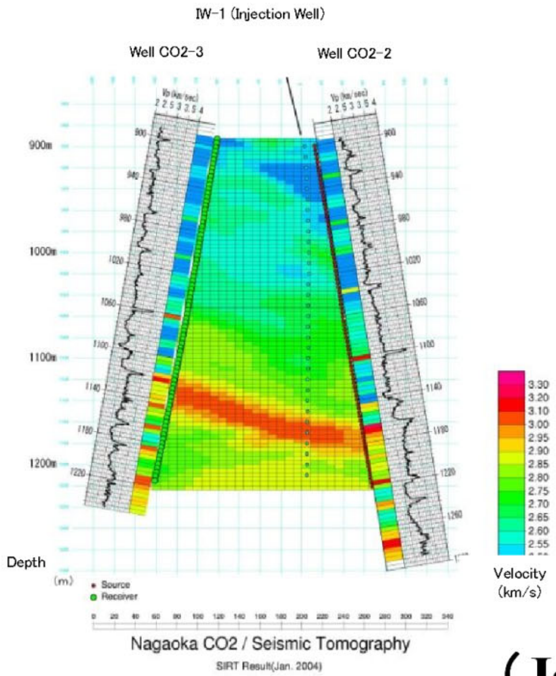


Vp: -23%

Cross-well Seismic Tomography

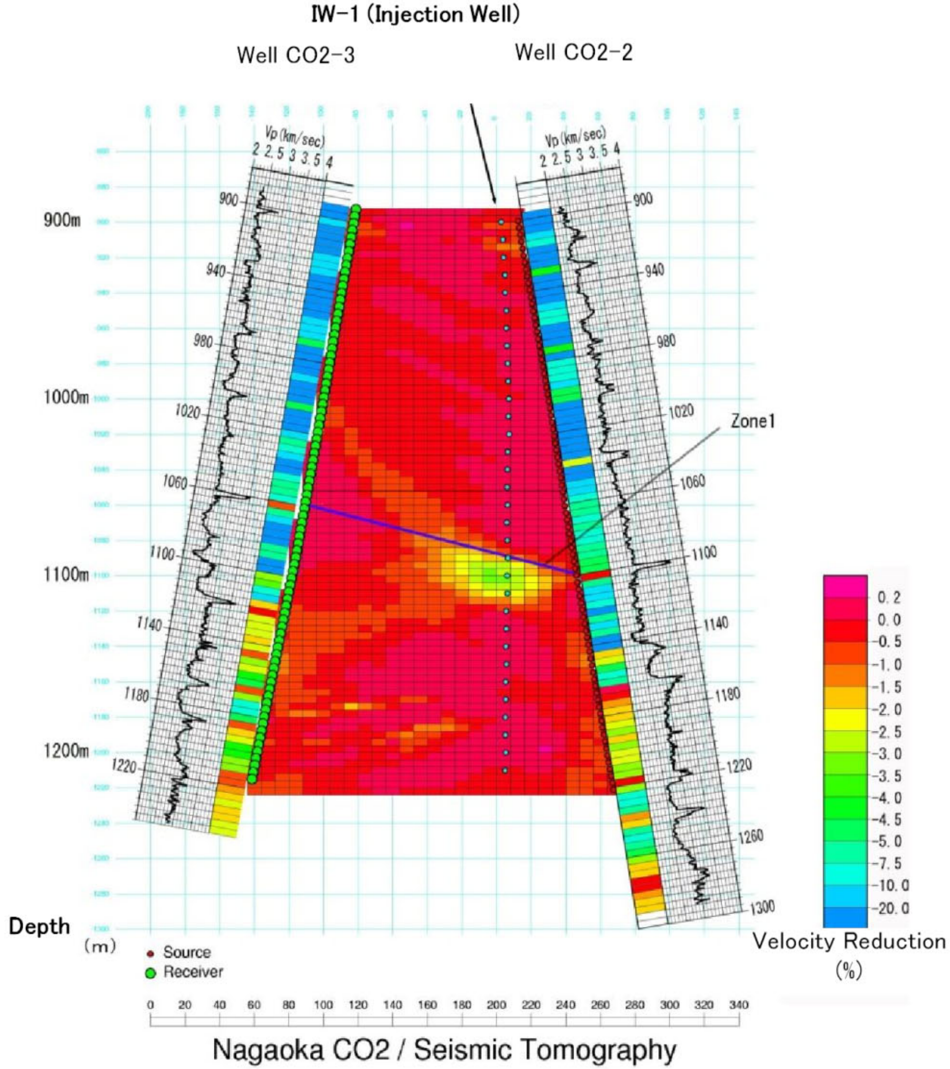


(Feb. 2003 :BLS)

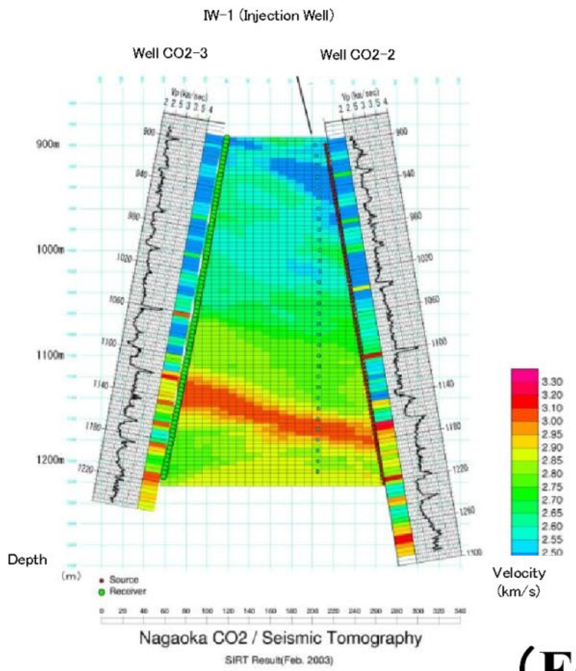


(Jan. 2004 :MS1)

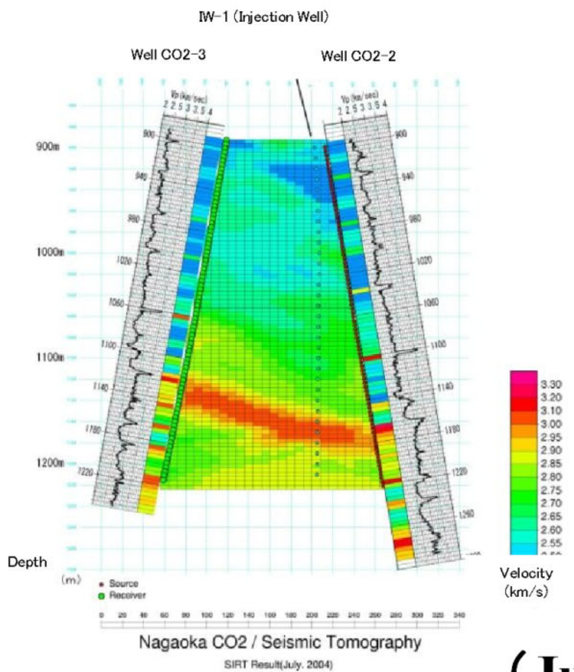
3,200 t



Max:　－3. 0%

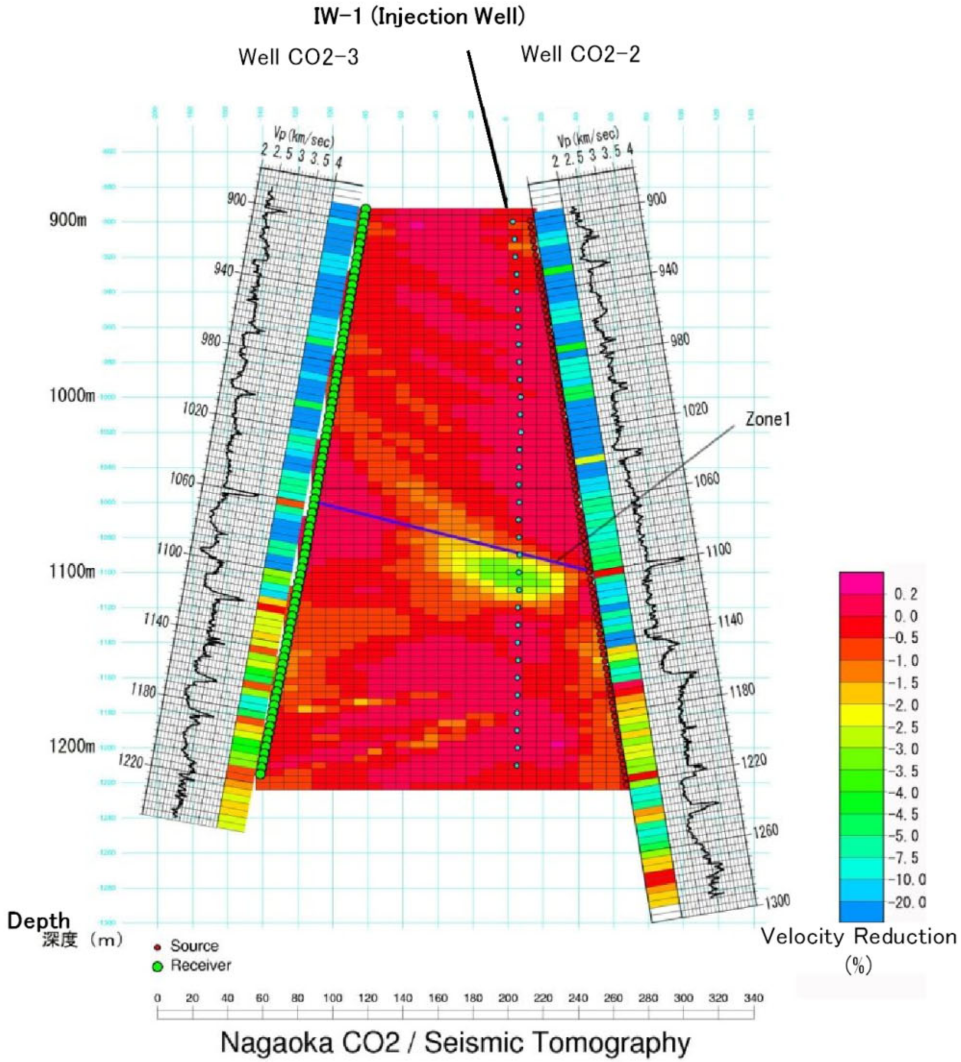


(Feb. 2003 :BLS)

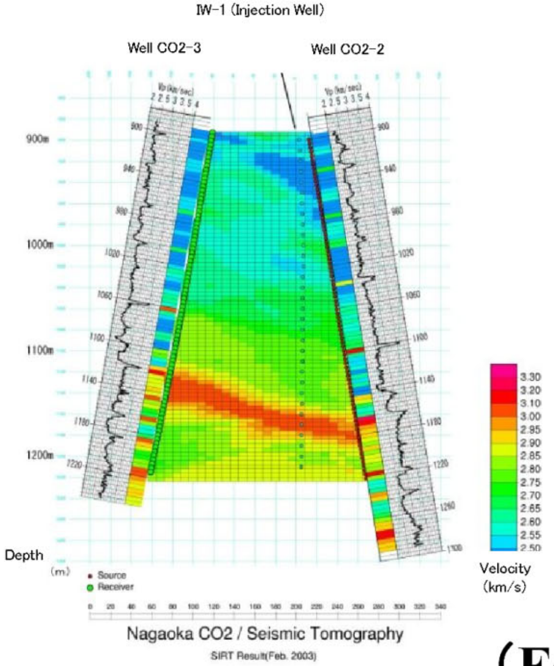


(July. 2004 :MS2)

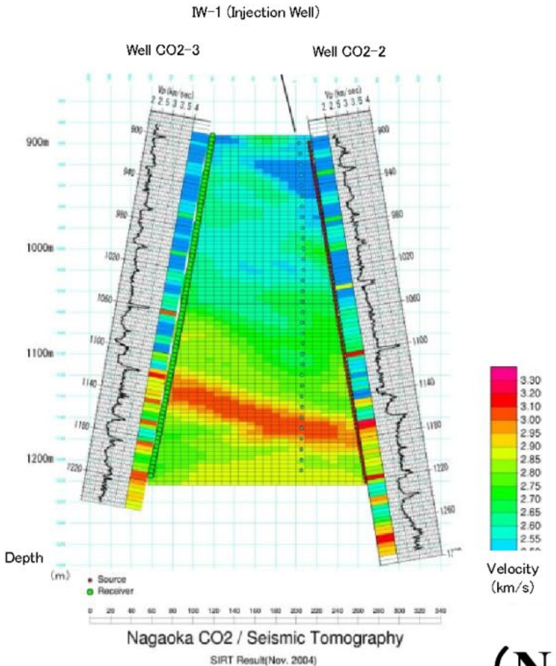
6,200 t



Max: －3．5%

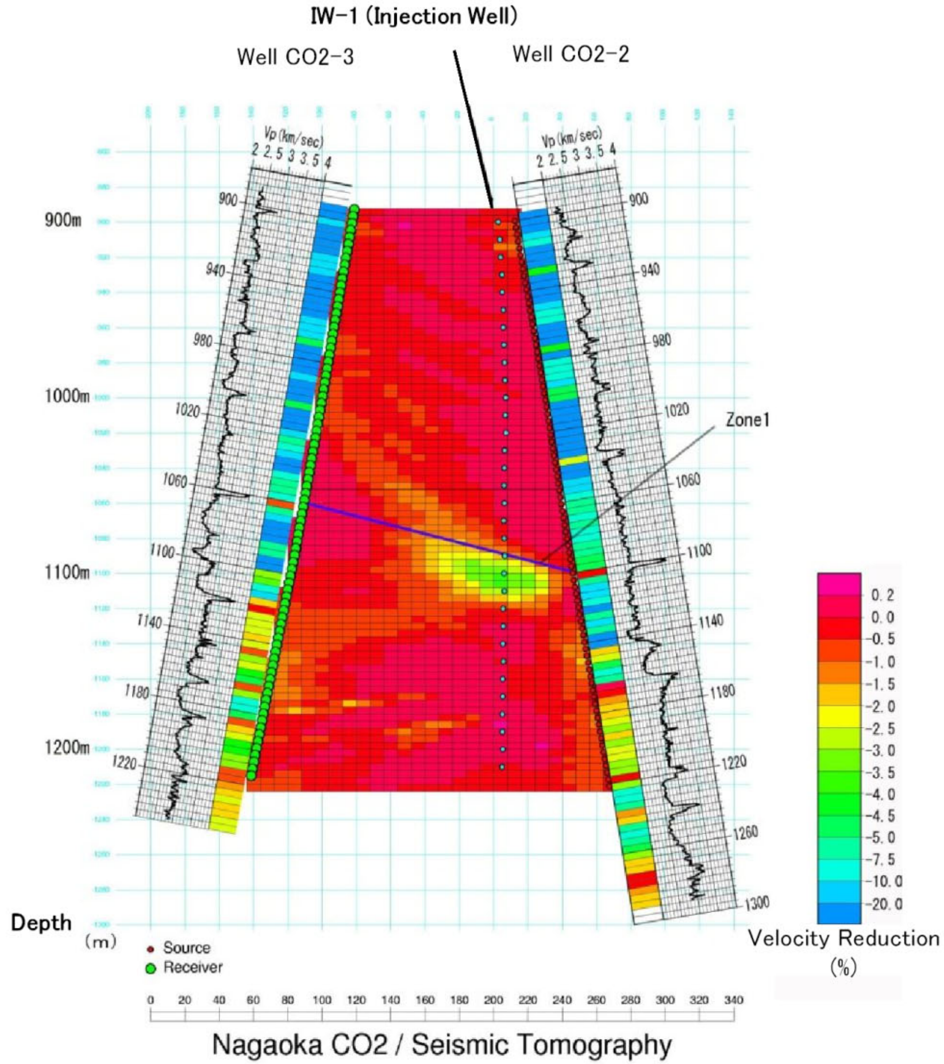


(Feb. 2003 :BLS)



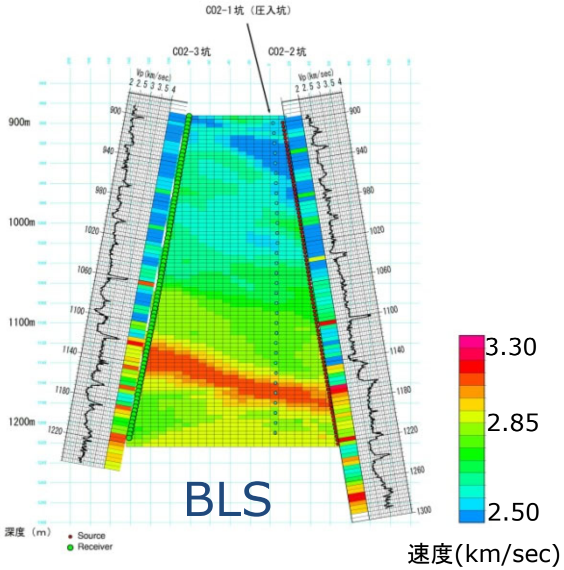
(Nov. 2004 :MS3)

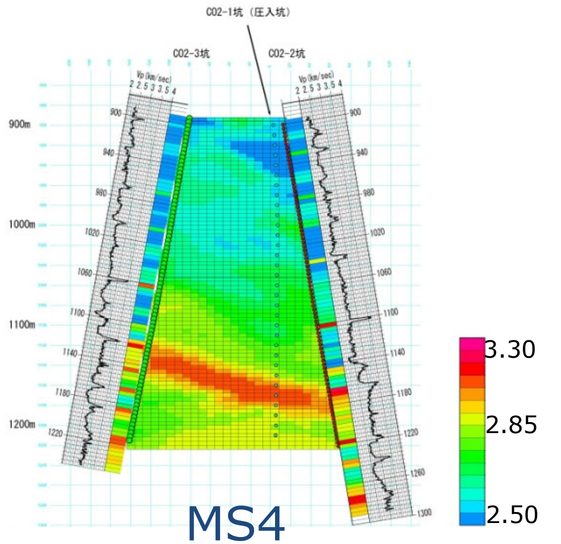
8,900 t



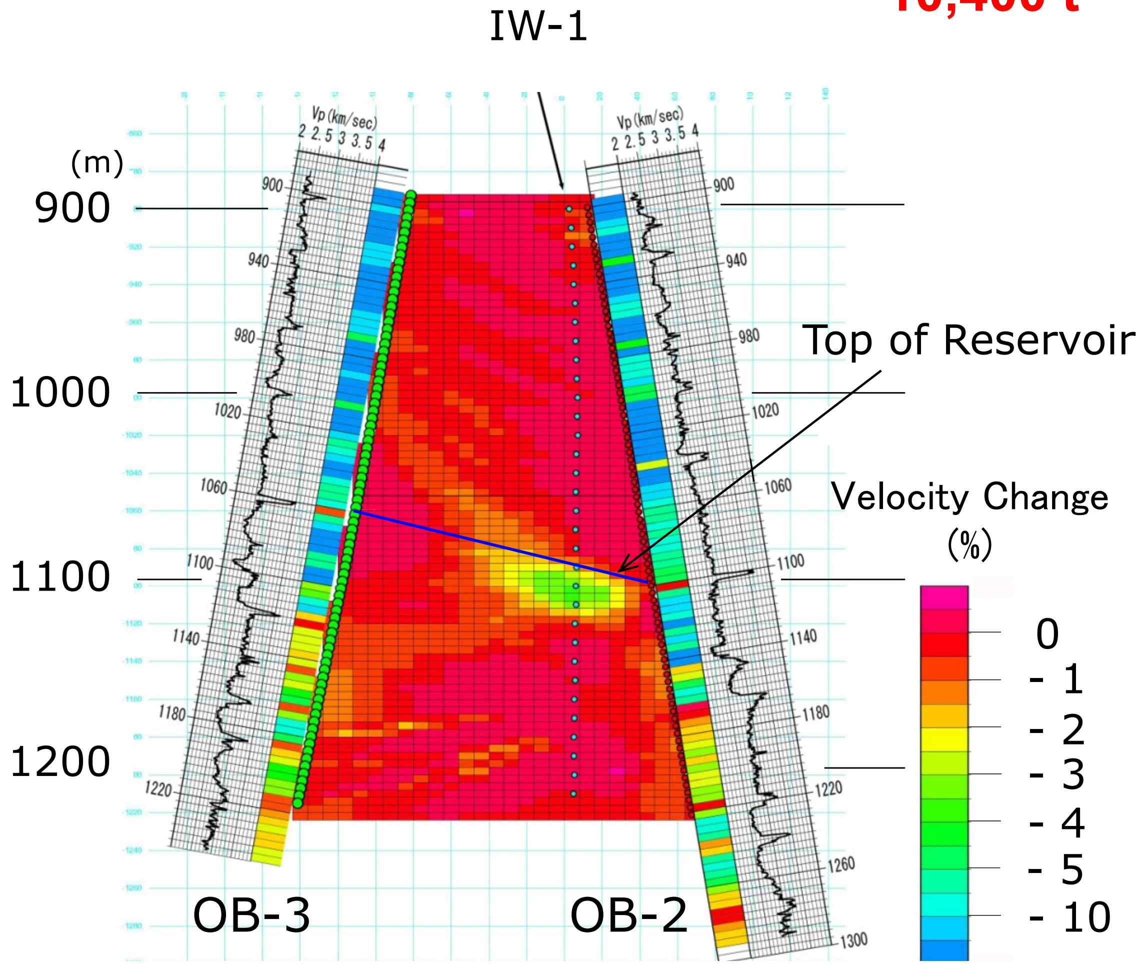
Max: -3. 5%

10,400 t





10,400 t-CO_2



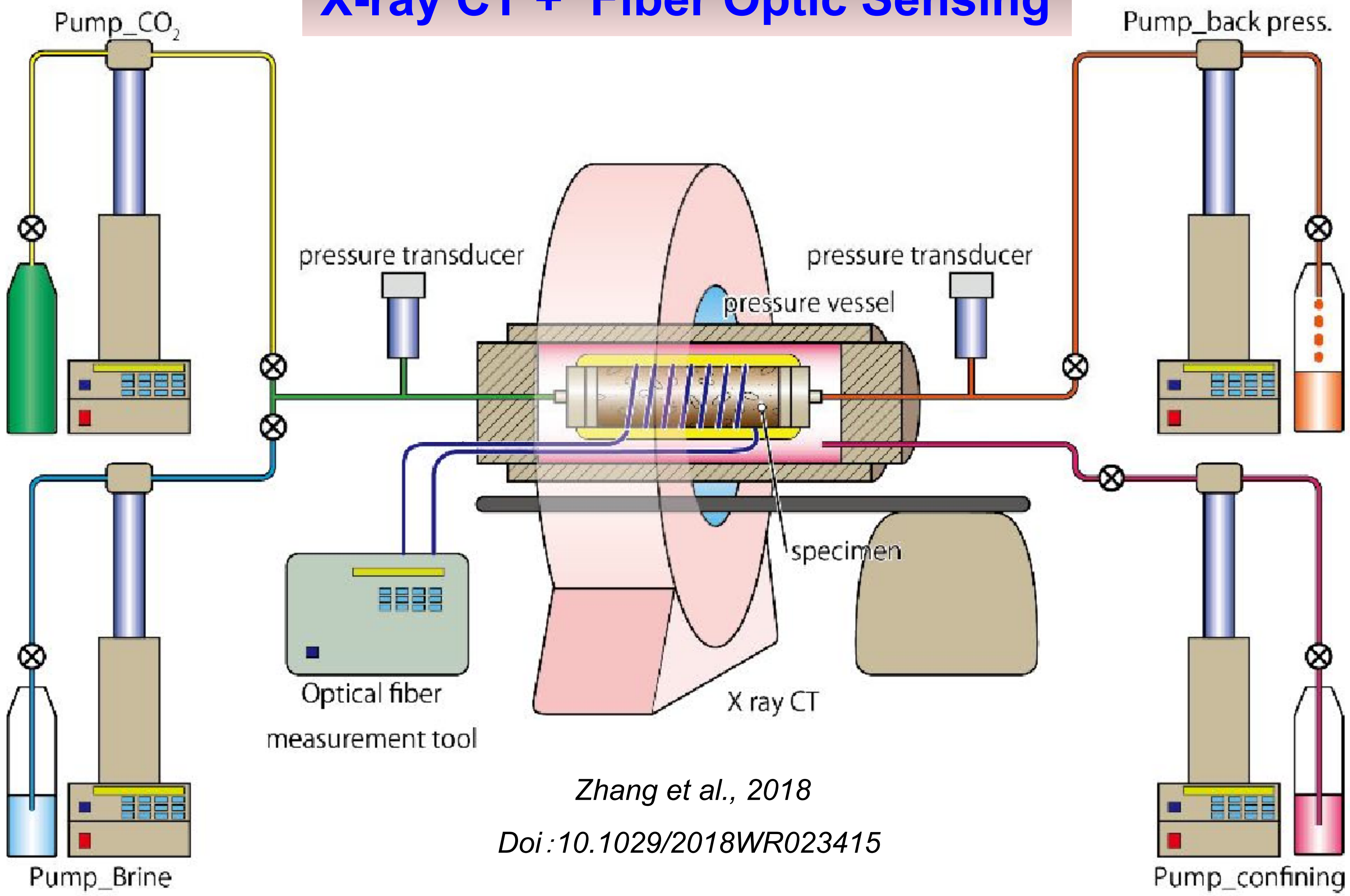
Max. Velocity Change= -3.5%

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

-- *Insights from our lab experiment* –

mobile phase (supercritical CO_2) trapped by seal

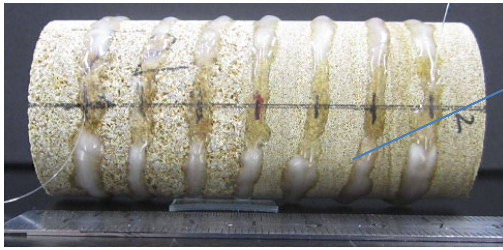
X-ray CT + Fiber Optic Sensing



Zhang et al., 2018

Doi :10.1029/2018WR023415

Visualization of the CO_2 plume and pressure fronts

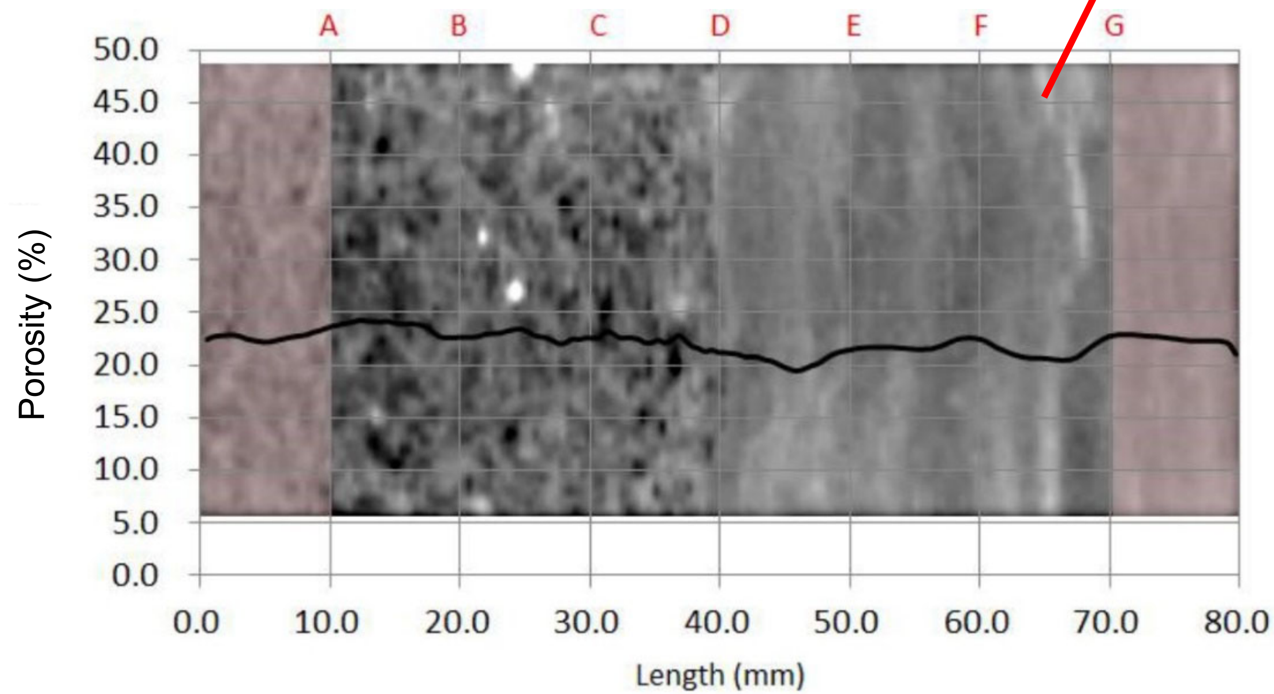


optic fiber cemented on the rock sample

Caprock (fine grain)

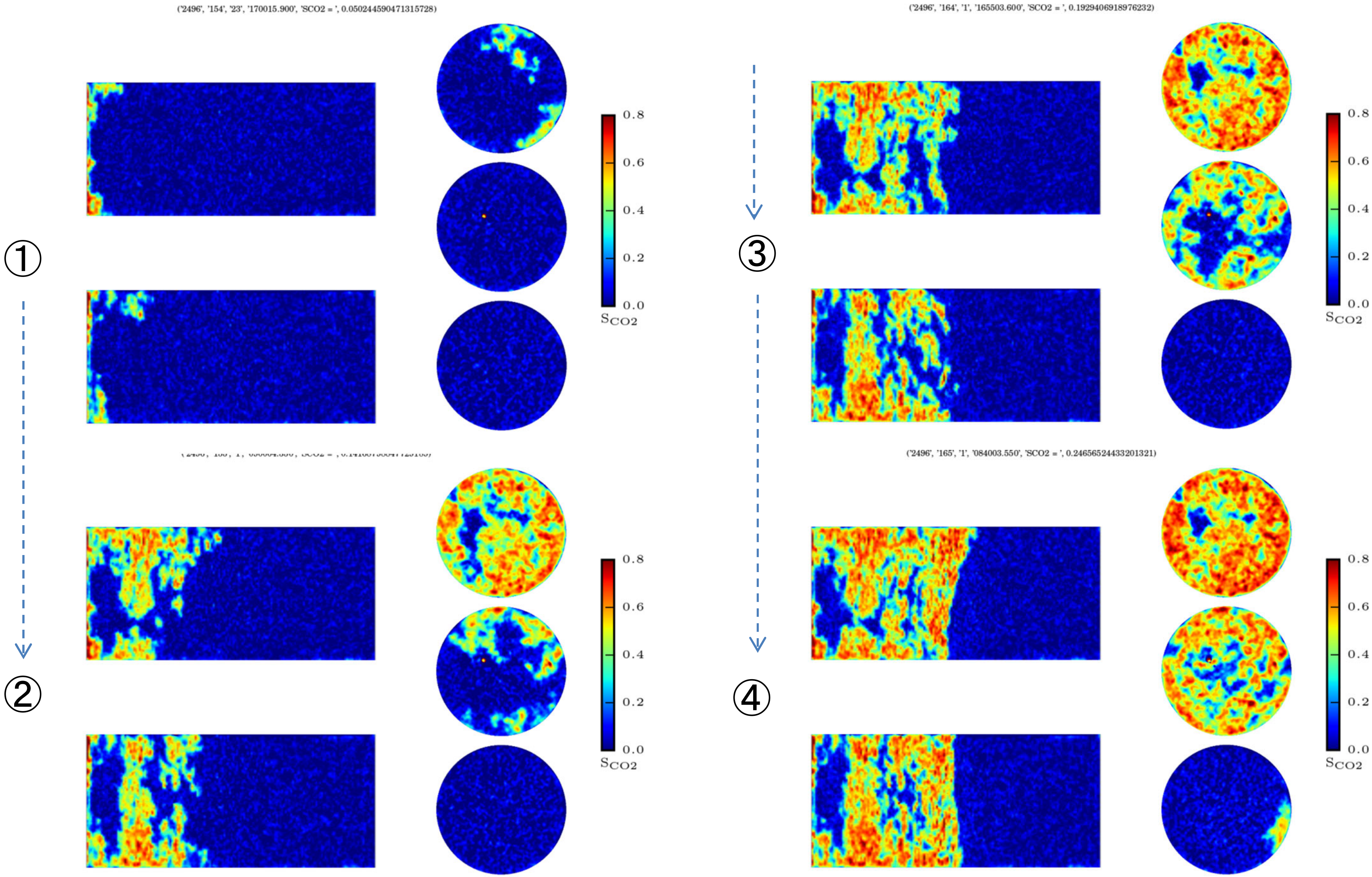
Reservoir (coarse grain)

X-CT image

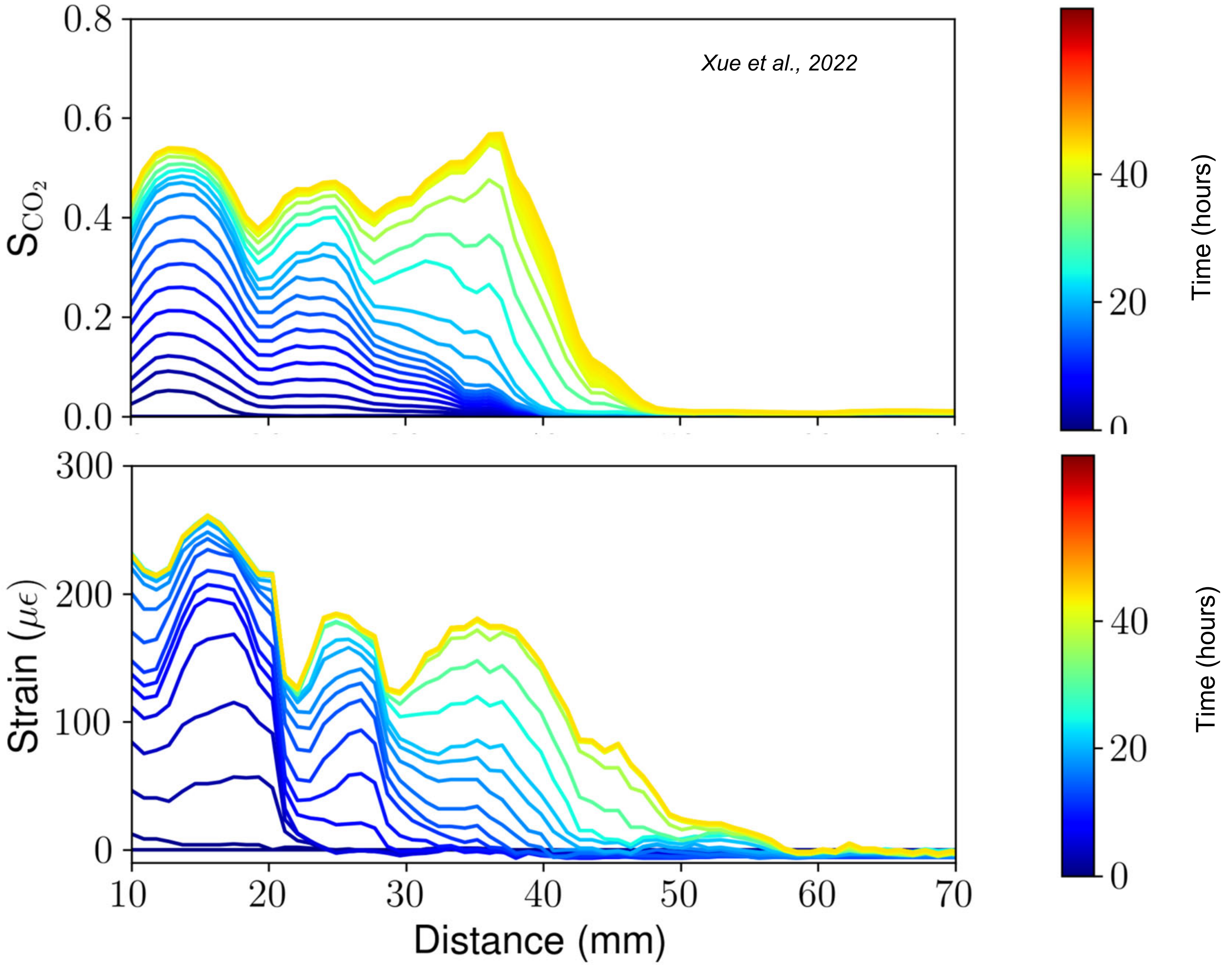


How optic fiber will response to CO2 penetration from "reservoir" to "caprock" ?

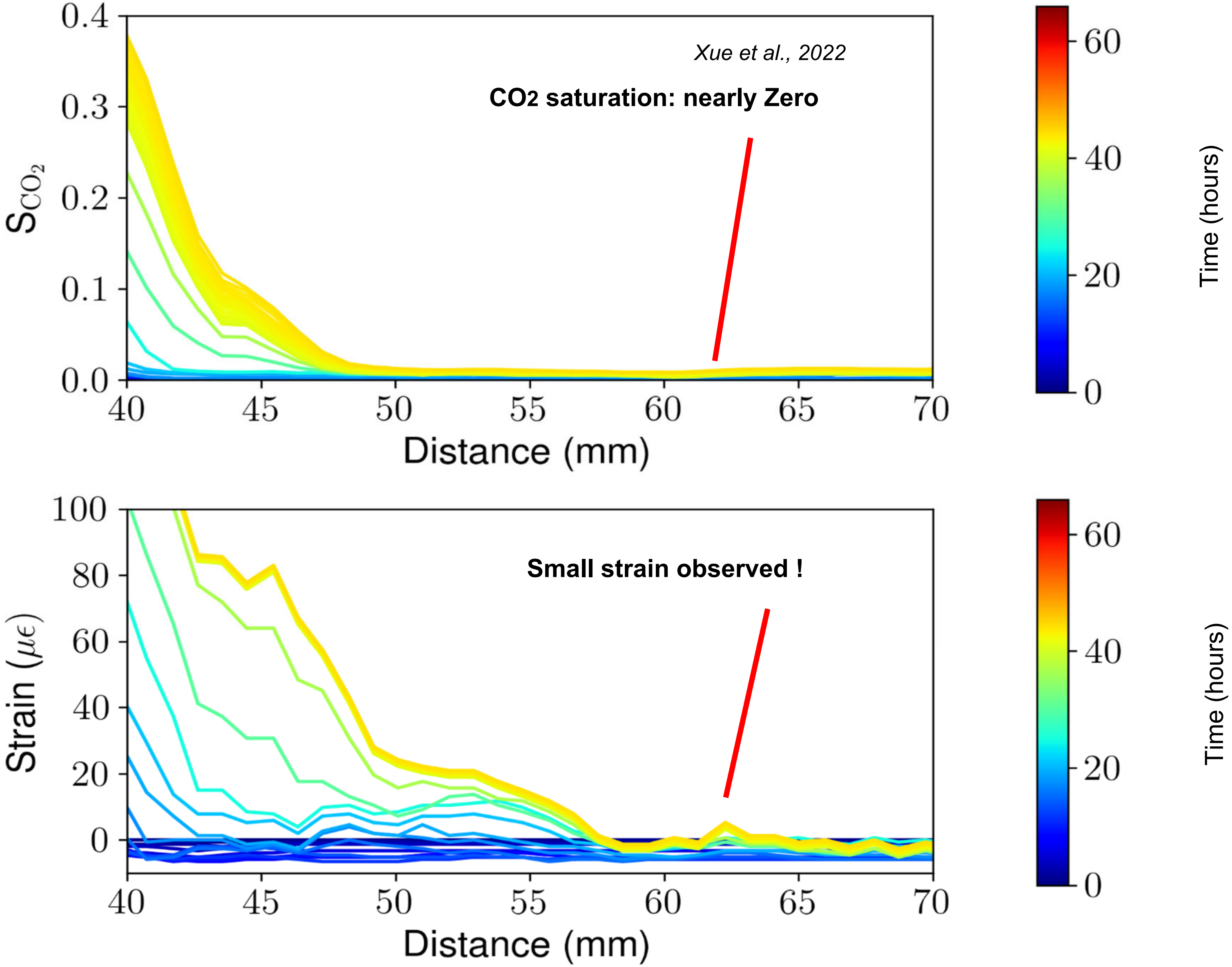
CO_2 accumulation in reservoir (coarse grain)



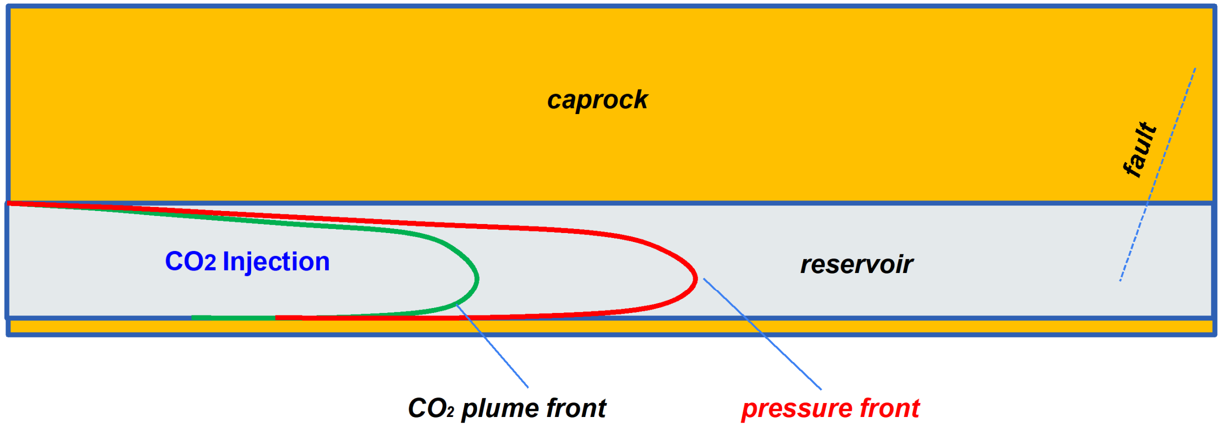
CO_2 saturation profile vs strain profile along the sample length

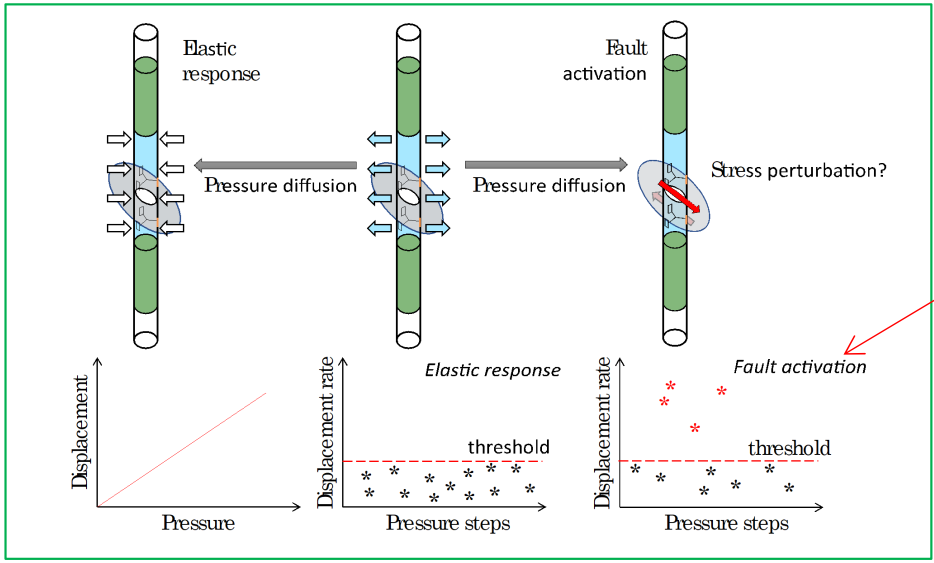


CO_2 saturation profile vs strain profile along the sample length



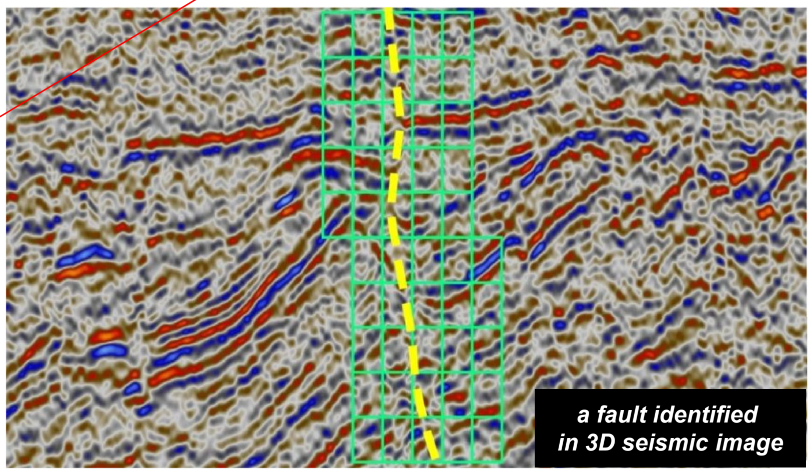
Fault Integrity Monitoring (reactivation, leakage) with Fiber Optic Sensing



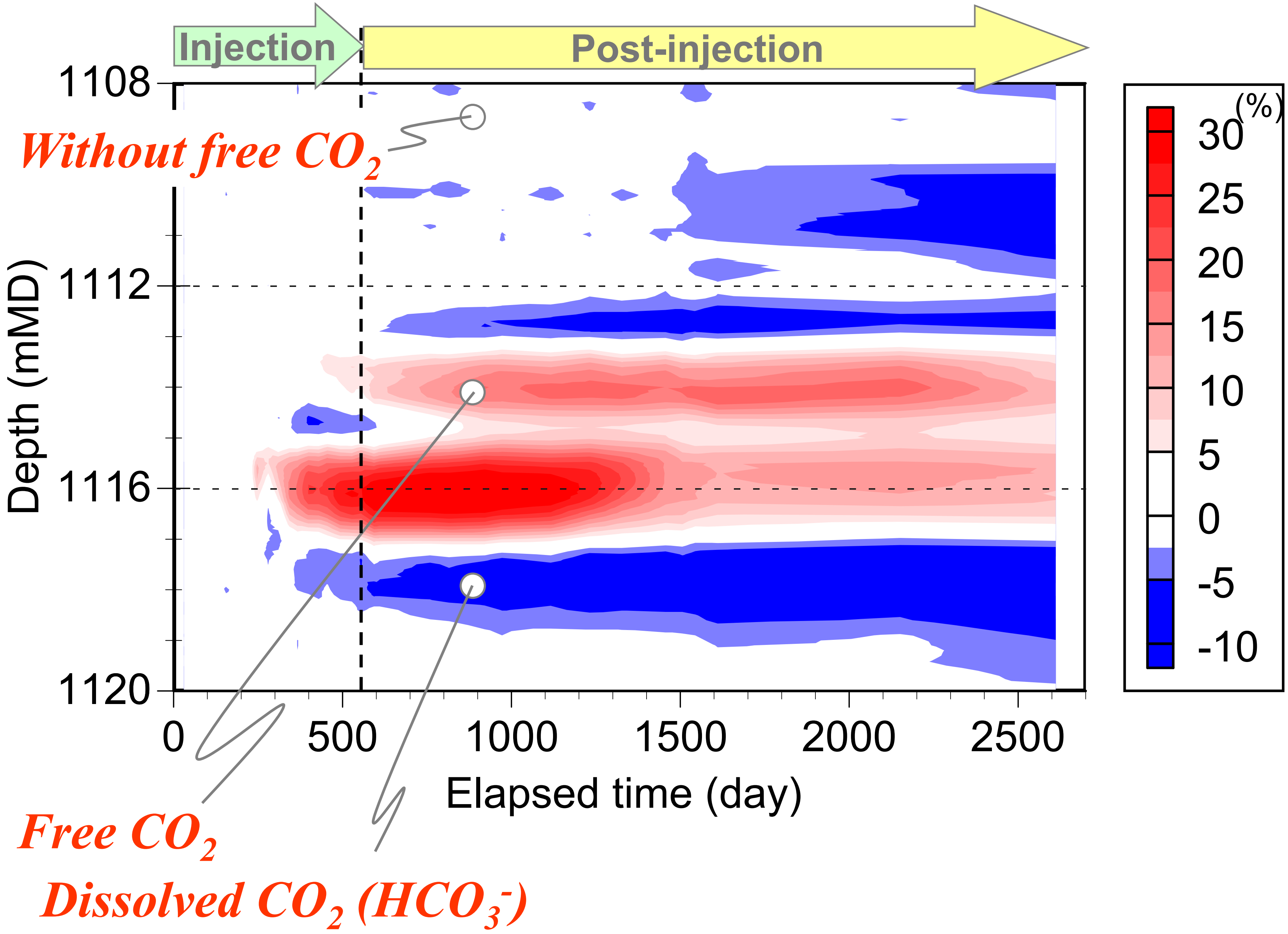


Kakurina et al, 2020

Installing fiber optic cables behind casing of monitoring wells for Distributed Strain, Temperature and Acoustic sensing

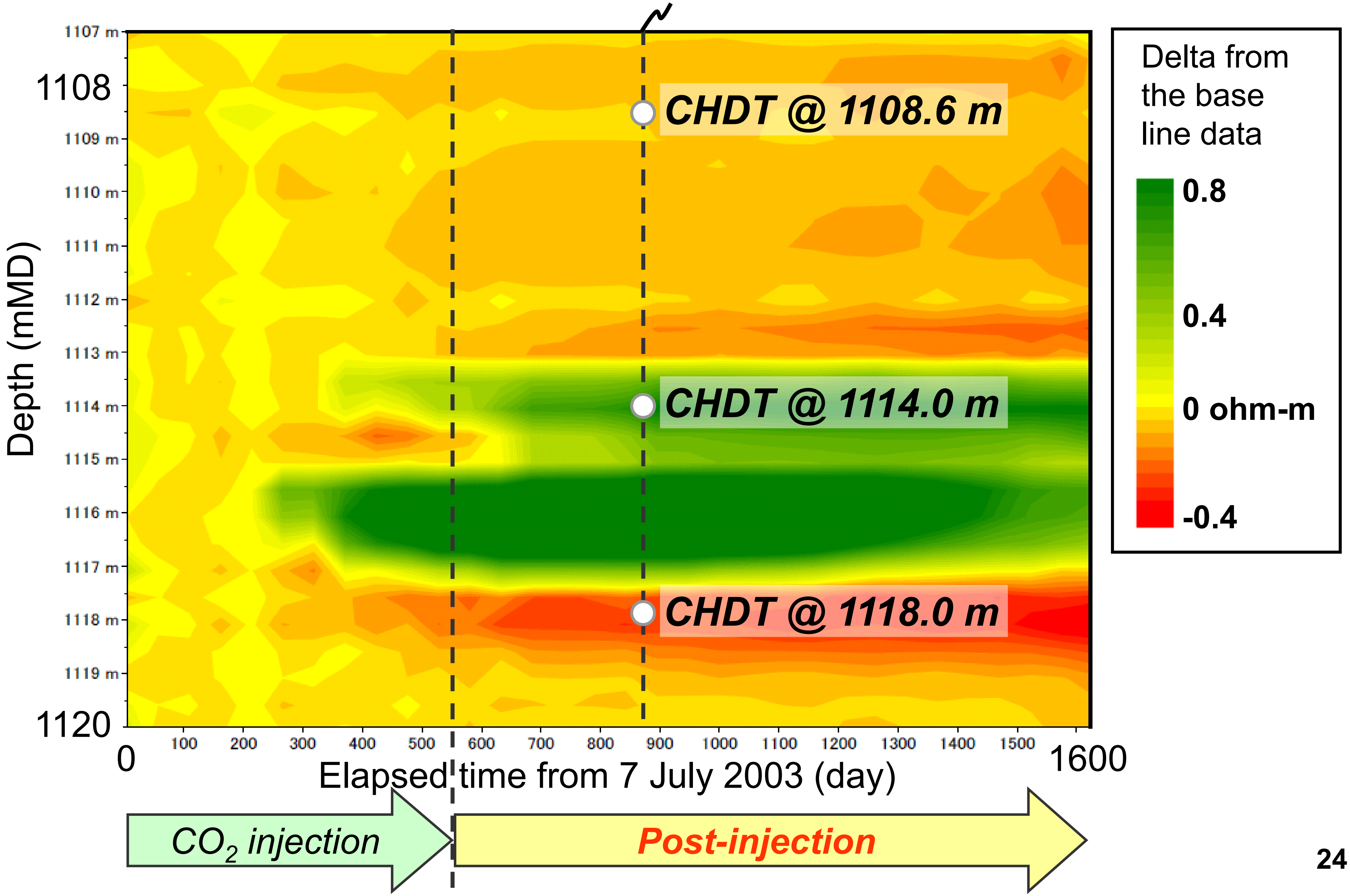


３．地球化学的視点：　地下に圧入されたCO₂挙動モニタリング



Resistivity Changes with Time @ OB-2

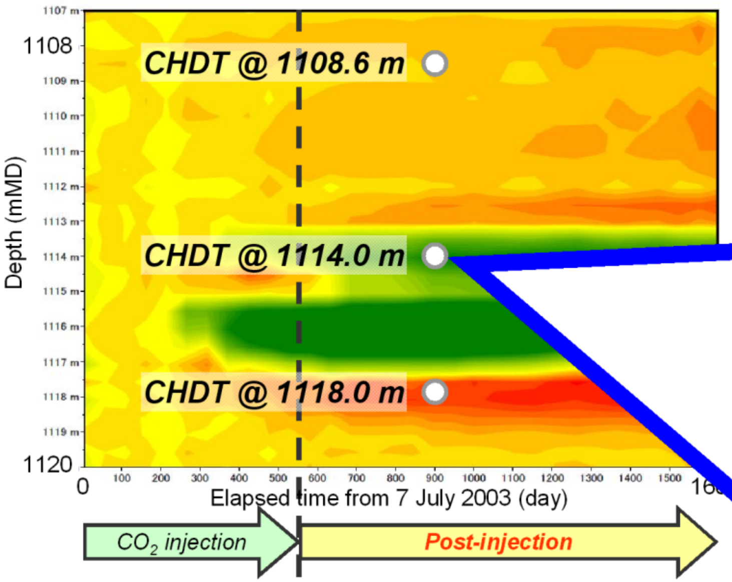
***Geochemical monitoring**: Fluid sampling by Cased Hole Dynamics Tester*

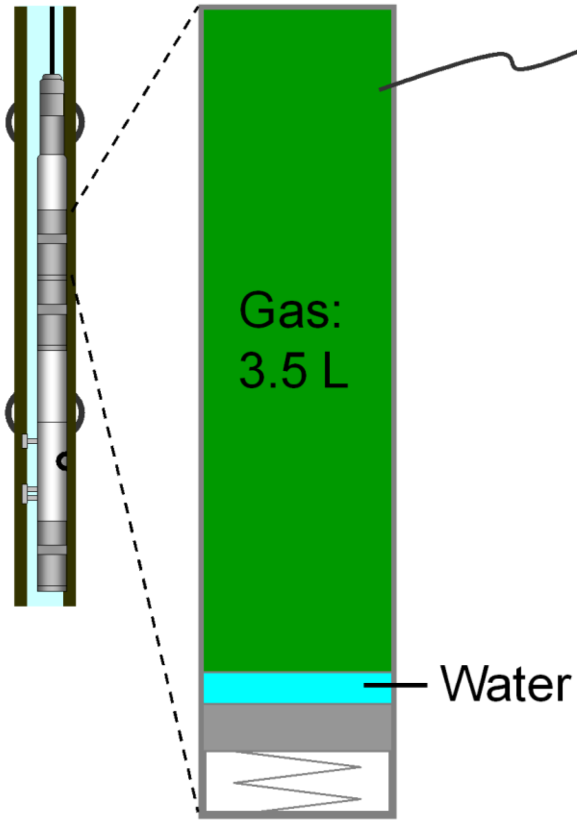


CHDT*(Cased Hole Dynamic Tester)

Drill

OB-2 @ 1114m: Mostly free CO_2



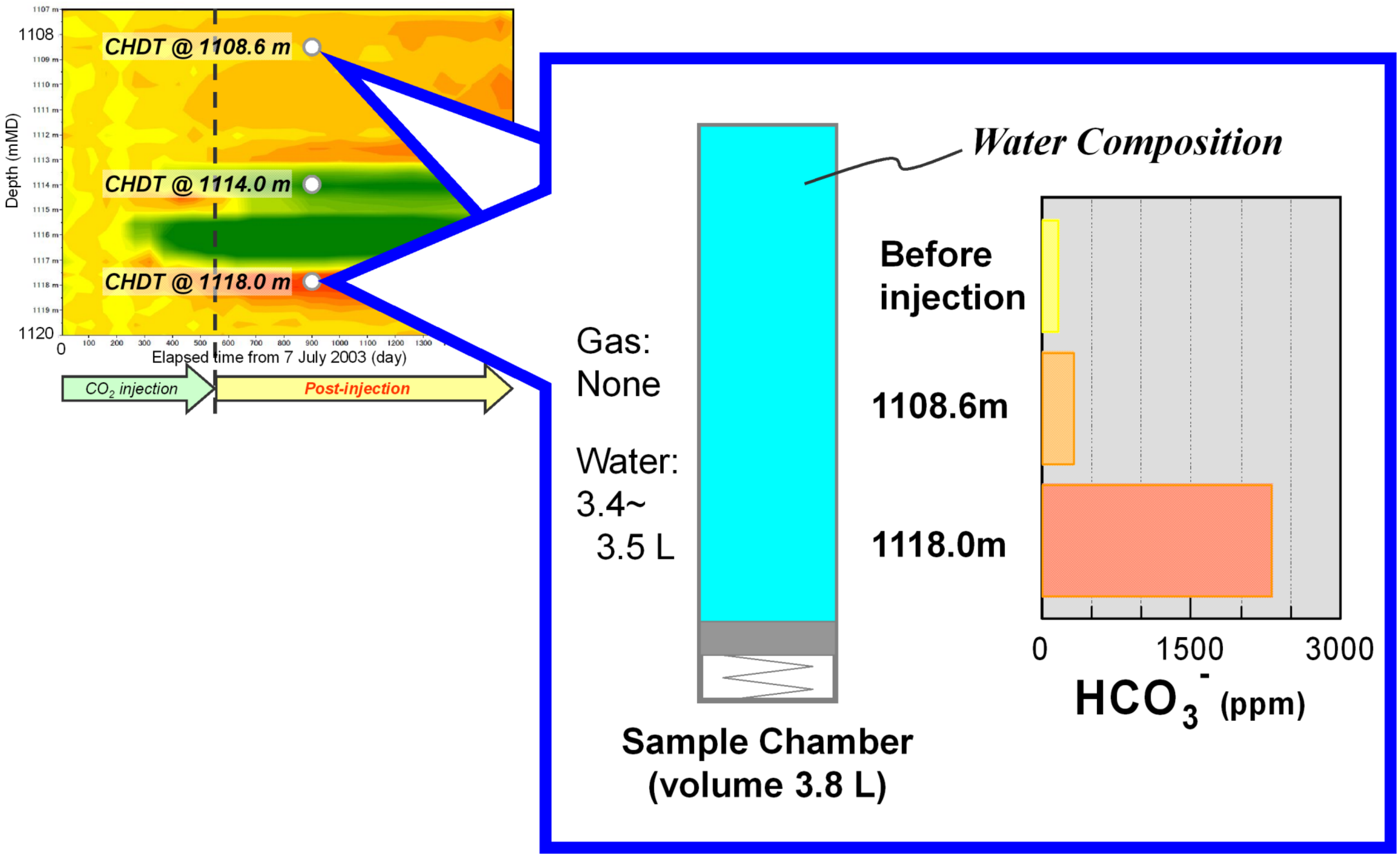


Sample Chamber
(volume 3.8 L)

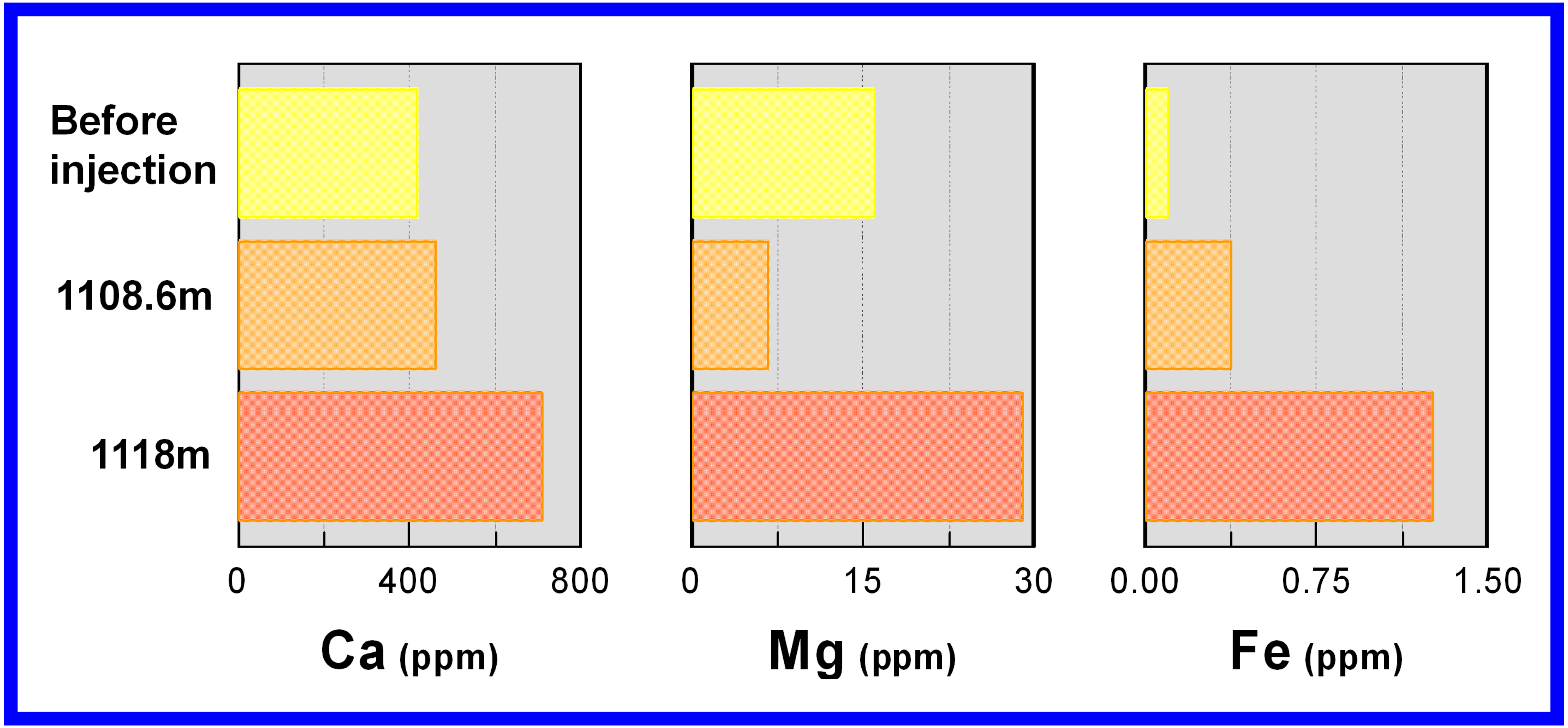
Gas composition

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

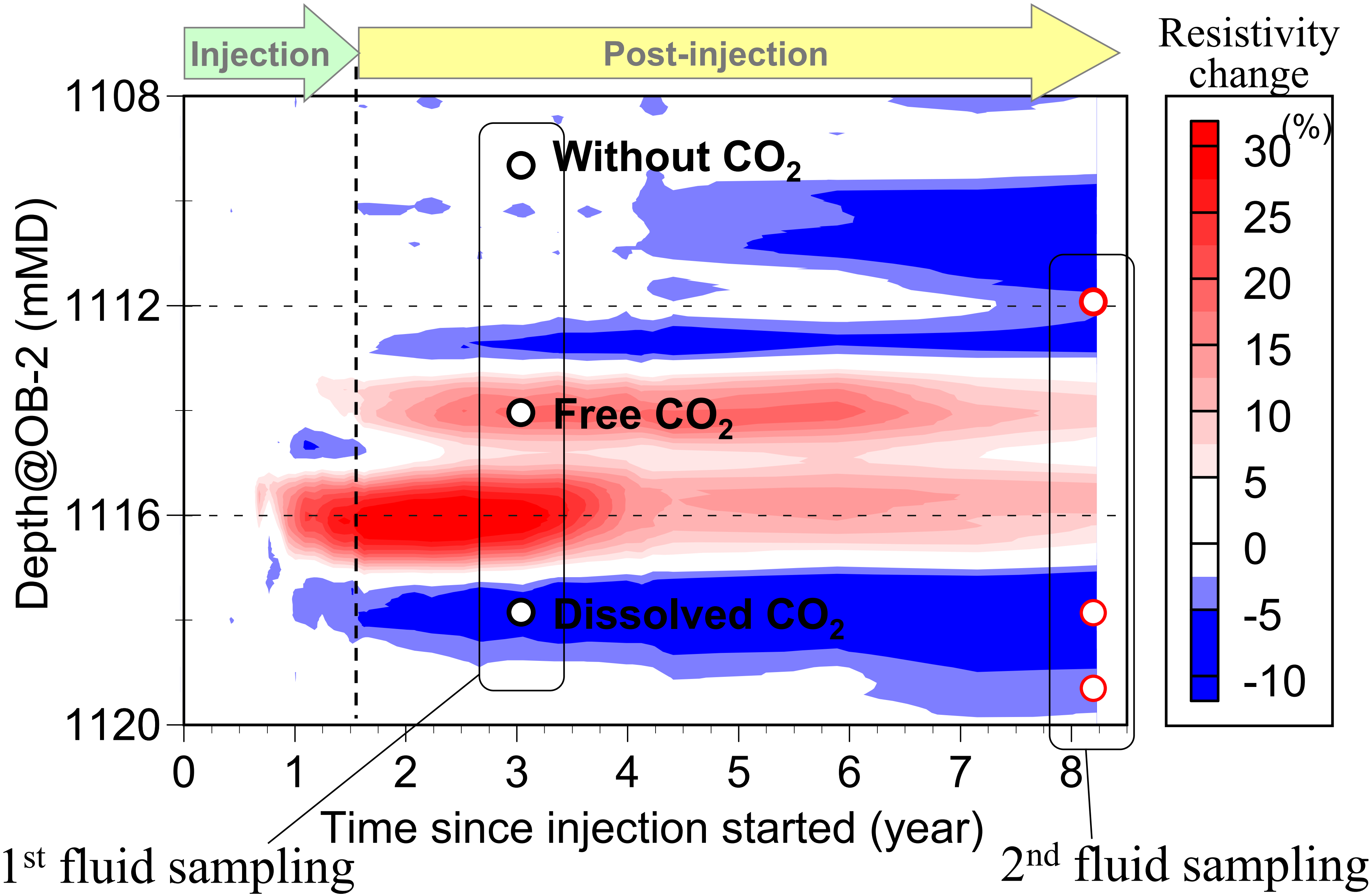


OB-2 @ 1108.6m&1118m：
Cations in the formation water



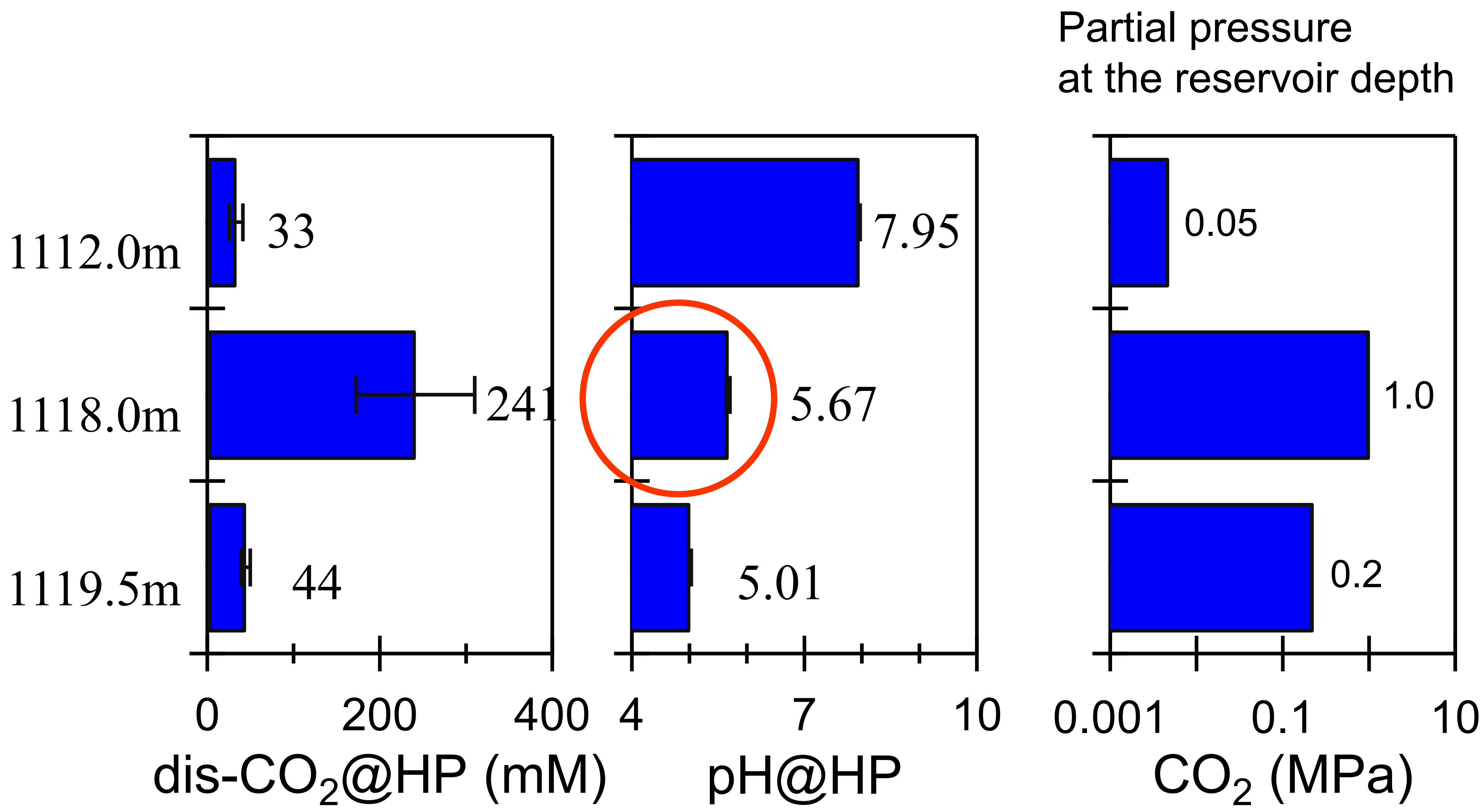
Increased: HCO_3^-, Ca, Mg and Fe @1118m

Formation Fluid Sampling at OB-2

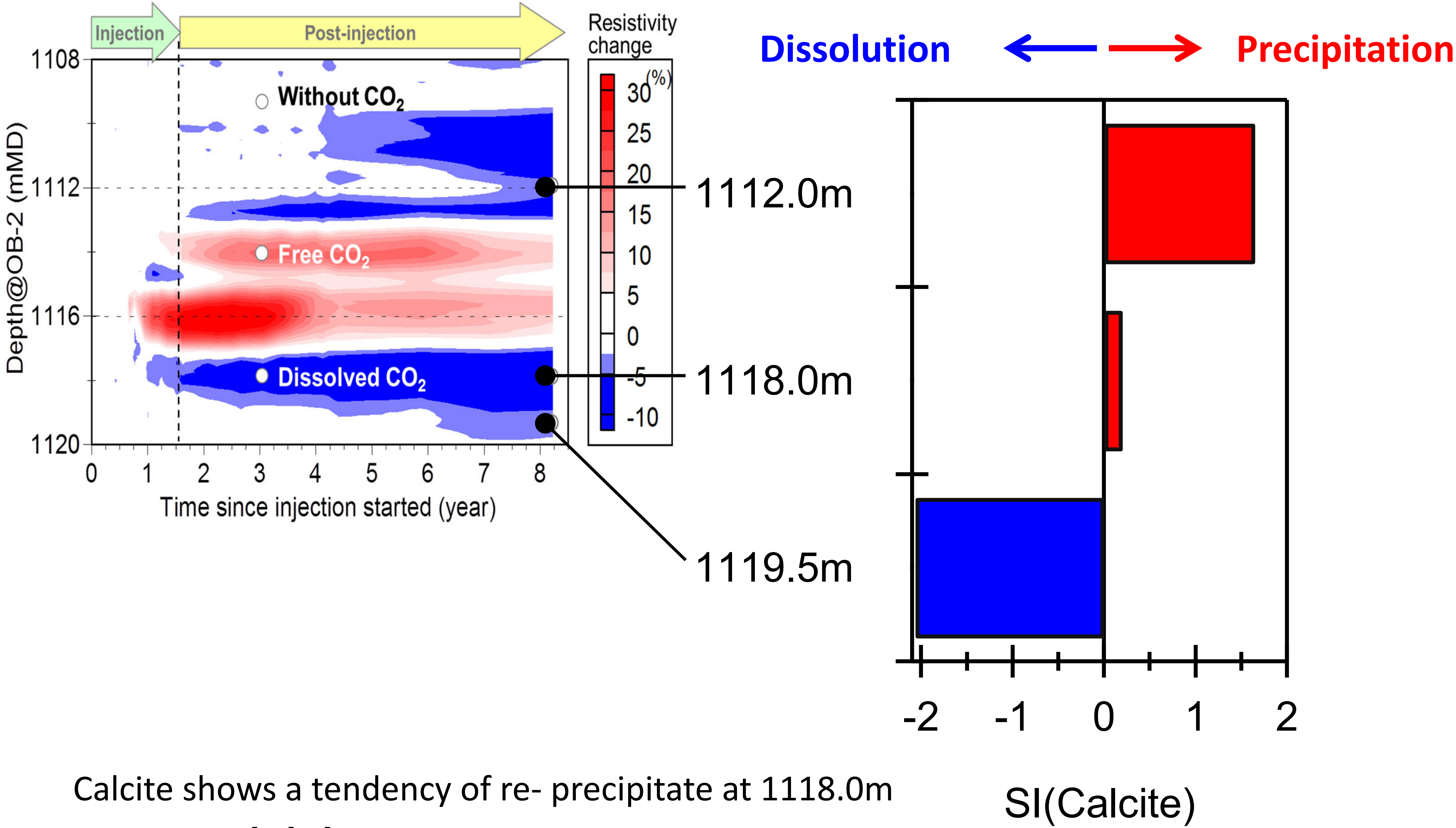


地球化学的手法によるCO_2挙動モニタリング

Successful measurement of dis-CO_2 & pH under high pressure condition



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



Calcite shows a tendency of re- precipitate at 1118.0m

→→→ *Mineral trapping of CO_2?*

CO_2 Trap Mechanisms Confirmed @Nagaoka Site

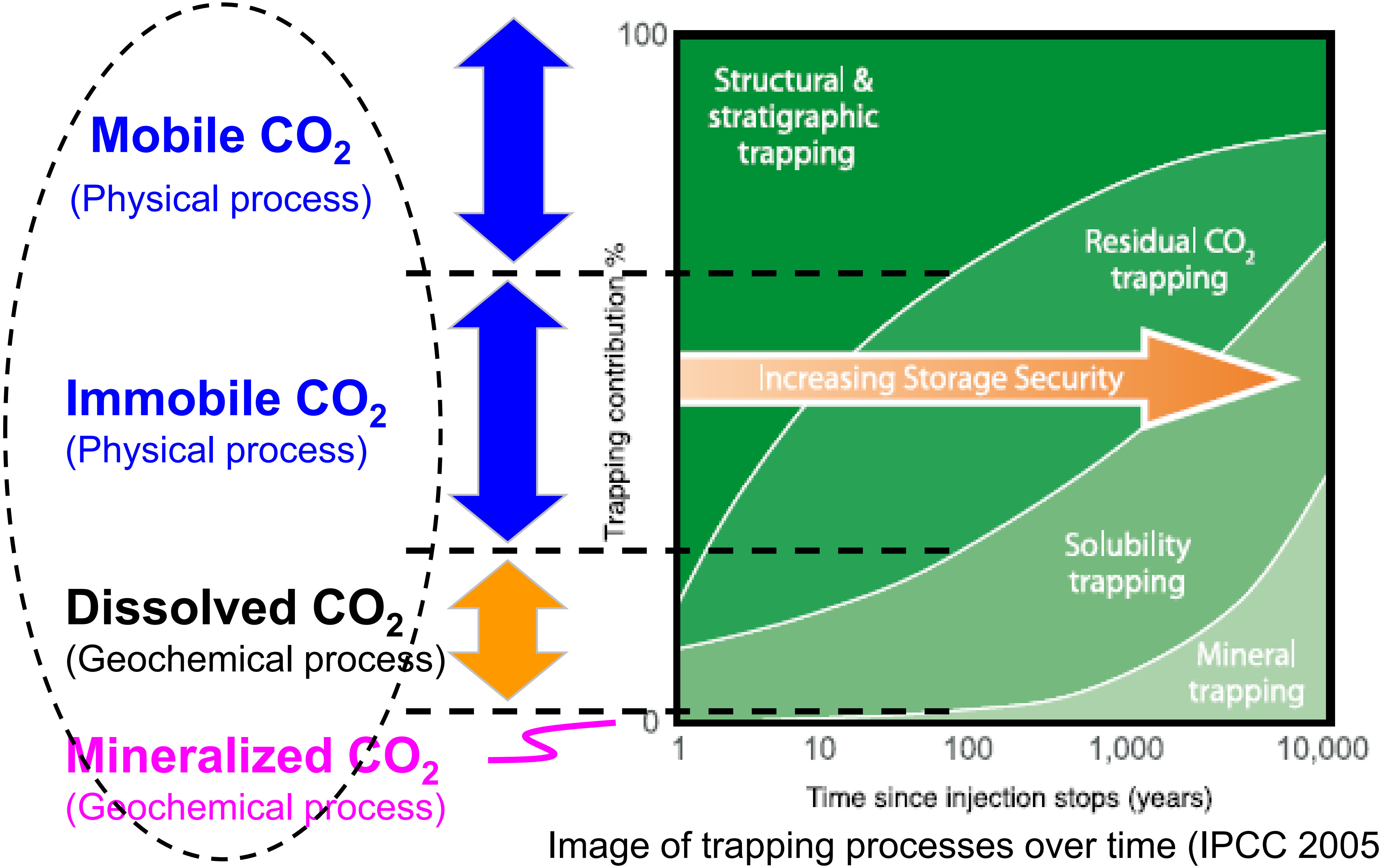


Image of trapping processes over time (IPCC 2005)

Rapid carbon mineralization for permanent disposal of anthropogenic carbon dioxide emissions

Published 10 June 2016, *Science* **352**, 1312 (2016)
DOI: 10.1126/science.aad8132

➢ カーボンニュートラルとCCSの社会実装

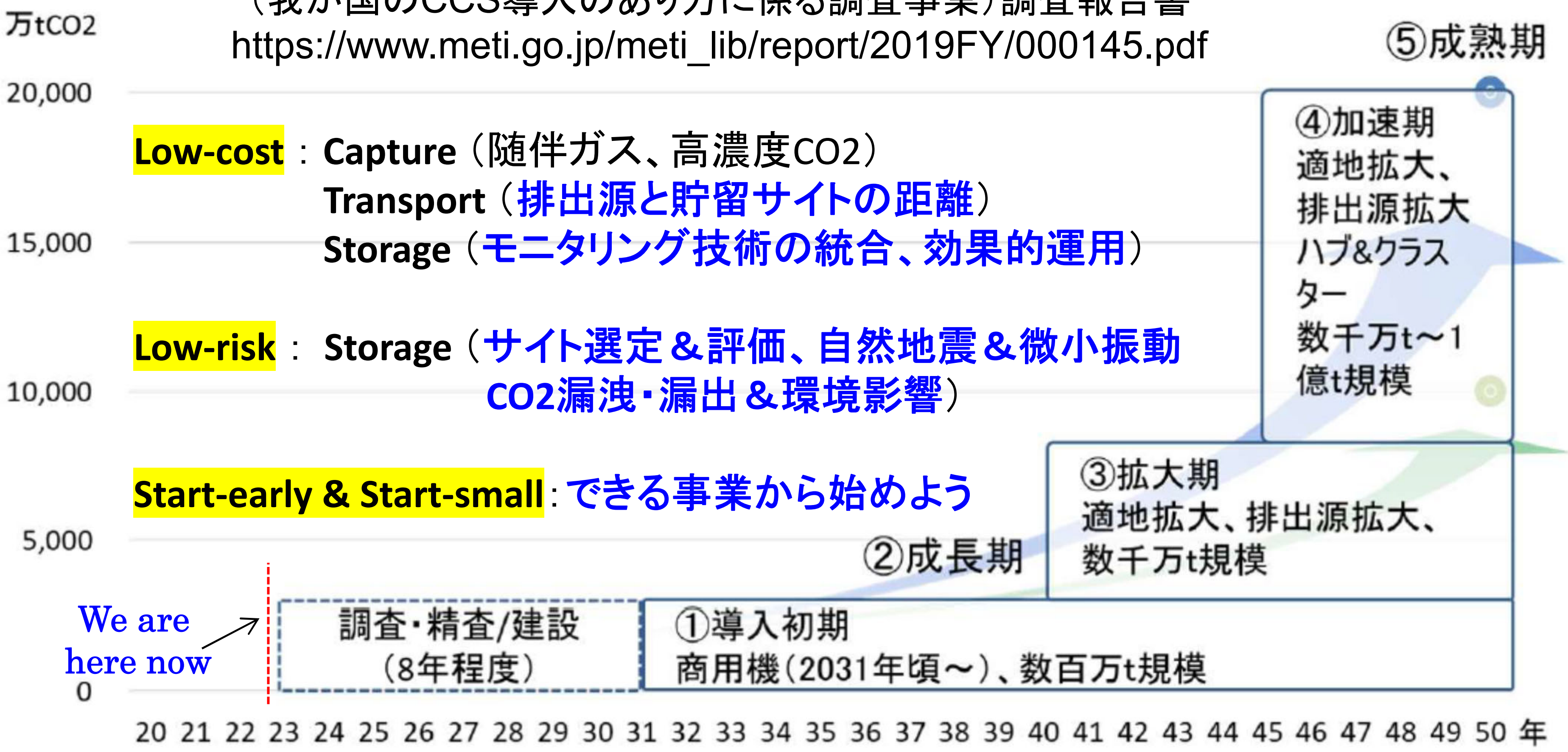
2050年に向けて、徐々に拡大するケース

（我が国のCCS導入のあり方に係る調査事業）調査報告書
https://www.meti.go.jp/meti_lib/report/2019FY/000145.pdf

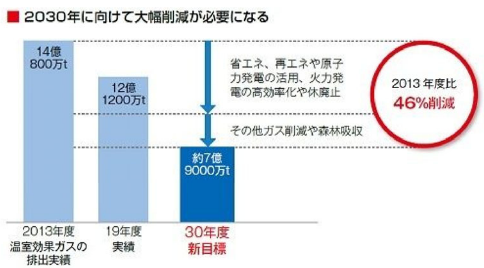
Low-cost ：Capture（随伴ガス、高濃度CO2）
Transport（排出源と貯留サイトの距離）
Storage（モニタリング技術の統合、効果的運用）

Low-risk ： Storage（サイト選定＆評価、自然地震＆微小振動
CO2漏洩・漏出＆環境影響）

Start-early & Start-small：できる事業から始めよう

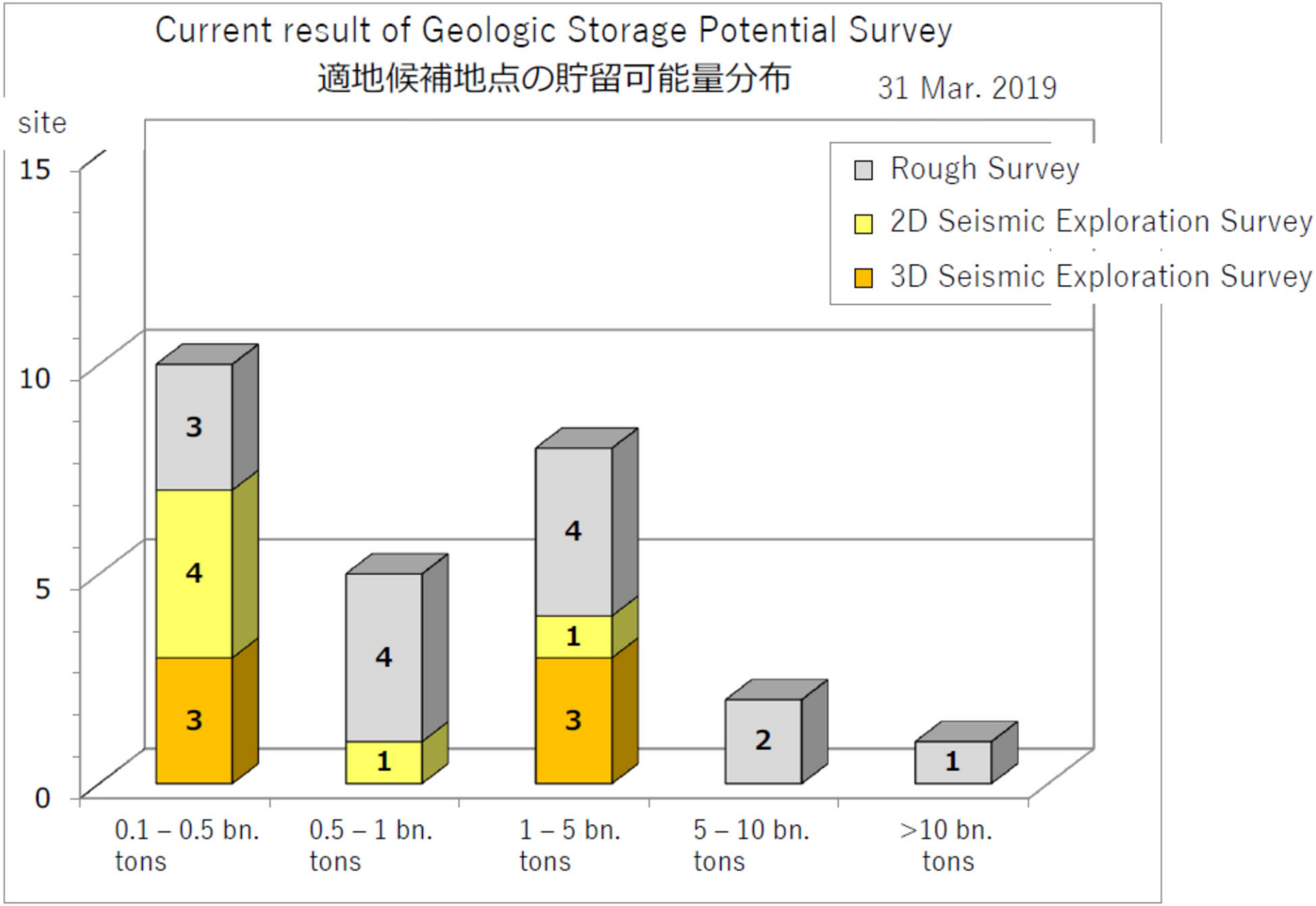


50年にカーボンニュートラル（実質排出ゼロ）を実現するために、今から毎年、同じ削減量で減らしていくと計算すると、30年時点では45.9％の削減が必要になる。この計算で割り出された数字を意識して、新目標が決まったとみられる。

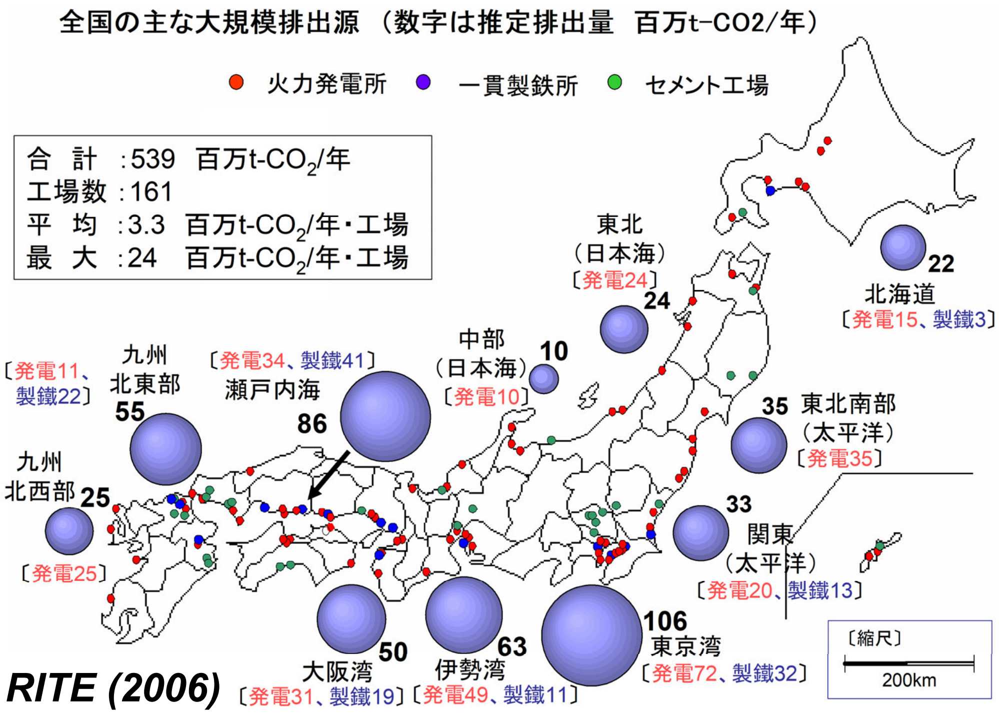


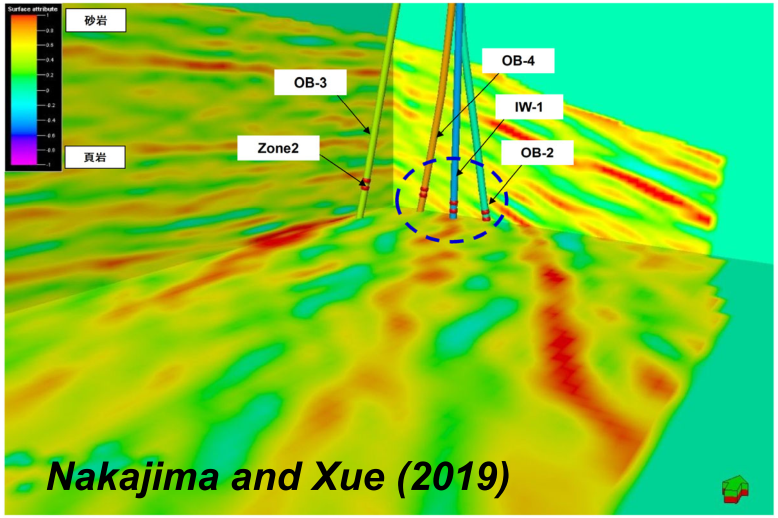
CO_2 Storage potential in Japan

METI(2020)

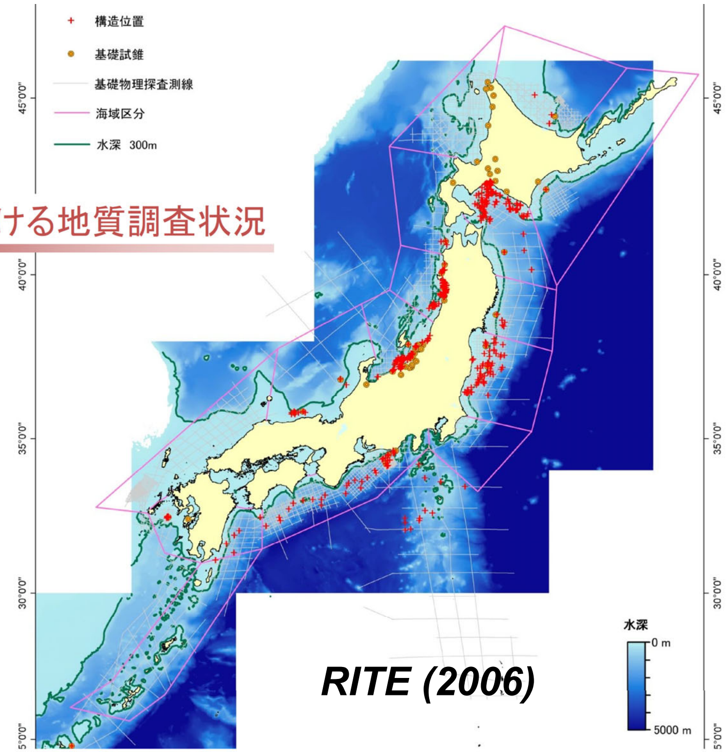


SRM: CO_2 Storage Resources Management（経済性評価込み）

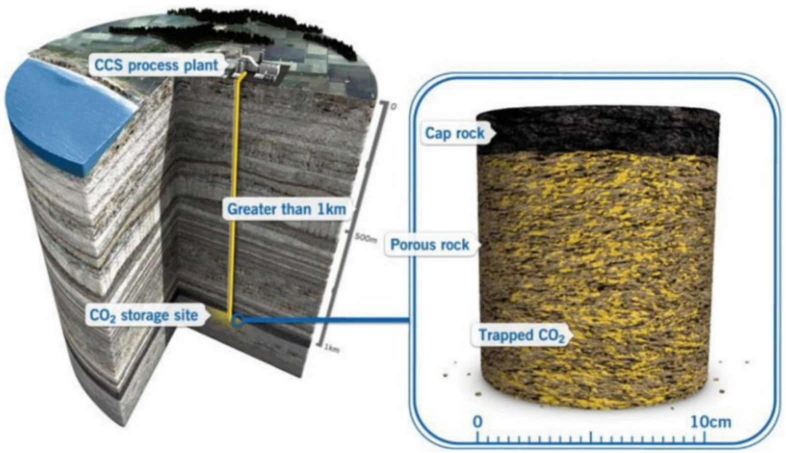




国内における地質調査状況



1. **Depth:** > 1 km
2. **Location:**
   - reservoir and containment
   - accessible
3. **Capacity:** Space to hold all the planned CO_2



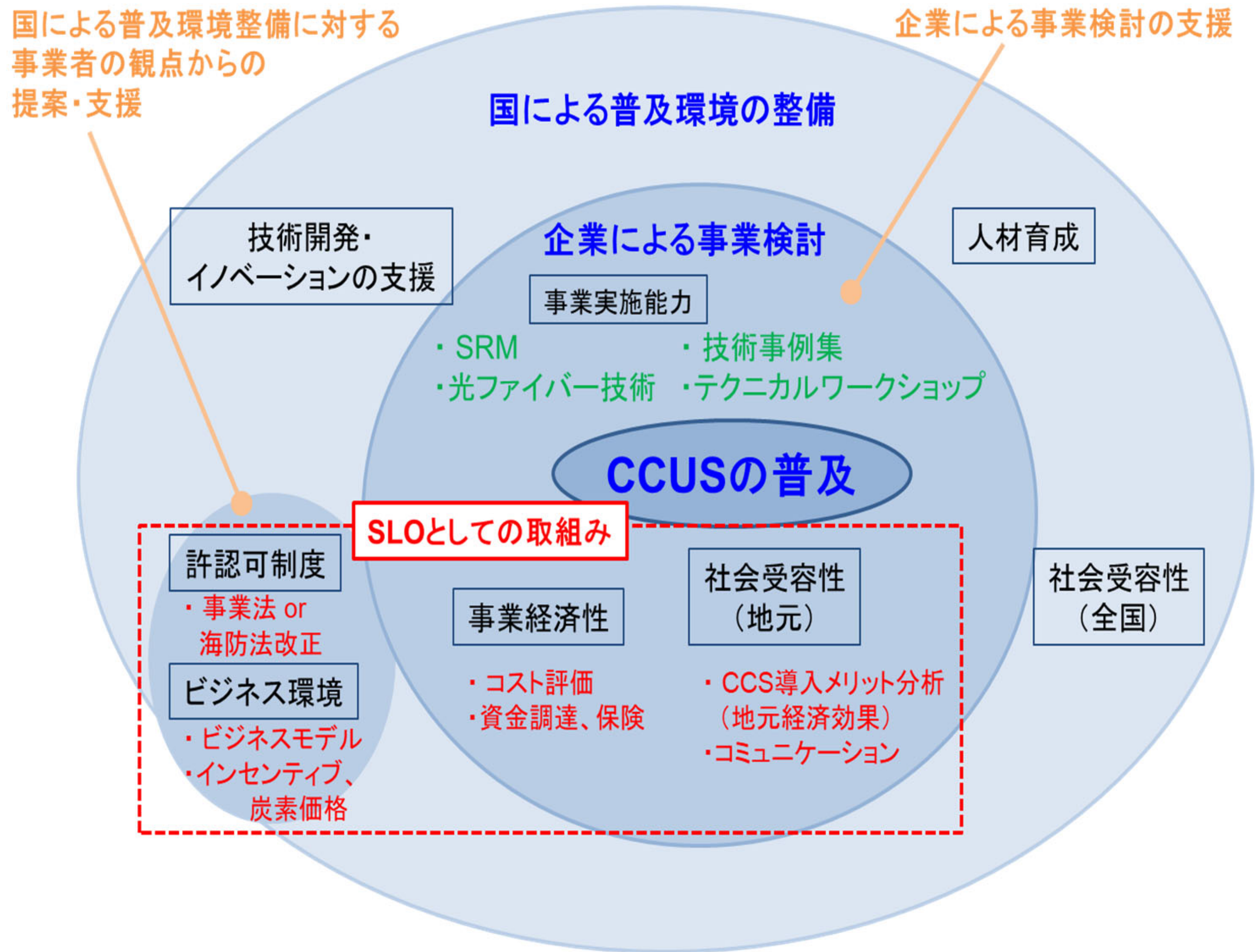
Source: GCCSI

貯留可能量、排出源（排出量、距離）、輸送手段、貯留規模、経済性、社会的受容性（SLO）、複数の実想定サイトを選定！

GRETCHEN WATKINS

Gretchen Watkins | President, Shell USA, Inc

Carbon capture and storage is not a **single technology**, but rather a series of **technologies** and **scientific breakthroughs** that work in **concert** to achieve a performed outcome, one that will play a **significant role** in the future of energy and our planet.



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