Microbubble CO_2 Injection for Enhanced Dissolution in Geological Storage and Improved Oil Recovery

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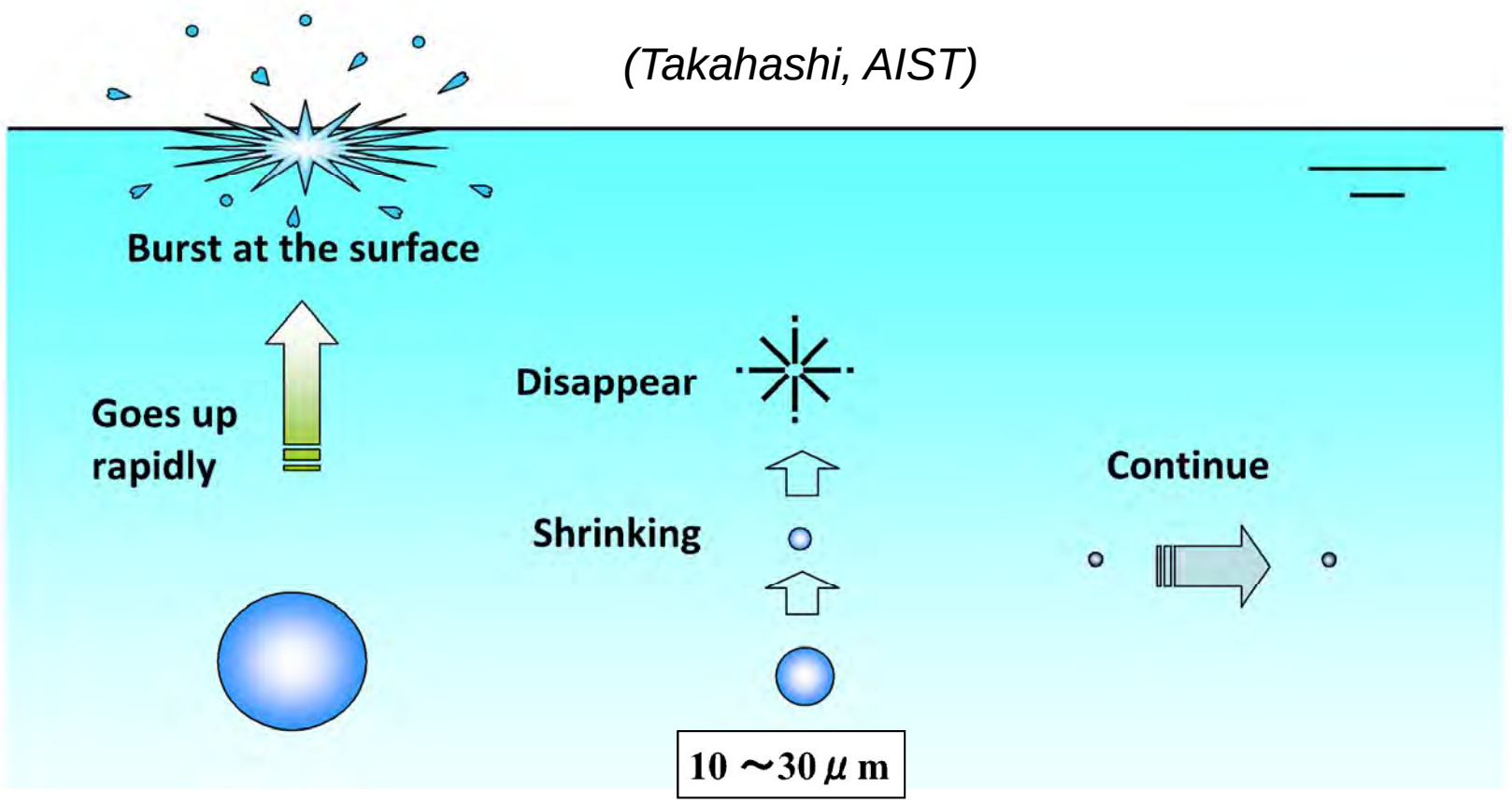
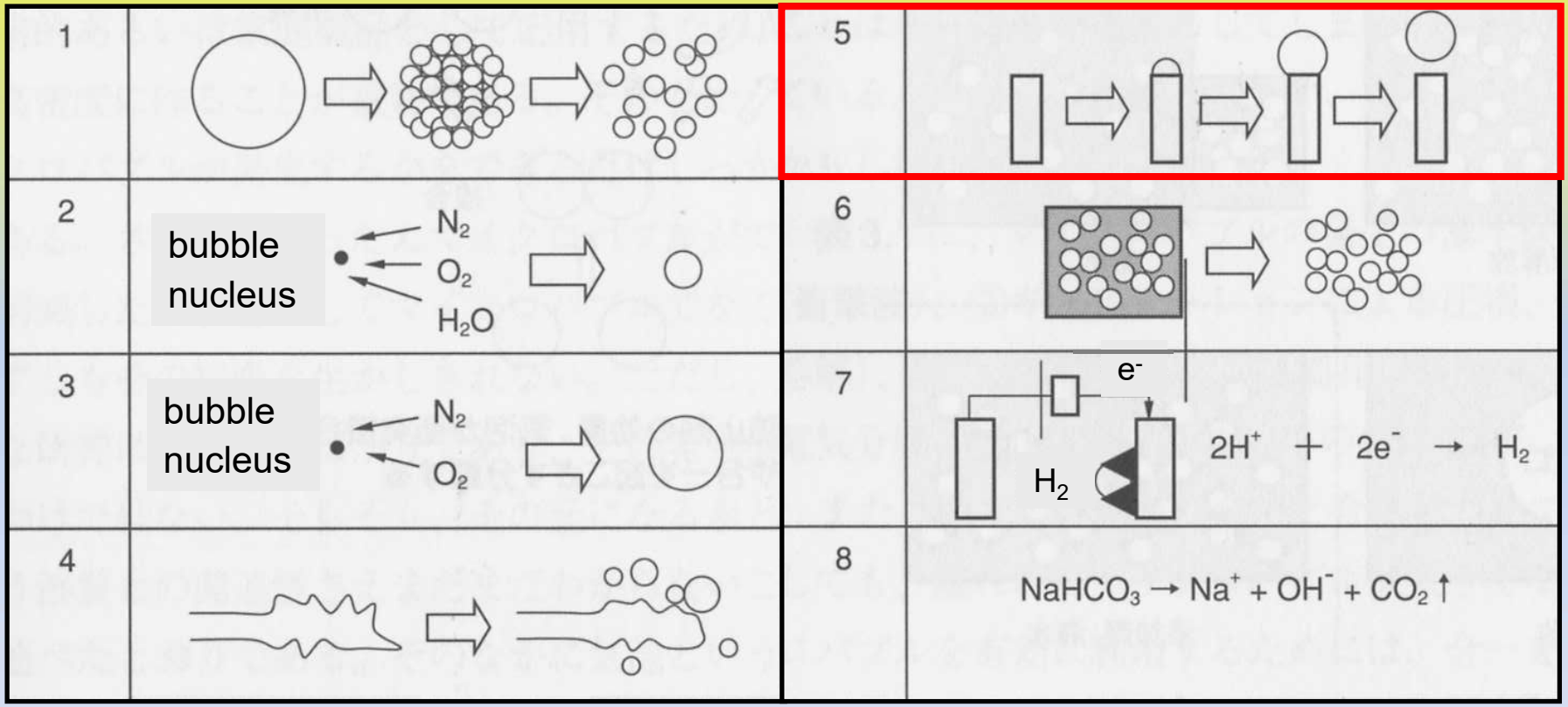
  - ✓**MB and NB in Sandstone, Monitoring**
- **Three-Phase: Brine, Oil and CO_2**
  - ✓**MB and NB in Sandstone, Sweep Efficiency, Oil Recovery (CO_2–EOR)**

What's Microbubble (MB)?

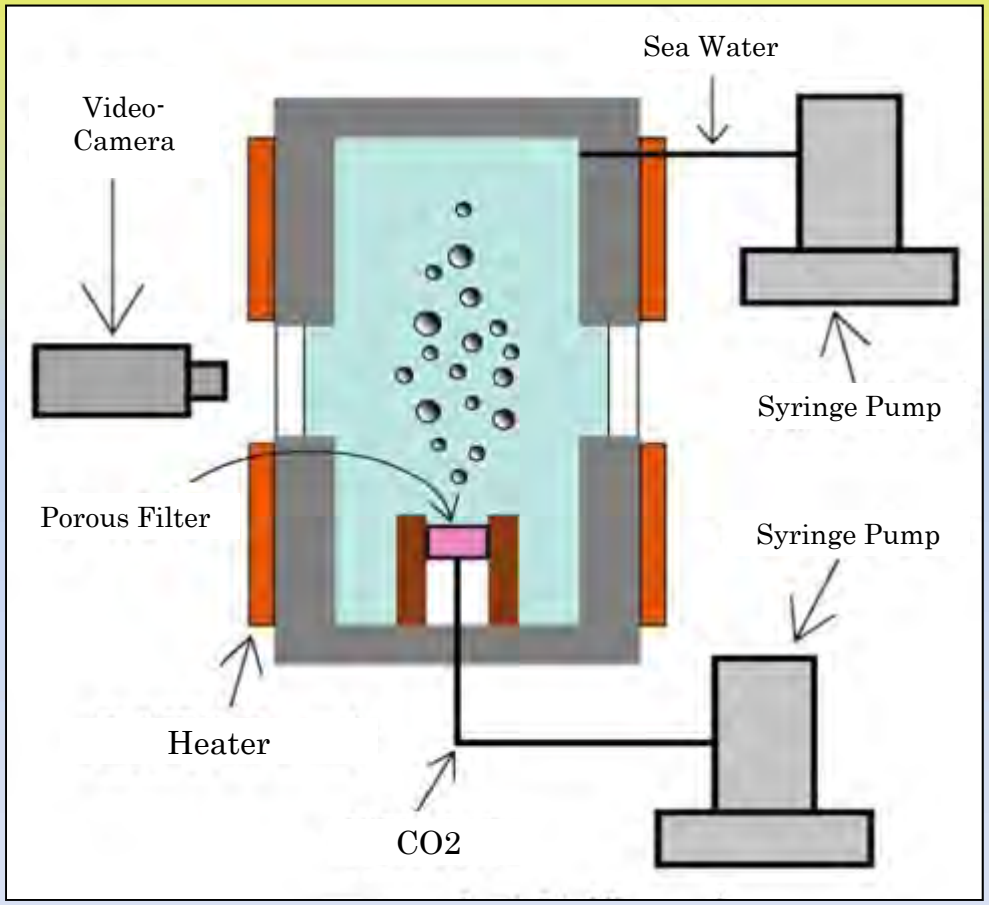


Methods for Generating Microbubble

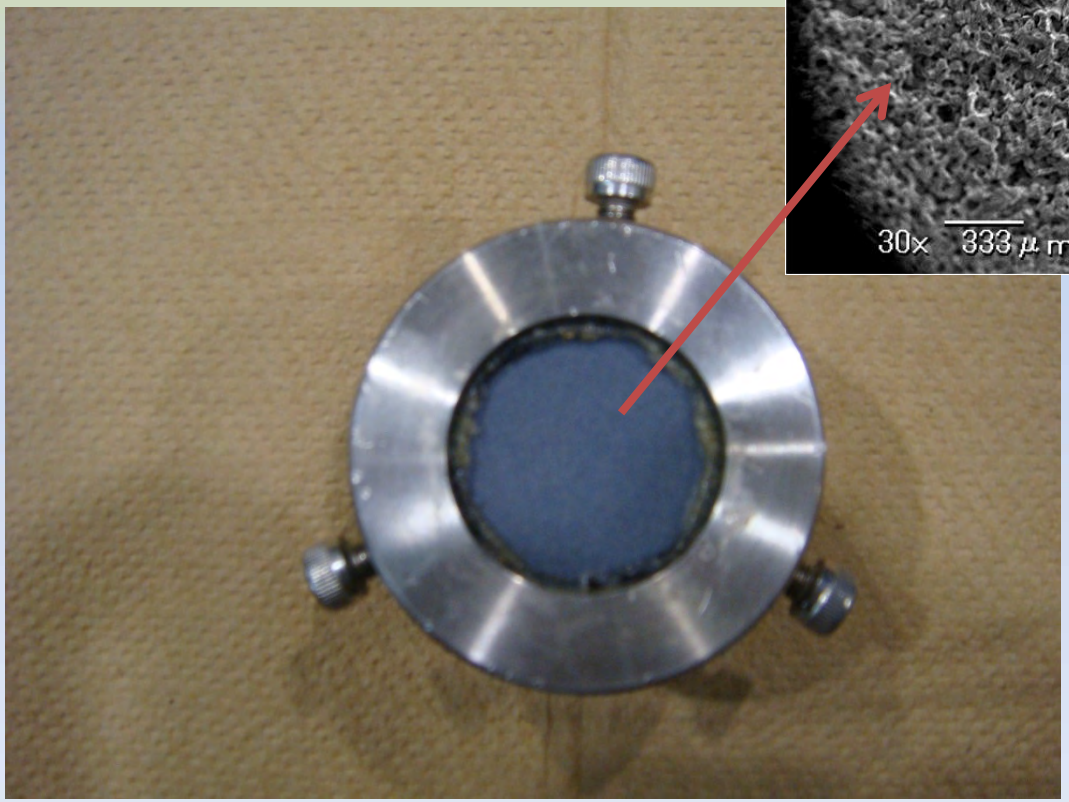


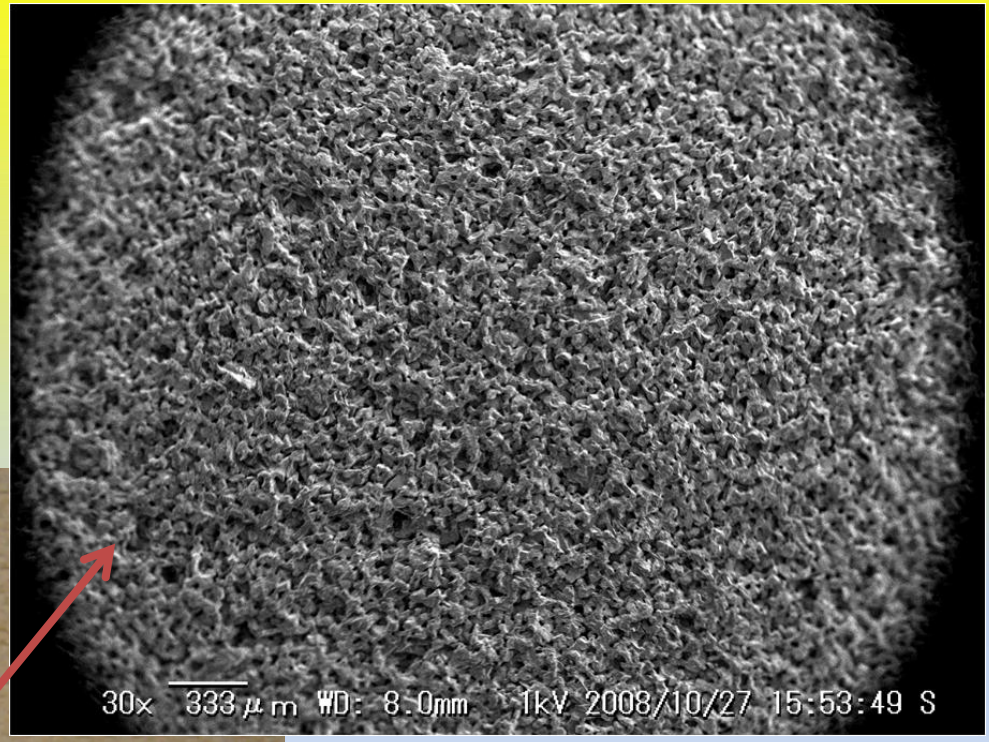
Deployed to deep formations (high pressure and temperature, corrosion in saline water, maintenance, operation costs)

Experimental Setup for Microbubble

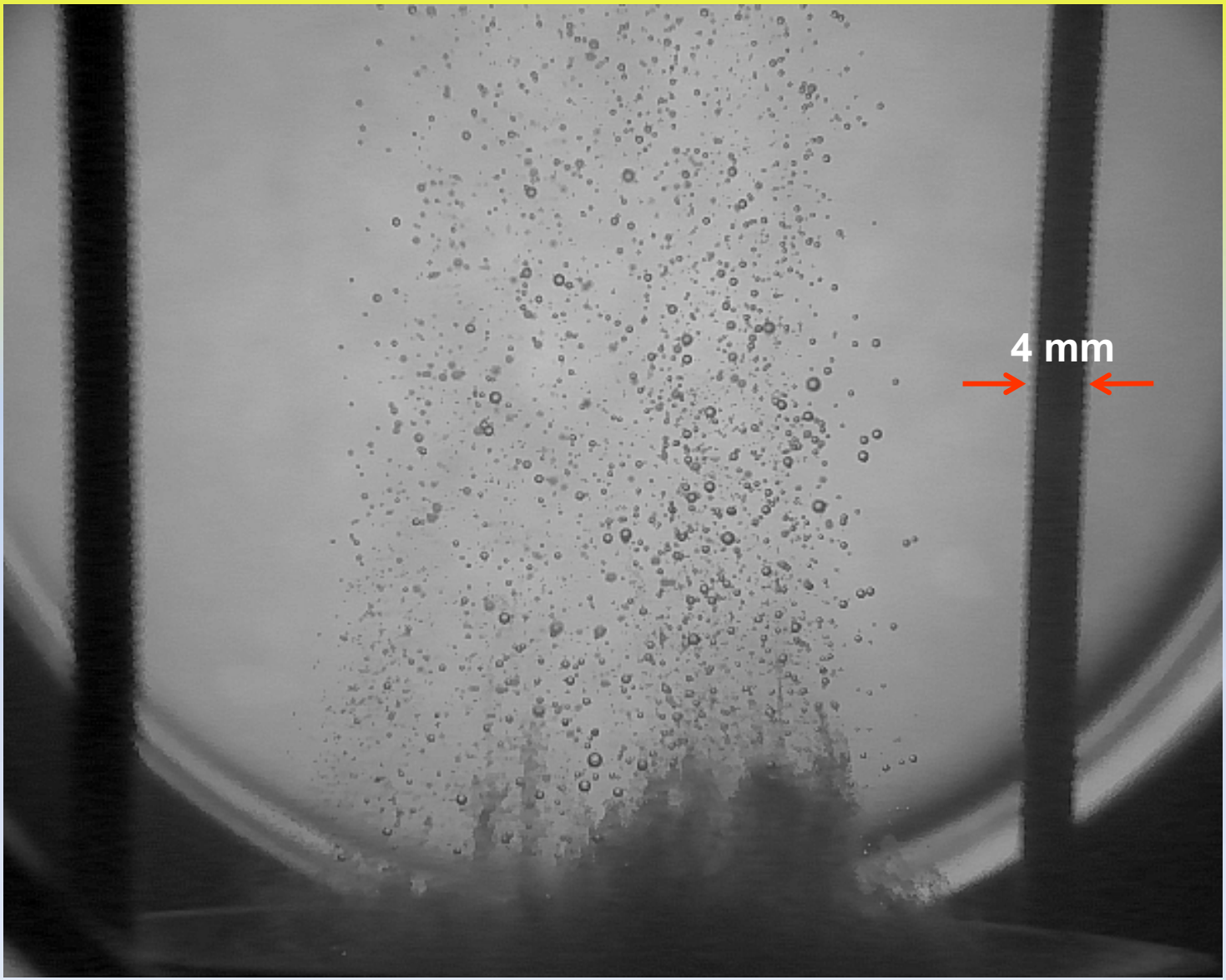


SEM image of a porous plate

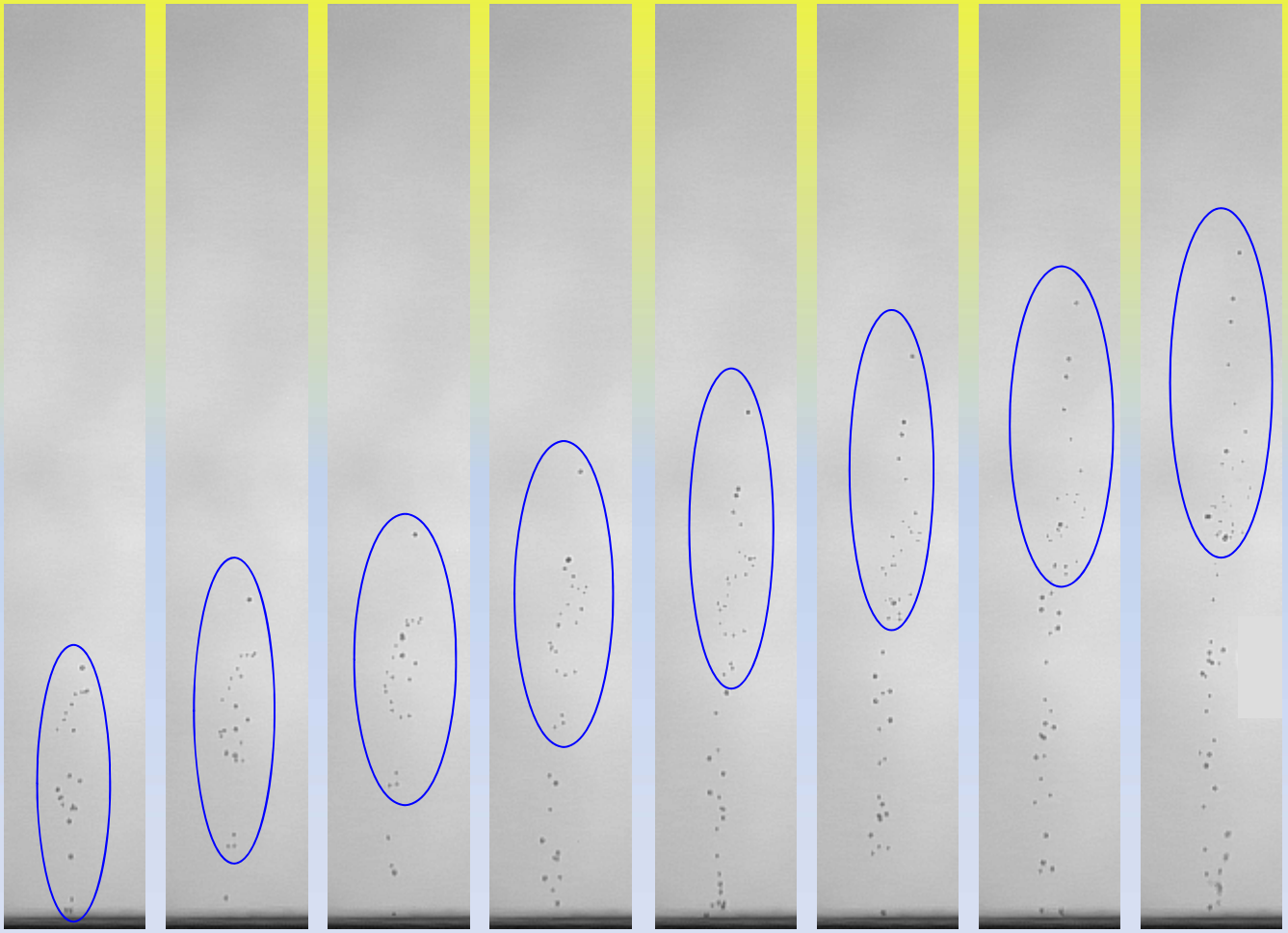




Microbuble: Supercritical CO_2



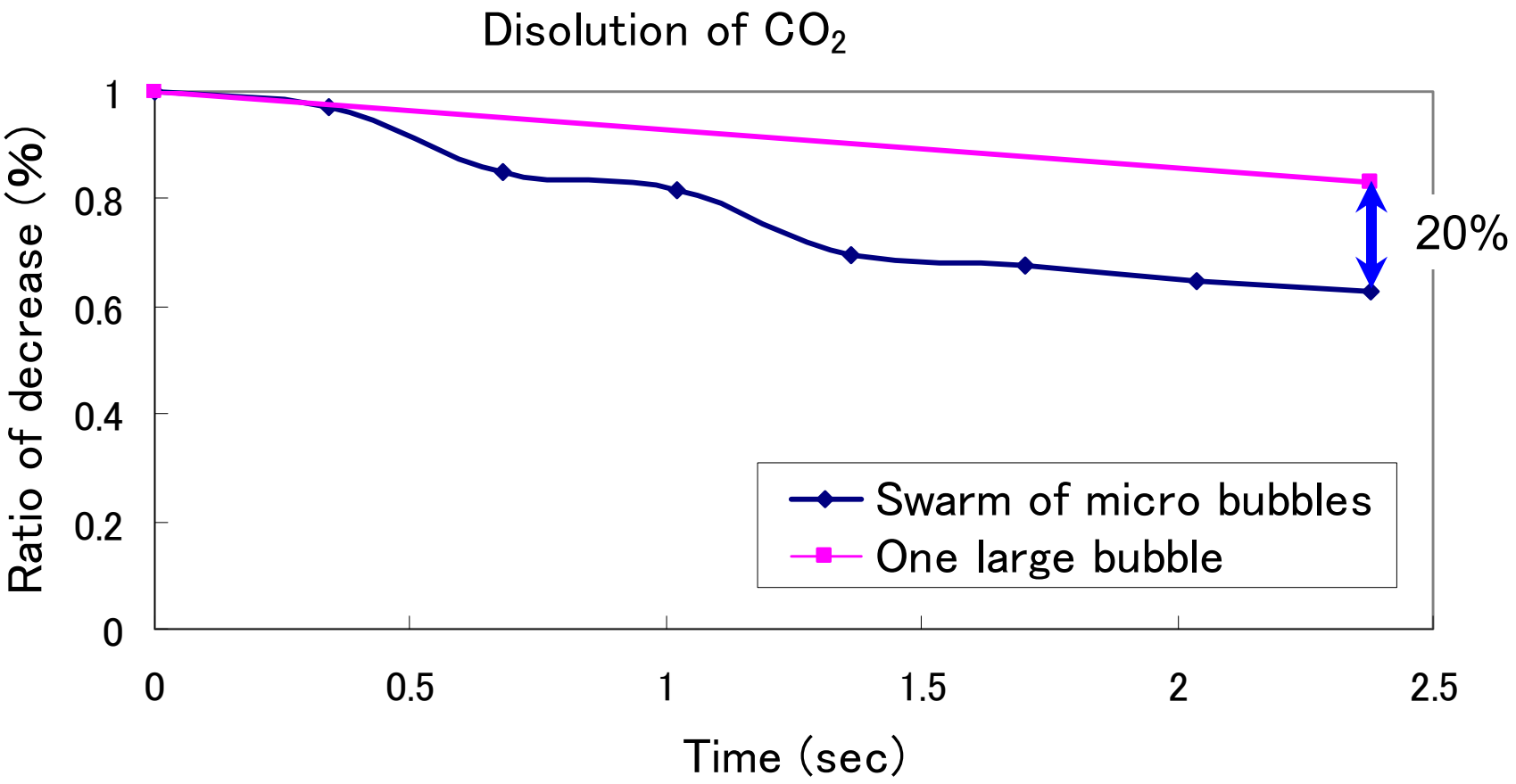
Dissolution of CO_2 microbubbles



○ Swarm of microbubbles (Diameter: 200μm~50μm) time step : 0.34 sec

Observe shrinking and dissolution of CO_2 microbubbles by image analysis

Comparison: dissolution rate



The difference of dissolved CO_2 volume within 2.3 sec is about 20%

CO_2 dissolution is prompted by microbubbles

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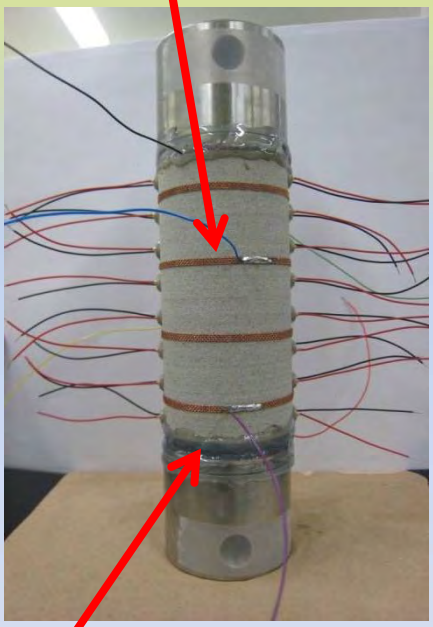
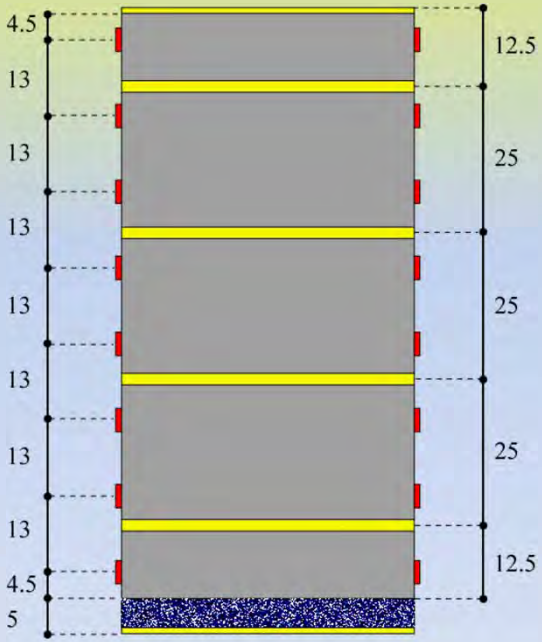
Microbubble CO_2 Injection into Berea Sandstone

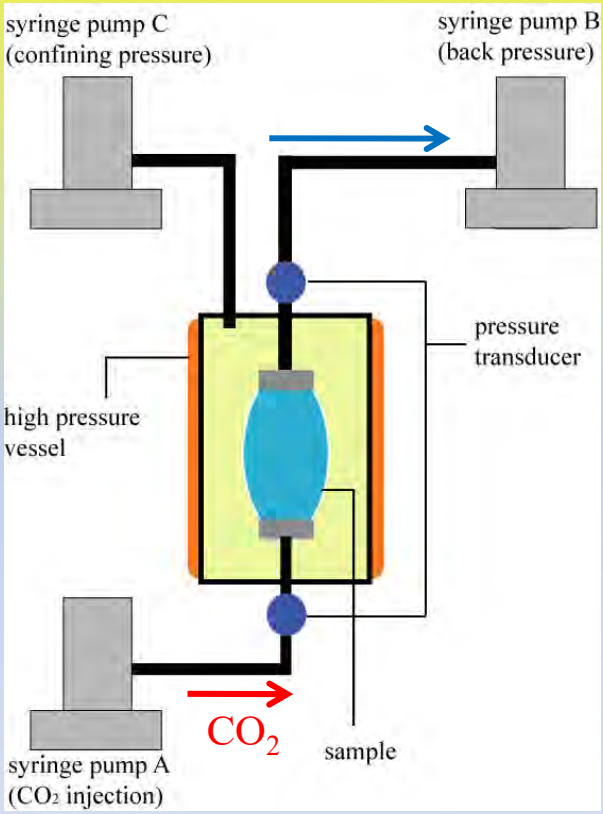
Berea sandstone



filter

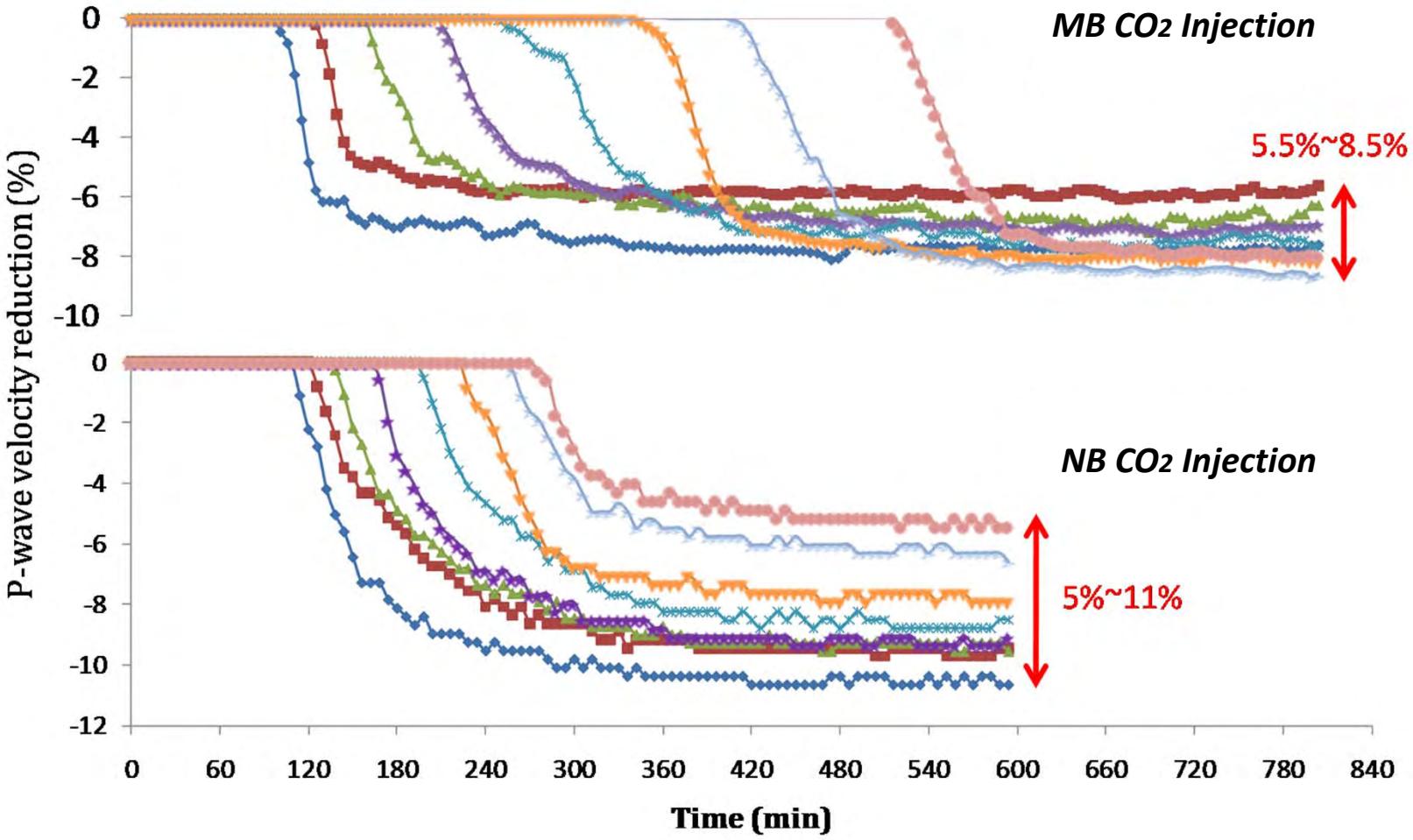
PZT array



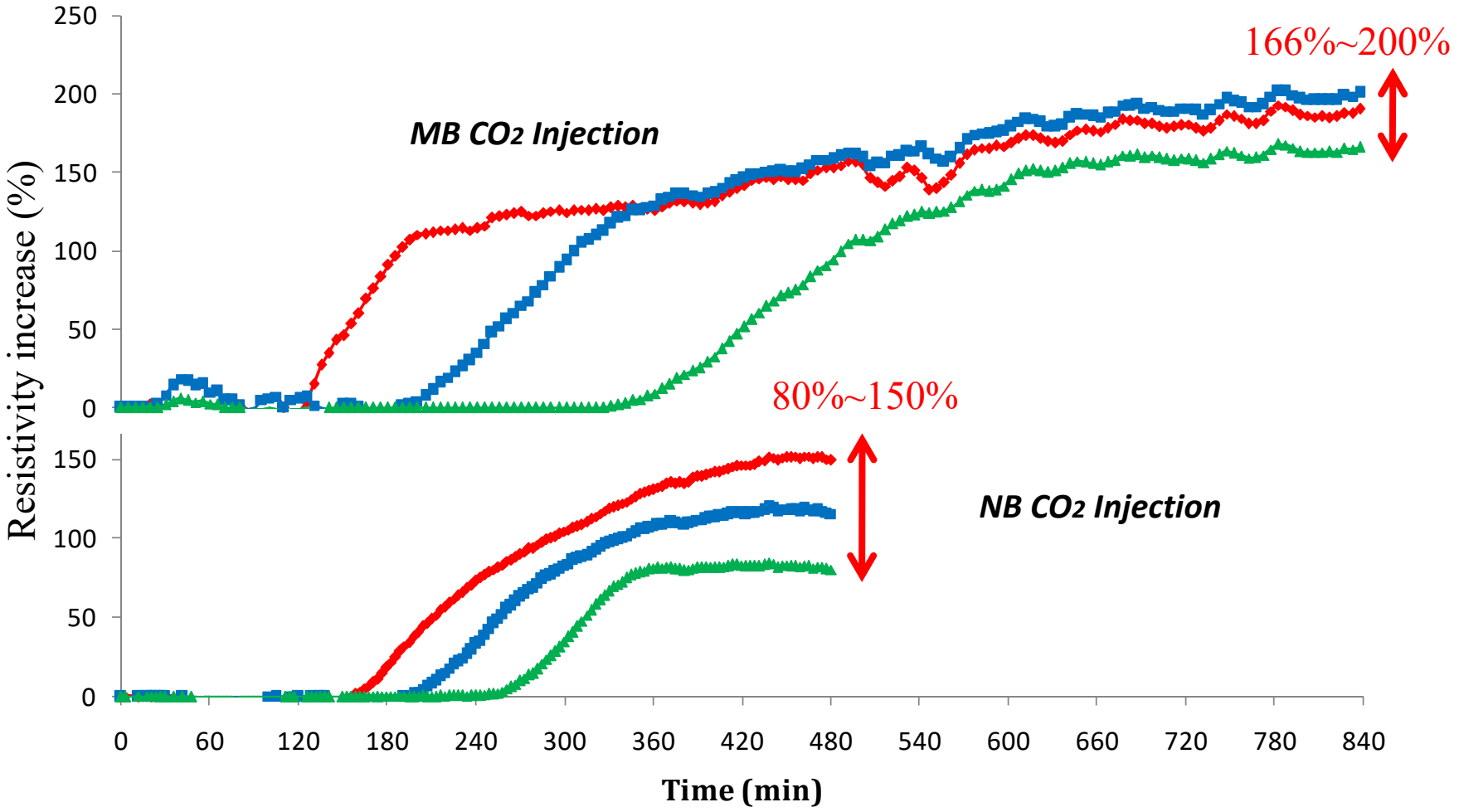


Temperature	40°C
CO_2 injection pressure	10.05MPa
Back pressure	10MPa

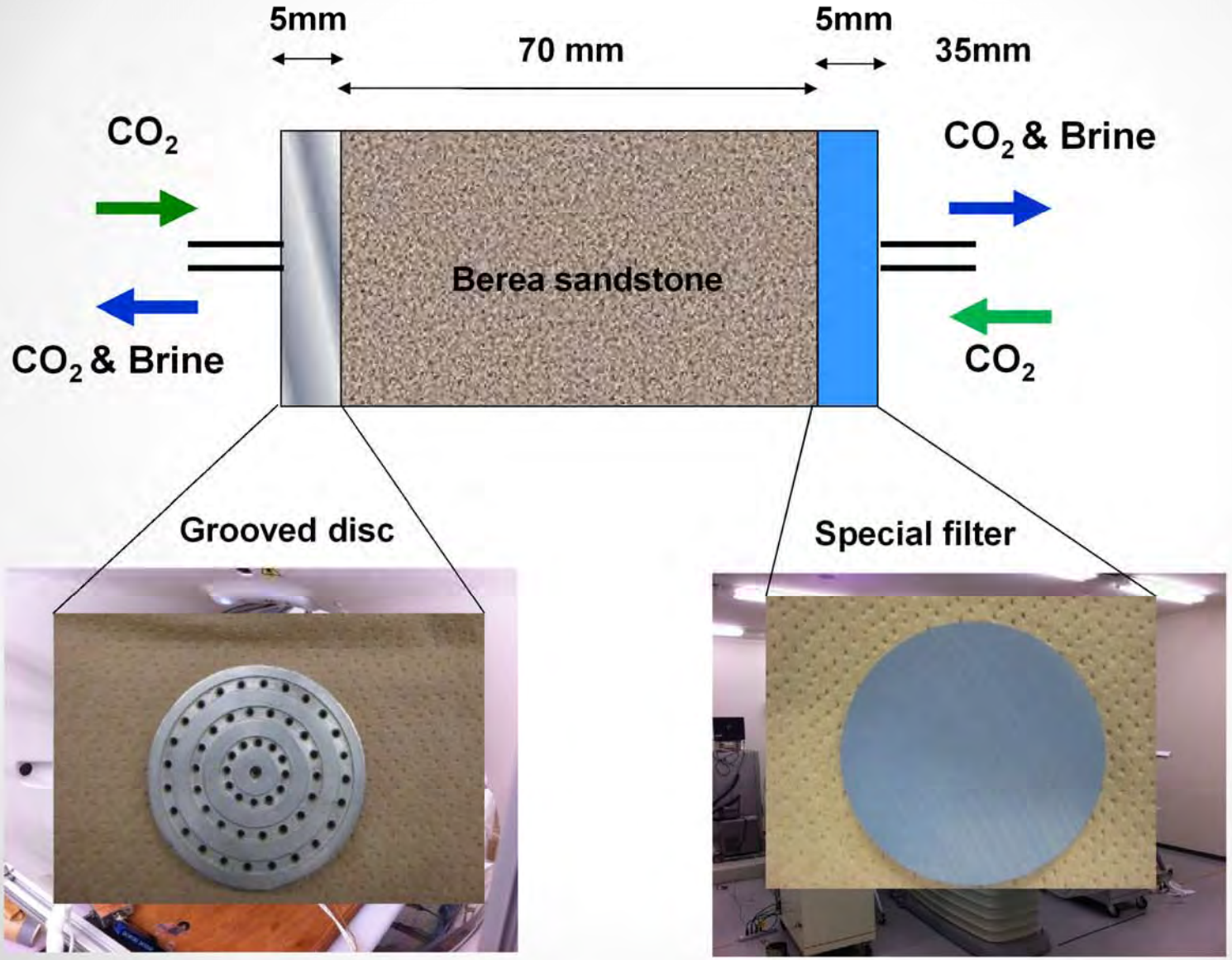
MB Injection vs NB Injection : effects on Vp



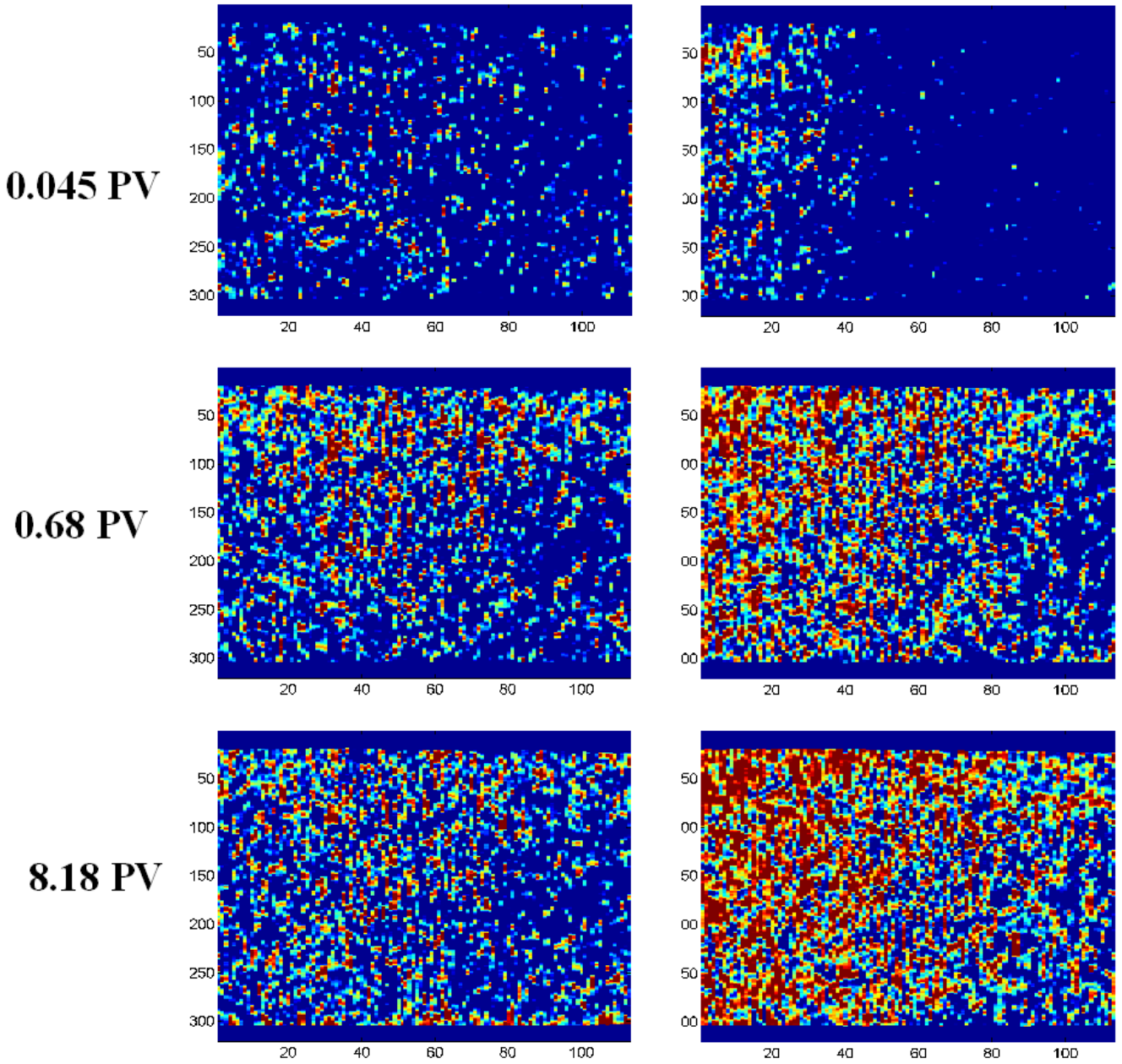
MB Injection vs NB Injection : effects on Resistivity



Sample arrangement for X-CT imaging

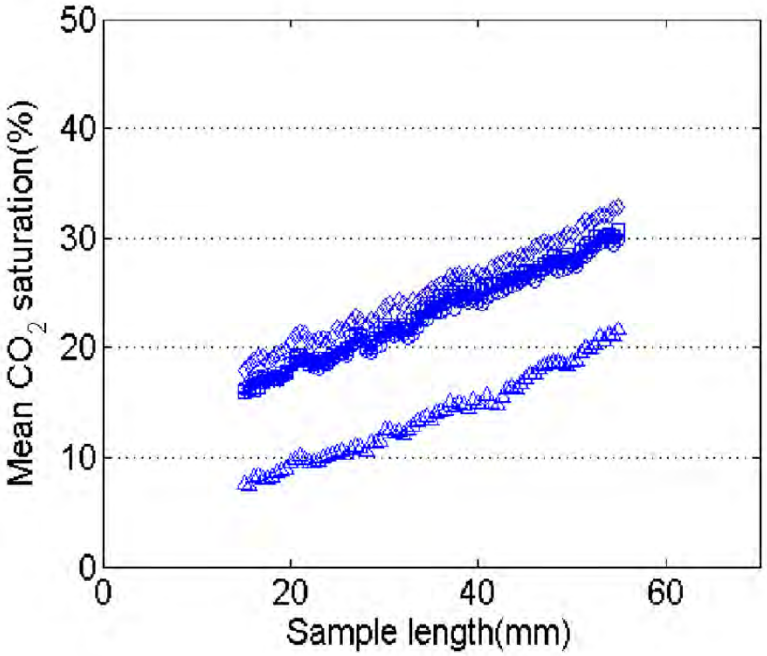


CO_2 distribution (left: grooved disc; right: special filter)

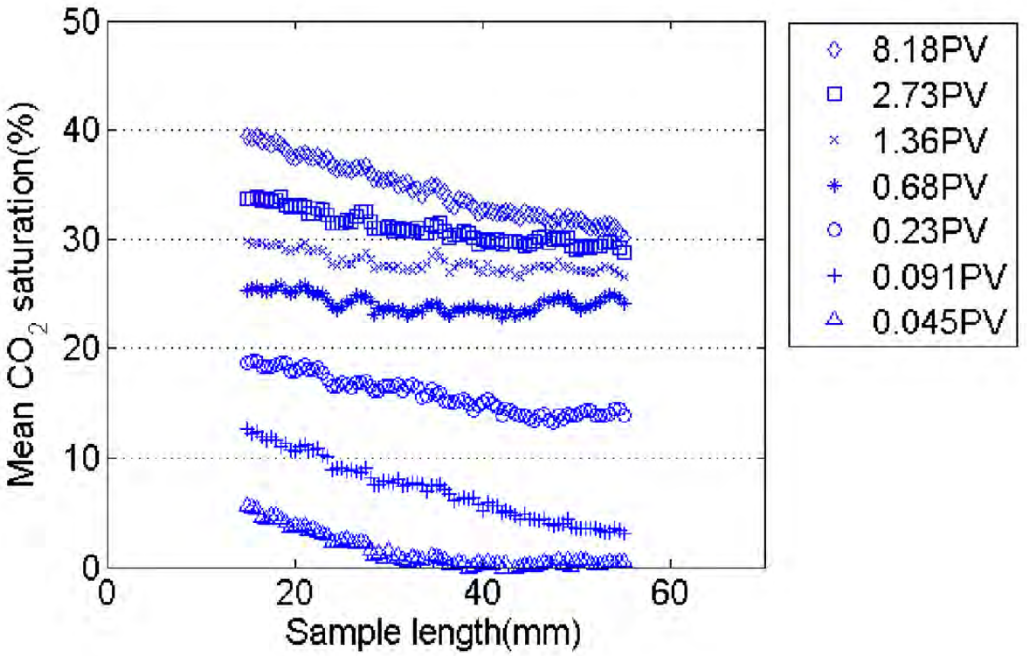


Mean CO_2 saturation (left: grooved disc; right: special filter)

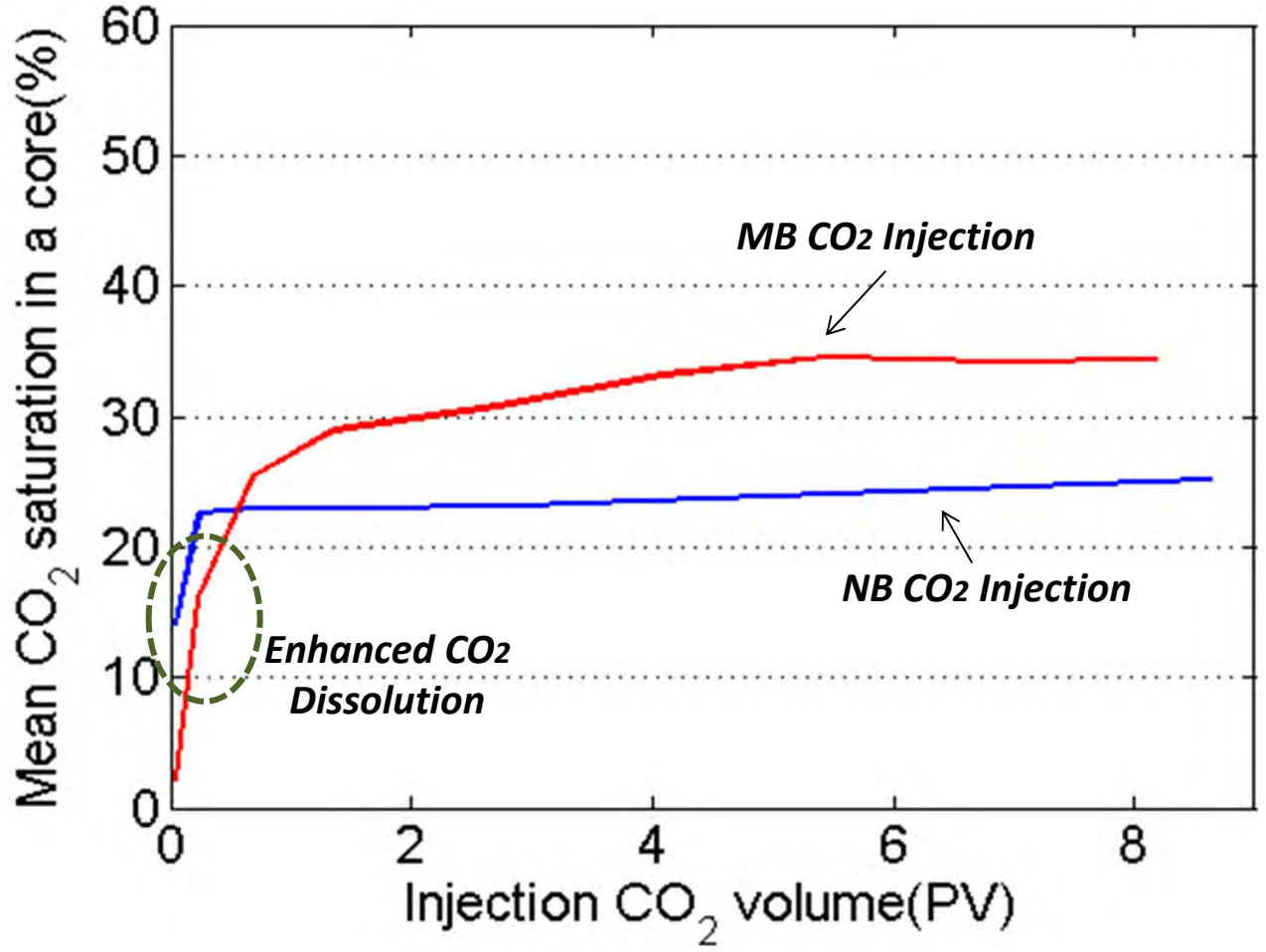
NB CO_2 Injection



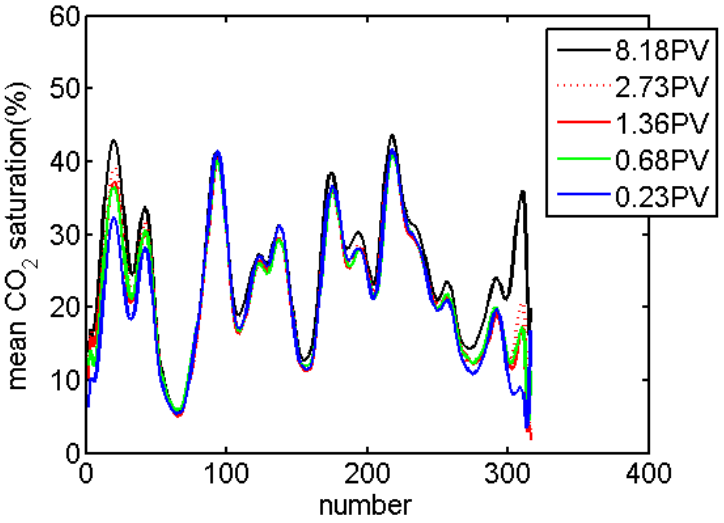
MB CO_2 Injection



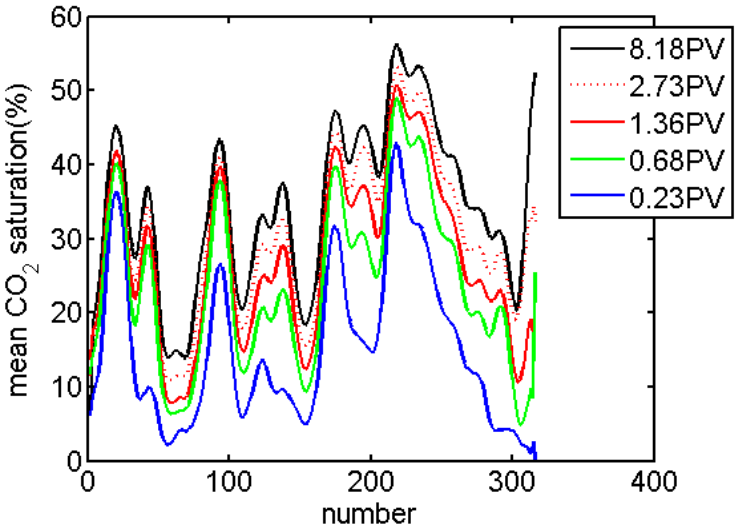
CO_2 Saturation: NB vs MB Injection



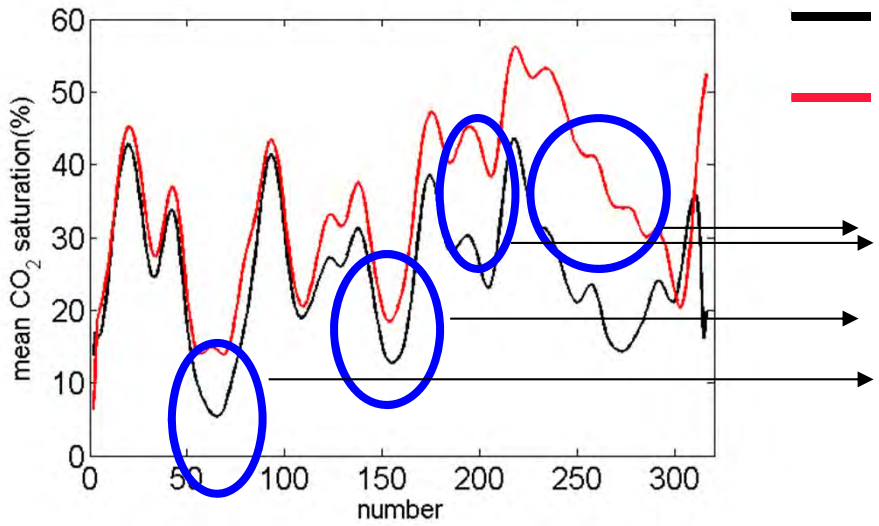
NB CO_2 Injection



MB CO_2 Injection



CO_2



NB CO_2 Injection

MB CO_2 Injection

Low permeable zone penetrated by injected MB CO_2

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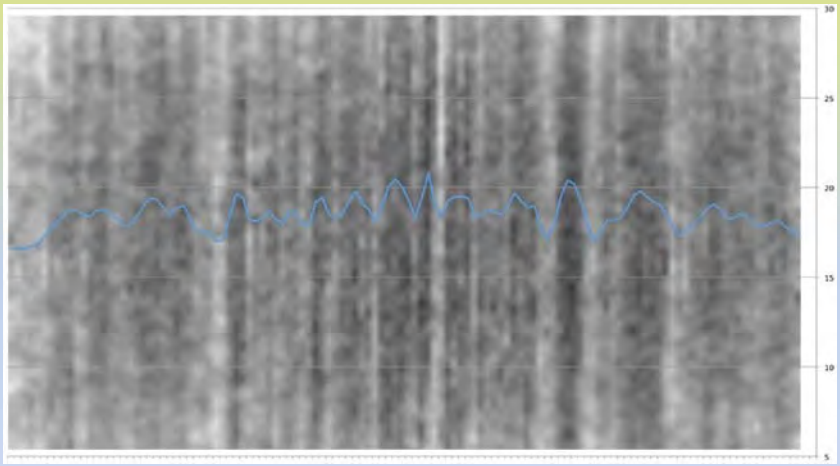
Tackling the Challenges in CO_2-EOR Process

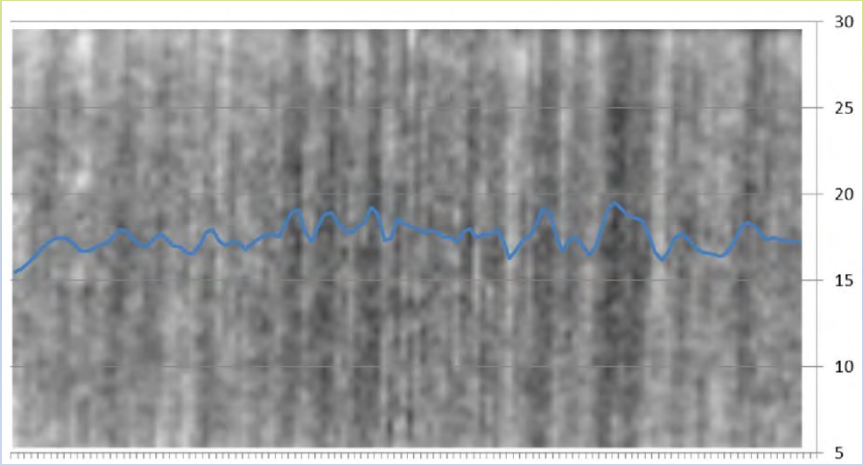
- **Reservoir Geology and Heterogeneity**

  *(**high permeable** streaks and fractures, reservoirs with **low permeability** on the order of several milidarcy)*

Injecting MB CO_2: Penetrate and Flood low permeability zones, Improve Sweep Efficiency

Two Berea Samples for NB and MB CO_2 Injection





MB: porosity, 18.5%

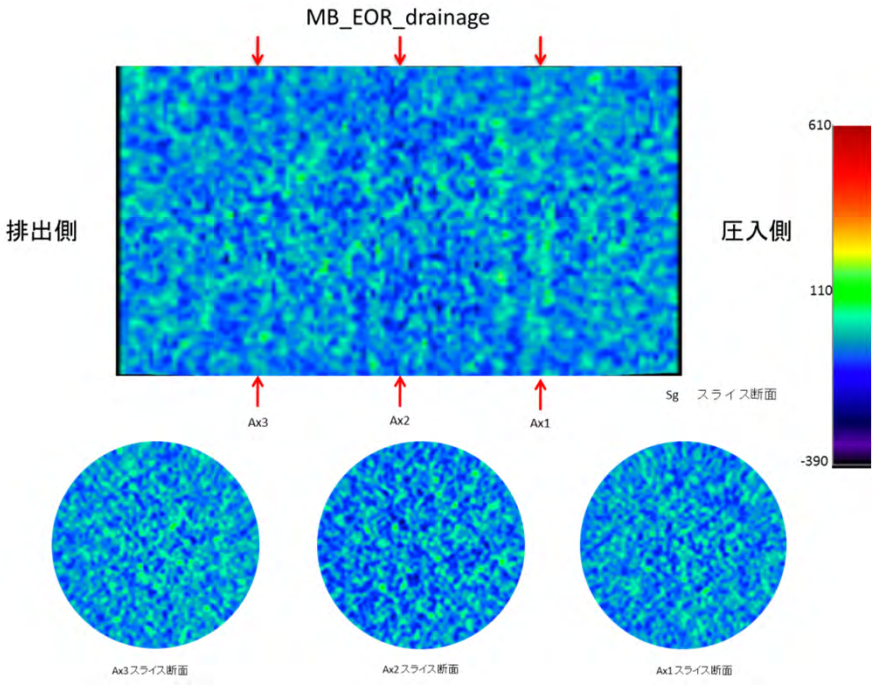
NB: porosity, 17.5%

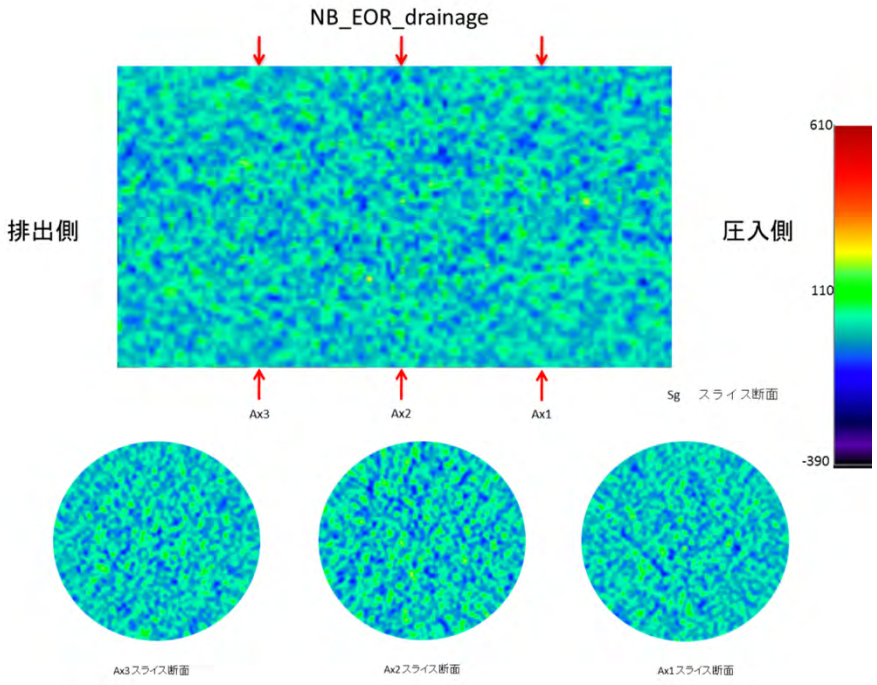
CO_2 flow : Normal to Bedding plane;

Sample size: D/35mm, L/70mm

(Xue et al., 2014)

Initial image before CO_2 injection



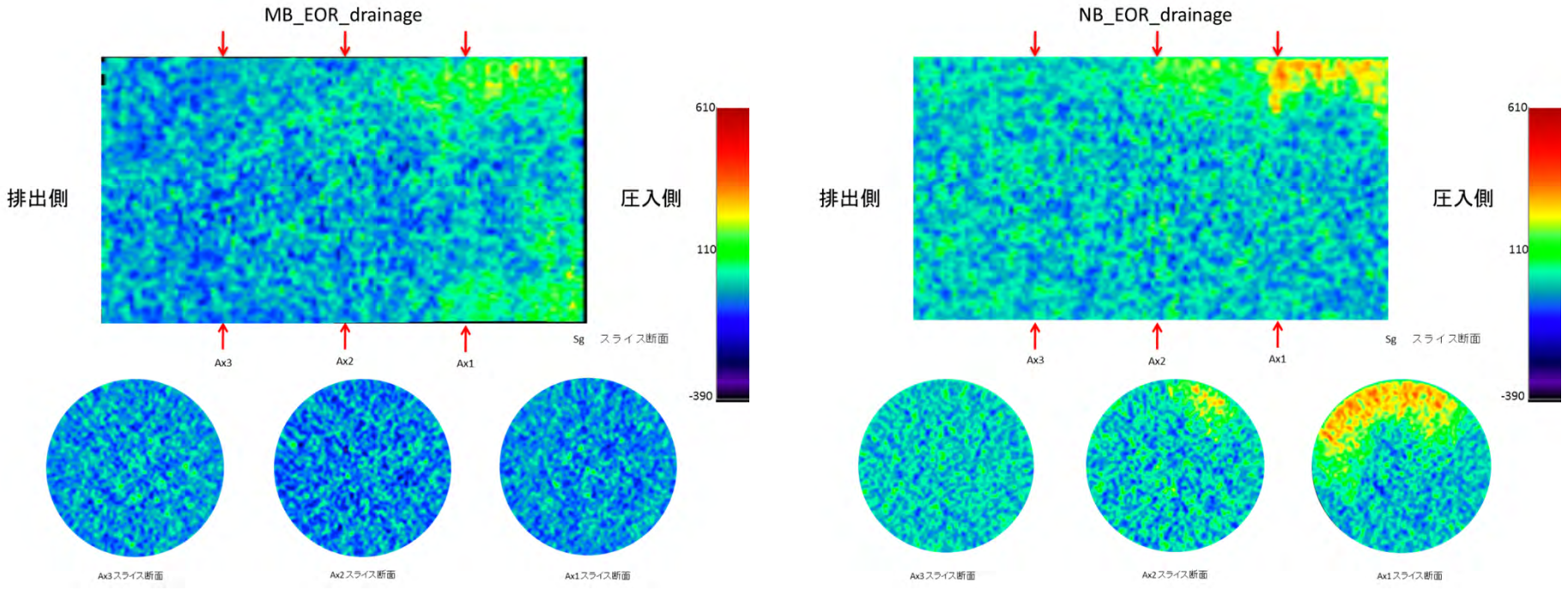


MB: I-decane, 67%

NB: I-decane, 65%

(Xue et al., 2014)

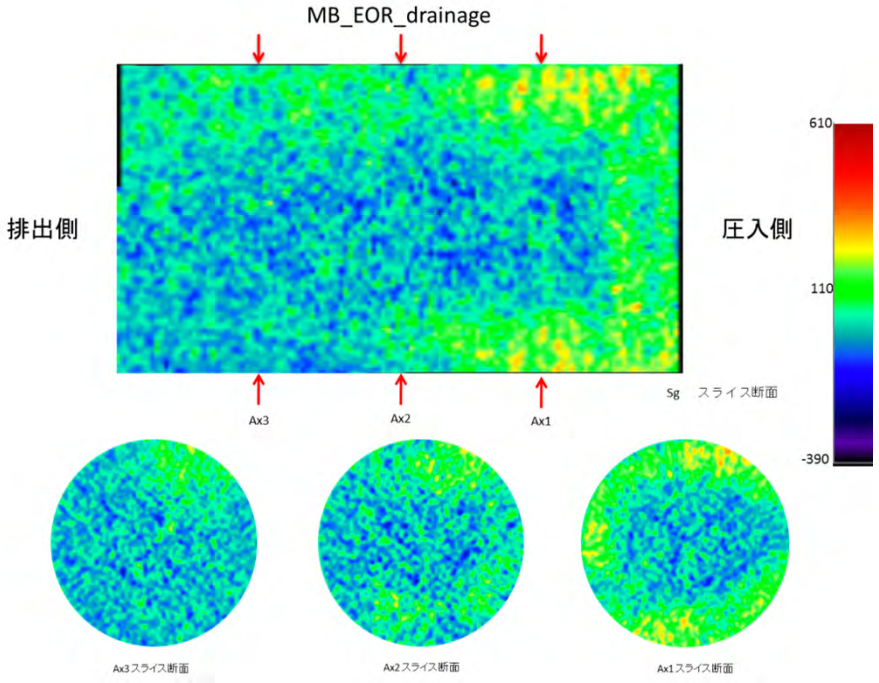
CO_2 Injection rate: 0.1ml/min

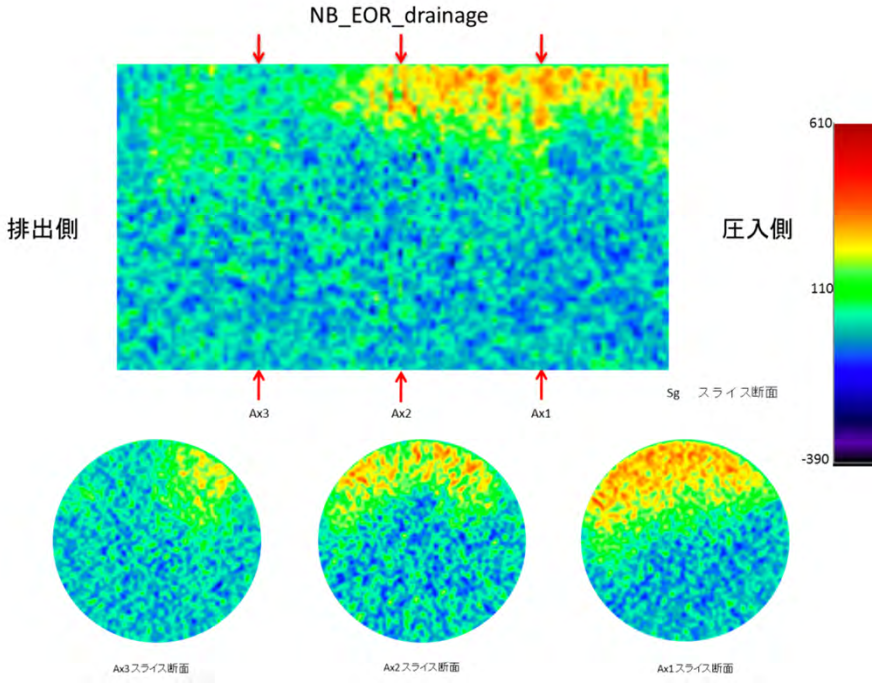


Elapsed time: 9 min; Left: MB-EOR; Right: NB-EOR

(Xue et al., 2014)

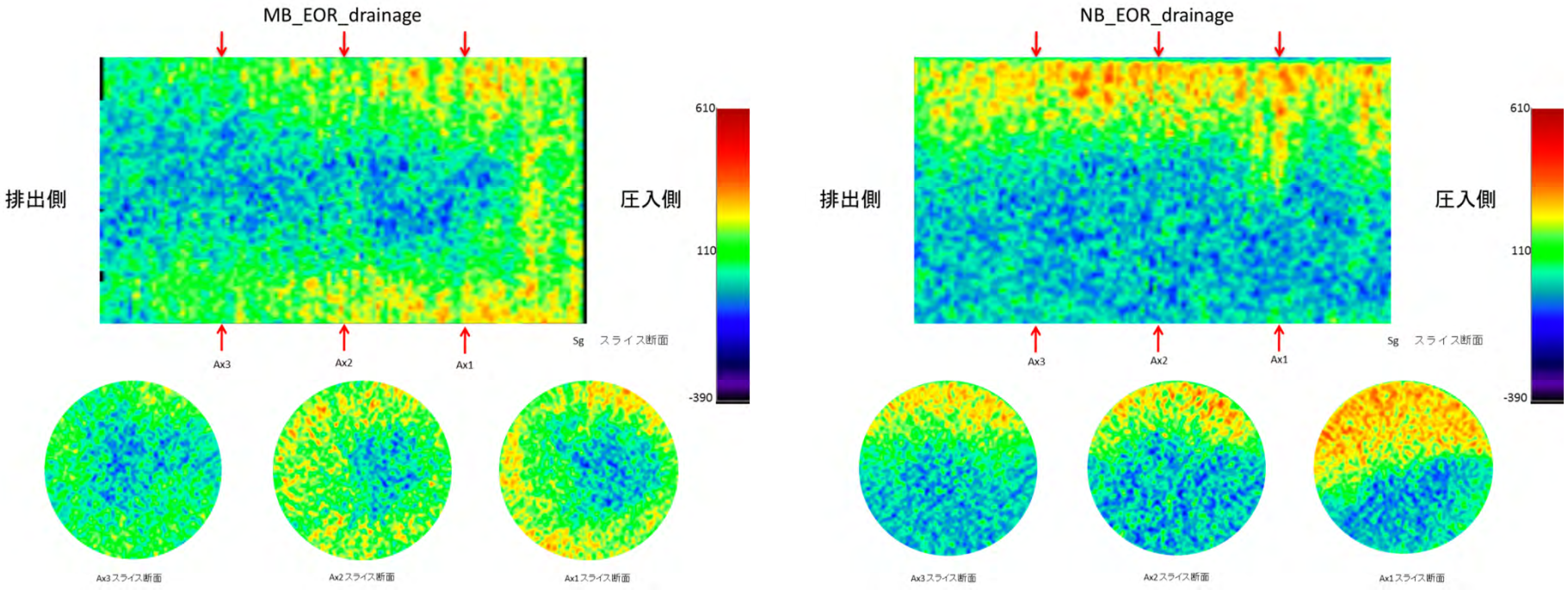
Elapsed time: 18 min; Left: MB-EOR; Right: NB-EOR





(Xue et al., 2014)

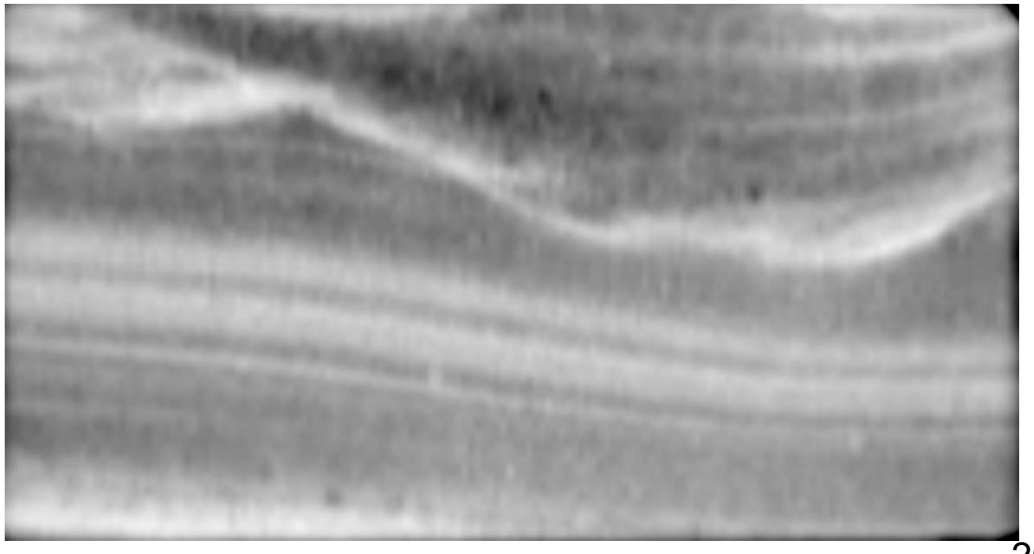
Elapsed time: 40 min; Left: MB-EOR; Right: NB-EOR

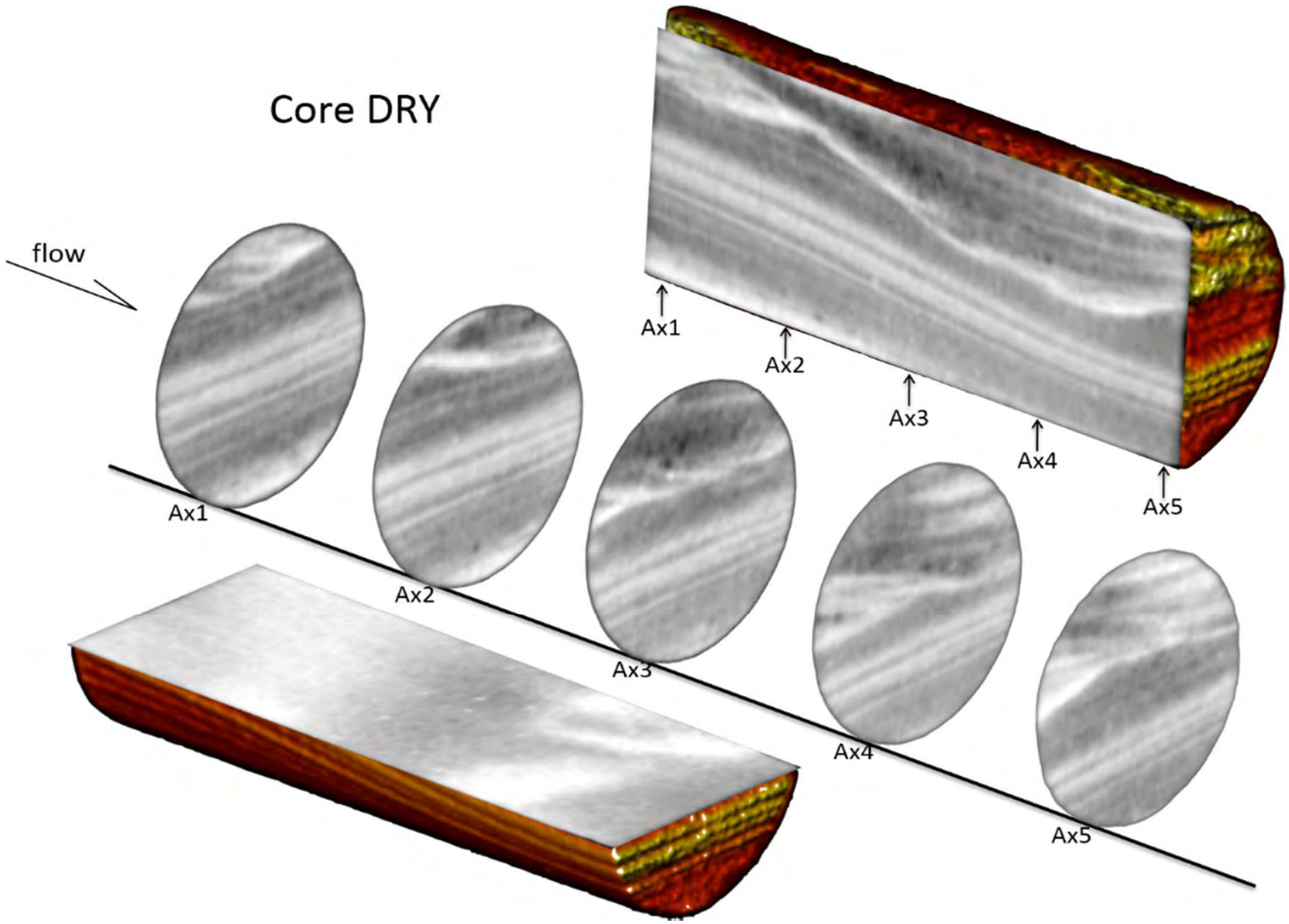


(Xue et al., 2014)

A sample
from Japanese Oil field

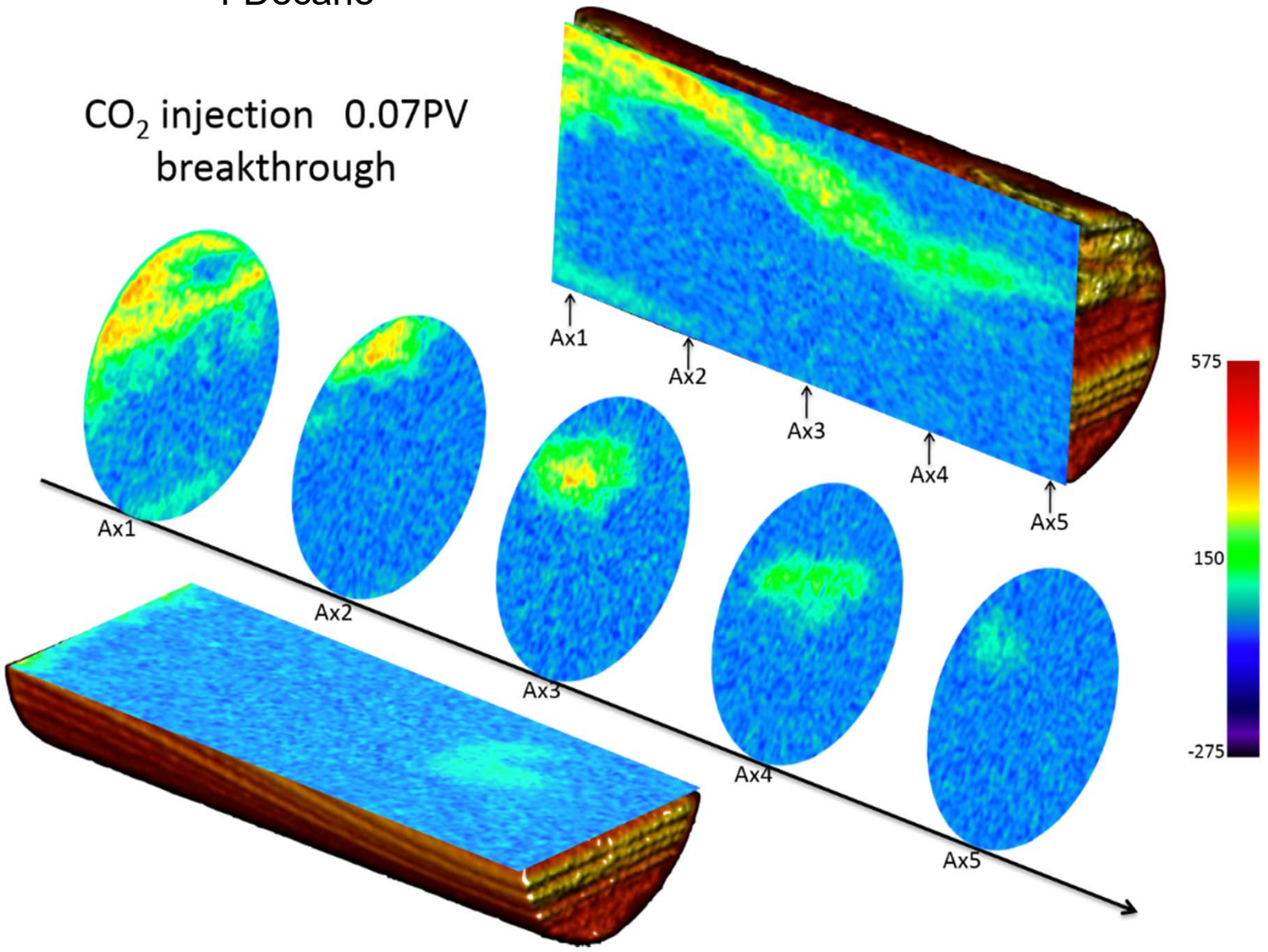
X ray CT Image

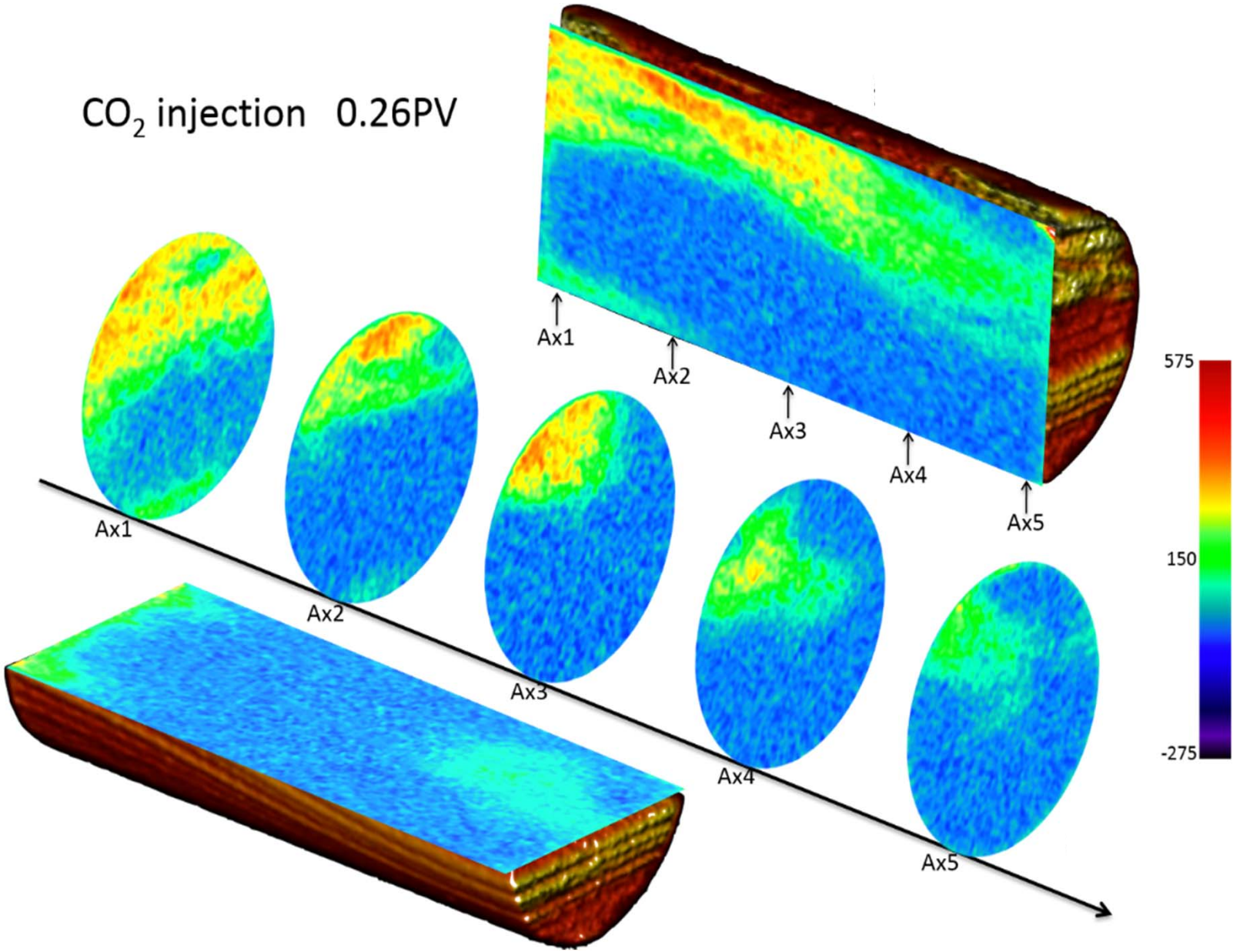


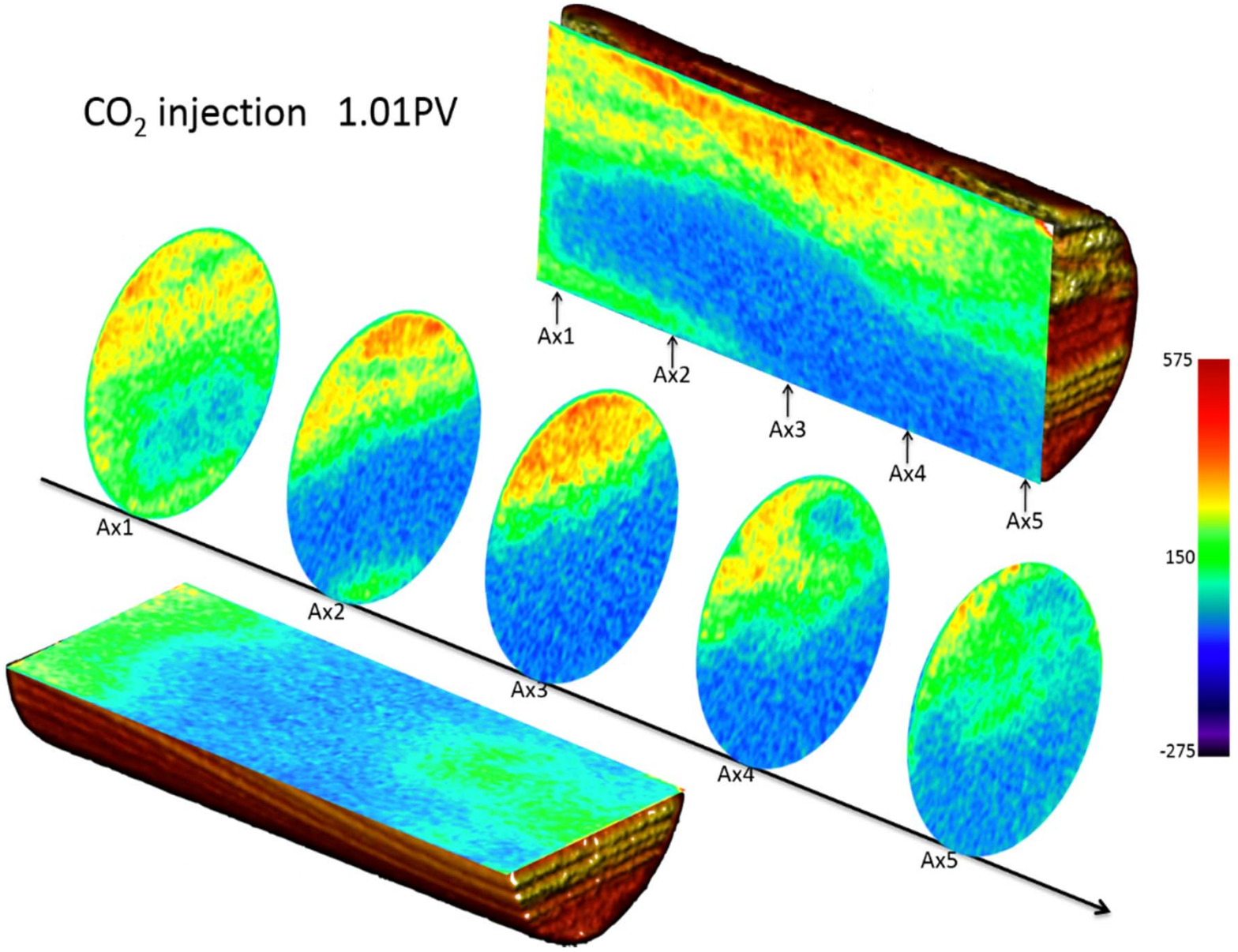

Core DRY
flow
Ax1
Ax2
Ax3
Ax4
Ax5
Ax1
Ax2
Ax3
Ax4
Ax5

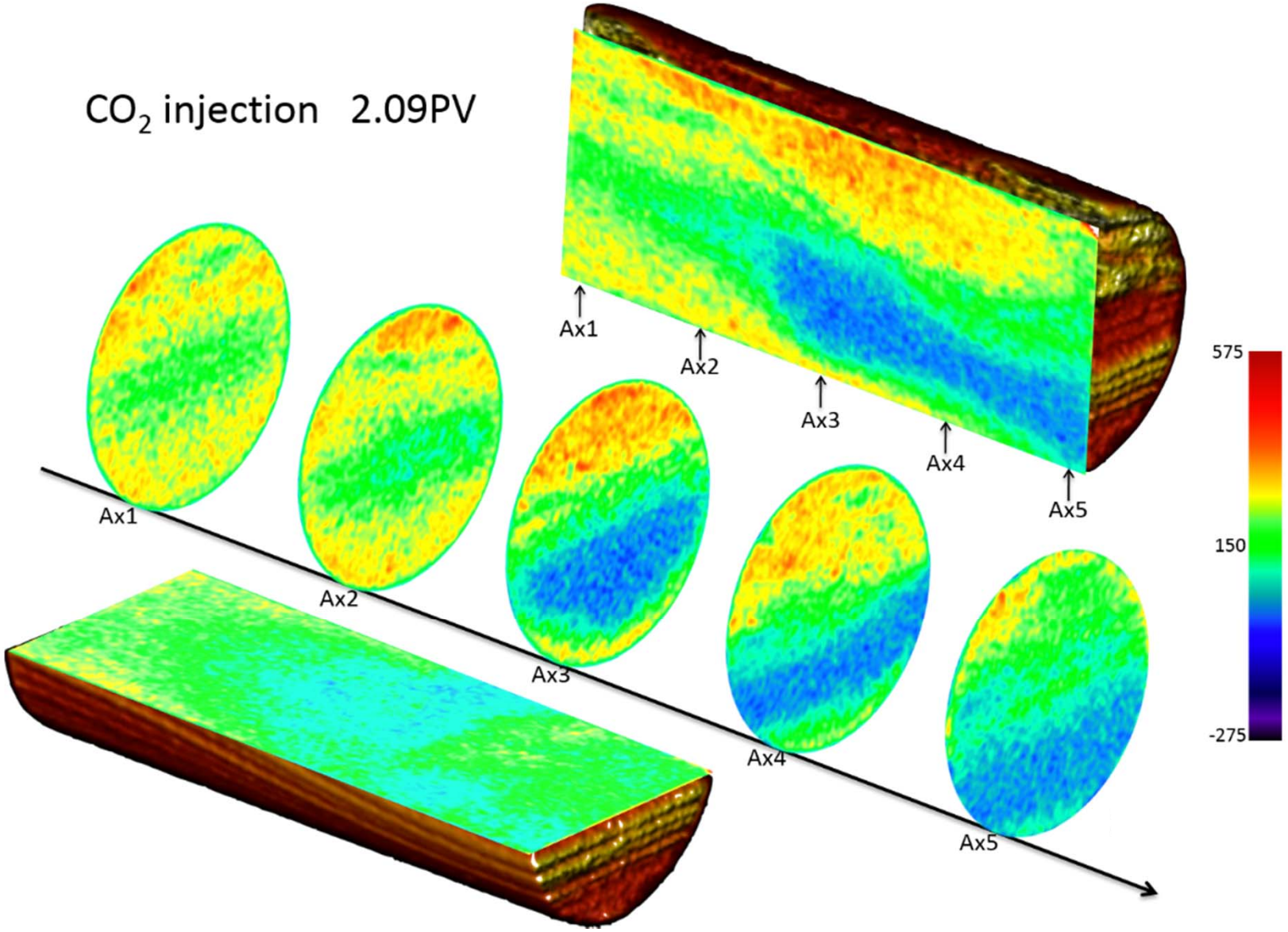
I-Decane

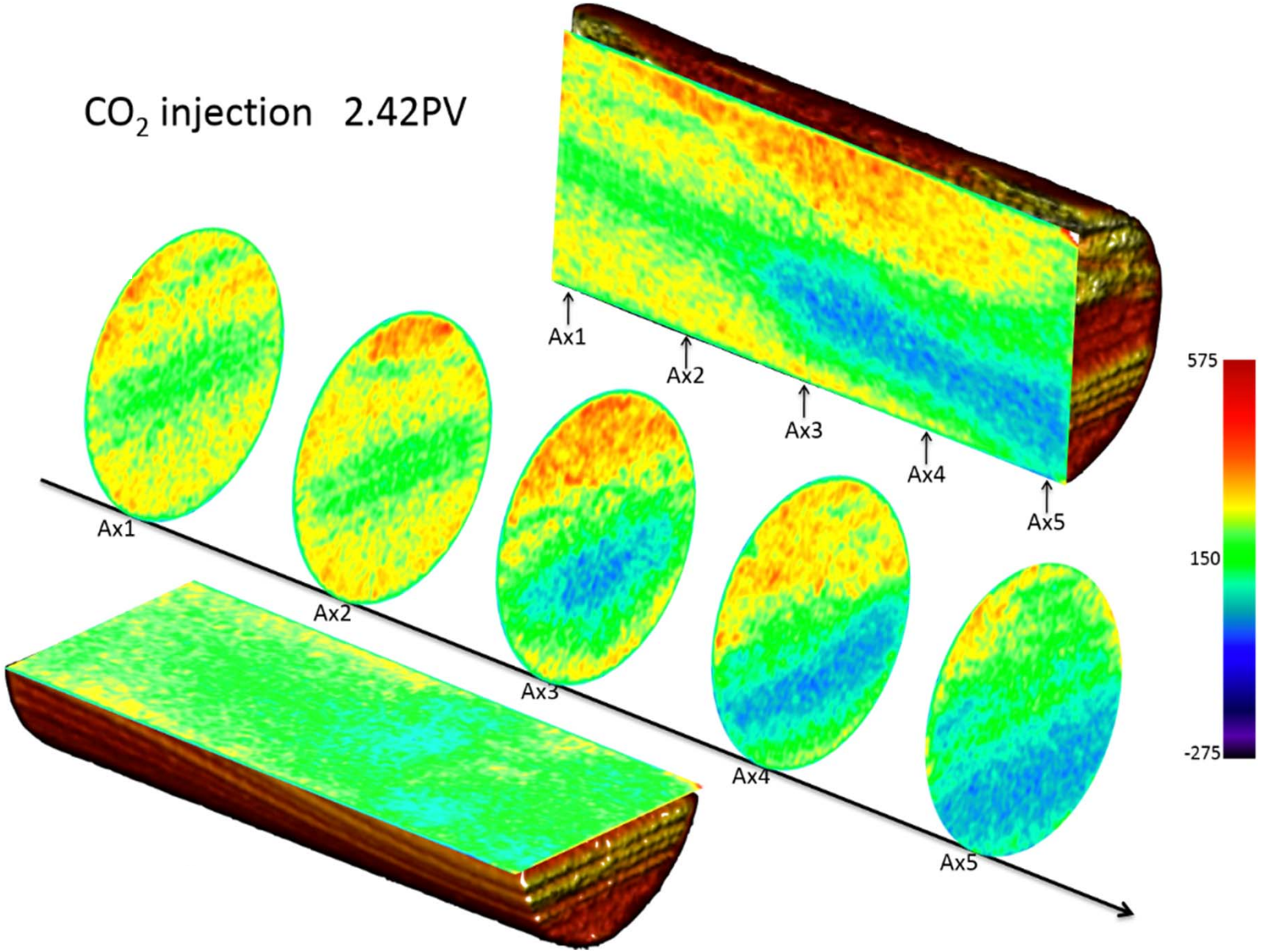
CO_2 injection 0.07PV breakthrough

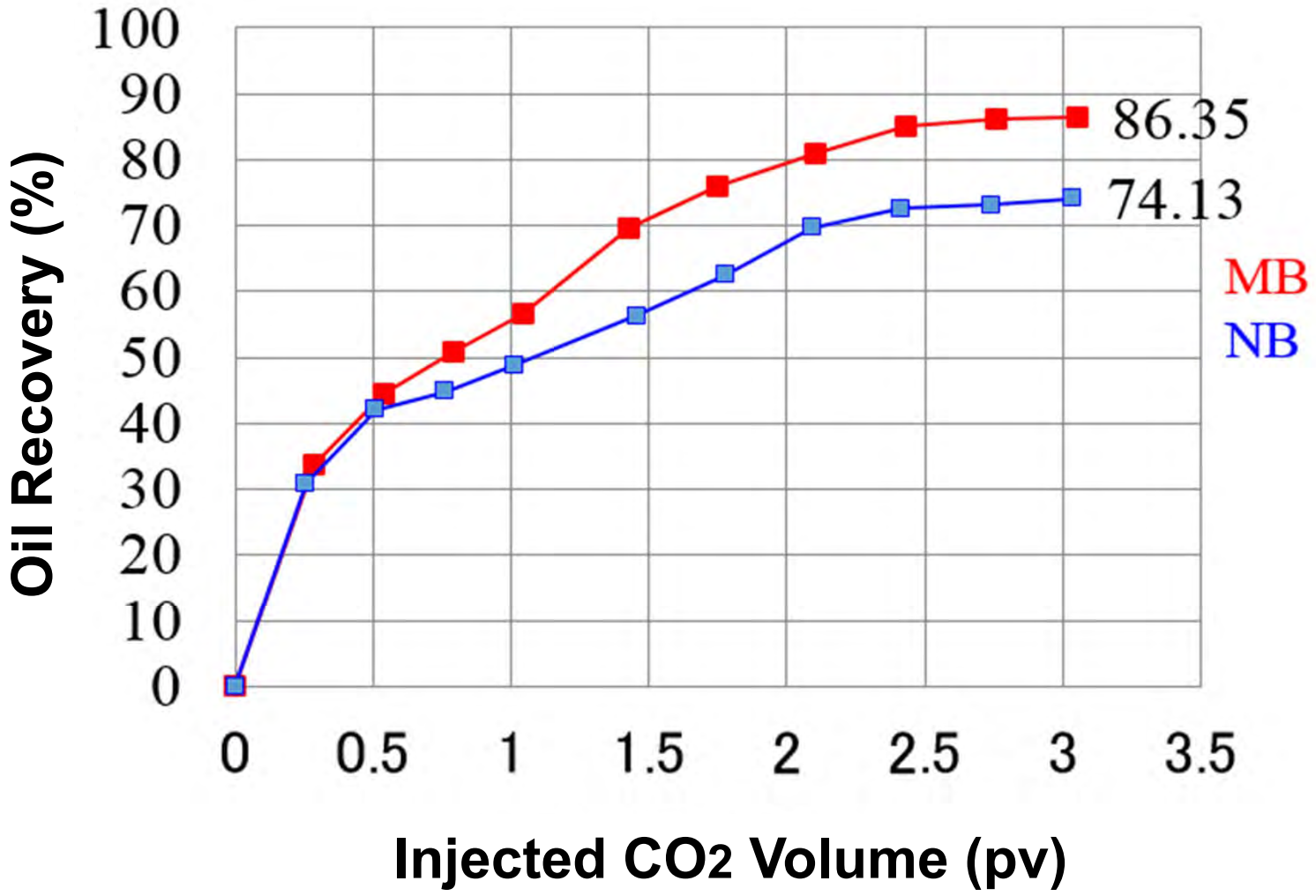



CO_2 injection 0.26PV
Ax1
Ax2
Ax3
Ax4
Ax5
Ax1
Ax2
Ax3
Ax4
Ax5
575
150
-275


CO_2 injection 1.01PV
Ax1
Ax2
Ax3
Ax4
Ax5
575
150
-275


CO_2 injection 2.09PV
Ax1
Ax2
Ax3
Ax4
Ax5
Ax1
Ax2
Ax3
Ax4
Ax5
575
150
-275


CO_2 injection 2.42PV
Ax1
Ax2
Ax3
Ax4
Ax5
575
150
-275


Oil Recovery (%)
100
90
80
70
60
50
40
30
20
10
0
0
0.5
1
1.5
2
2.5
3
3.5
86.35
74.13
MB
NB
Injected CO2 Volume (pv)

Summary

- **MB CO_2 injection accelerates CO_2 dissolution into formation water at least 20% and MB CO_2 can be monitored as well as NB CO_2 by geophysical methods.**

- **X-CT visualization indicates advantages of MB CO_2 in the effective use of pore space and the higher sweep efficiency contributes to enhanced oil recovery in low permeability reservoirs.**

- **NB CO_2 injection leads unexpected early breakthrough due to its higher buoyancy and MB CO_2 can reduce such risks in high permeability reservoirs (foam blocking effects).**

Further Steps

- **More case studies with oil field samples under in-situ pressure and temperature conditions, to verify the advantages of the CO_2 microbubble EOR technology.**

- **Pilot tests to compare the higher sweep efficiency of CO_2 microbubble injection with conventional CO_2 injection.**

- **Collaboration with engineering and well service companies to build up this innovative technology for both oil recovery and CO_2 storage.**

ACKNOWLEDGMENTS

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