New Concepts for Safe and Low-cost CCS

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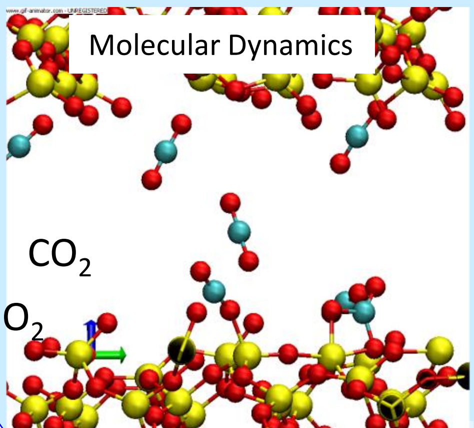
Projects relevant to CCS in our lab

Project 1
Molecular scale(nm-μm)

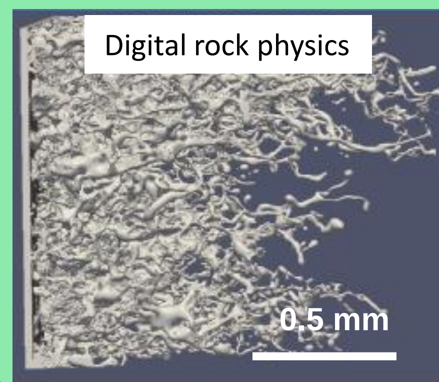
Main effort:
- CO_2 mineralization
- Low purity CO_2 storage



Liang et al. 2017
Accounts of Chemical Research

Project 2
Pore scale (μm-m)

Main effort:
- Optimal CO_2 storage conditions
- Relationship among hydraulic, seismic and electric properties



Tsuji et al., 2016
Advances in Water Resources

Project 3
Reservoir scale (m-km)

Main effort:
- Continuous monitoring system
- Minimal seismic source system for monitoring
- Develop distributed acoustic sensing

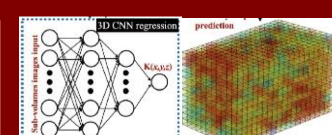
Tsuji et al., 2022
Seis. Res. Letts.

Project 4: Linkage of multi-scale phenomena

- Evaluate influence of slip flow
- Machine Learning for upscaling

Singh et al., 2017 Phys. Rev. E

Jiang et al., 2023 WRR



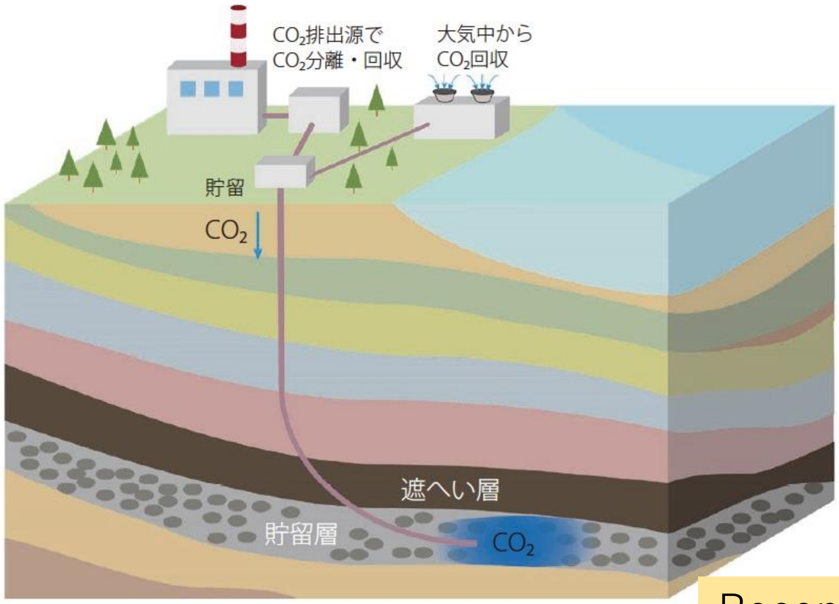
Carbon Capture and Storage

Reduce CO_2 emission by injecting CO_2 into subsurface reservoir

- Near-term impact
- Huge potential

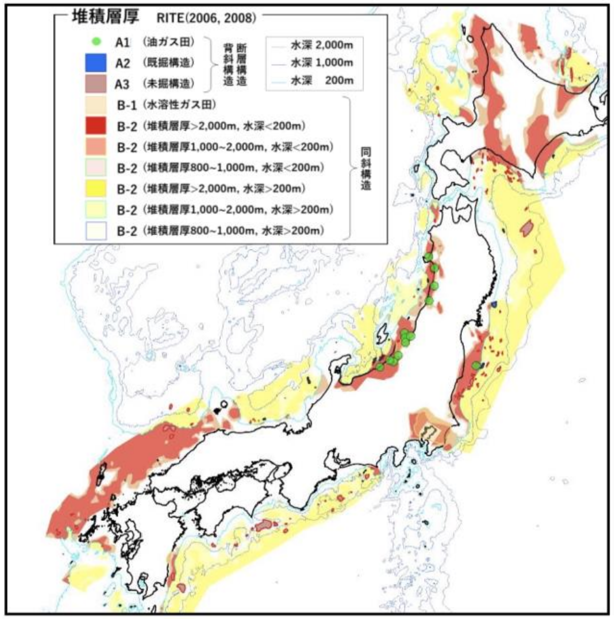
- **Cost?**
- **Safety?**

- **We can inject >100 billion tons of CO_2 only around Japanese Island (*Ogawa et al. 2011)***
- **100 years of total CO_2 emission from Japan**



辻, 2023

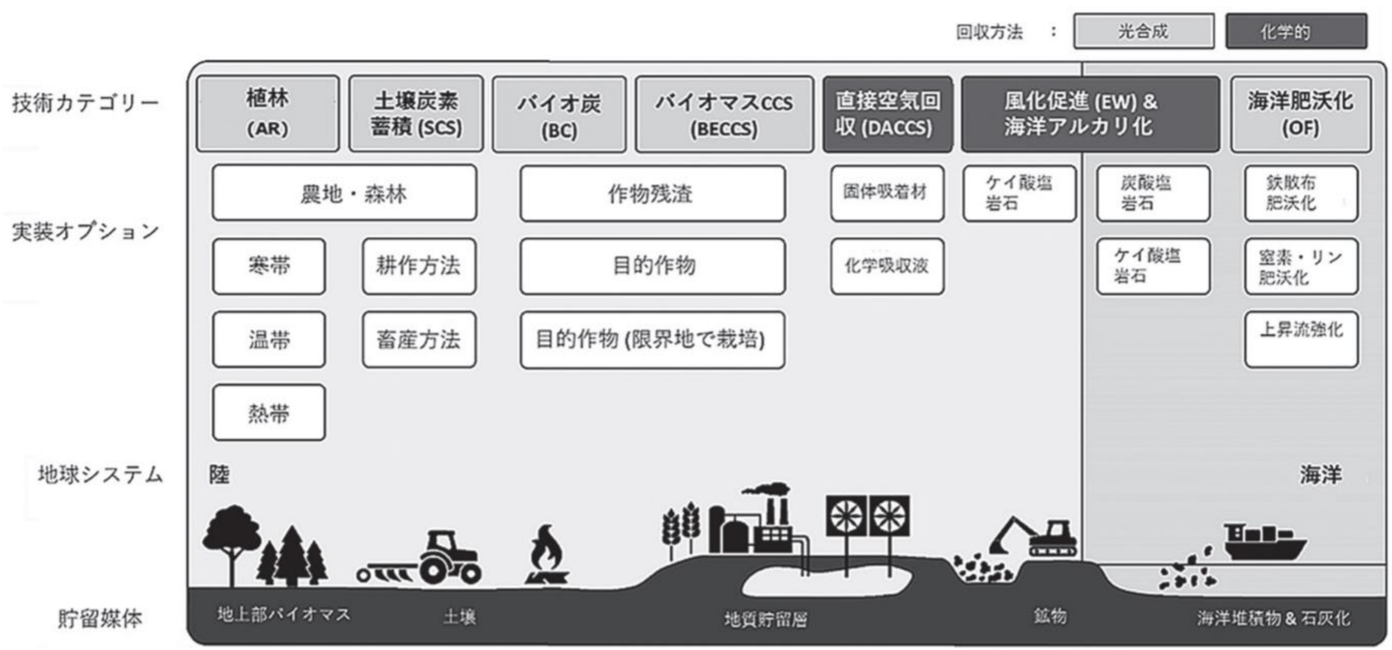
【CO2貯留層賦存量マップ（出典：RITE、編集：JCCS）】



Recent evaluation based on detailed geophysical data identified 11 sites for CO_2 storage (METI, 2023).

Negative emission to achieve carbon-neutral in 2050

- **Capture CO2 from atmosphere and store it into the geological formation**
  - Bioenergy with Carbon Capture and Storage （BECCS）
  - Direct Air Carbon Capture and Storage（DACCS）

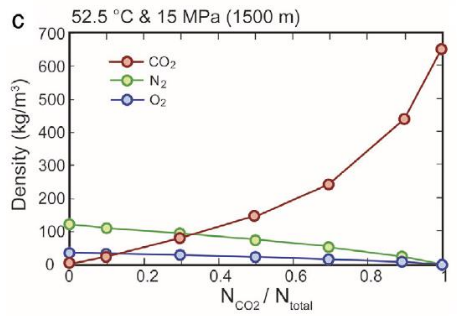


出所）加藤悦史（2020）大気中CO2を除去するネガティブエミッション技術の動向～パリ九奥底の長期目標達成のために～, 基本エネルギー総合工学 Vol.42 No.4 2020.1

- Capture of high-purity CO2 needs high cost…

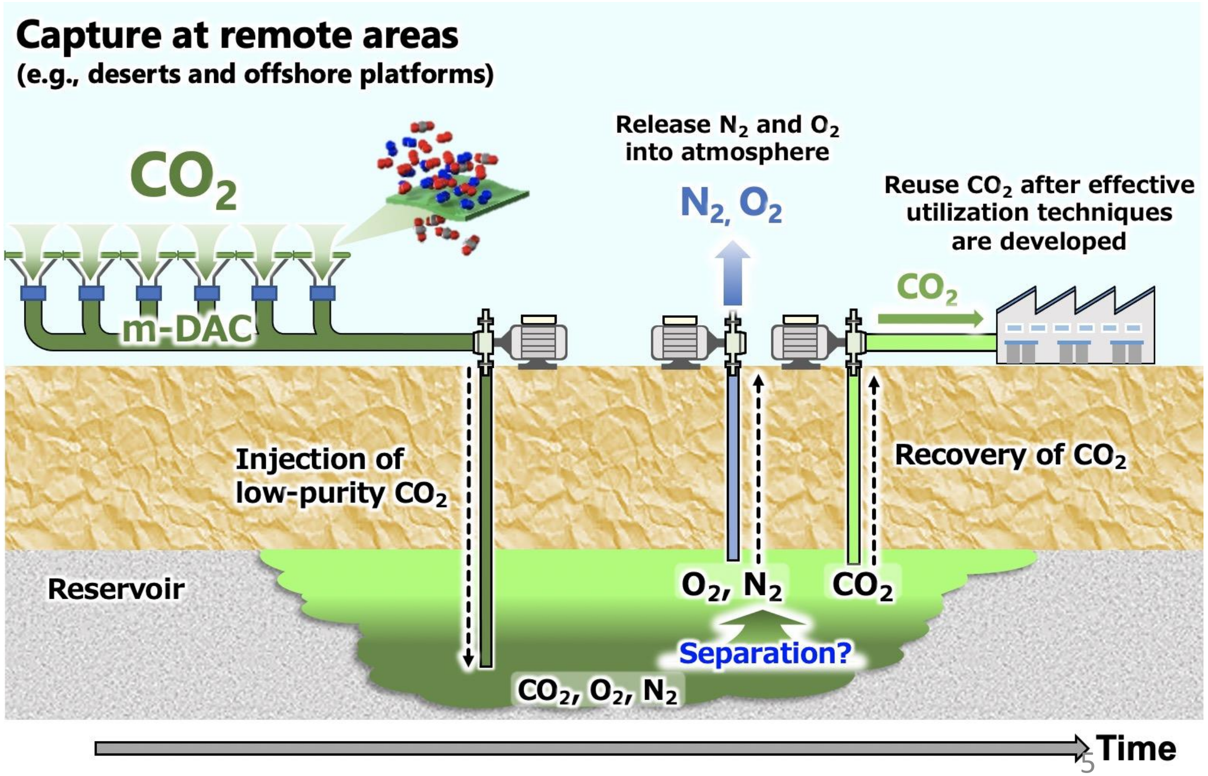
Storage of low-purity CO_2 storage from membrane-DAC

- CO_2 captured at plants (including SOx and NOx) must be refined to high purity
- But, the CO_2 captured via m-DAC consists of non-hazardous components (N_2 and O_2)
  - ➢ Storage of low-purity CO_2 from DAC reduces capture costs



If this concept is acceptable, we can conduct at any places

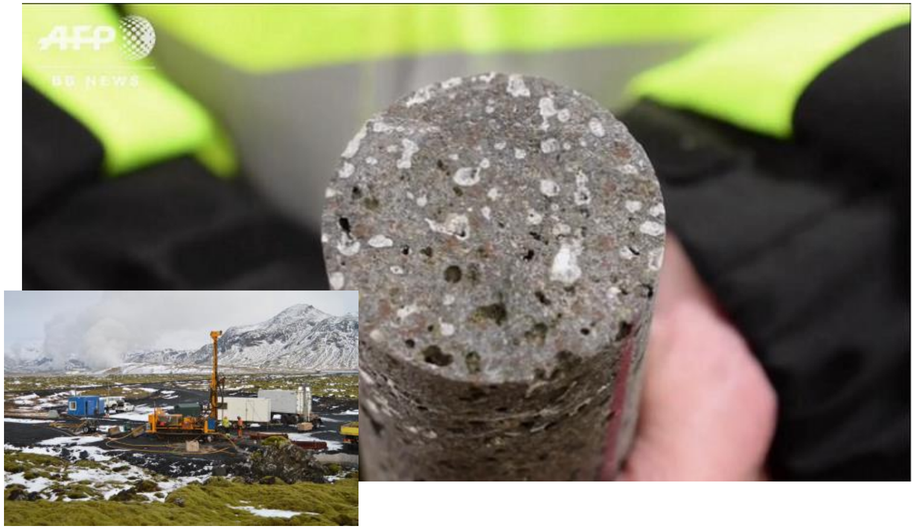
- **Desert (depleted oil/gas reservoir)**
- **Offshore platform with wind turbine**



Tsuji et al. 2021 GHG

Concept to increase potential and safety

Carbfix project in Iceland *Matter et al., 2016*



CO2 mineralization

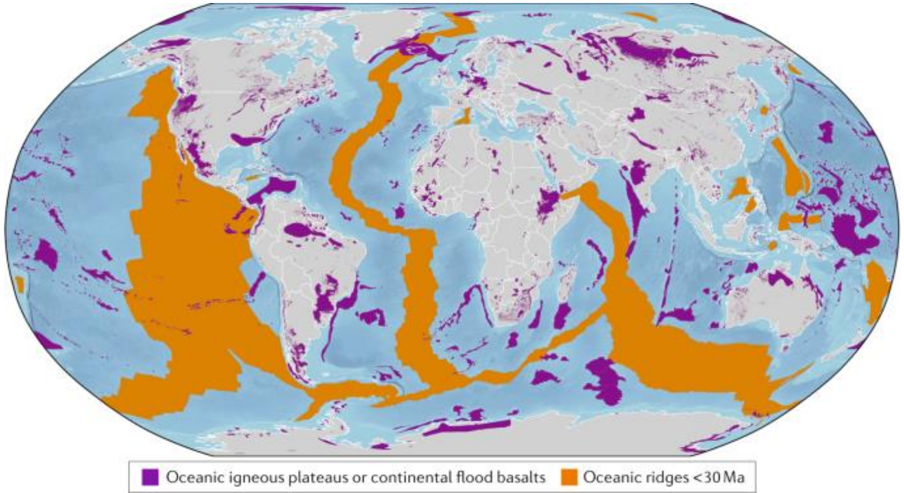
- >95% of the injected CO_2 into basaltic rock has transformed to carbonate minerals within 2 yr

➢ Basalt is common on the earth

➢ Large potential and safe storage

Kagoshima, south Kyushu

Potential site for CO_2 mineralization (*Snæbjörnsdóttir et al., 2020*)

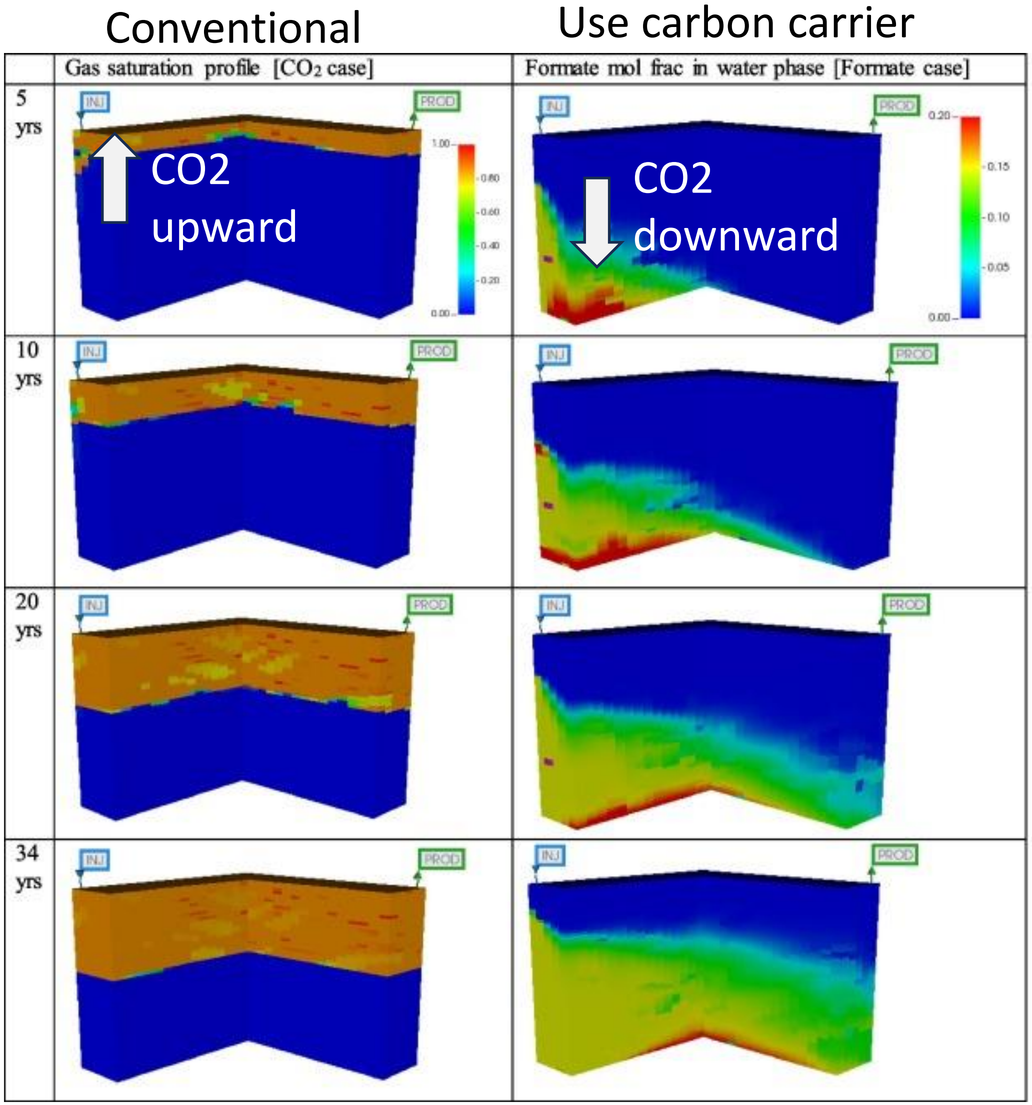


Concept to increase potential and safety

Use carbon carrier for safe CO_2 storage

- Formate solution and nano bubble CO_2 are proposed as a carbon carrier for geological storage

  - CO$_2$ and formate injection (or nano-bubble CO_2 injection) showed no upward buoyancy-driven flux, unlike the conventional CO_2 injection
  - Reduce the CO_2 leakage
  - Suitable approach in reservoir close to faults?

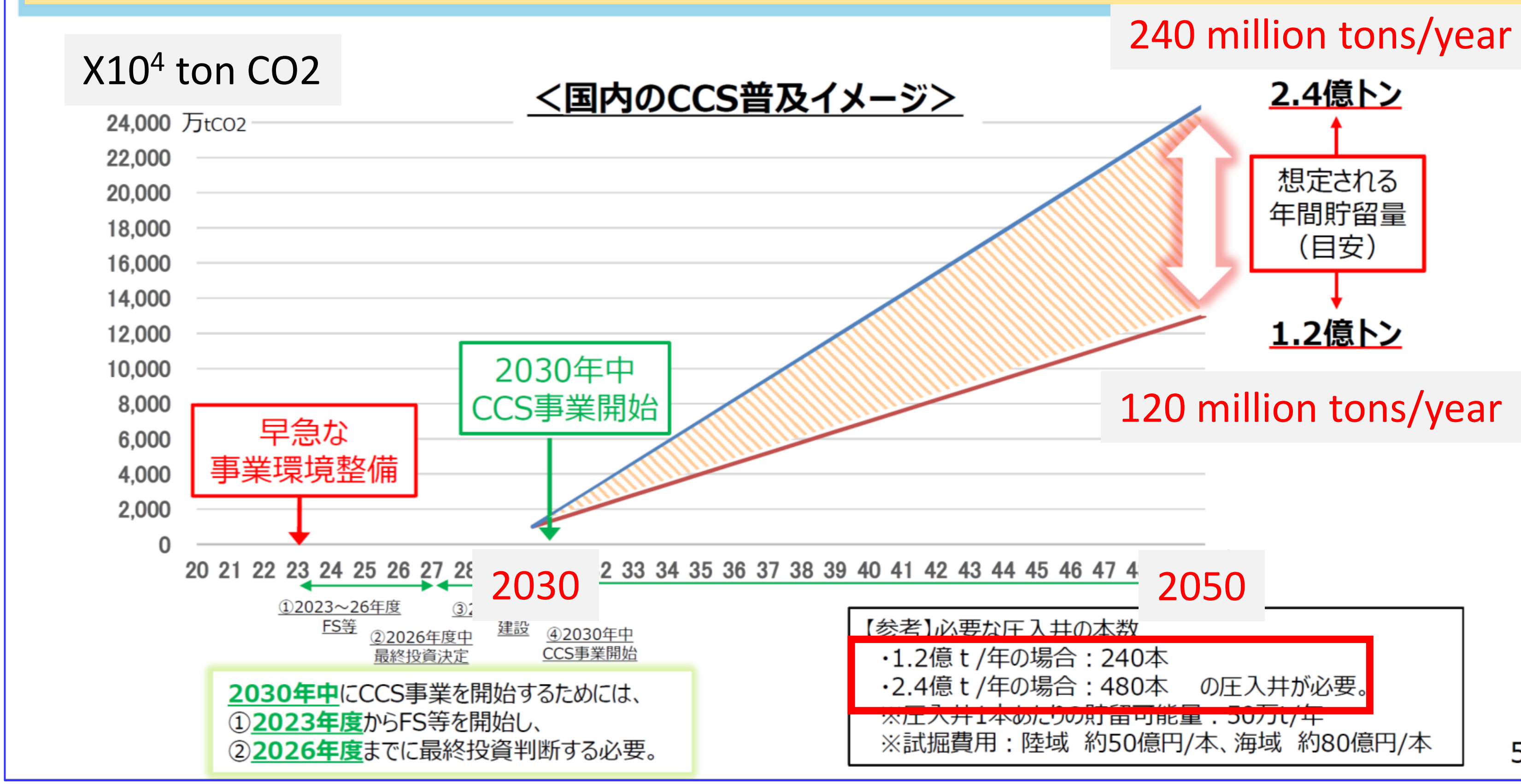


Oyenowo et al., 2023 FUEL

CCS roadmap in Japan

The roadmap envisages 120 to 240 million tons CO2 stored per year by 2050

- Need to launch new CCS projects and increase the annual storage capacity by about 6 to 12 million tons annually during 20 years from 2030 to 2050



Japanese ministry of economy trade and industry (METI), 2022

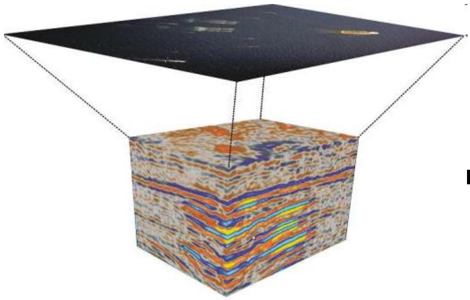
https://www.meti.go.jp/shingikai/energy_environment/ccs_choki_roadmap/jisshi_kento/pdf/001_04_00.pdf

Need to manage large number of CO_2 storage sites

- Monitoring is the most crucial to obtain public acceptance

Common monitoring approach

Time-lapse seismic survey



Before

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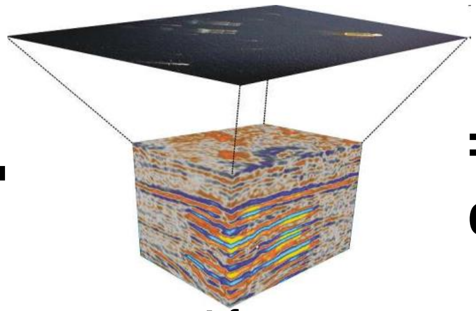
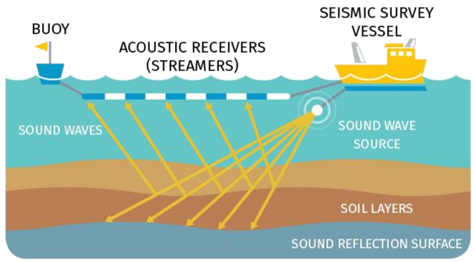
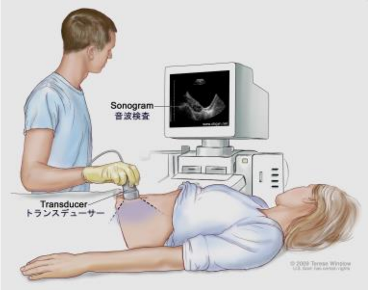


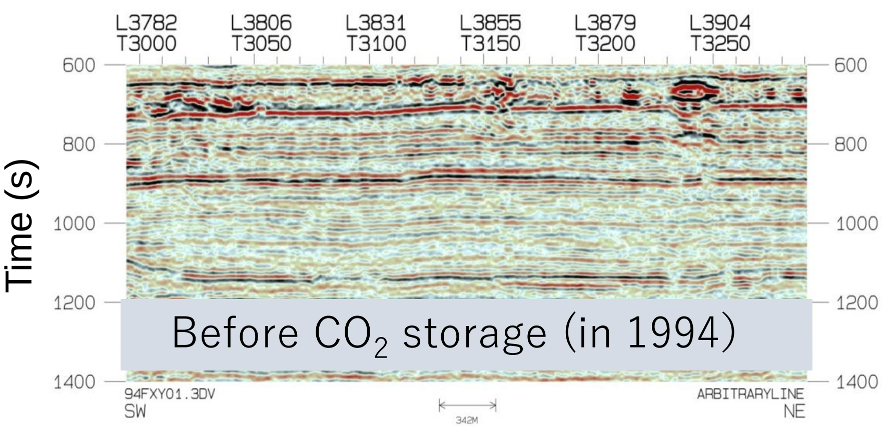
After

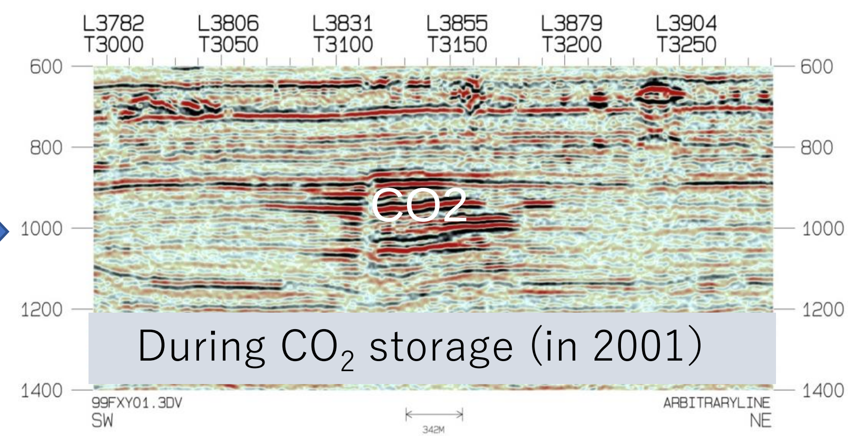




= Change in seismic attributes due to CO_2 injection

Sleipner CCS project (Arts et al. 2008)





High cost

- **Longer time interval for data acquisition (low temporal resolution)**
- **Difficult to identify rapid CO_2 leakage**

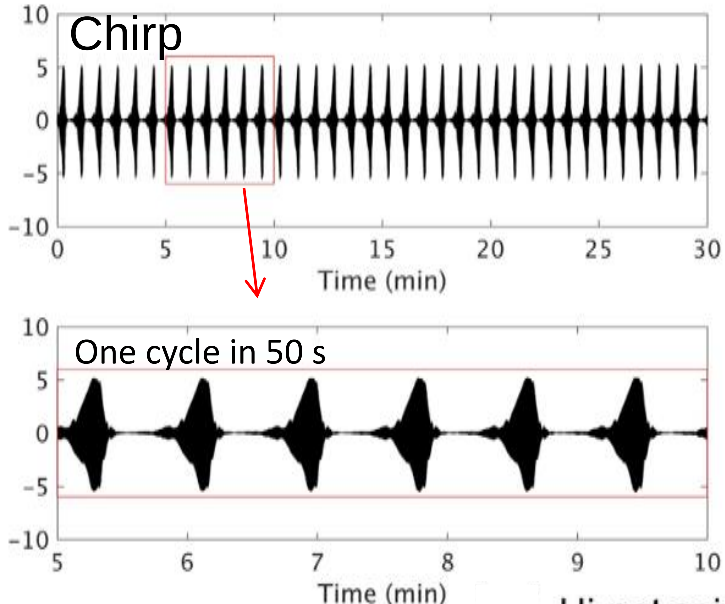
Develop permanent monitoring system

- **Low cost**
- **Continuous**

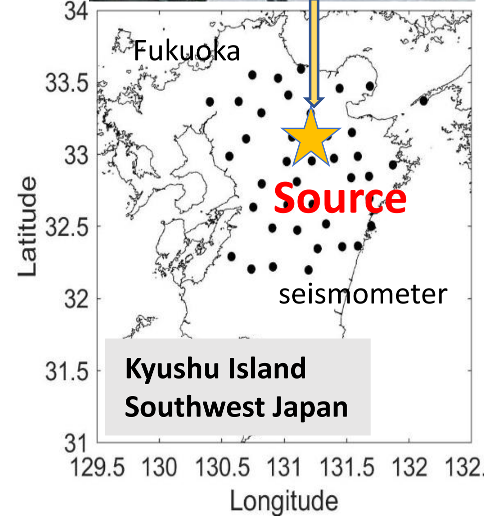
Develop permanent active seismic source
for accurate monitoring of CO_2 storage reservoir

Size: ~1m

Eccentric Mass (10 kg)
8000N at 20 Hz



Deploy at geothermal station

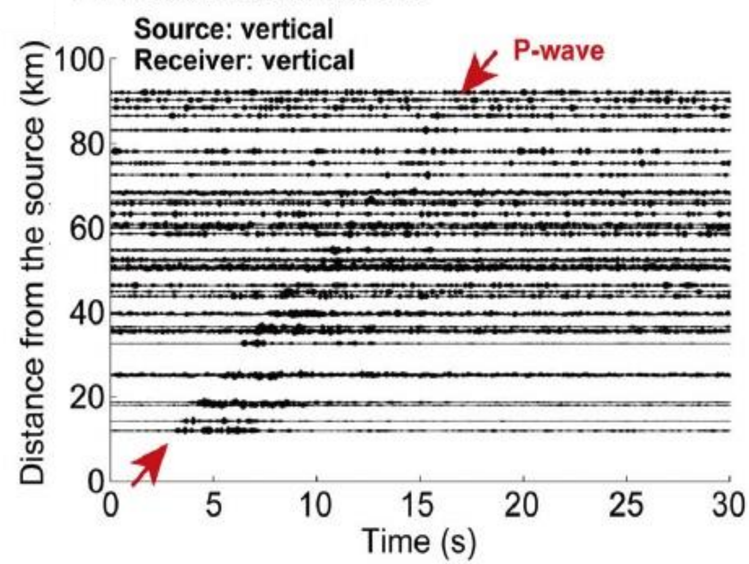


- Continuously generate the vibration (sweep)
- Improve S/N by stacking the longer-term signal

Signals from the monitoring source reach **~80 km by 4 months stacking**

➢ Monitor extensive area (multi CO_2 storage sites)

Hi-net seismometers



Tsuji et al., 2021 Scientific Reports

Portable Active Seismic Source (PASS)

Size: ~1 m

Tsuji et al., 2021 Sci Rept

~80 km propagation

Downsize

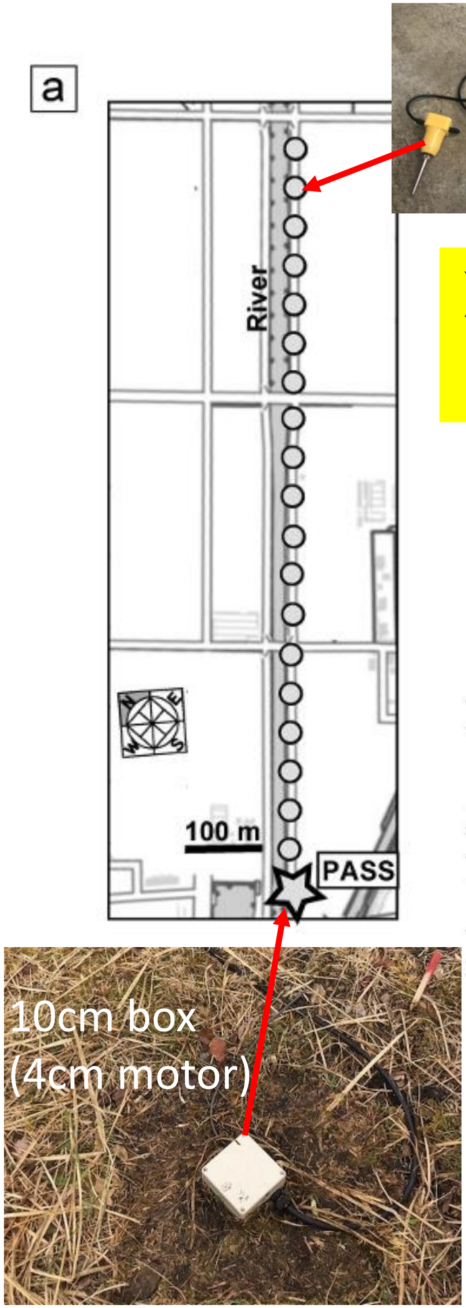
P A S S
Portable Active Seismic Source

Size: ~0.1 m
4 cm motor

Tsuji et al., 2023 SRL

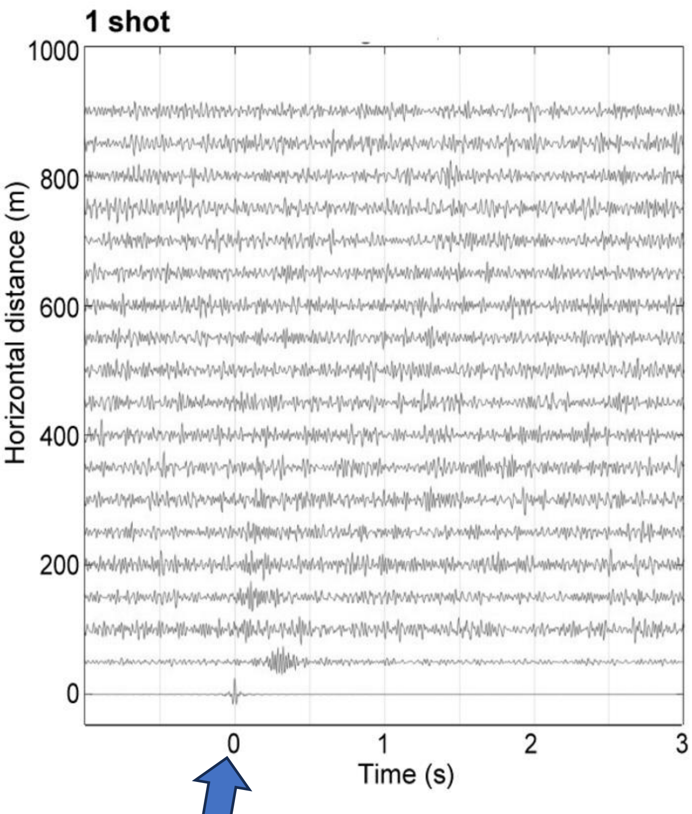
? m propagation

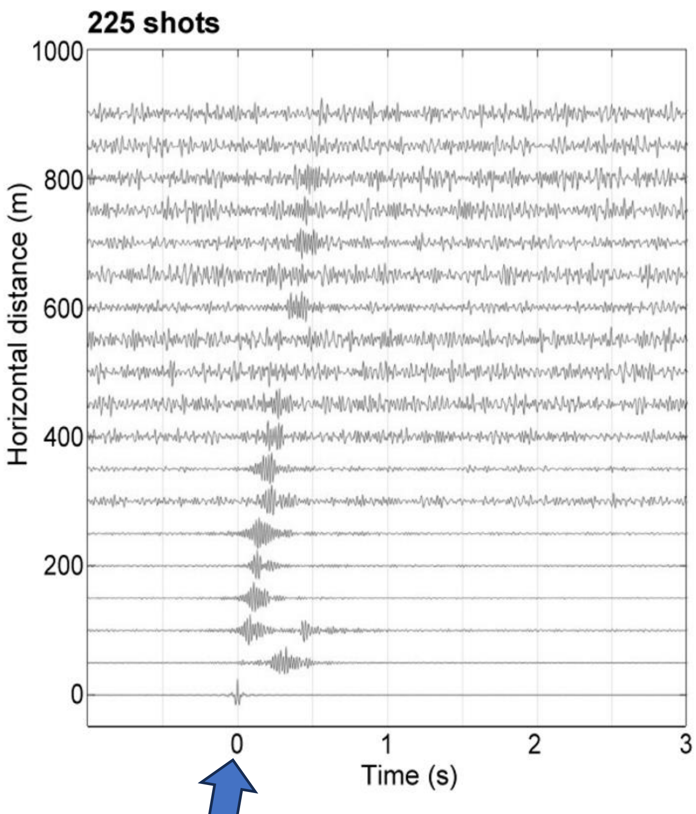
Signal enhancement by stacking



- **Signal from PASS with ~4cm motor propagated ~1 km!**

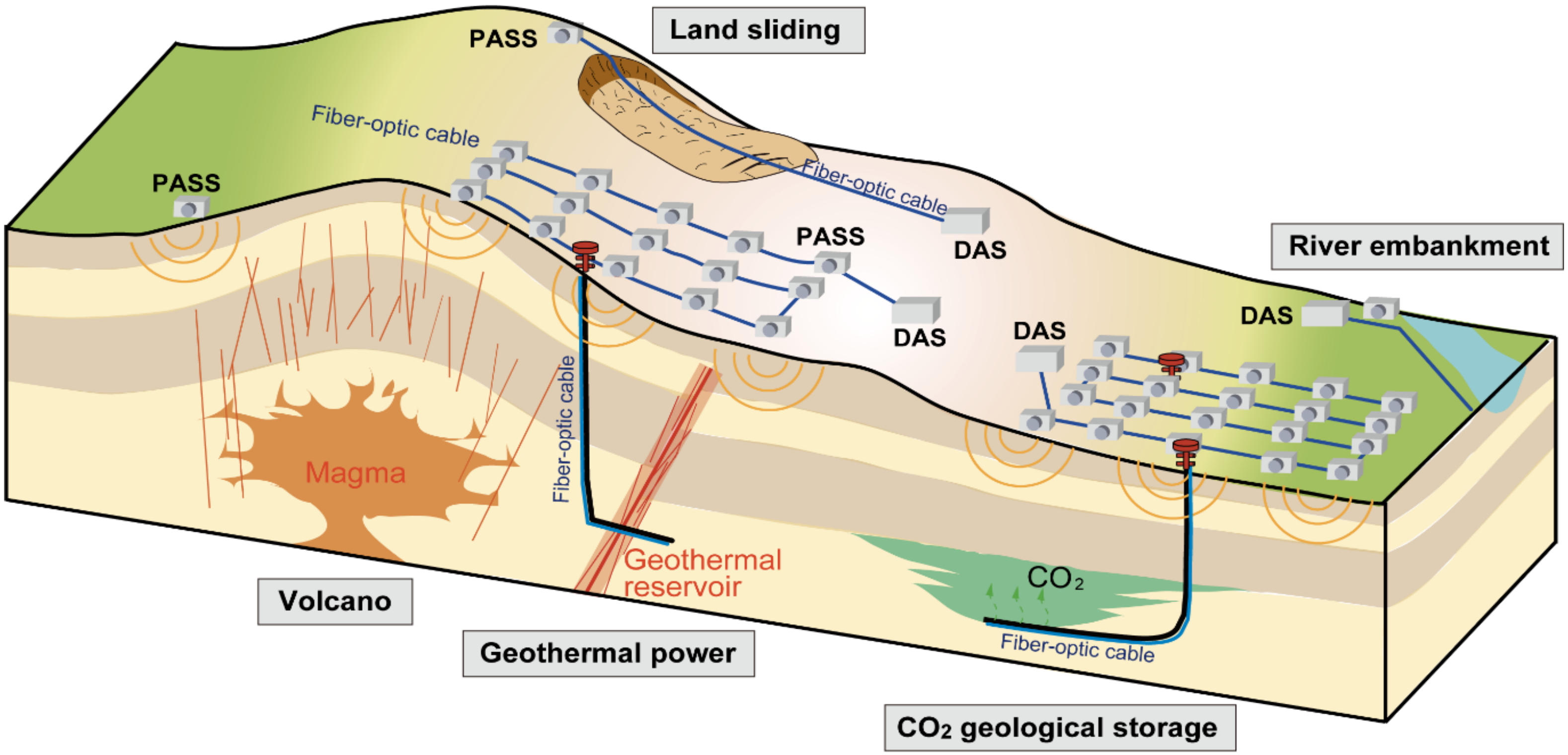
Tsuji et al., 2023 SRL





Continuous monitoring for CO_2 storage sites

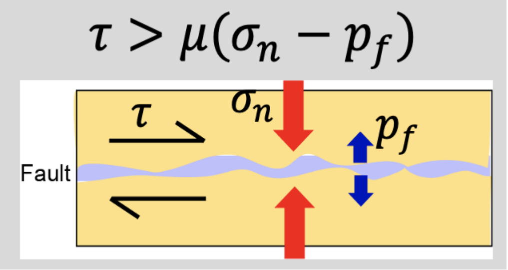
- Deploy many receivers (e.g., new type receivers, such as DAS)
- Generate monitoring signal using many small sources (PASS)
- Continuously monitor several CO_2 injection sites with low-cost



Method to distinguish between natural and CO_2 induced earthquakes

Chhun and Tsuji, 2020, Sustainability

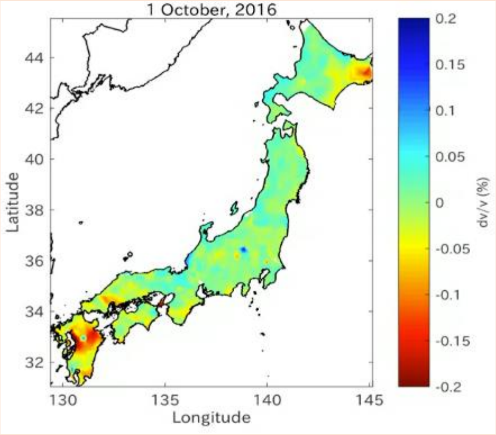
1. Measure natural pore pressure variation due to weather or remote earthquake from monitoring
2. Measure (or calculate) artificial pore pressure variation due to CO_2 injection via numerical simulation



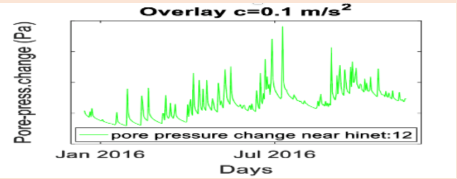
- If (1) natural pore pressure variation is much larger than (2) artificial pore pressure variation, the EQ could be natural one.

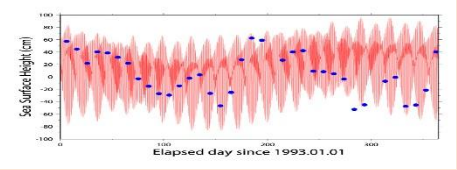
1. Natural pore pressure variation due to weather and remote EQ

From seismic velocity



From hydraulic monitoring





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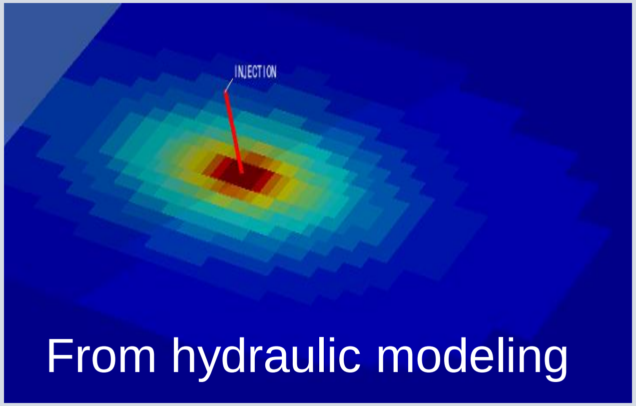
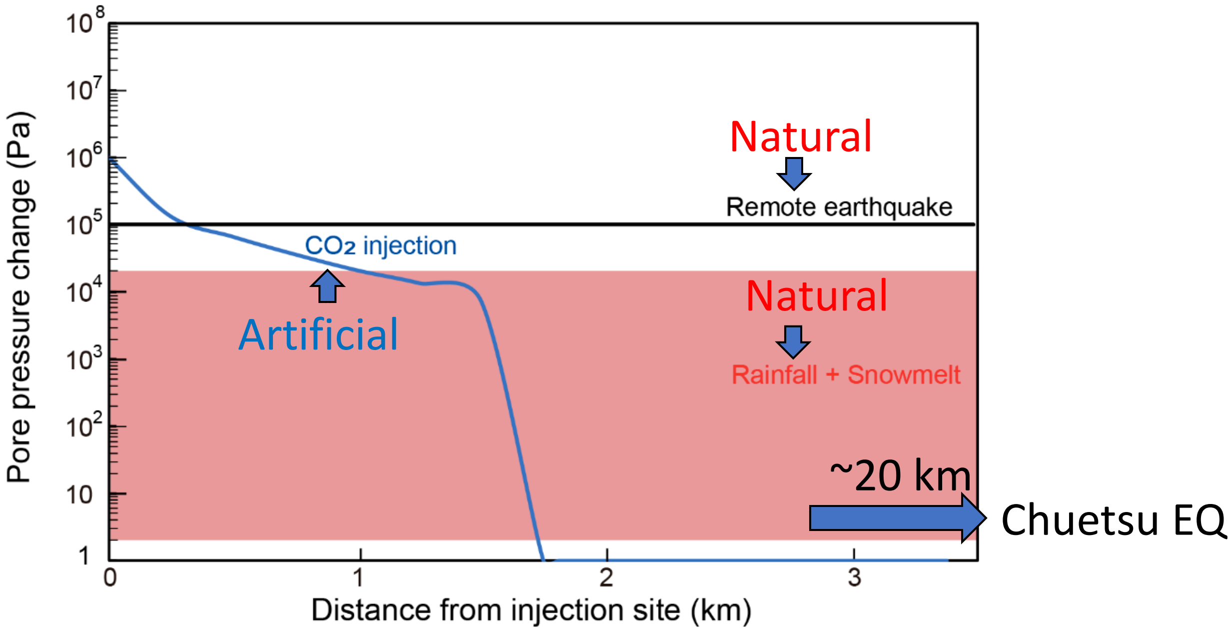
2. Artificial pore pressure variation due to CO_2 injection



Evaluate the Chuetsu earthquake (Mw6.8) close to the Nagaoka CCS site, using our evaluation method

- Natural pore pressure variation is larger than the artificial pore pressure variation due to CO_2 injection at >1km far from CO_2 injection site.
- Epicenter of the Chuetsu EQ was at ~20km from the injection site

➢ The Chuetsu earthquake could be natural one



Chhun and Tsuji, 2020 Sustainability

➢ Provide scientific-based approach to classify these earthquakes!

Summary

CCS/CCUS could be one of the key technology for carbon neutral world

- ➢ Japanese government and private companies try to launch new CCS projects and increase the annual storage capacity

- We should consider safe and low-cost CO2 storage
  - Low-purity CO2 storage
  - CO2 Mineralization
  - Use carbon carrier (e.g., formate solution)
  - New monitoring system (device and method)
    - New seismic source (PASS)
    - Distinguish natural and CO2 injection-induced earthquakes
  - Others