CO_2地中貯留安全性評価技術開発の取り組み

Research and Development of Safety Assessment Technology for CO_2 Storage in Deep Saline Aquifer

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Contents

- **Safety / Risk Assessment in CO_2 Storage**
  - Definition, Diversity and Uncertainty
  - Safety / Risk Assessment & Management
- **Geologic Modeling and Monitoring Tech.**
  - Heterogeneous Reservoir (Vertical & Lateral Variations)
  - Monitoring, Verification, Accounting (MVA)
  - Fiber Optic Sensing (Distributed, Repeatable, Permanent)
- **Risk Management & Communication**
  - Reducing the Levels of Uncertainty and Risk
  - Scientific Knowledge and Evidence-based Risk Communication

➢Safety/Risk Assessment in CO_2 Storage (1/3)

·Definition, Diversity and Uncertainty

◆ Risk: the **possibility** due to **uncertainties and threats** affecting storage process, included in all activities with different degrees

- ✓ **Identifying the risks**
- ✓ **Analysing the risks**
- ✓ **Evaluating the risks**
- ✓ **Monitoring and reviewing the risks**

➡➡ **Controlling the risks (without further risk treatment required)**

Mitigating the risks →→→ Securing the safety

(Safety assessment = Risk assessment)

◆ **Business or investment-related risks (Fiancial & Market), Communication risks (Stakeholders), Global risks without CCS (Climate change)**

➢Safety/Risk Assessment in CO_2 Storage (2/3)

・Definition, Diversity and Uncertainty

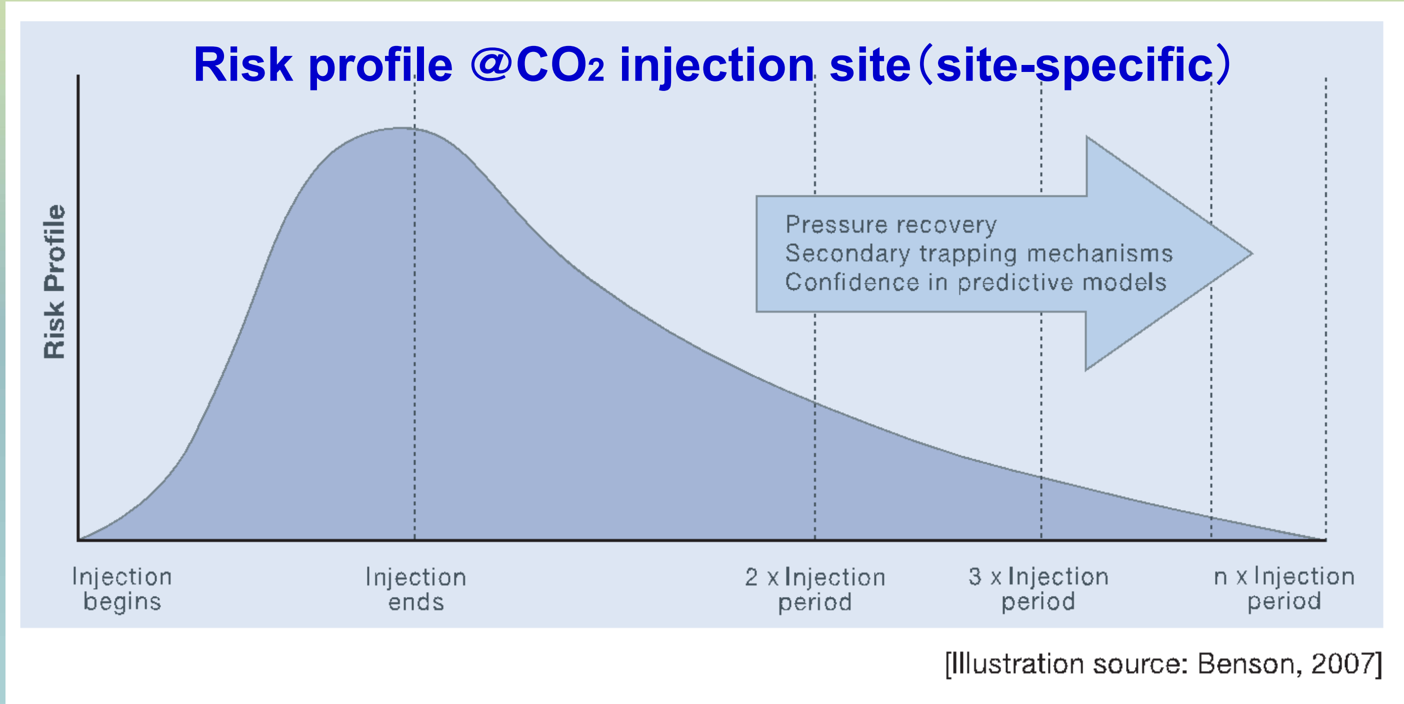
◆High Subsurface Uncertainties:

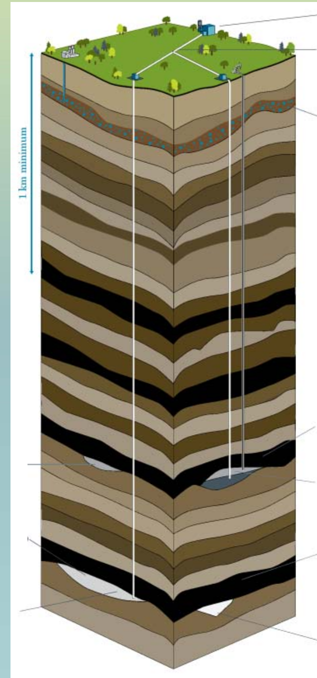
- ✓ Multiple and <u>site-specific</u> subsystems (injection & monitoring wells, aquifers, caprocks, aquitards, freshwater, faults….)
  - ✓ Many **interacting components** (rock minerals, CO_2, formation fluids….)
    - ✓ **Various models** (geological model, reservoir model, geochemical model, geomechanical model….)

Advantages and Limitations of Technologies used in All CO_2 Storage Activities!

➢Safety/Risk Assessment in CO_2 Storage (3/3)

· ***Potential* Risks**





Losses of Injectivity, Capacity and Containment,
Induced Seismicity, Environmental Impacts

Research Areas & Program (US/DOE)

Core R&D Research Areas

Key Technology Areas Research Pathways

(DOE, 2015)

Geologic Storage Technology Area
(Storage Technologies and Simulation and Risk Assessment)

- Wellbore construction and materials
- Mitigation technologies for wells and natural pathways
- Fluid flow, reservoir pressure, and water management
- Geochemical effects on formation, brine, and microbial communities
- Geomechanical impacts on reservoirs- seals and basin-scale coupled models; microseismic monitoring
- Risk Assessment databases and integration into operational design and monitoring

Monitoring, Verification, Accounting & Assessment (MVAA) Technology Area

- Atmospheric Monitoring and remote sensing technologies
- Near-Surface Monitoring of soils and vadose zone
- Subsurface Monitoring in and near injection zone

Onshore

/ Offshore

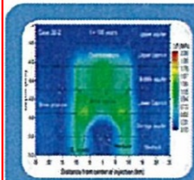
(Gulf of Mexico)

Carbon Storage Program

Addressing Future Technical Challenges

Offshore Storage Resource Assessment

- Prospective Storage Resource for East Coast and/or Gulf of Mexico
- Depleted Oil and Natural Gas Reservoirs and Saline Formations



Fit-for-Purpose Field Project– Brine Extraction Storage Test (BEST)

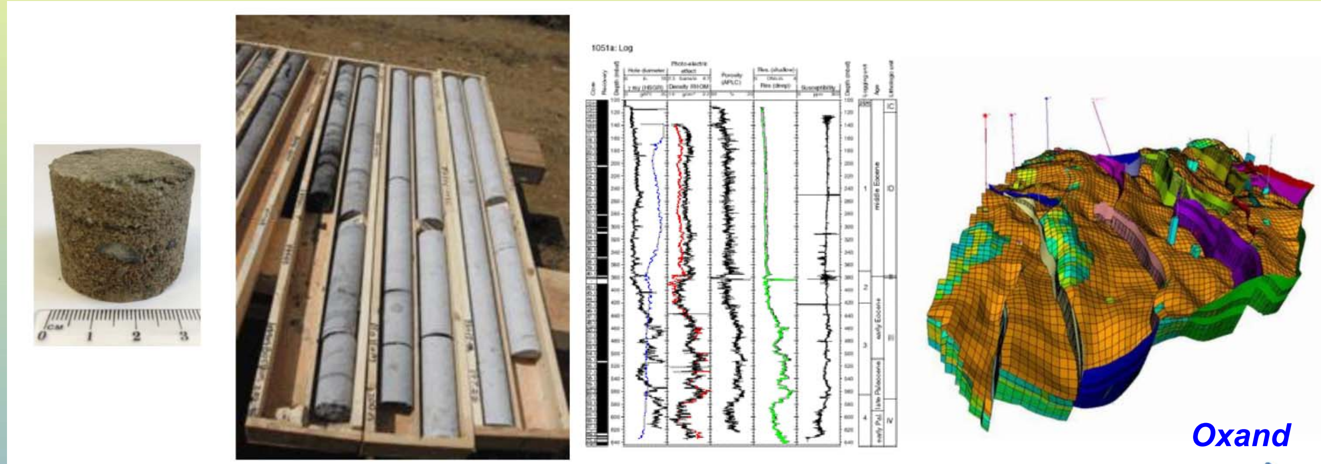
- Managing formation pressure and movement of differential pressure and CO_2 plume through brine extraction and treatment of extracted brine for re-use

Intelligent Monitoring Systems and Advanced Well Integrity and Mitigation

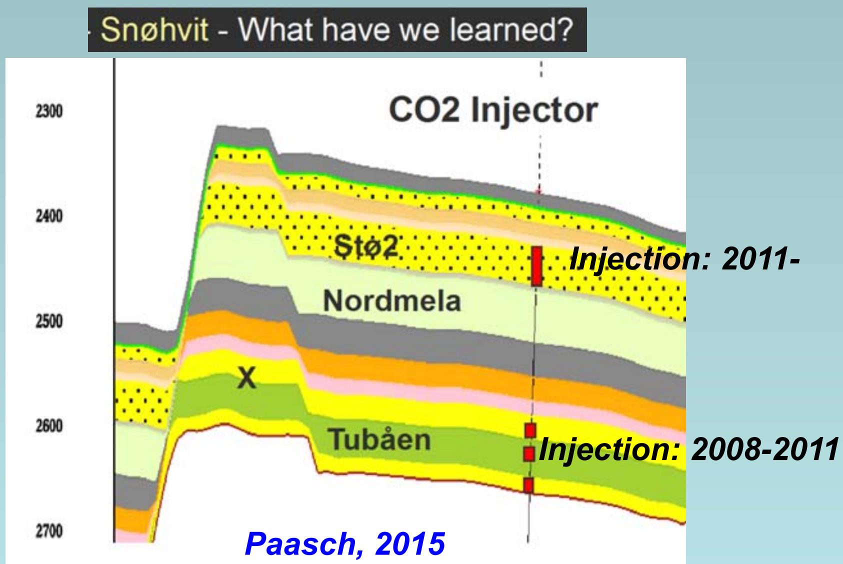
- Next generation technologies to monitor, control and optimize CO_2 injection
- Advanced tools and methods for assessing wellbore integrity (identifying and quantifying wellbore leakage) and mitigation

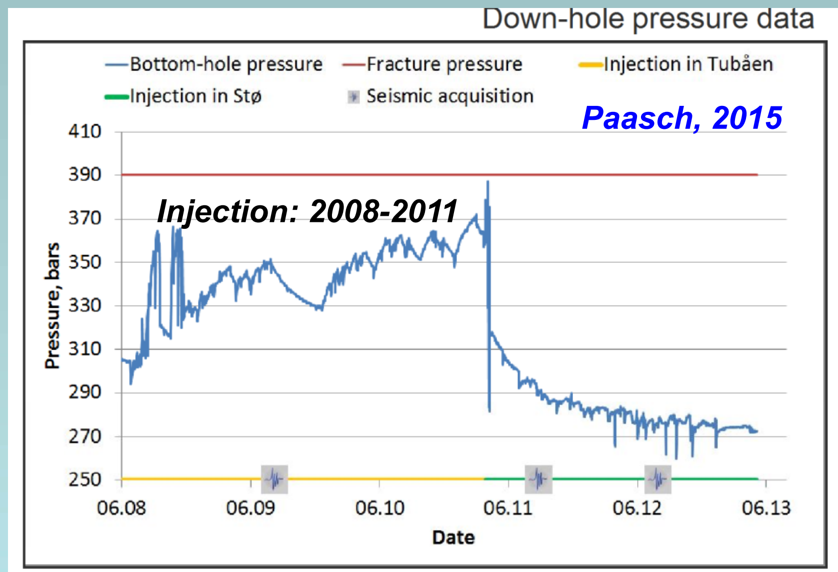
- ***R&D focused on: Cost (Capture) and Confidence (Storage),***
- ***Demonstrations: Integration and Learning***

Storage Capacity & Monitoring Tech (1/3)



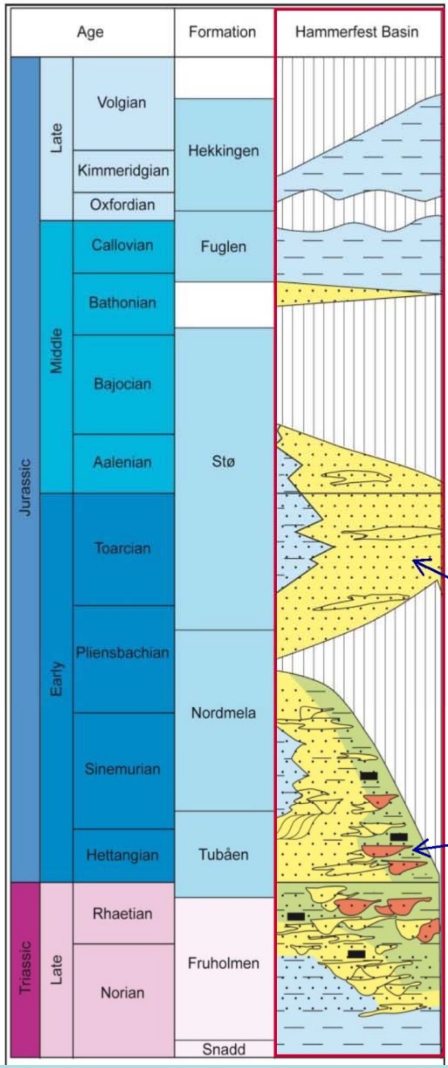
- ***Reservoir characterization: Heterogeneity and Injectivity***





Stratigraphy and Depositional Environment

@ Snohvit



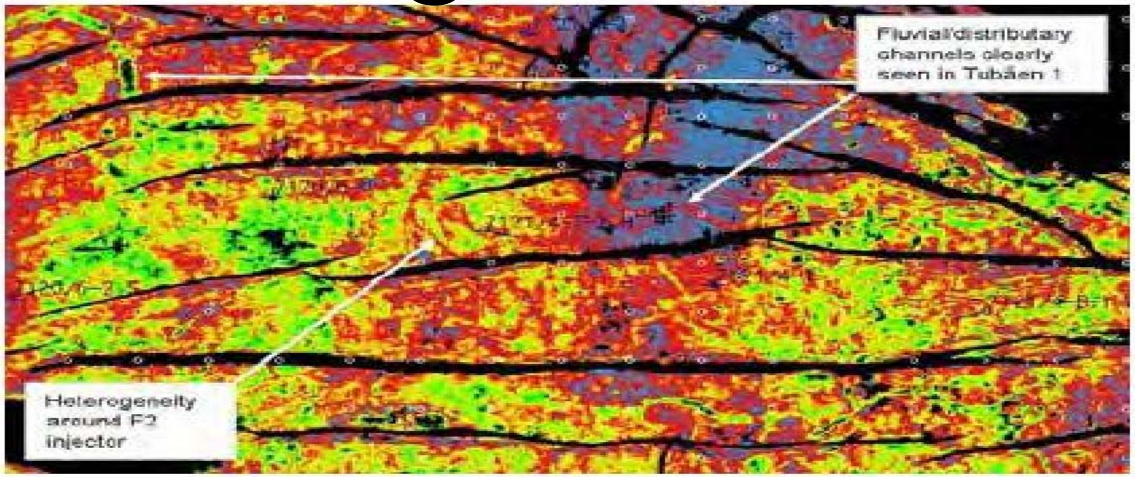


Figure 3: Amplitude map of the base Tubåen Fm reflection. Green colours are high amplitudes and blue colours low amplitudes.

Stø (main reservoir)

- Shallow-marine environment
- Good lateral and vertical communication

Tubåen

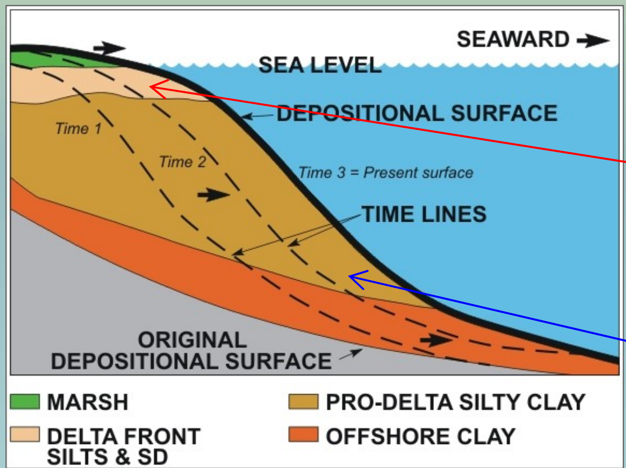
- Densely stacked fluvial channels
- Poor lateral and vertical communication

Paasch, 2015

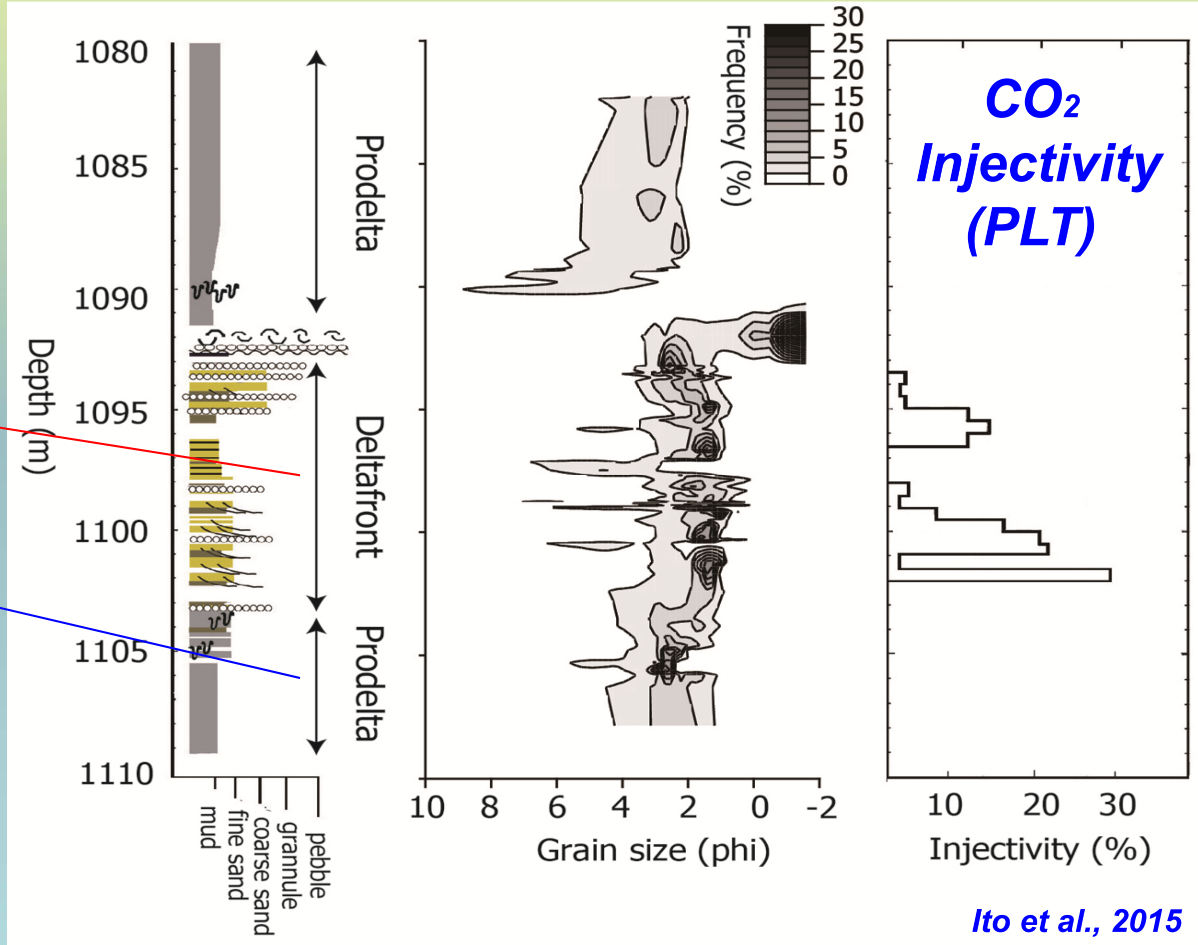
Integrating aspects from both 3D seismic and sequence stratigraphy

Application of Sequence Stratigraphy @ Nagaoka (injection well)

Clay content, γ-ray log

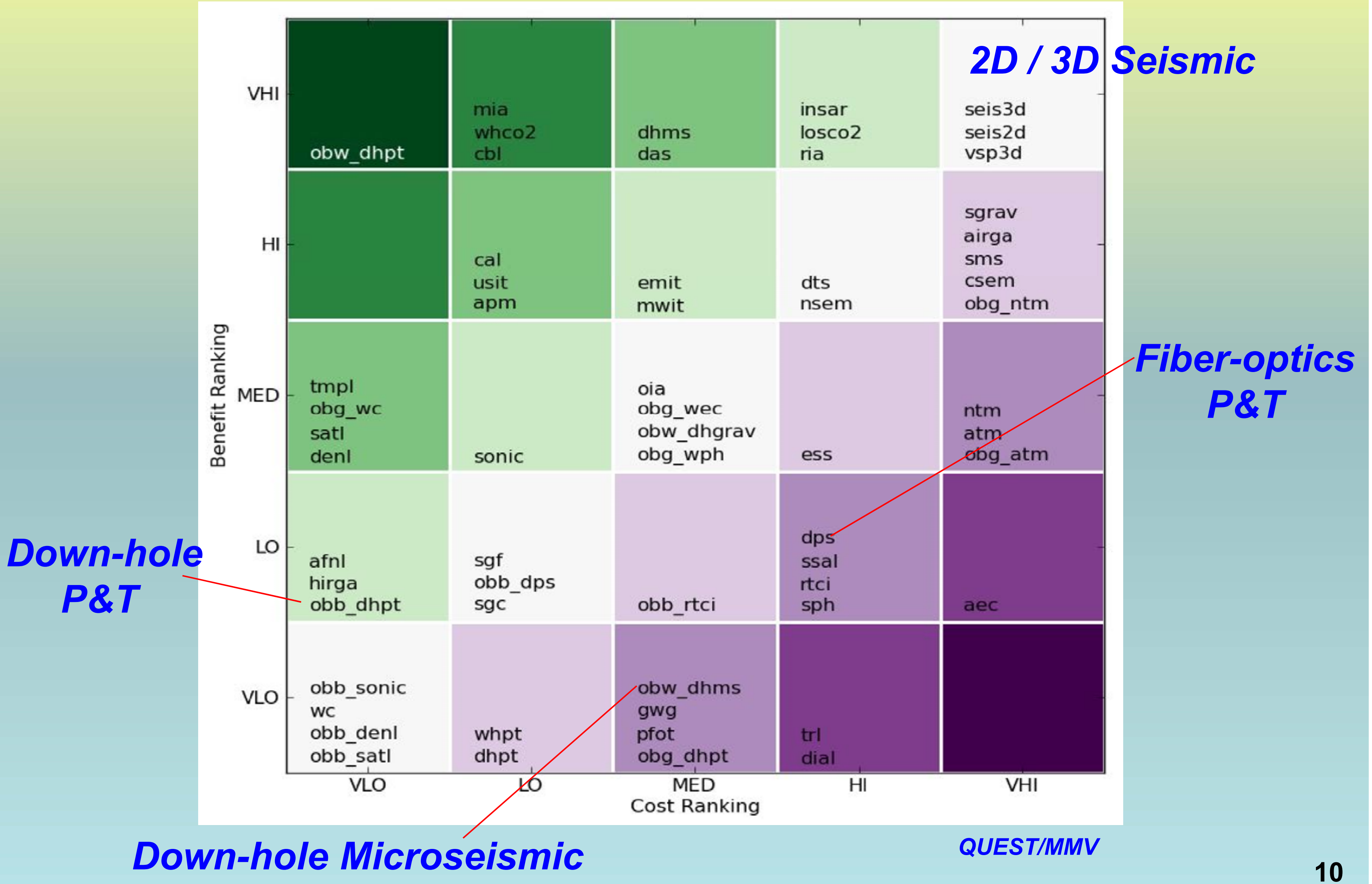


Porosity, Permeability



Detailed information at wells: Local to Spatial

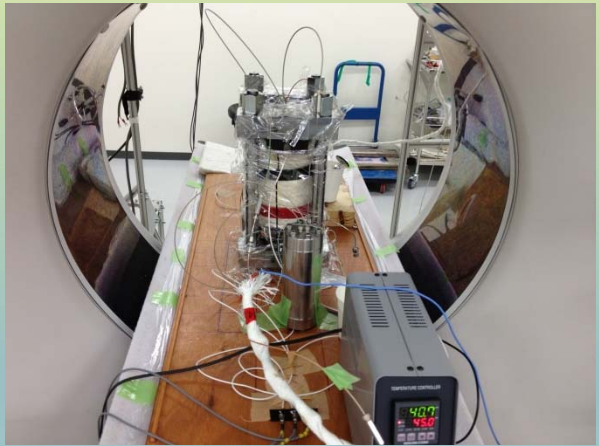
Monitoring Techs & Cost-Benefit Ranking

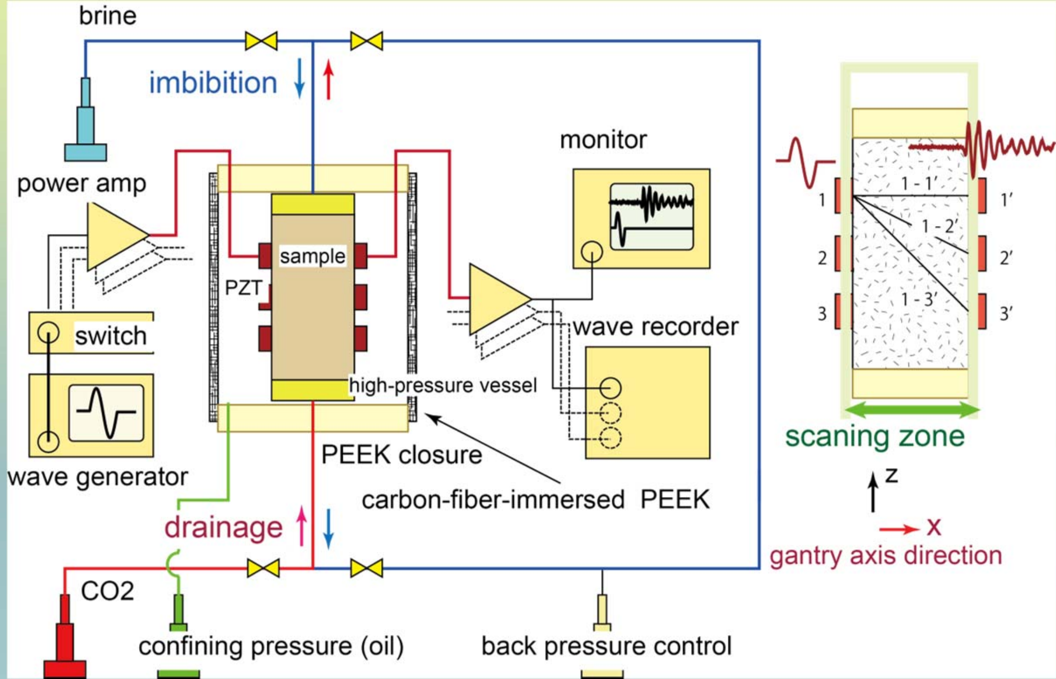


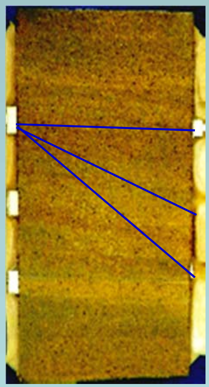
QUEST/MMV

Measuring **Wave Velocity** while Scanning

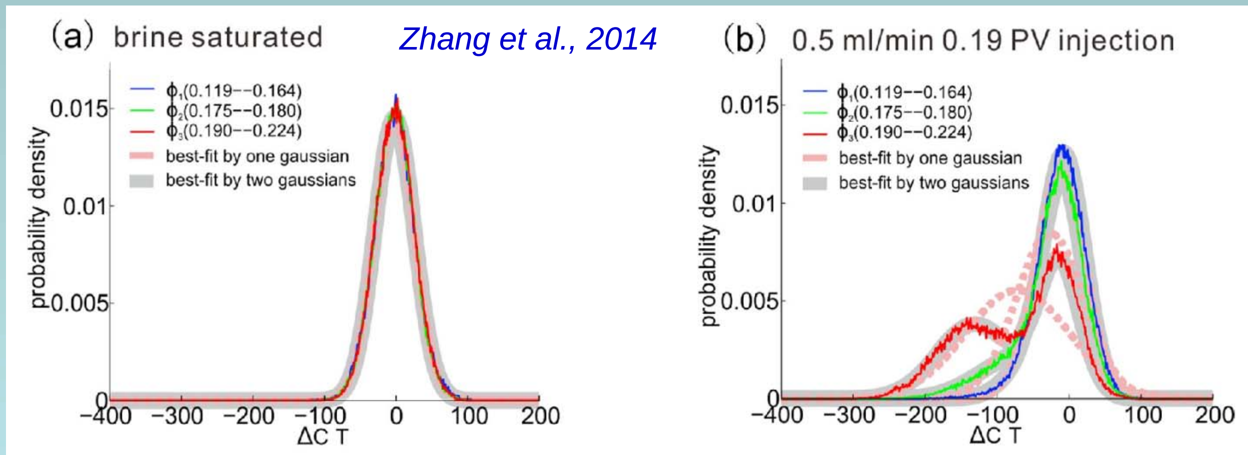
High pressure vessel





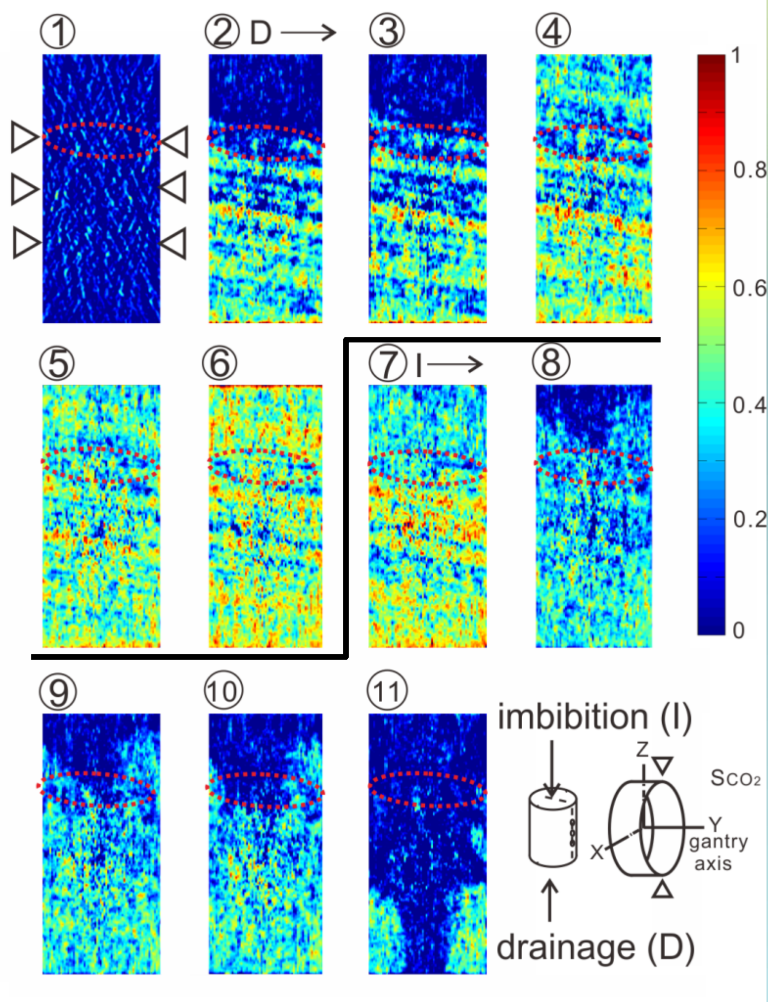


Sandstone (ϕ5cm,10cm)

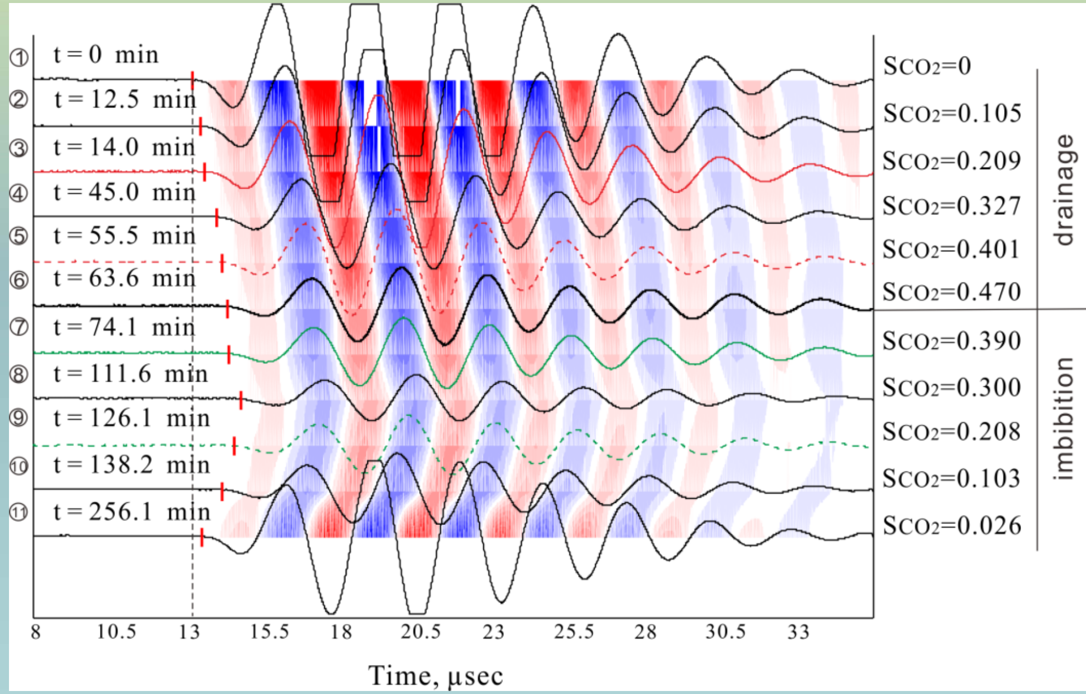


Lab test: CO_2 Saturation Image & Waveform

X-ray CT images



Waveforms during drainage imbibition

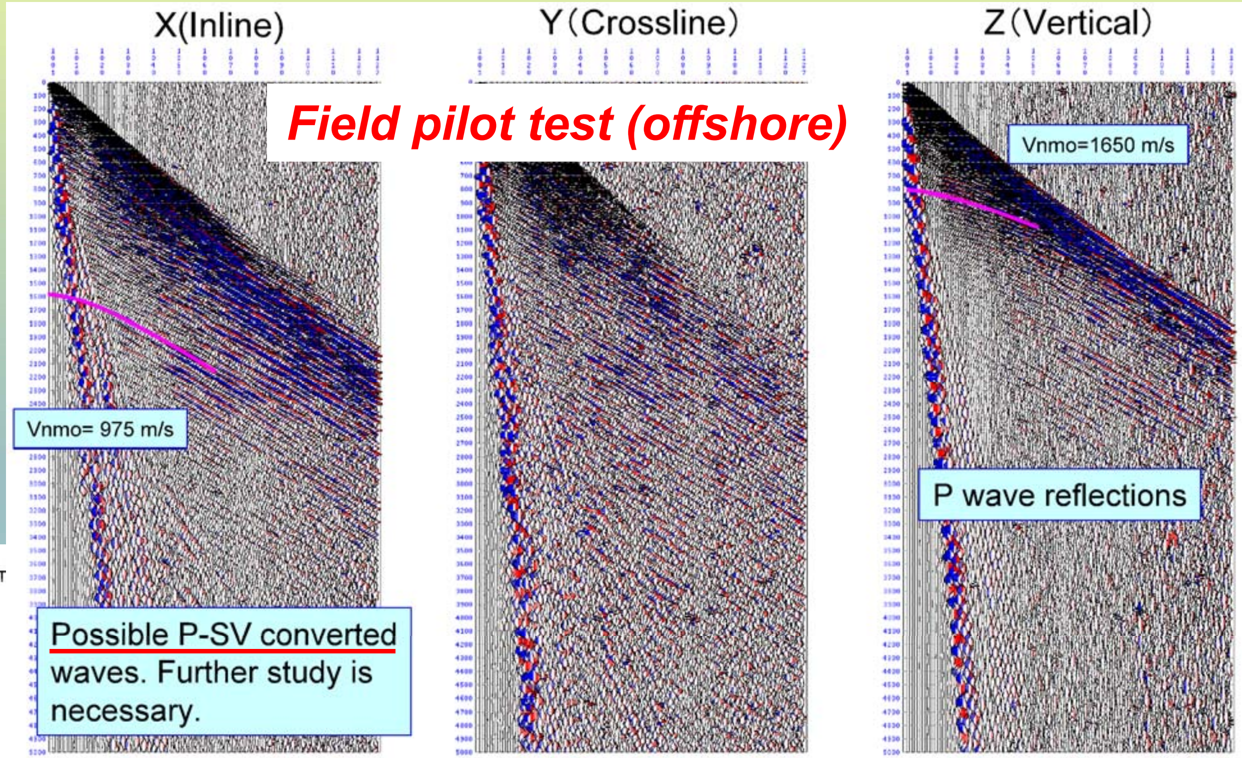


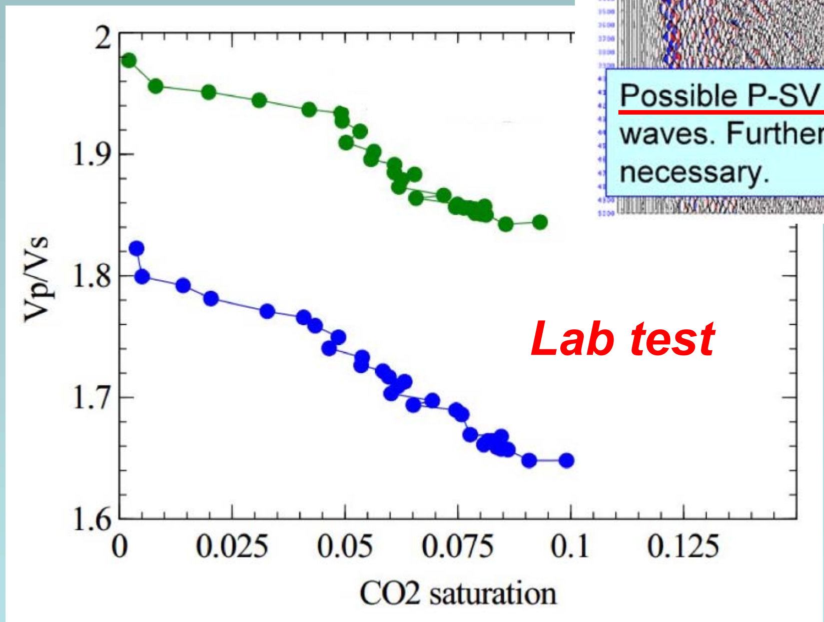
Zhang et al., 2014

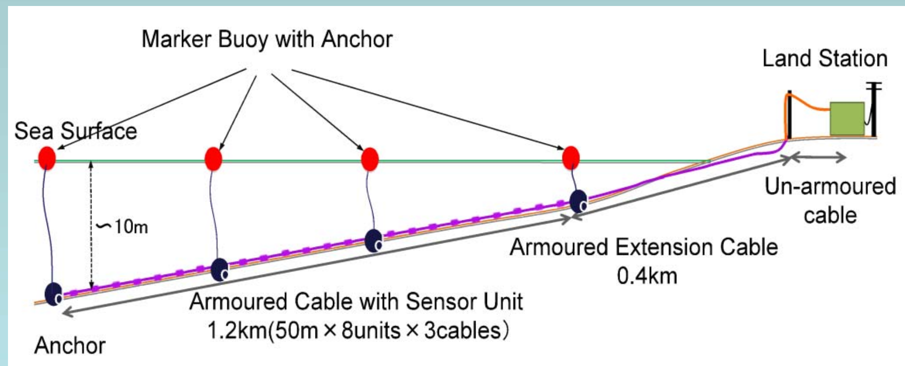
Vp, Vs, Vp/Vs *vs* CO_2 Saturation in highly heterogeneous core samples

CO_2 Monitoring with Integration of S-wave

Ocean Bottom Cable



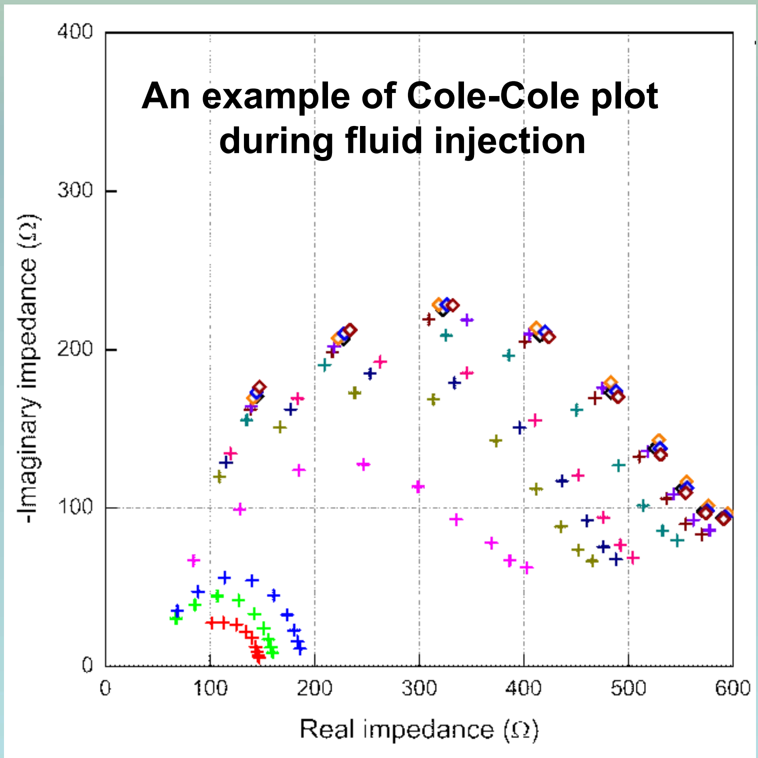


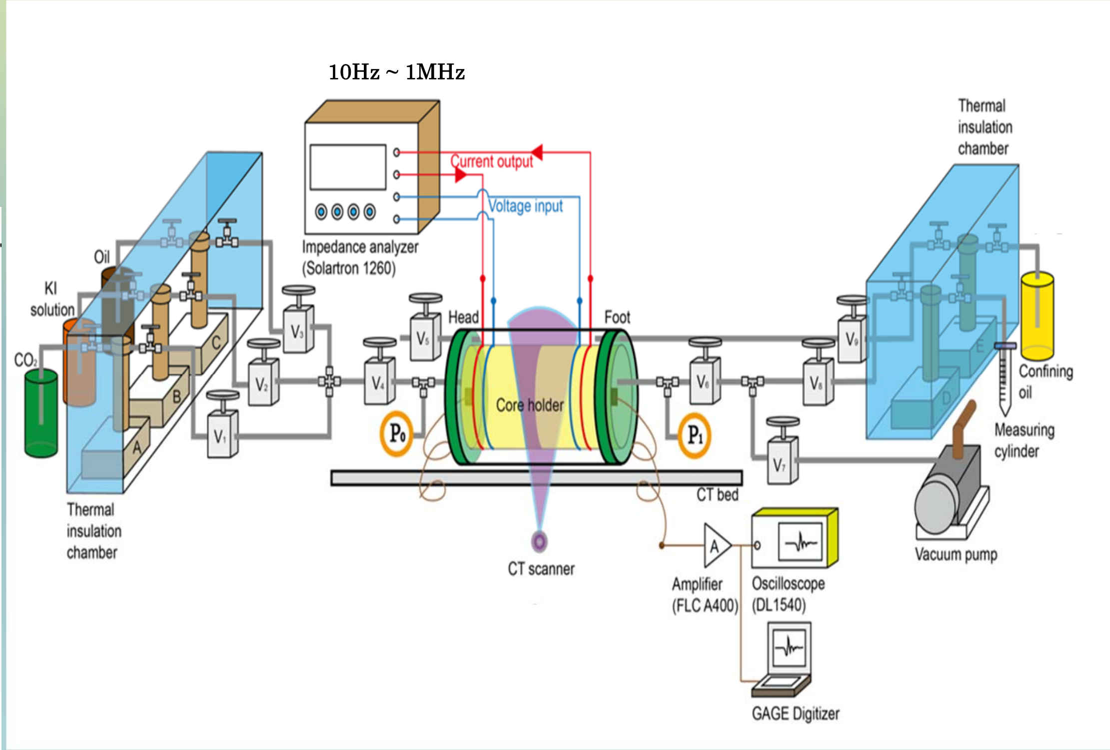


Measuring Impedance while Scanning

Complex electrical impedance

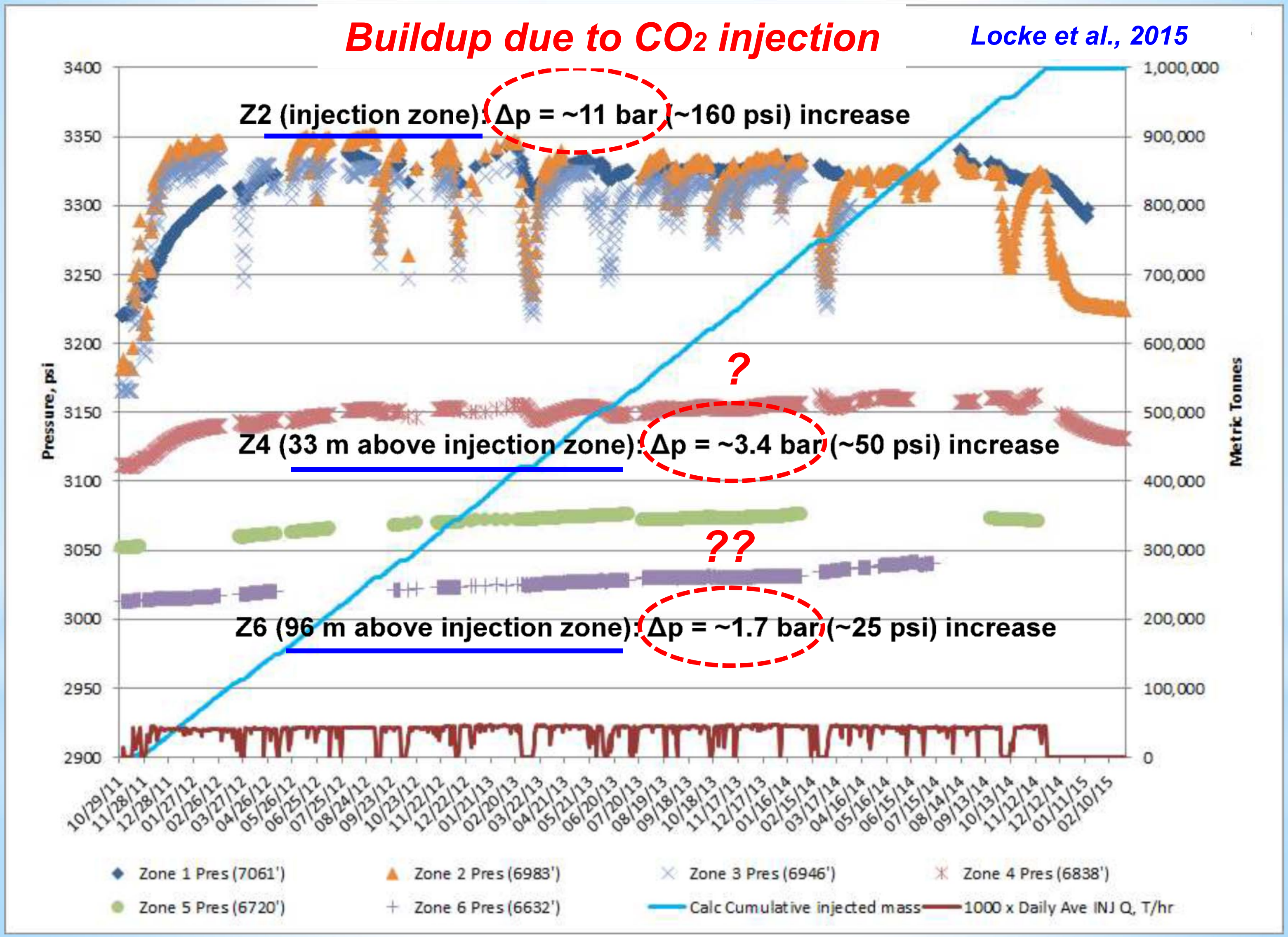
Liu et al., 2015





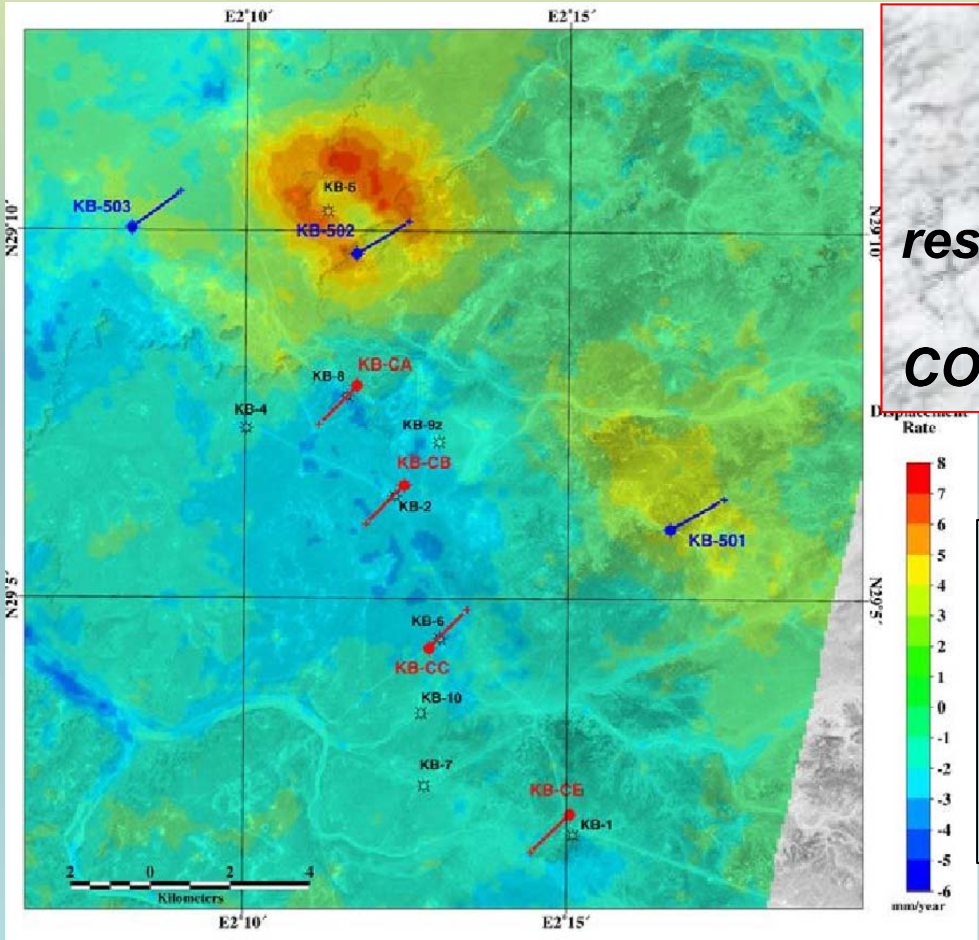
Electrical Impedance *vs* CO_2 Saturation

Pressure Monitoring @ Decatur (Illinois)



Geomechanics: ***Pressure change →→→ Deformation***

Uplift Caused by Pressure Buildup at In Salah During CO_2 Injection



Pressure buildup depending on

reservoir porosity & permeability,

CO_2 injection rate & volume.

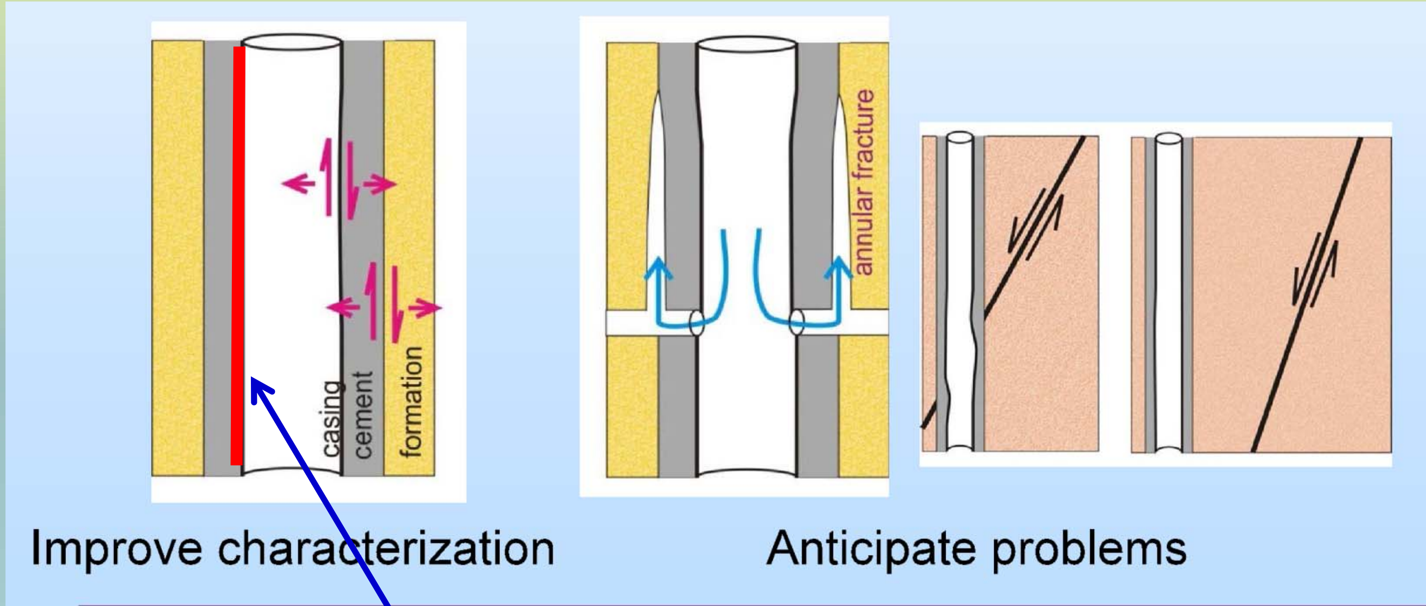
Uplift at ground surface

How to interpret?

Pressure buildup at subsurface

Need continual strain data along depth?

Wellbore Deformation Tool
BSM by Baker Hughes



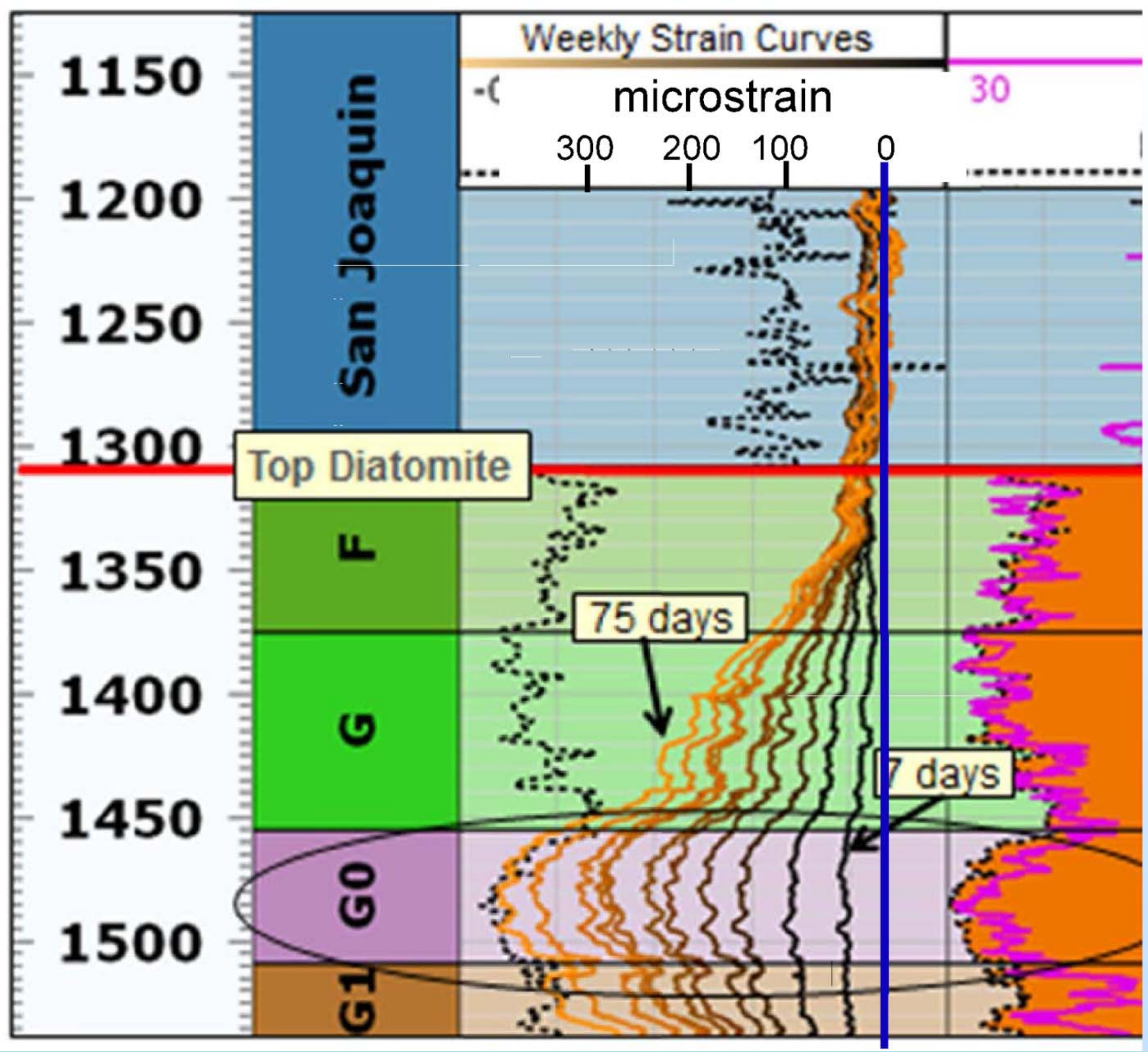
Baker *WIRE*

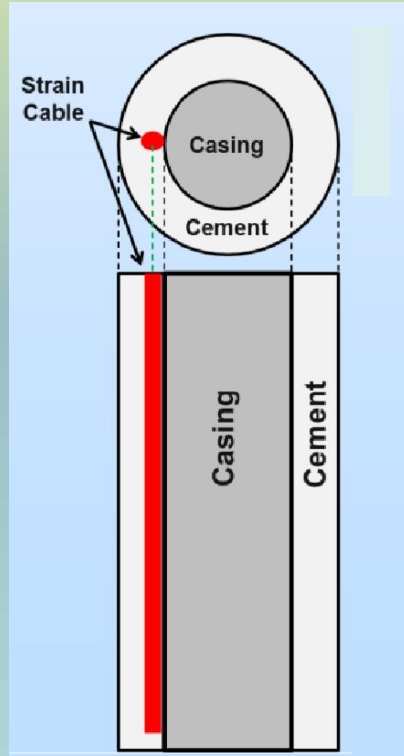
- Multicomponent
- ~1 μe
- Optical
- Part of casing

Murdoch et al., 2014

Field Test of *WIRE* in Belridge Field, California

from Roger Duncan, Baker Hughes



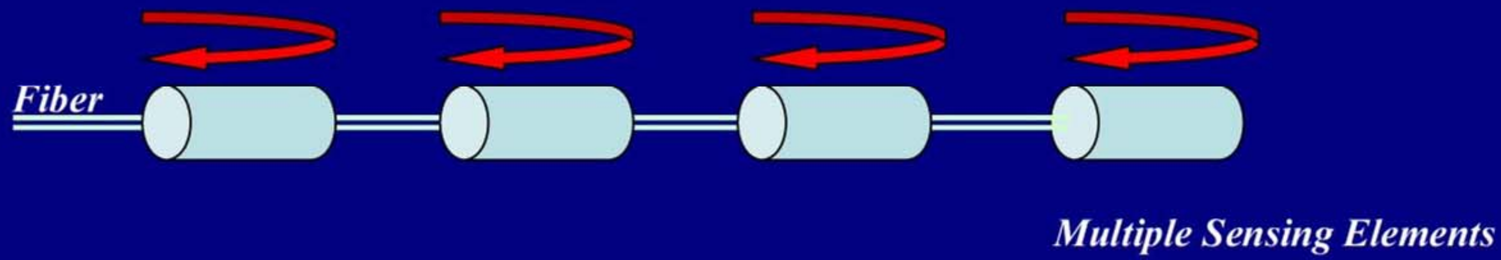


Murdoch et al., 2014

Single → Multi → Distributed

- Single Point Sensor

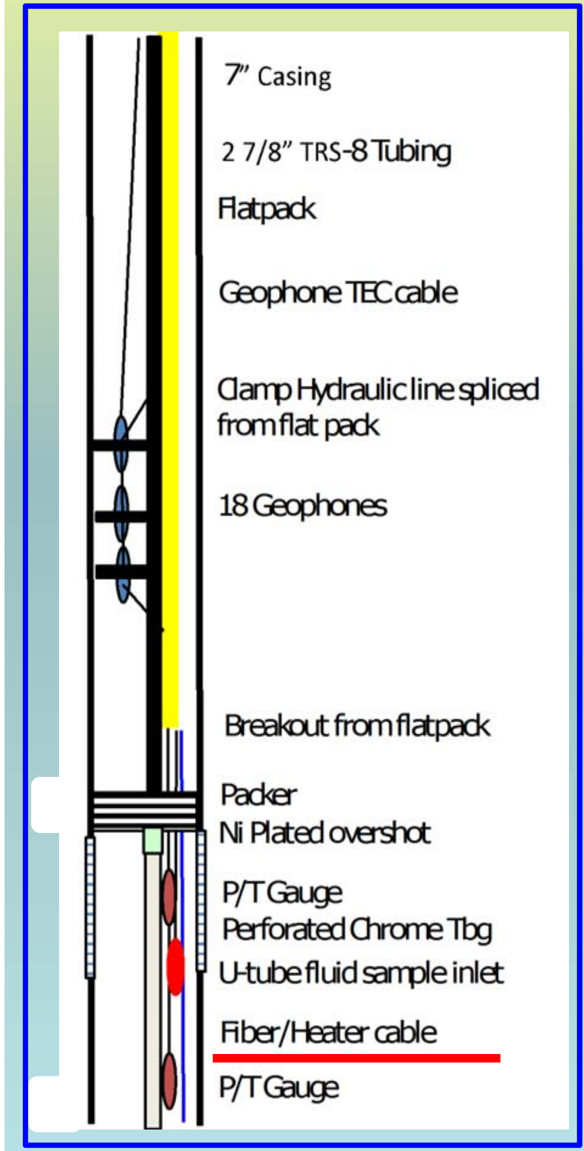
- Multi-point (quasi-distributed) Sensor



- Distributed Sensor

(Dria, SPE/DL 2012)

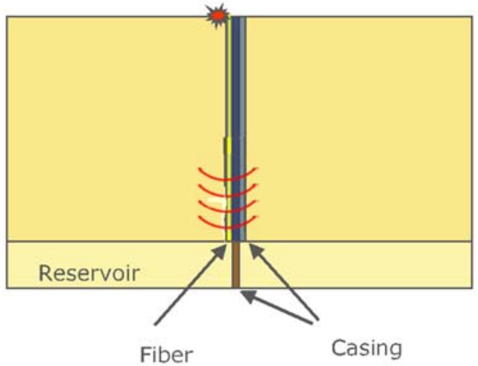
Application of Fiber Optics@QUEST



QUEST Project

Zero-Offset Source for CO_2 Leak Detection

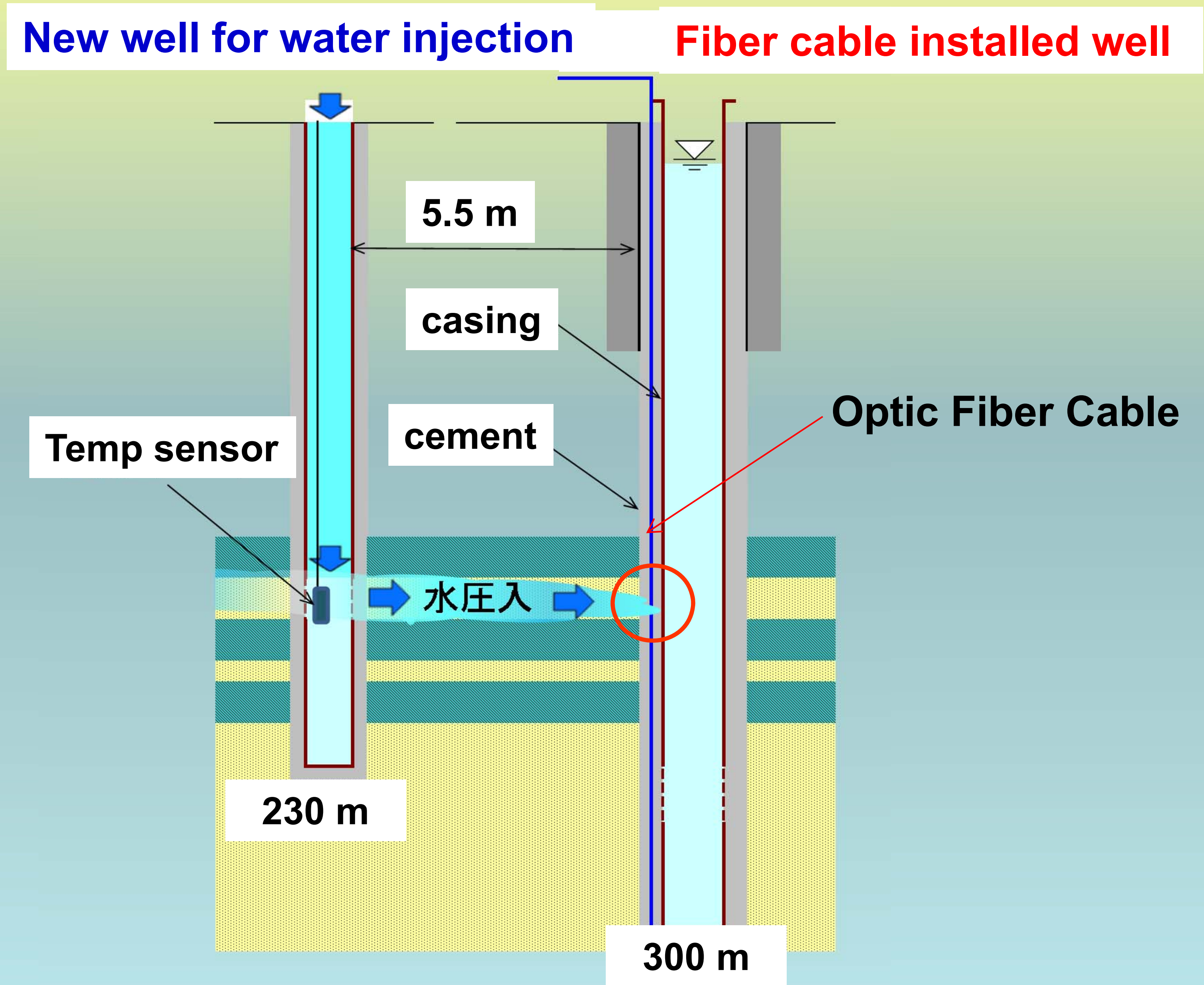
Velocity change in overlying formations



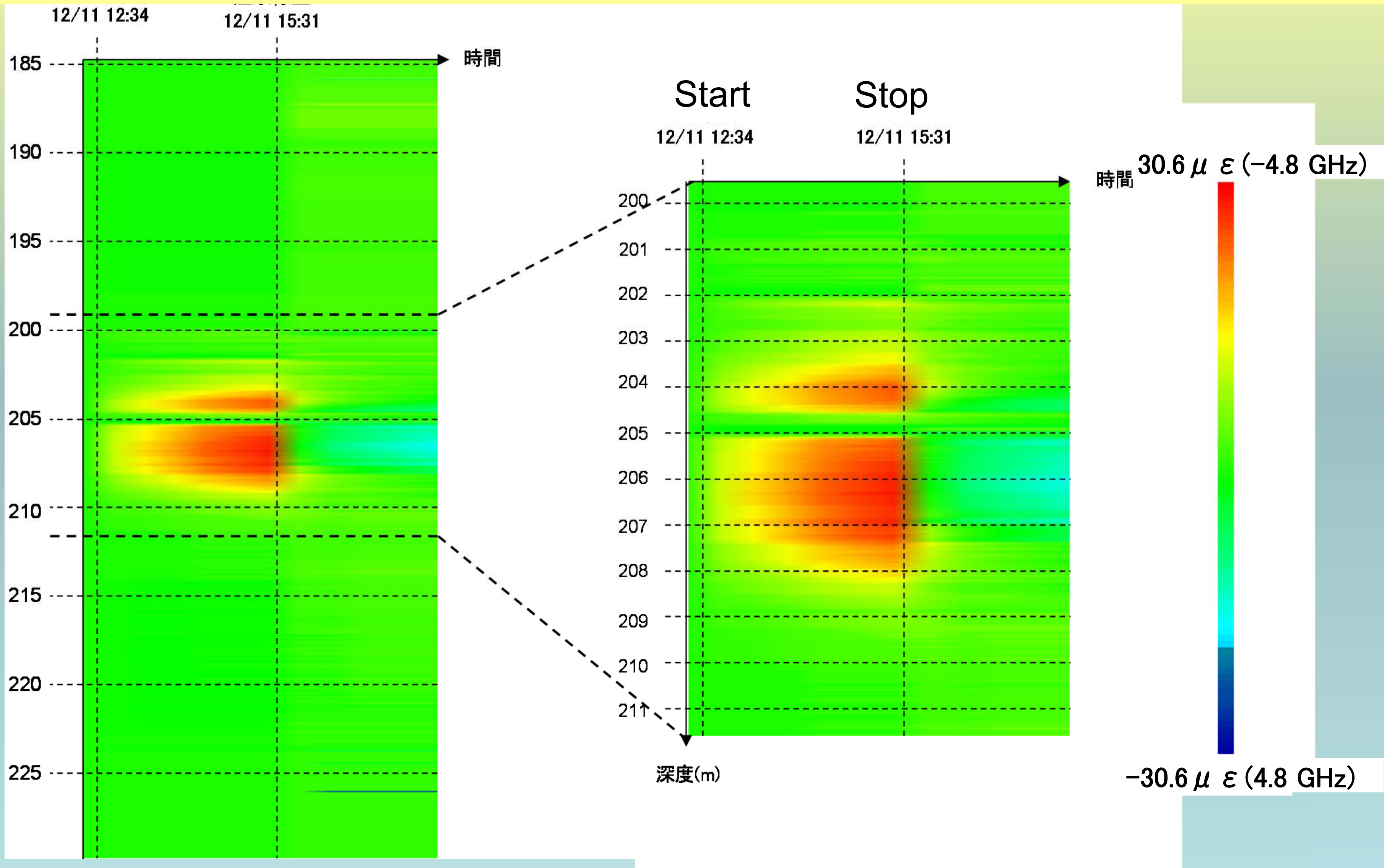
DTS - Distributed Temperature System

DAS - Distributed Acoustic System

Fiber Optics: Water Injection Test

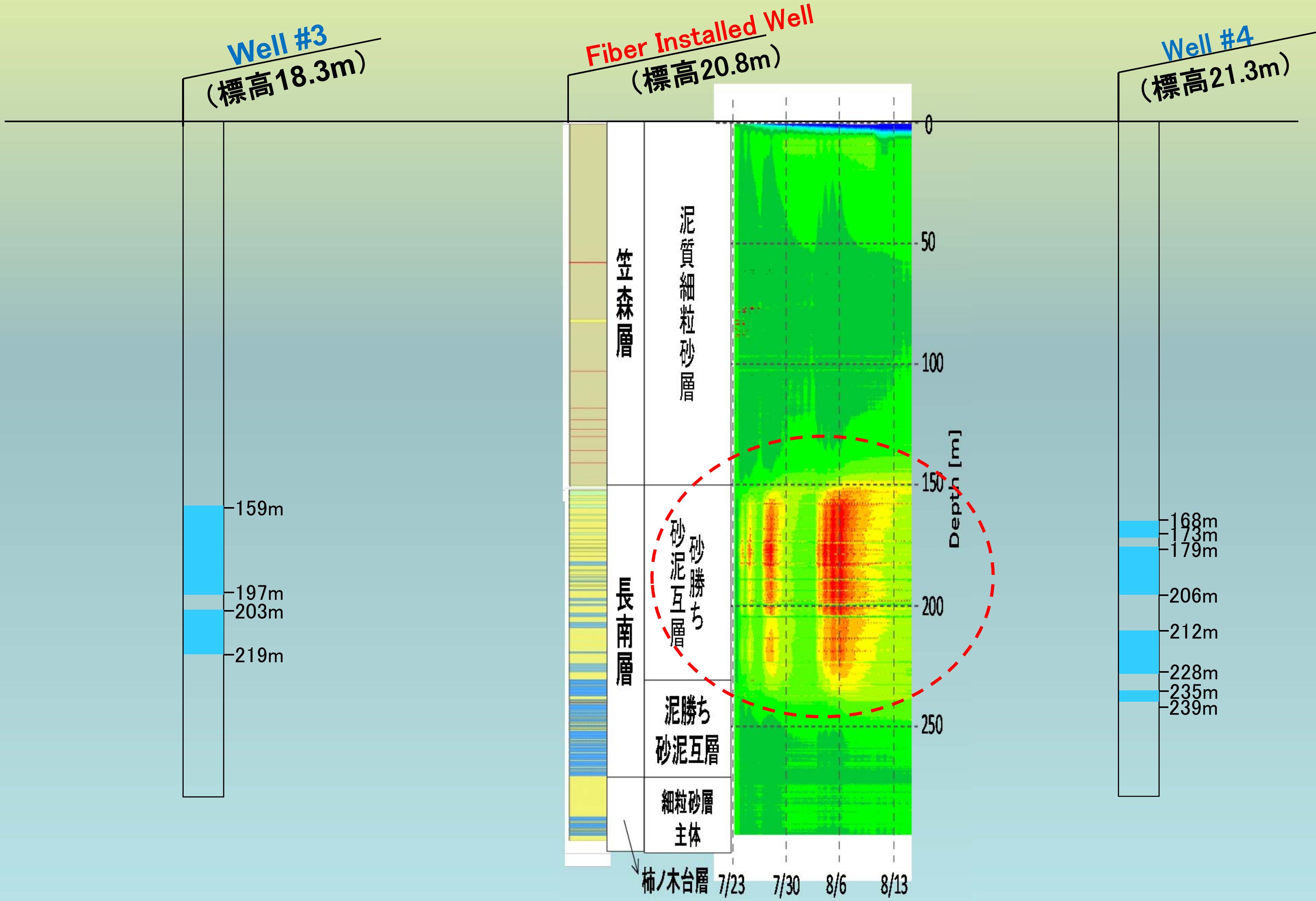


Strains estimated during water injection



Response to Water Extraction (1/2)

Response to Water Extraction (2/2)

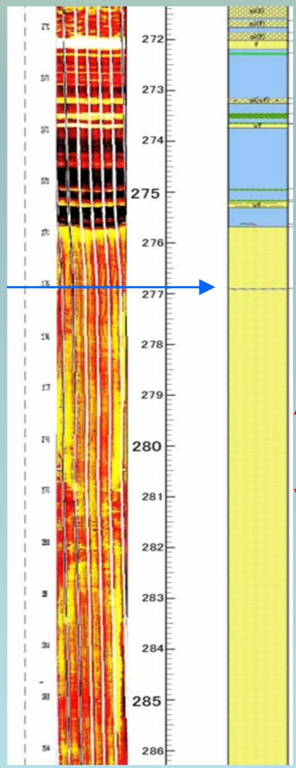


Impacted Zone Detected during CO_2 Injection

Impacted zone detected from fiber cable

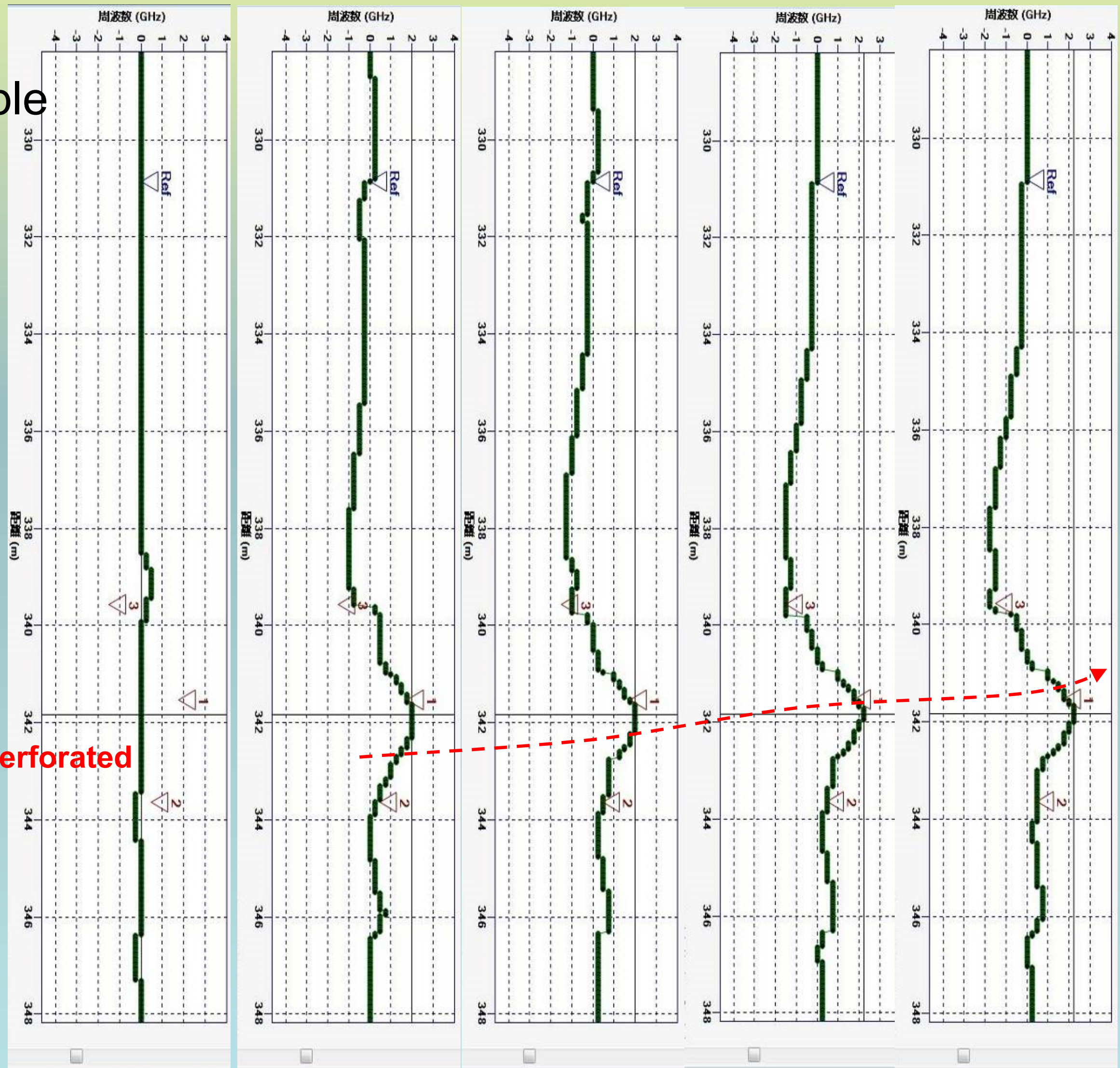
Xue et al., 2015

EMI

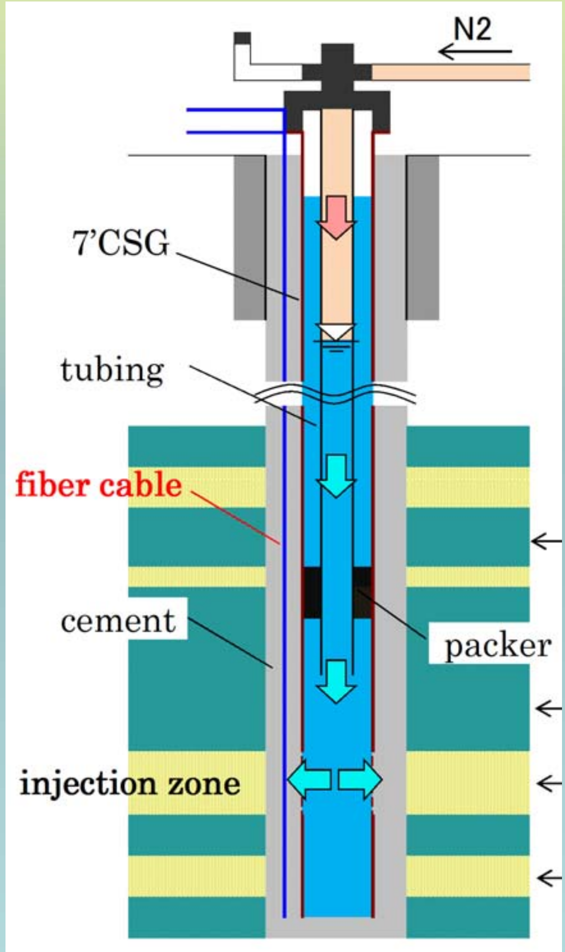


perforated

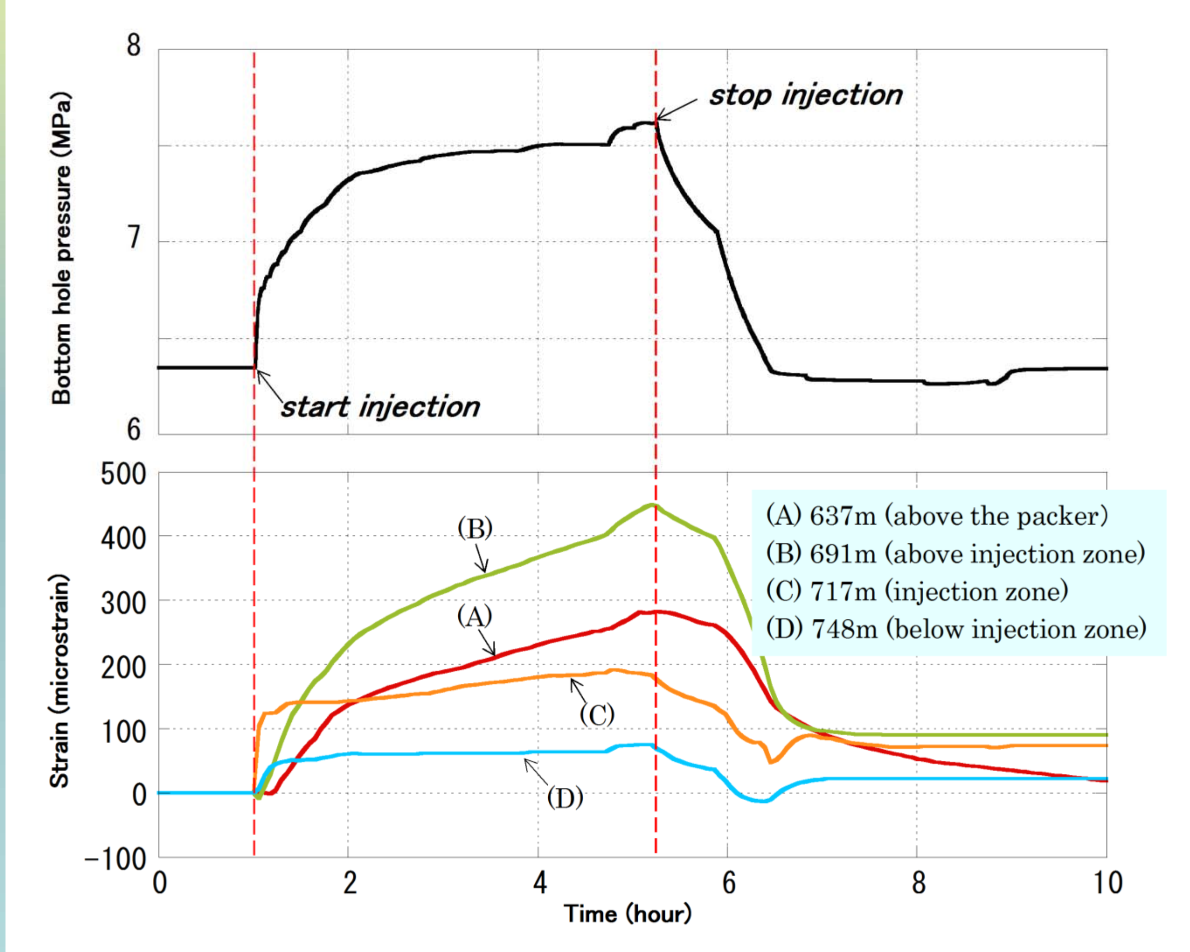
1 hr later | 3 hrs later | 5 hrs later | 10 hrs later | 15 hrs later



Impacted Zone Detected at the Deep Well

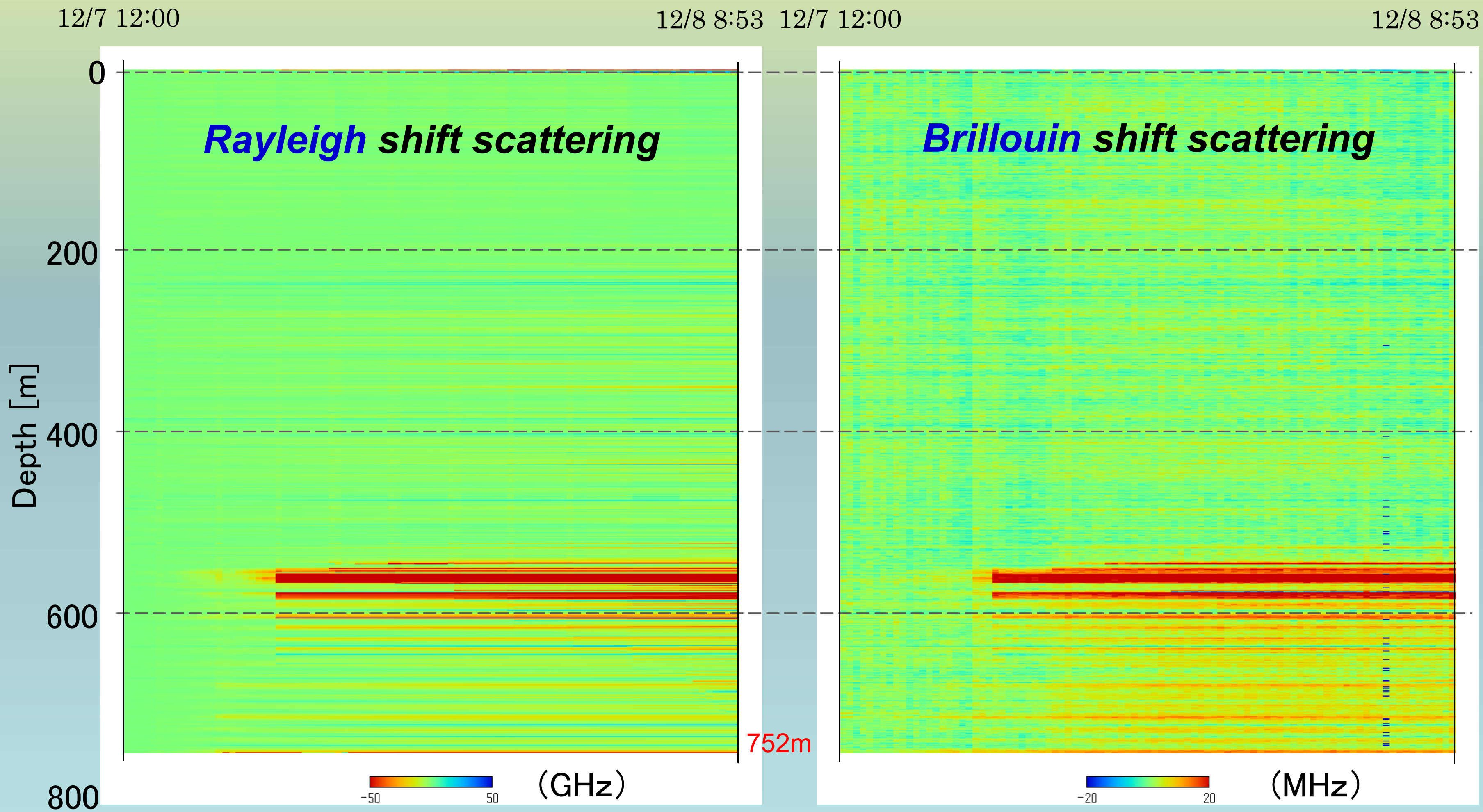


Well depth: 880m

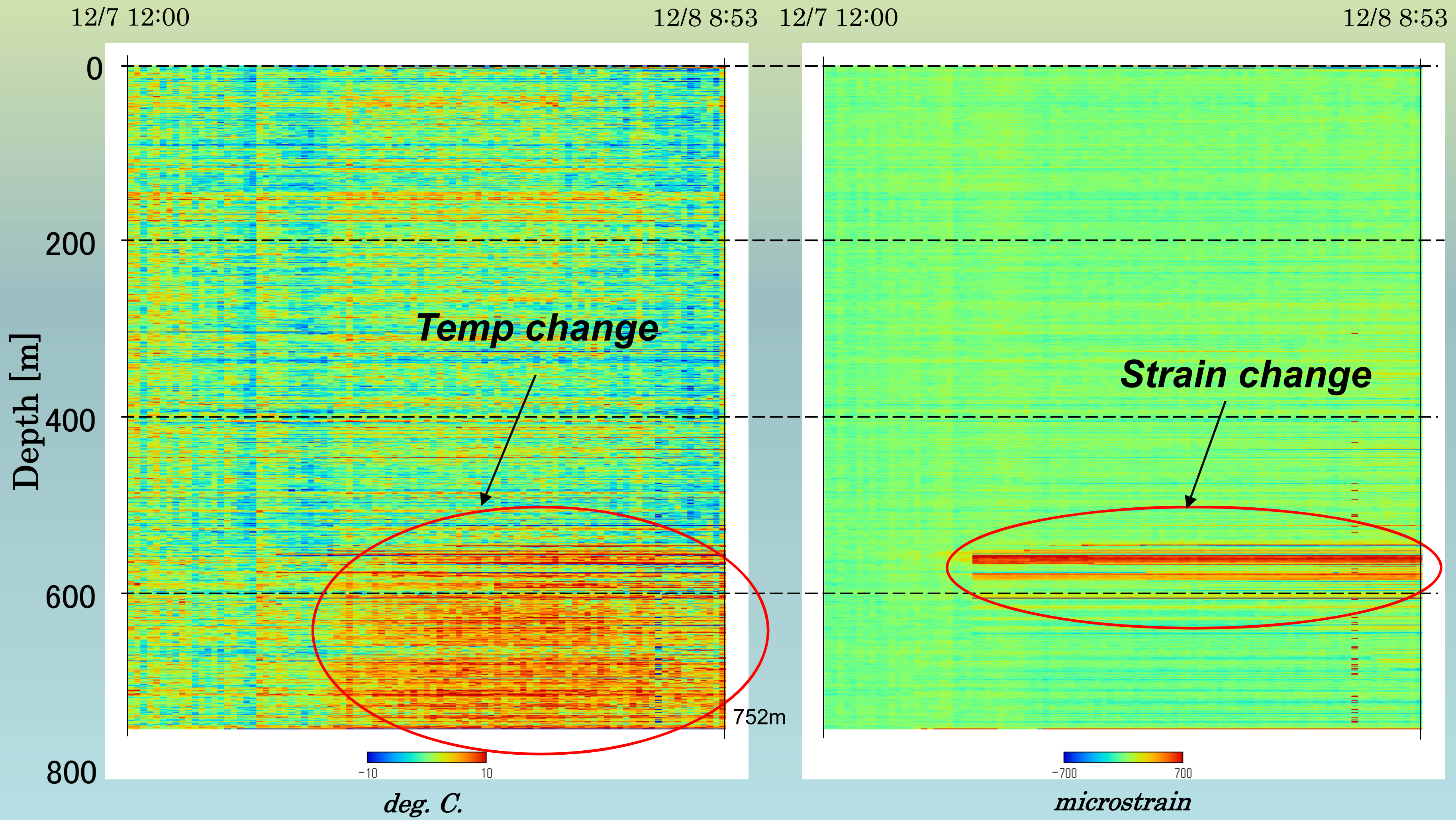


Strains estimated at different depths in N_2 injection

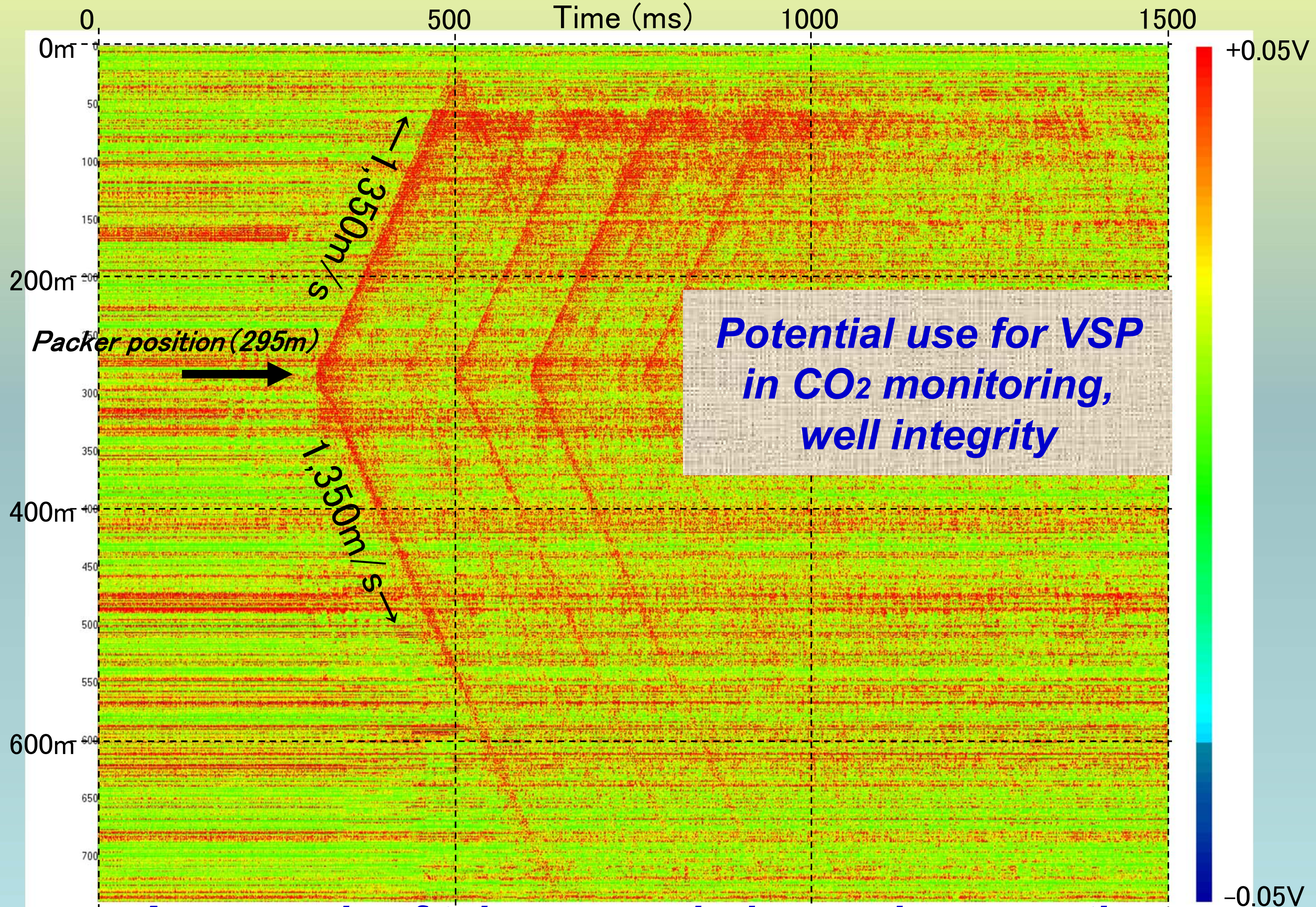
Combined effects of temperature and strain in recorded frequency shifts



Temperature and Strain Separation from the Observed Frequency Shifts in Rayleigh & Brillouin Scattering

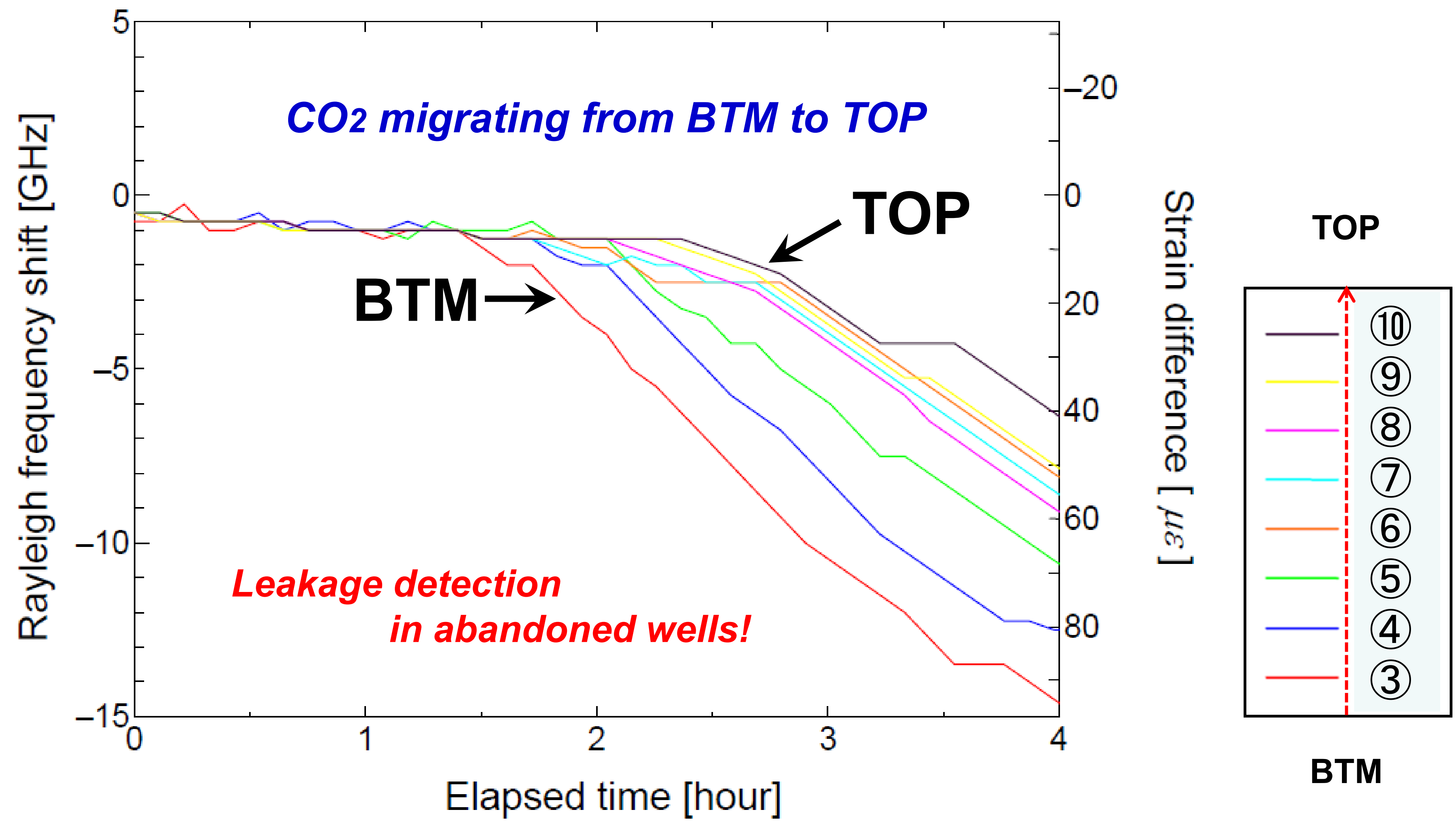


Distributed Acoustic System（DAS）



An example of tube waves during packer operation

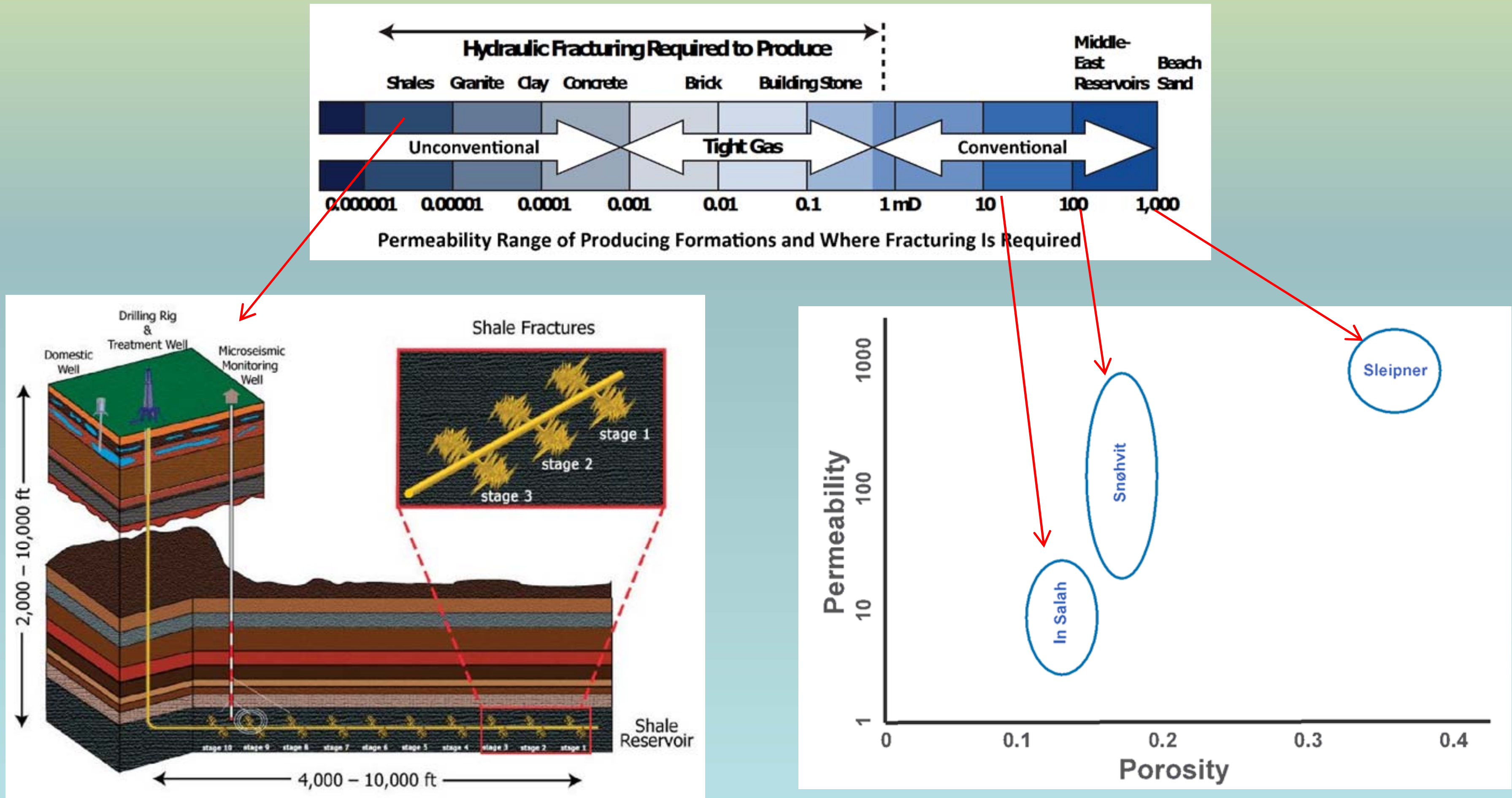
Lab test: CO_2 front migration detection



A field test planned this year !

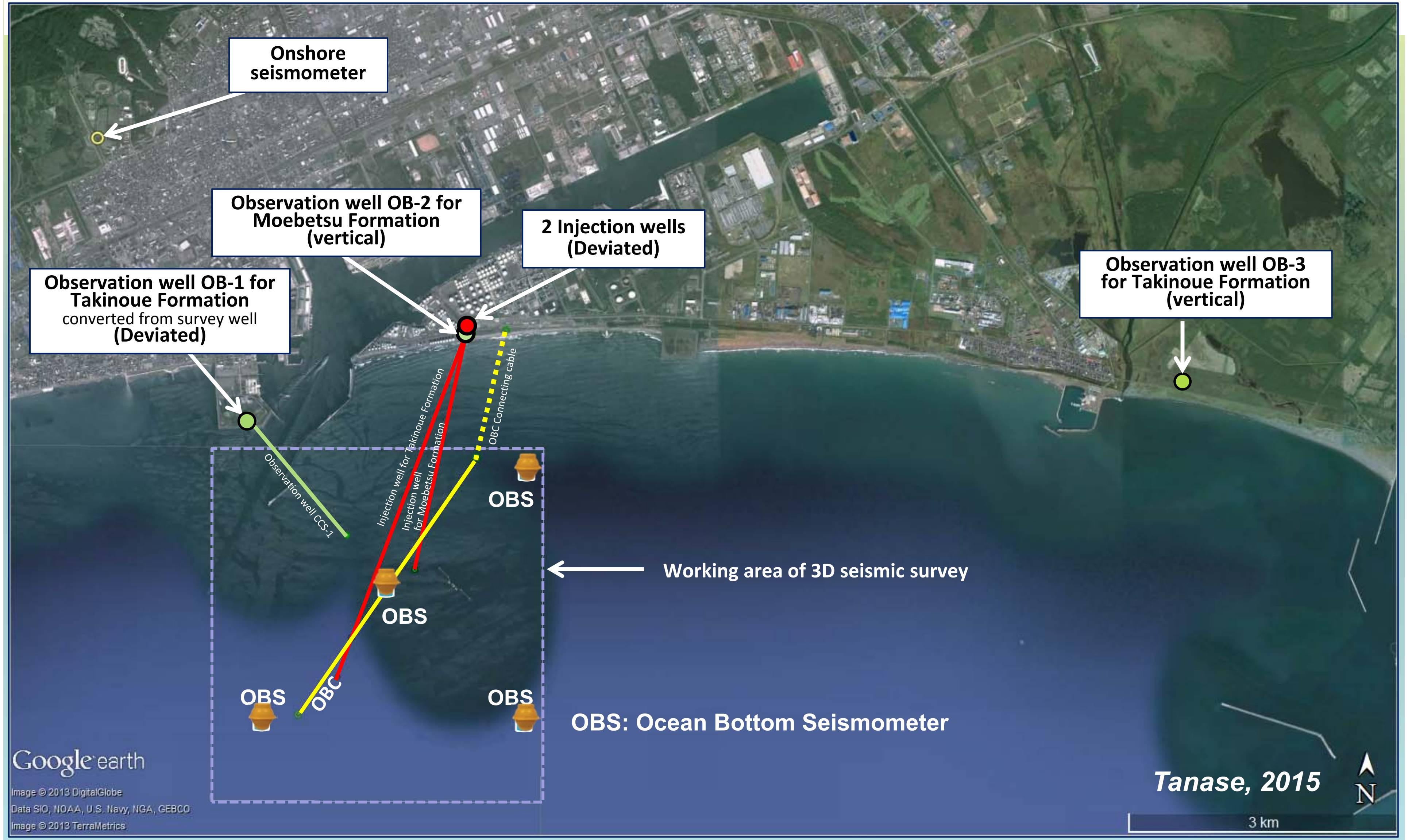
Induced Seismicity Potential in ENERGY TECHNOLOGIES

Geothermal, Conventional and Unconventional Oil & Gas, Waste Water Disposal, CCS

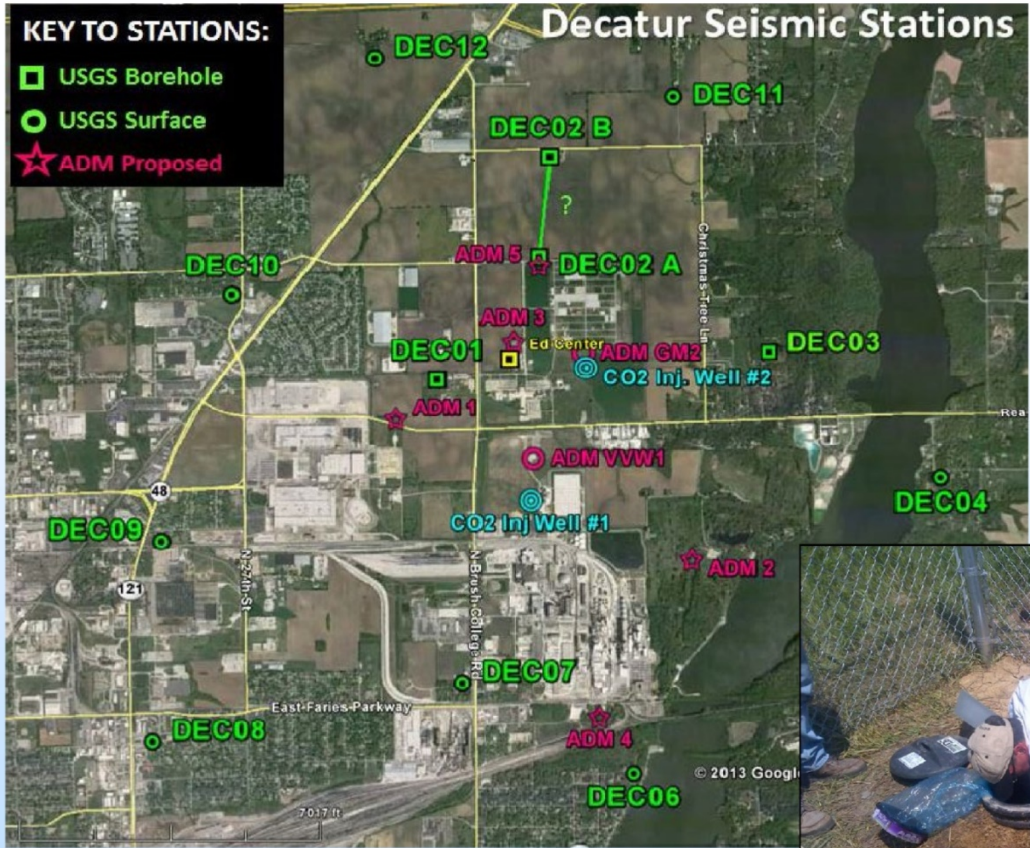


National Academy of Sciences, 2013

A Dense Microseismic Monitoring Network @Tomakomai (*offshore*)



A Dense Microseismic Monitoring Network @ Decatur, Illinois (*onshore*)



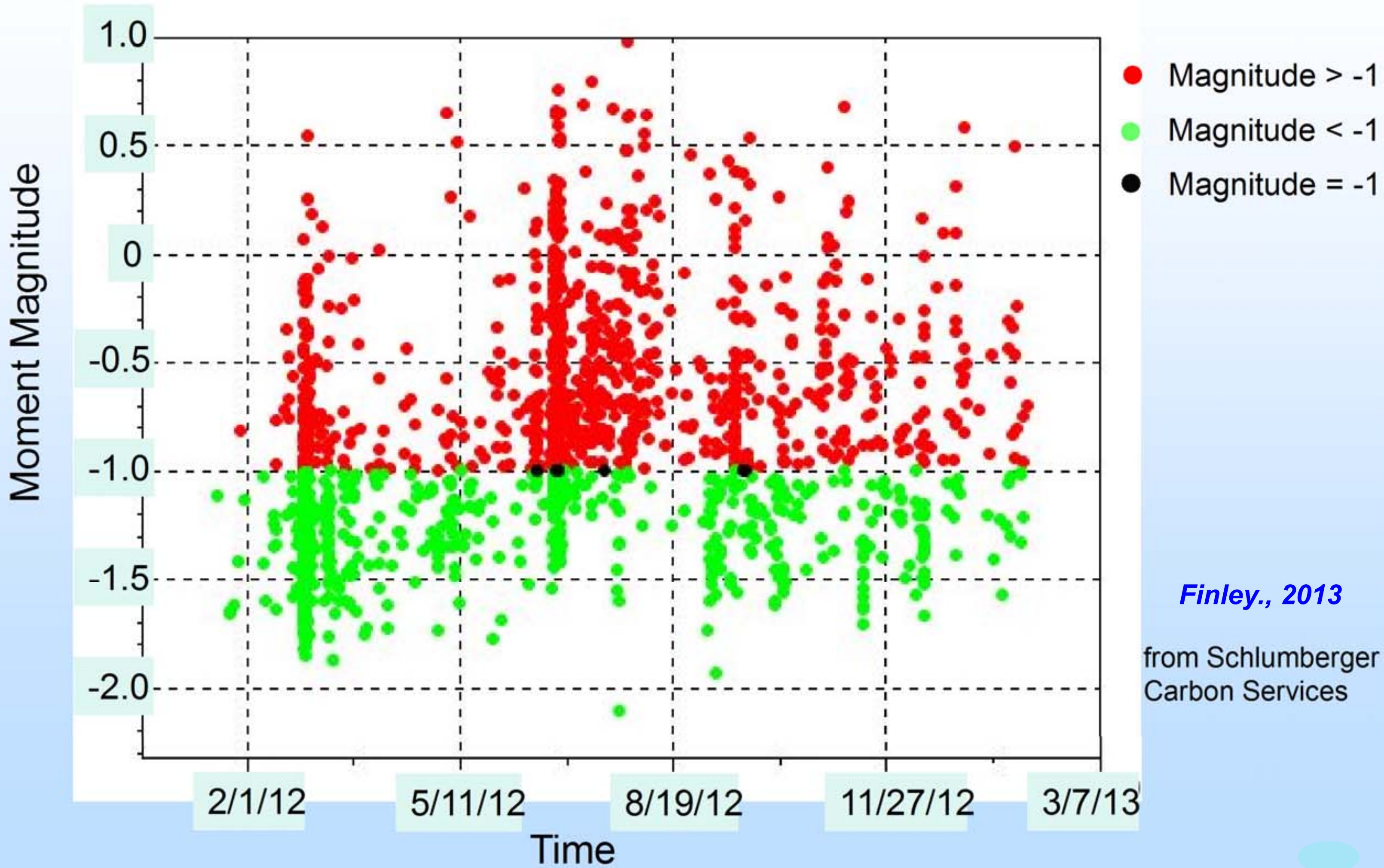
MGSC Installed Five Surface seismic Stations: ADM1-5

Inject, Monitor, and Model

Finley., 2013

Inject, Monitor, and Model

General Trends in Activity: Moment Magnitudes vs. Time

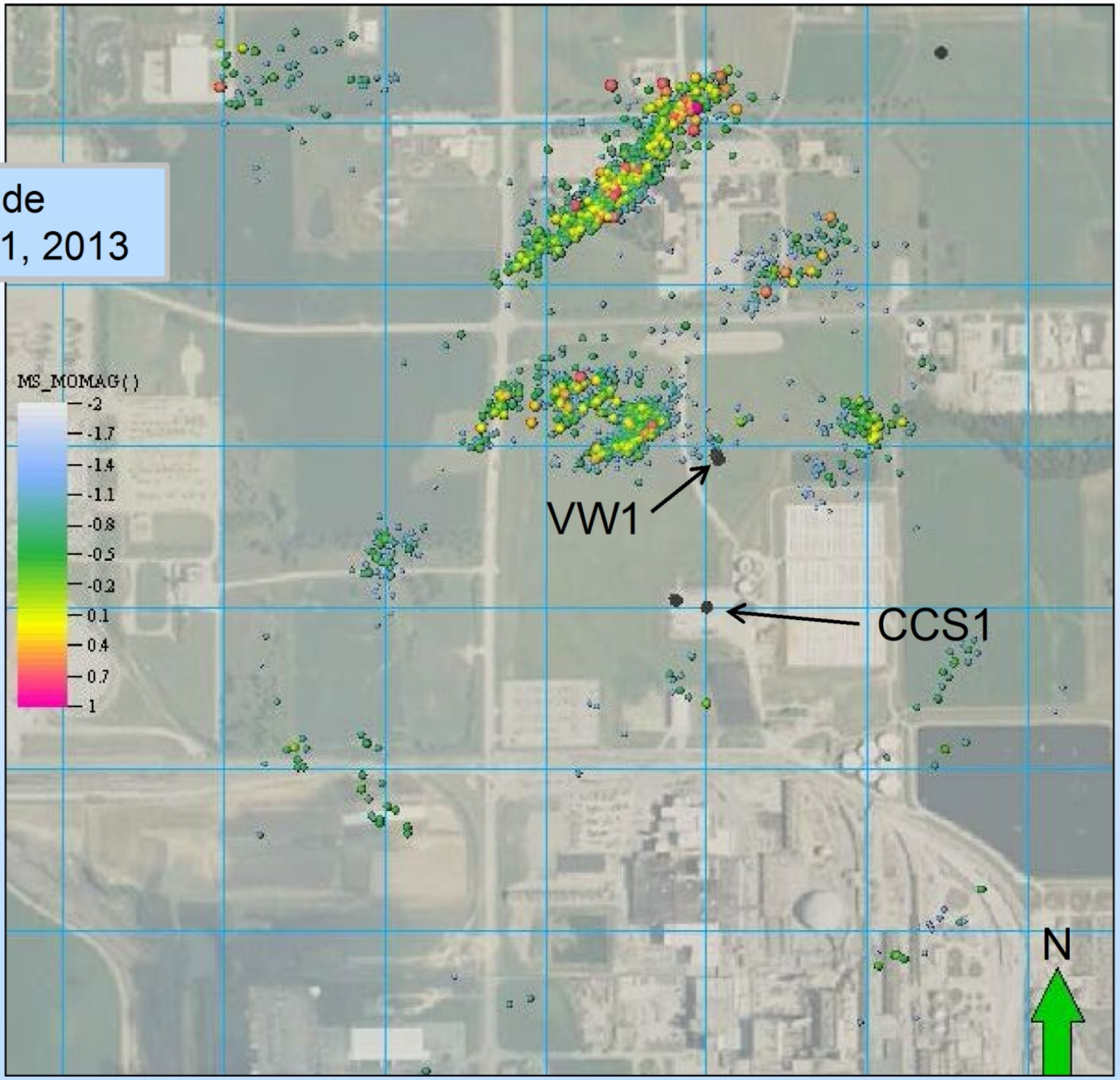


Finley., 2013

from Schlumberger Carbon Services

Microseismic Cluster Activity: Cluster Locations with Relation to Surface

Moment Magnitude
Jan 18, 2012 – July 31, 2013



Inject, Monitor, and Model

Finley., 2013

from Schlumberger Carbon Services

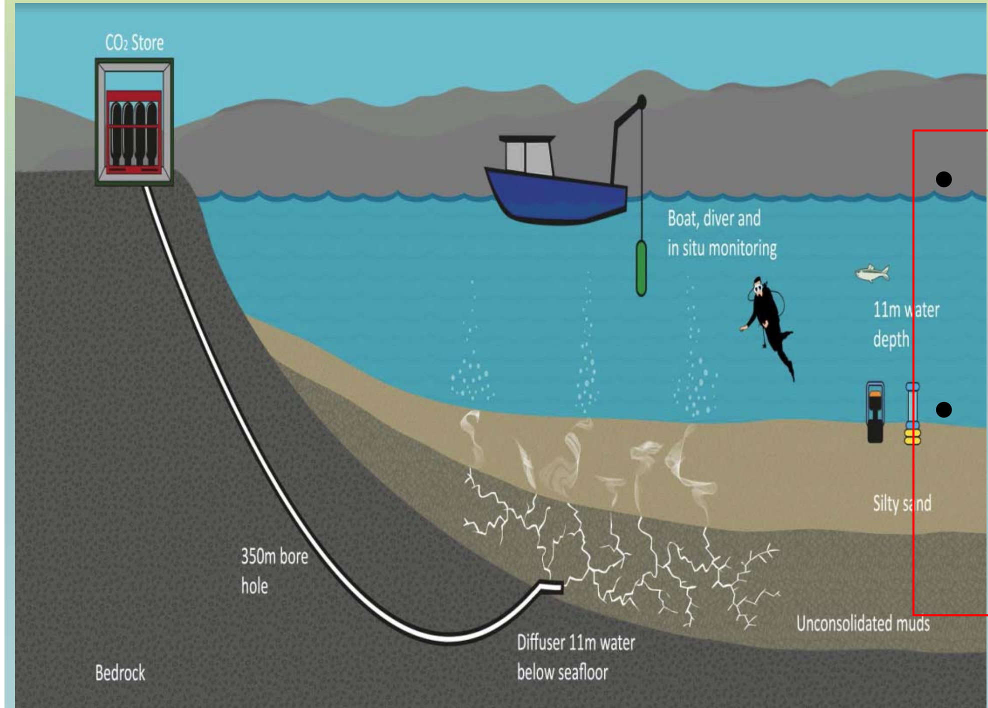
Summary Information about Historical Felt Seismic Events Caused by or Likely Related to Energy Tech Develop in US

Energy Technology	Number of **Current** Projects	Number of **Historical** Felt Events	**Historical** Number of Events M≥4.0	Locations of Events M≥2.0
Geothermal				
Vapor-dominated (The Geysers)	1	300-400 per year since 2005	1 to 3	CA
Liquid-dominated	23	10-40 per year	Possibly one	CA
EGS	~8 pilot	2-10 per year	0	CA
Oil and gas				
Withdrawal	~6,000 fields	20 sites	5	CA, IL, NB, OK, TX
Secondary recovery (water flooding)	~108,000 wells today	18 sites	3	AL, CA, CO, MS, OK, TX
EOR	~13,000 wells today	None known	None known	None known
Hydraulic fracturing for shale gas recovery	~35,000 wells today	1 sites	0	OK
Waste water disposal wells (Class II)	~30,000 wells today	8 sites	7	AR, CO, OH, TX
Carbon capture and storage (small scale)	2	None known	None known	None known

National Academy of Sciences, 2013

Controlled CO_2 Release Experiment in the Ocean
QICS: UK – Japan Collaboration

Quantifying and Monitoring Potential Ecosystem Impacts



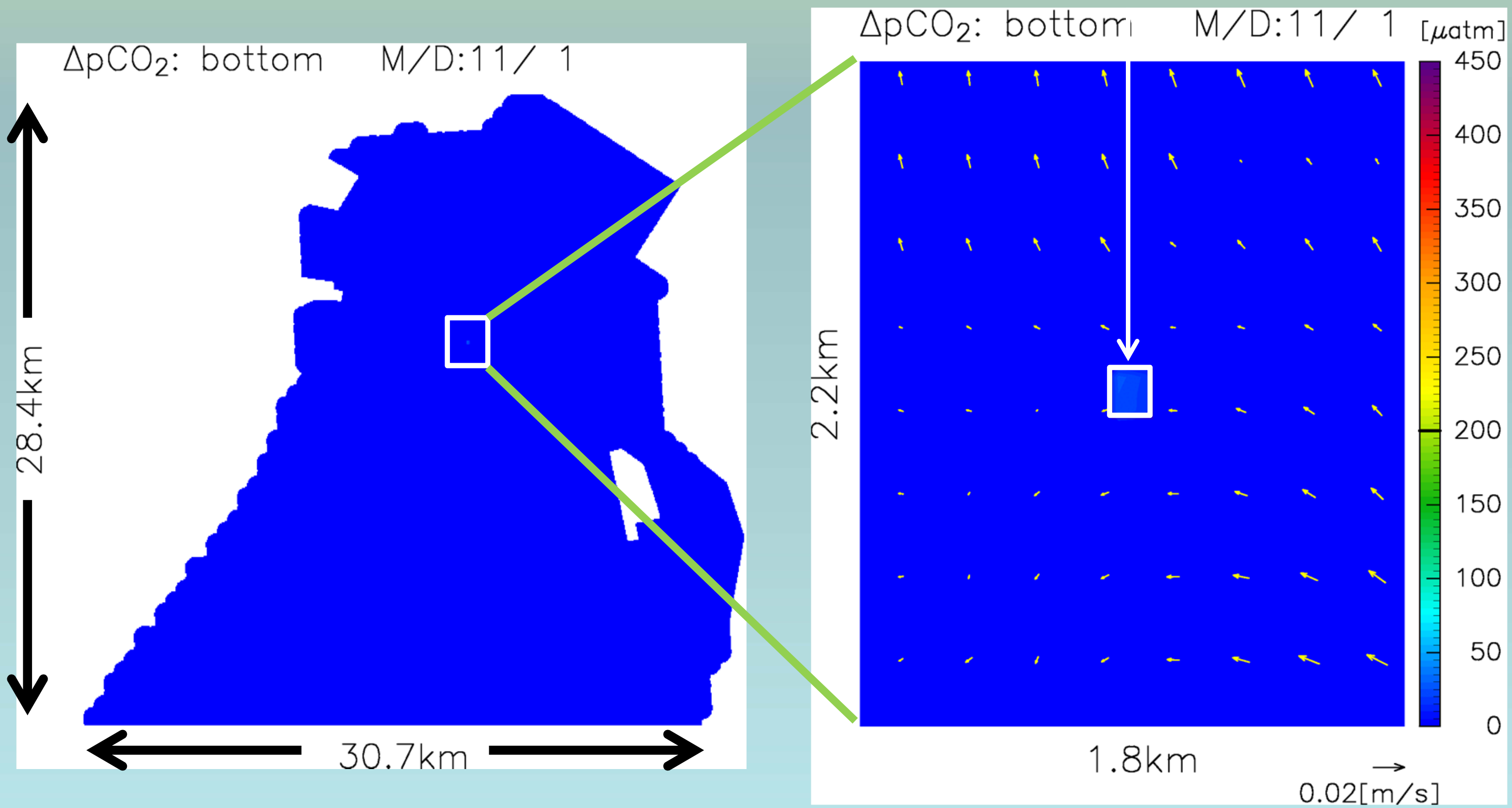
- CO_2 Leakage detection using the geophysical, acoustic, geochemical methods
- Evaluation of ecological impacts by gene-analysis, photo-graphics observation etc.

QICS special issue: CCS and the Marine Environment
21 research papers, Int. J. Green Gas Control: Vol.38, 2015

Simulating Leaked CO_2 in the Ocean

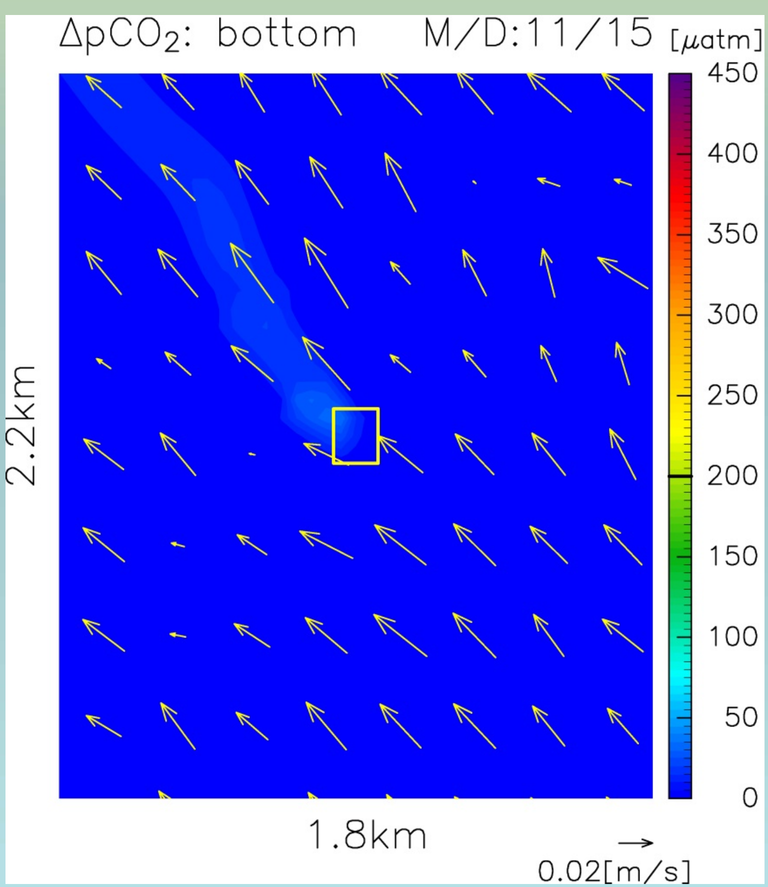
Modeling area driven by temporally variable heat flux and wind stress at sea surface ⇒ Able to represent seasonal variation

- *CO2 leakage: 250 tonnes/year within 150m×150m*

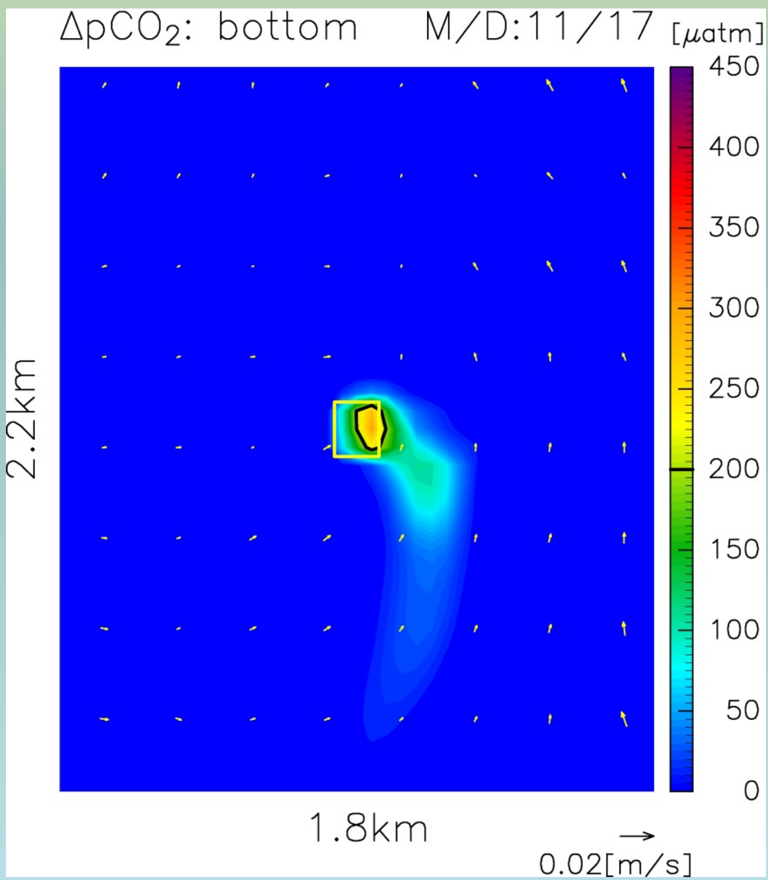


ΔpCO₂ predicted in two flow fields at same leakage rate

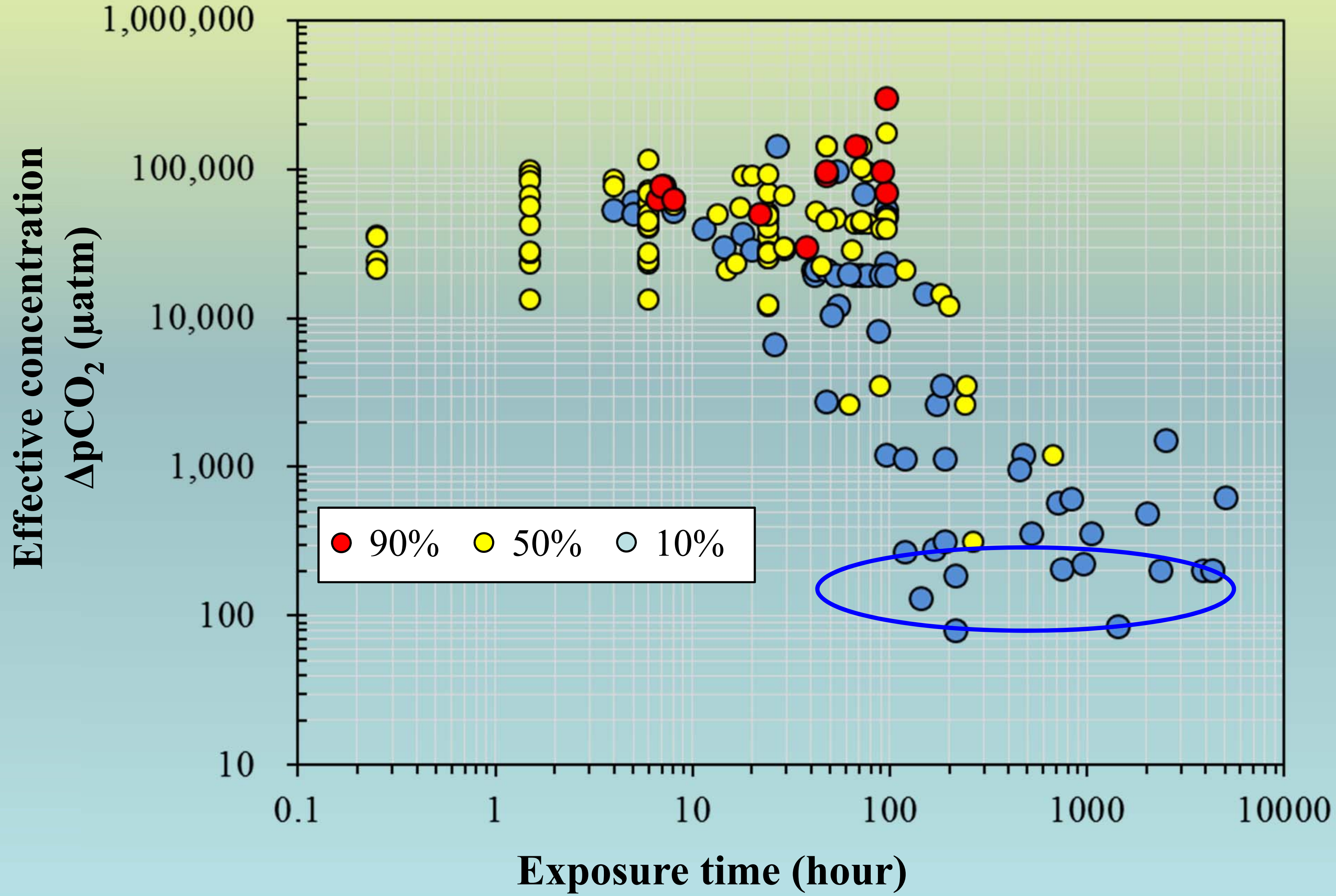
Strong flow field



Weak flow field



Threshold for Ecological CO_2 Impacts
Estimated from a Biological Impact Database



EIA at the Tomakomai offshore project

Act for the Prevention of Marine Pollution and Maritime Disasters

- **May 2007**: The act was amended for permit procedure on dumping CO_2 stream into sub-seabed formation.

- ***Preliminary Assessment Document***

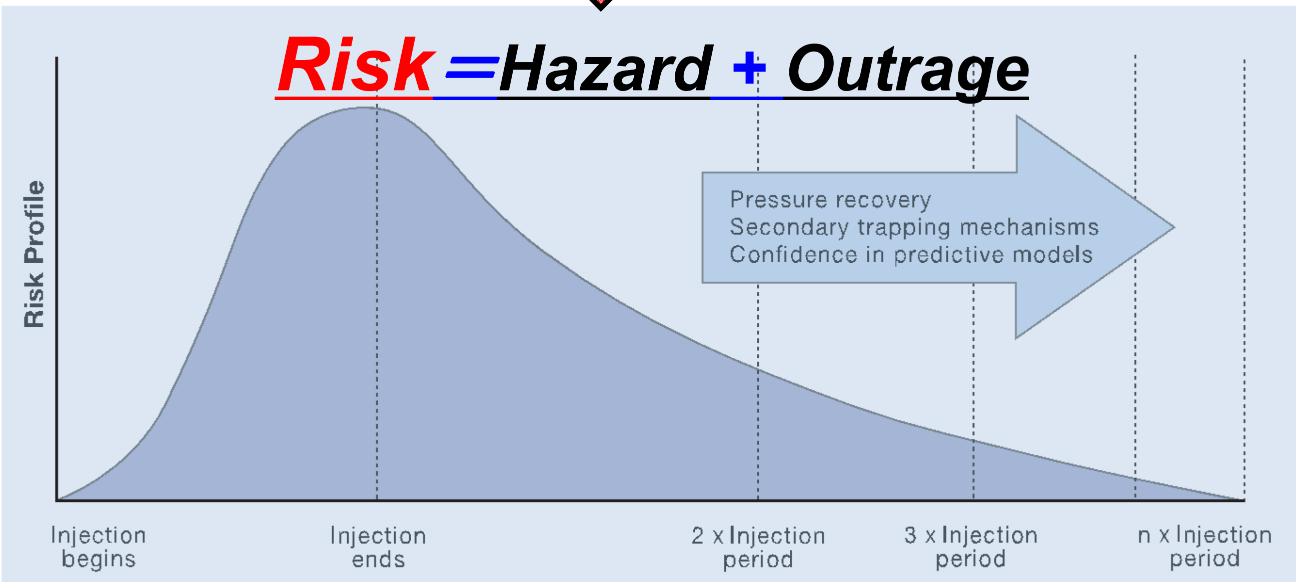
  *"Estimation of CO_2 dispersion and its impact assessment **on the assumption that stored CO_2 leaks out to the sea**"*

Learning from Demonstration Projects
Understanding Uncertainty and **Managing** Risks

Risk＝Consequence Severity x Probability

Scientific Knowledge & Evidence-based Risk Communication

Risk＝Hazard + Outrage



[Illustration source: Benson, 2007]

Reducing Uncertainty／Mitigating Risks
to the Manageable Levels !