◆ CCS Technical Workshop 2020 ◆

二酸化炭素地中貯留技術研究組合における安全な地中貯留技術開発の取り組み

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

Ziqiu Xue (xue@rite.or.jp)

RITE
Research Institute of Innovative Technology for the Earth

2019年度事業内容

研　究　課　題		実施組合員
①大規模CO_2圧入・貯留の安全管理技術の開発	①-1.圧入安全管理システムの開発	RITE、JAPEX、INPEX
	①-2.CO_2長期モニタリング技術の確立	AIST
	①-3.大規模貯留層を対象とした地質モデルの確立	JAPEX、RITE 応用地質
	①-4.大規模貯留層に適したCO_2挙動シミュレーション、長期挙動予測手法の確立	RITE、大成建設、応用地質
	①-5.光ファイバーを利用した地層安定性や廃坑井の健全性監視システムの開発	RITE、INPEX、AIST
	①-6.CO_2漏出検出・環境影響評価総合システムの構築	RITE
	①-7.リスクマネジメントツール（NRAP）をはじめとする日米CCS協力や海外機関とのCCUS技術開発の連携	RITE
②大規模貯留層の有効圧入利用技術の　開発	②-1.CO_2圧入井や圧力緩和井の最適配置技術の確立	大成建設、RITE
	②-2.マイクロバブルCO_2圧入技術の適用による貯留率の向上	RITE、JAPEX
③CCS普及条件の整備、基準の整備	③-1.CO_2貯留安全性管理プロトコル（IRP）の整備	RITE
	③-2.苫小牧実証試験サイトや海外プロジェクトの成果や情報を用いた、CCS技術事例集の作成、国際標準化（ISO TC265）との連携	RITE
	③-3.CCSの広報活動を通した社会受容性向上方策の検討	RITE、AIST

➢大規模CO_2地中貯留の実用化に向けて

✓油ガス田開発技術・経験・ノウハウを活用しても、まだ取り組むべき技術課題がある

✓現在の商業規模のCCS事業サイトは、既存油ガス田或いはその近傍に立地し、豊富な地下データに恵まれている

✓ 安全性（リスクマネジメント）、経済性（コスト削減）、社会的受容性の向上

Research & Development

技術や知見の提供 →

← 技術開発ニーズのフィードバック

Demonstration, Deployment

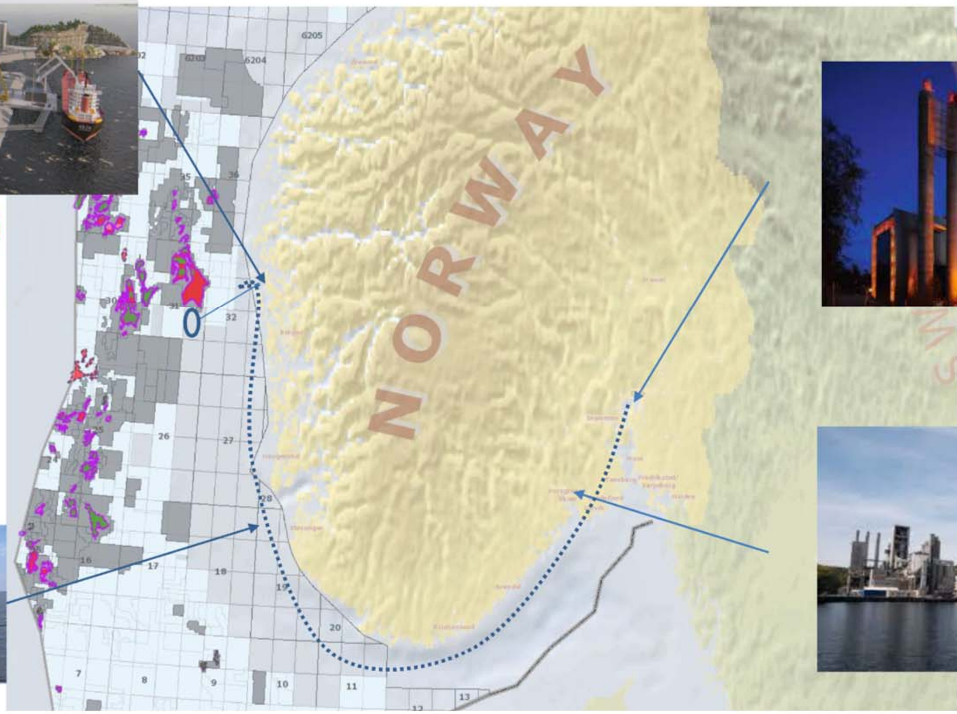
１．大規模CO_2地中貯留の実現に向けて （現状・課題）

Carbon Capture and Storage (CCS): The Way Forward

The Norwegian CCS demonstration project

equinor TOTAL

Ship transport from capture to storage terminal – pipeline to offshore storage complex



fortum

Waste-to-energy 400 000 tonnes CO_2 per annum

NORCEM
HEIDELBERGCEMENT Group

Cement production 400 000 tonnes CO_2 per annum

Olje- og energidepartementet

23 years experience with CCS and CO_2 Storage offshore Norway

"...realise a cost-effective solution for full-scale CCS in Norway, provided that this incite technology development in an international perspective".

- Start FEED - summer2018
- QA - prepare investment decision – 2019/2020
- Investment decision 2020/2021
- Development 2020/2021→
- Operation - 2023/2024

Scope of US-Norway CCUS Collaboration

- Characterization - new methods for cost-effective site selection decisions
- Monitoring Verification and Accounting - making it smarted and more cost-effective
- Wellbore construction, materials, integrity - smart wells, re-use of old wells, P&A technologies

- Focus on reduction of uncertainties and pressure management
- Real storage domains have complex geologies and pressure barriers

- Where to find the best sands?
- There are some faults in the area, can they cause any migration challenges?

➢ A plan for monitoring of pressure and potential leakage

地中貯留技術開発の現状認識（米国／DOE）

Much Progress on Carbon Storage, But Uncertainties Remain

	Then CCS Program Initiated (1997)	**Now** Progress to Date	**Future** CCS Broad Commercial Deployment
Storage R&D	• Little known	• Knowledge gained and **tools** being developed and tested	• “Commercial **toolbox**” developed
Infrastructure/Field Tests	• Little known; Sleipner project initiated	• Increased visibility; Knowledge gained and lessons learned	• Potential realized; Frameworks in place for market deployment

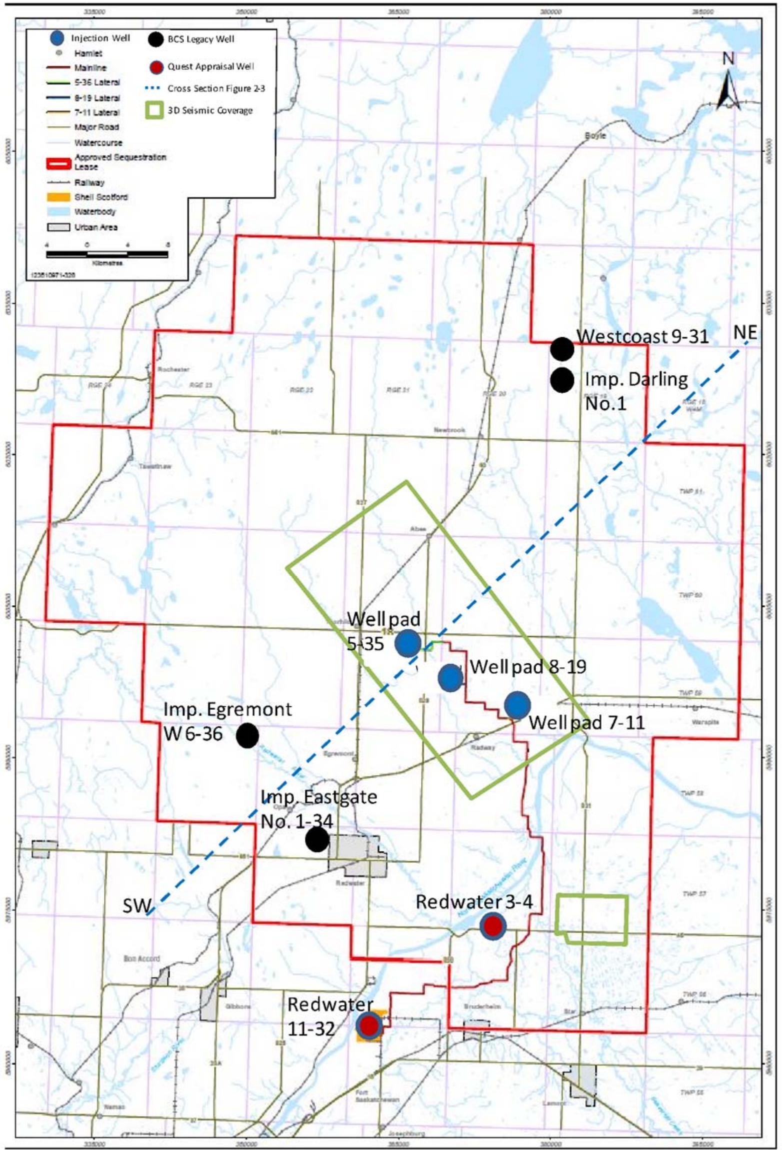
➢ **If cost issues lie with capture, risk issues lie with storage**

- **Questions about *scale up*, liability, *performance***

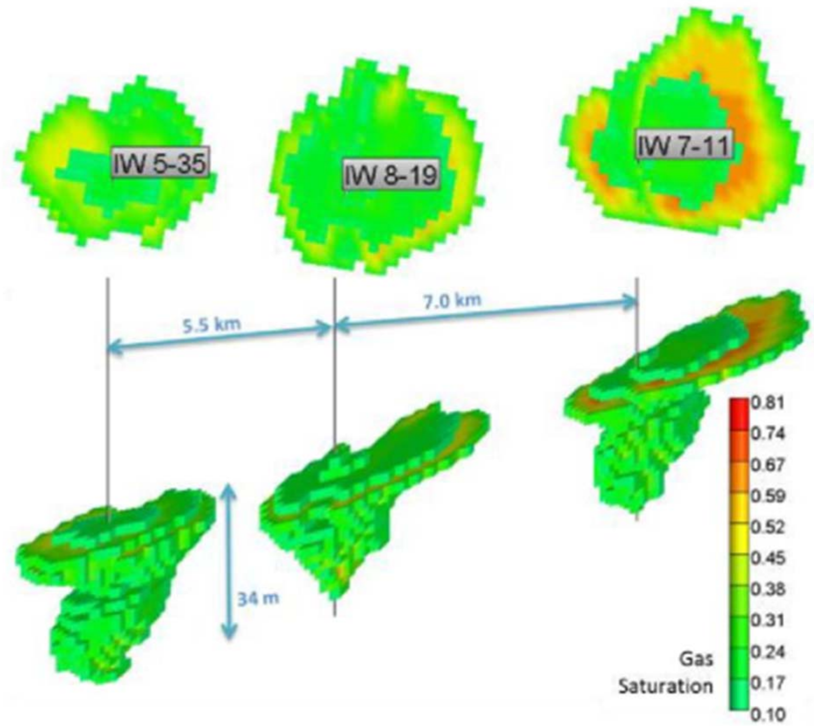
·***R&D focused on: Cost (Capture) and Confidence (Storage),***

·***Demonstrations: Integration and Learning***

Quest CCS Project

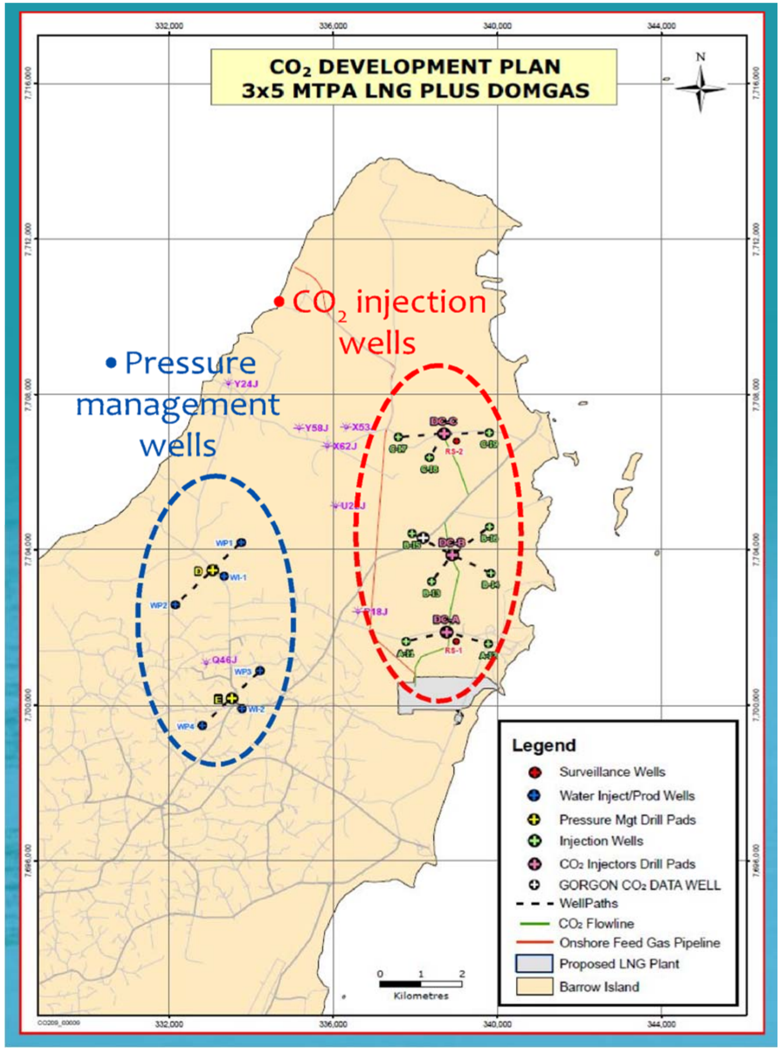


約100万ton／年、2015.11～25年間継続



CO_2分布予測シミュレーション結果

Gorgon Project



Pressure management required to reduce impact of rising pressure on CO2 injection performance:

- Maintain injection rates
- Avoid reaching bottom hole pressure limit
- Optimise storage capacity

Monitoring

- Wellhead pressure and flow rate
- Continuous down-hole pressure gauges

High Level Carbon Storage Program Goals (Current Goals)

- 永久的･経済的･安全に（permanently, economically and safely）
- 貯留効率向上（*Improve Reservoir Storage Efficiency*）
- 貯留量評価（predict storage capacity within ±30%）

Carbon Storage R&D Challenges

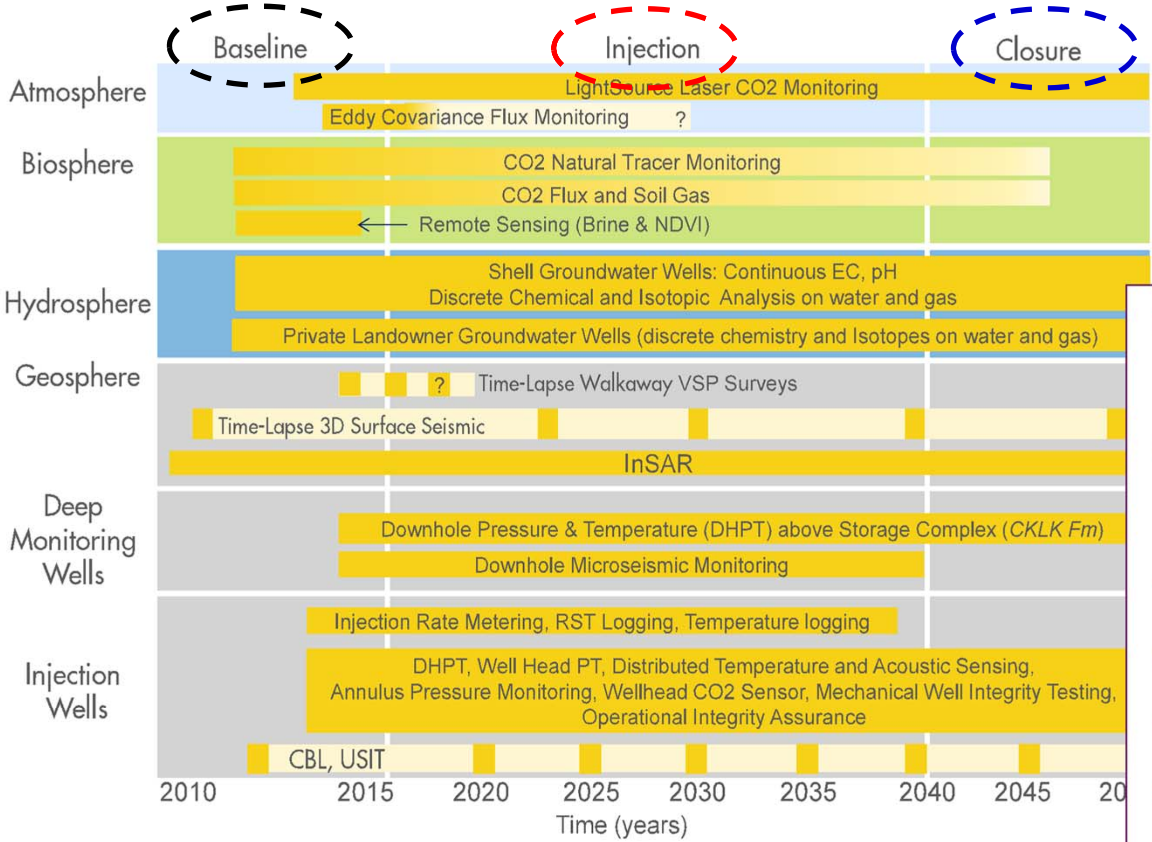
Storage Infrastructure

- 安全に･永久的･費用対効果（Safe, Permanent and Cost-effective）
- 陸域＆海域貯留（Onshore and Offshore）
- 費用対効果に優れた貯留･モニタリング技術（Cost-effective Integrated Tech）
- CO_2-EOR＆貯留層圧力制御技術（Reservoir Pressure Management）
- 効果的なPA/PO（Effective Public Outreach）

２．CO_2地中貯留研究開発・実証プロジェクトの役割

Research, Development and Deployment of CO_2 Storage
(Up-Scaling Injection and Down-Sizing Costs)

MMV plan throughout the project life @QUEST



(based on ISO standard)

- First o f a kind – conservative approach
- Comprehensive: from atmosphere to geosphere
- Risk-based
- Site-specific
- Independently reviewed
- Combination of new and traditional technologies
- Baseline data collected before start-up

MMV: Measurement, Monitoring and Verification

➢ Advanced Monitoring by US/DOE

- Monitoring at a carbon storage site is necessary to **track the movement** of CO_2 and **assure permanence** for geologic storage.

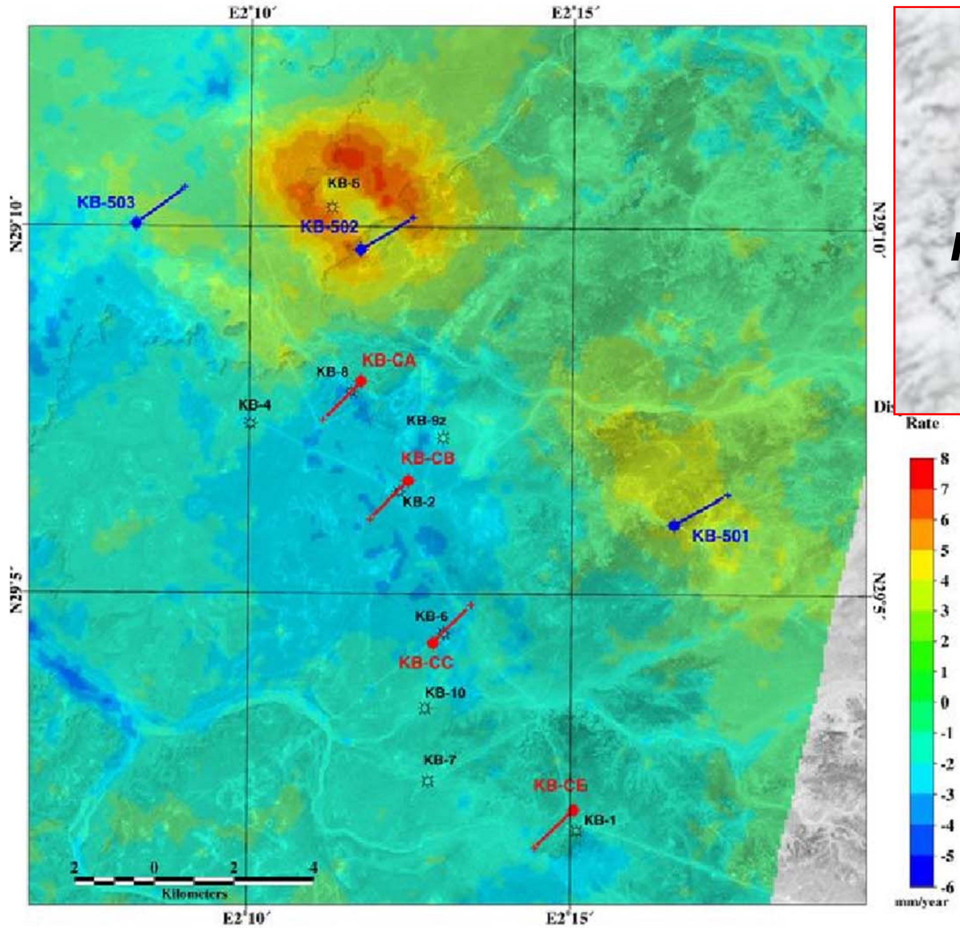
- **Advanced monitoring** technologies are needed to **decrease the cost and uncertainty** in measurements and satisfy regulations.

- Giving site operators the ability to: (1) measure **critical subsurface parameters** associated with the injected CO_2, (2) provide measurements of **down-hole** and reservoir conditions for **real-time decision making** and **process optimization**, and (3) provide **long-term** post-injection monitoring of the fate of injected CO_2.

- **Transformational sensor** to support demonstration and deployment of advanced coal power with CCS **beginning in 2025**.

Fiber Optic Sensing: temperature, pressure, strain, acoustic, fluid chemistry

Uplift at In Salah CO_2 Injection Site



Pressure buildup depending on

reservoir porosity & permeability,

CO_2 injection rate & volume.

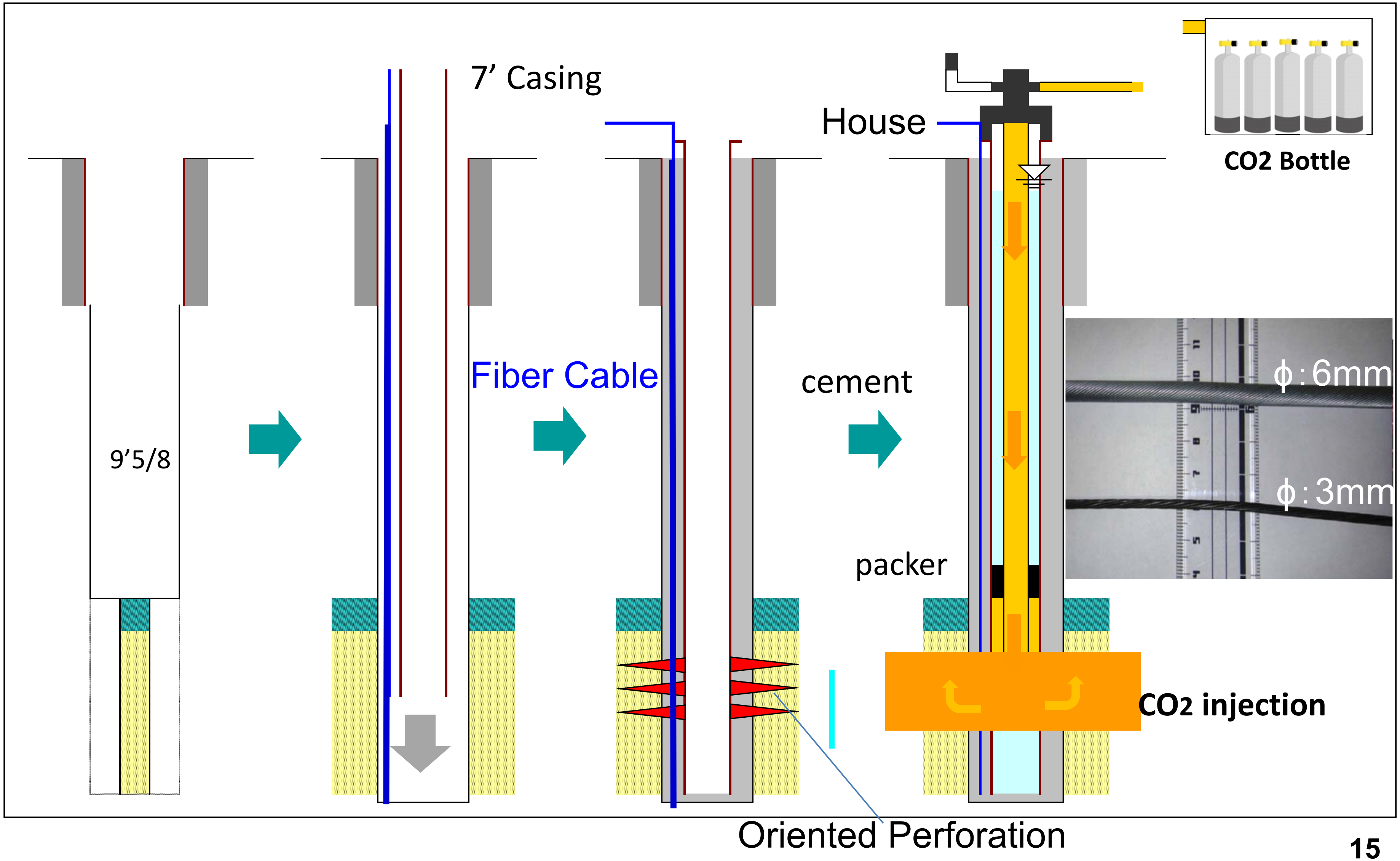
Uplift at ground surface

How to ⬇ *interpret?*

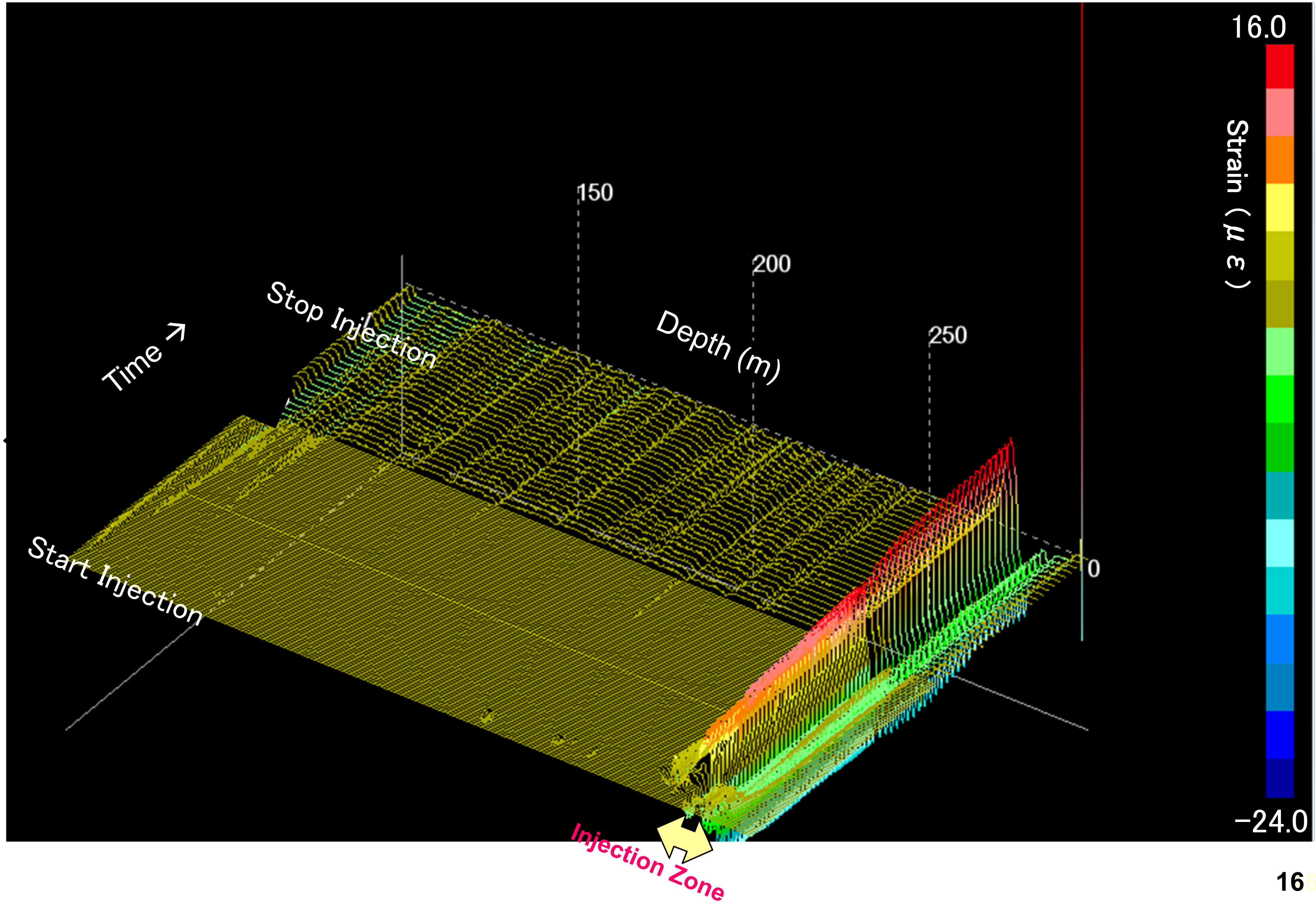
Pressure buildup at subsurface

Need continual strain data along depth?

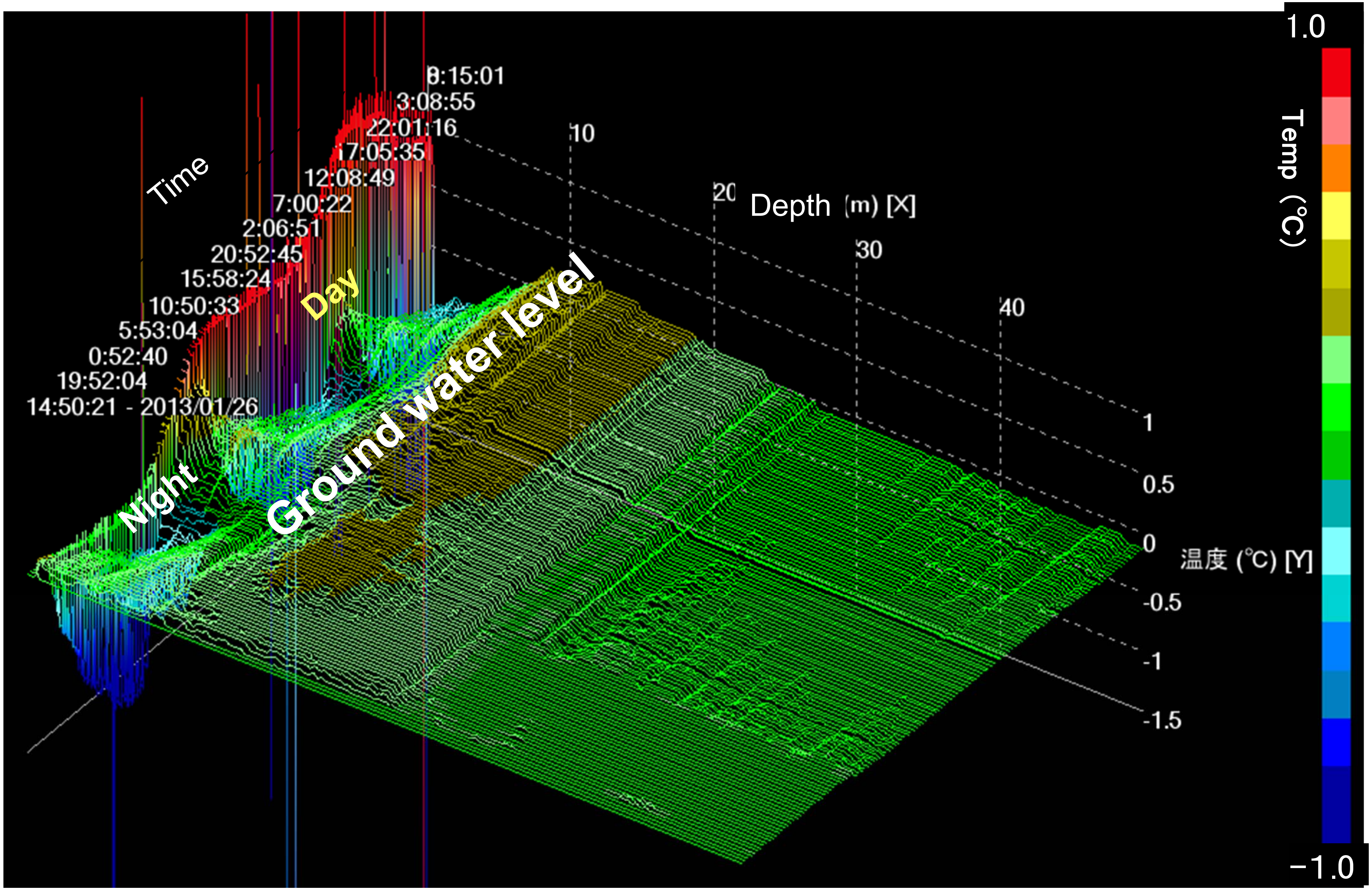
A Field Test of Fiber Optic Sensing at a shallow well (depth: 300m)



Geo-mechanical Response during CO_2 Injection

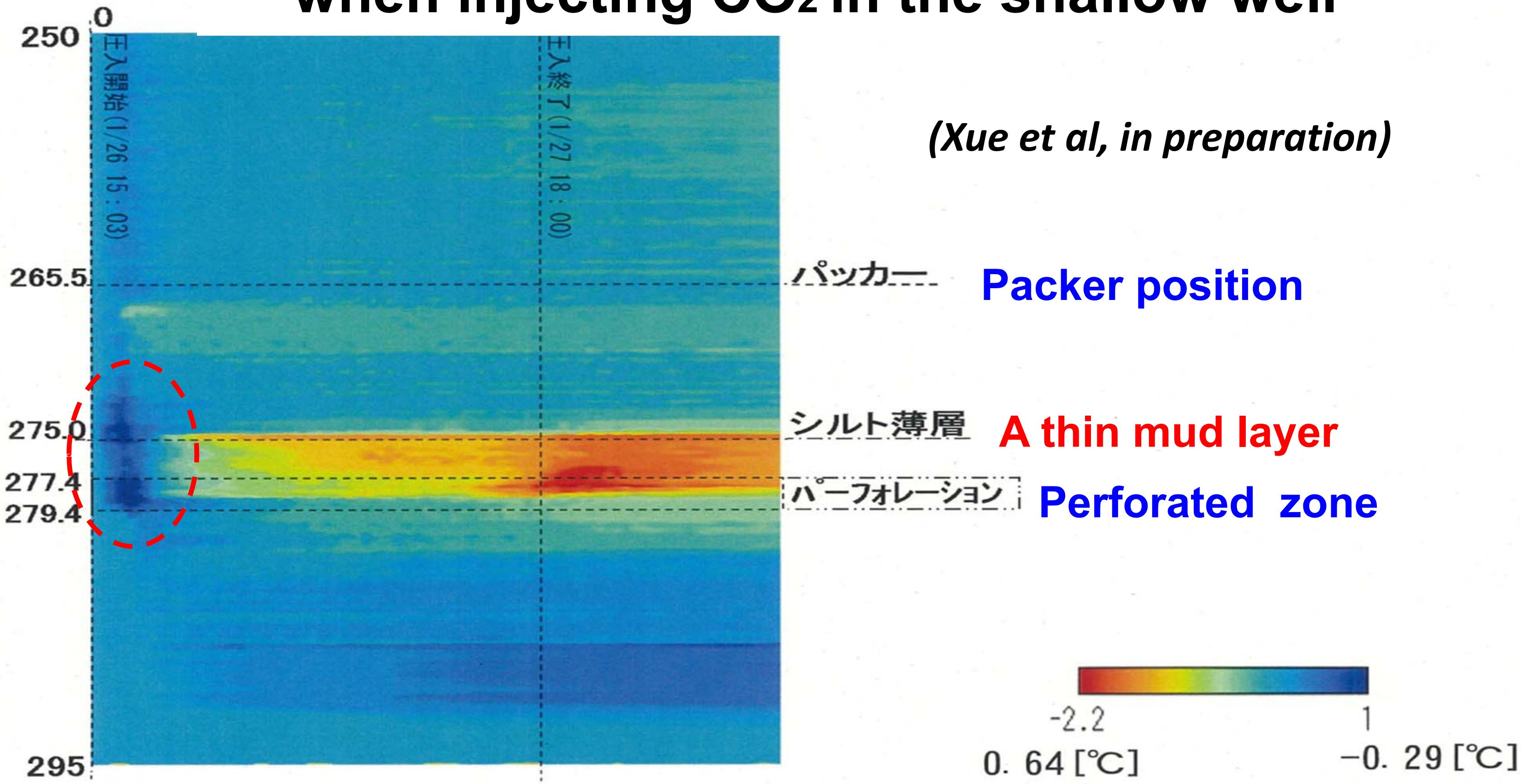


Daily Change of Temperature（0-50m）



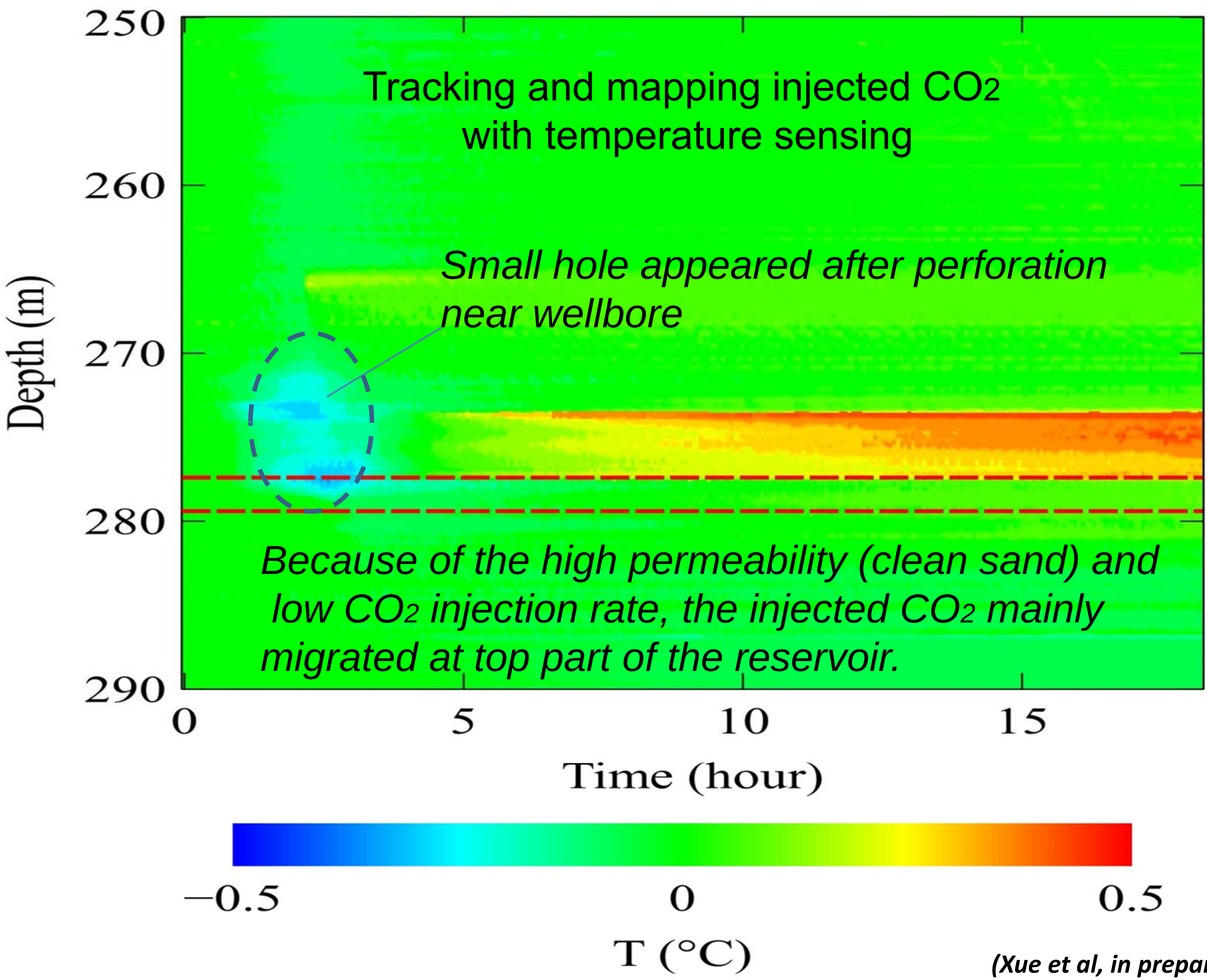
Temperature sensing enables us to monitor ground water level changes!

Temperature Sensing Results (short term) when injecting CO_2 in the shallow well



Response due to residual water (cold water in tubing)

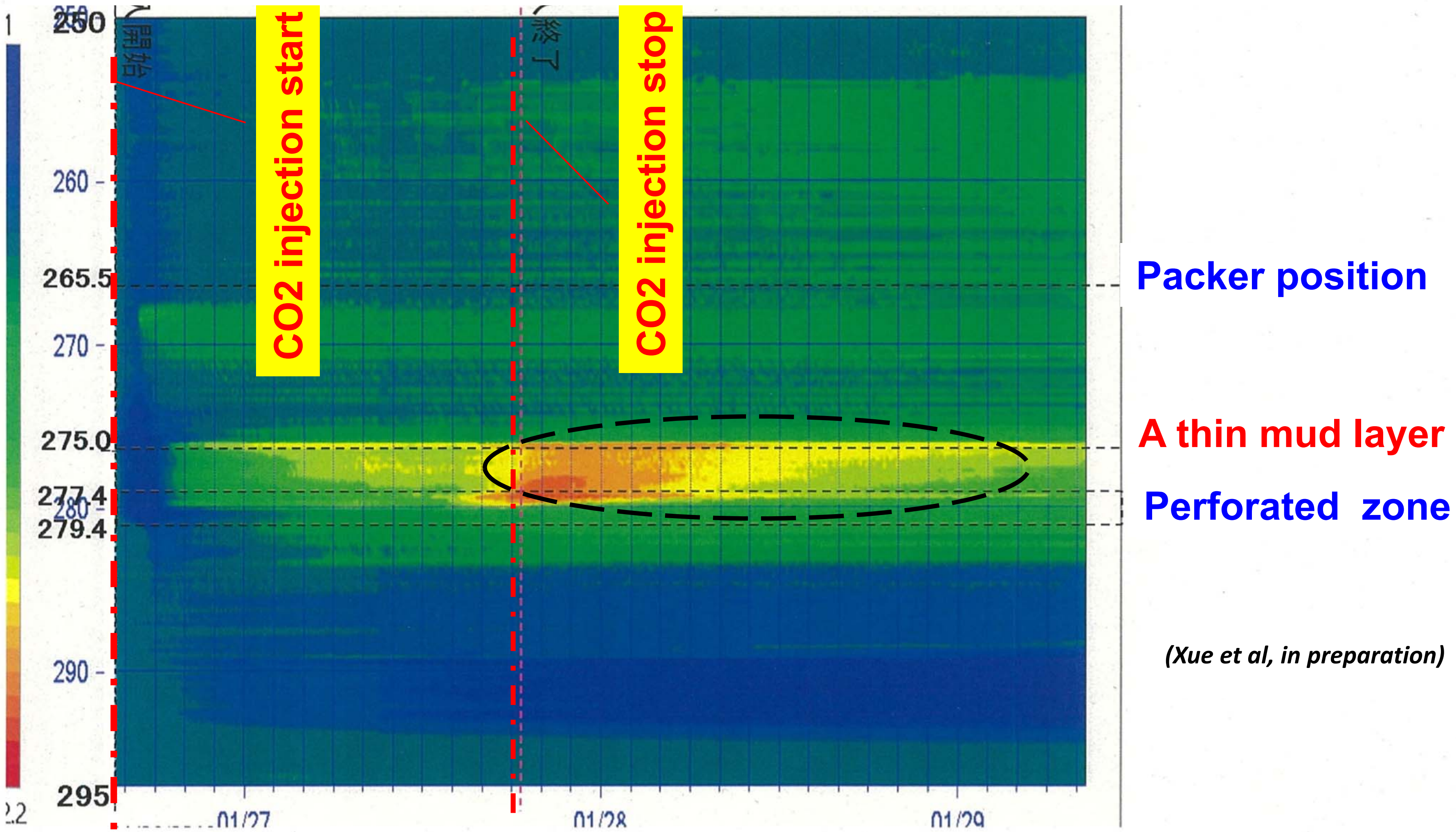
- ***Above the thin mud layer T-fiber (behind casing) also showed temp reduction, but No change appeared during CO_2 injection.***
- ***Under the thin mud layer and perforated zone temp changes observed simultaneously when cold water and warm CO_2 reached.***



(Xue et al, in preparation)

Temperature change* estimated from *Rayleigh frequency shift* observed by *T-fiber* (FIMT: Fiber in Metal Tube) in short-term *during CO_2 injection.

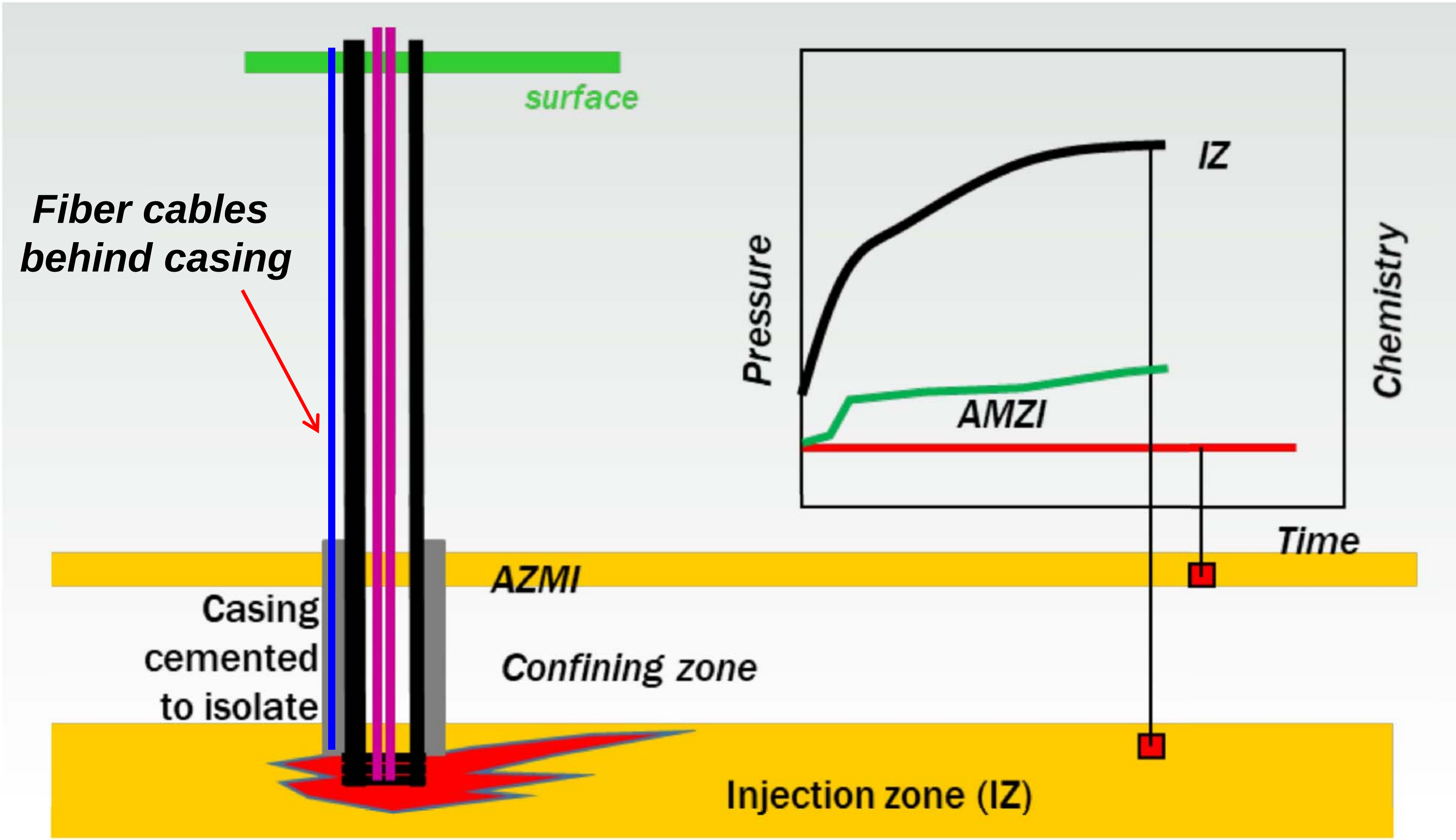
Temperature Sensing Results (long term) when injecting CO_2 in the shallow well



(Xue et al, in preparation)

- *Temperature change disappeared gradually in post- CO_2 injection period*
- *Due to sand trouble under the thin mud layer and perforated zone connected well. The CO_2 injection rate/volume was unable to fill the whole zone.*

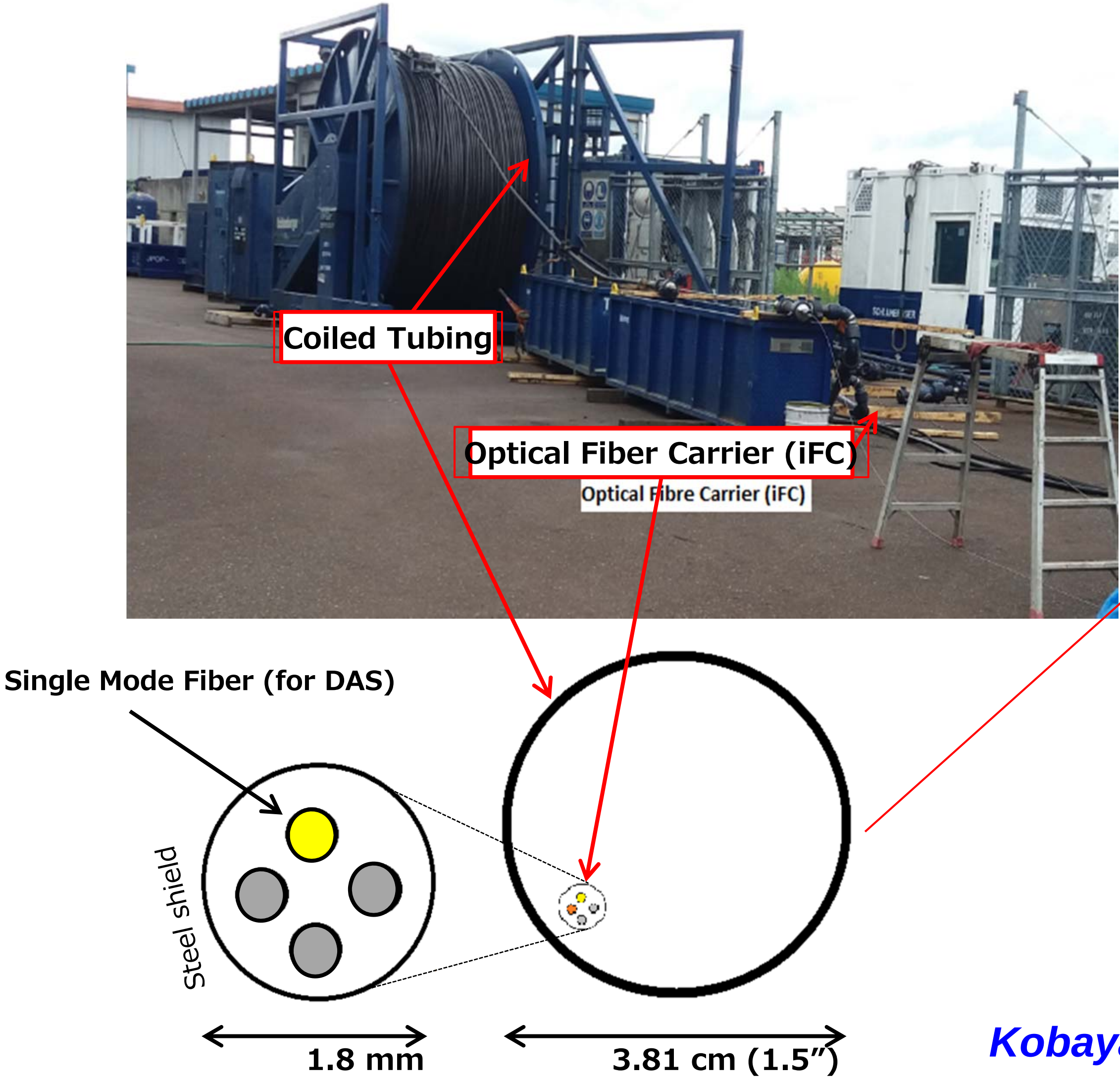
Application for well integrity monitoring, combined with AZMI (Above-Zone Monitoring Interval) pressure monitoring



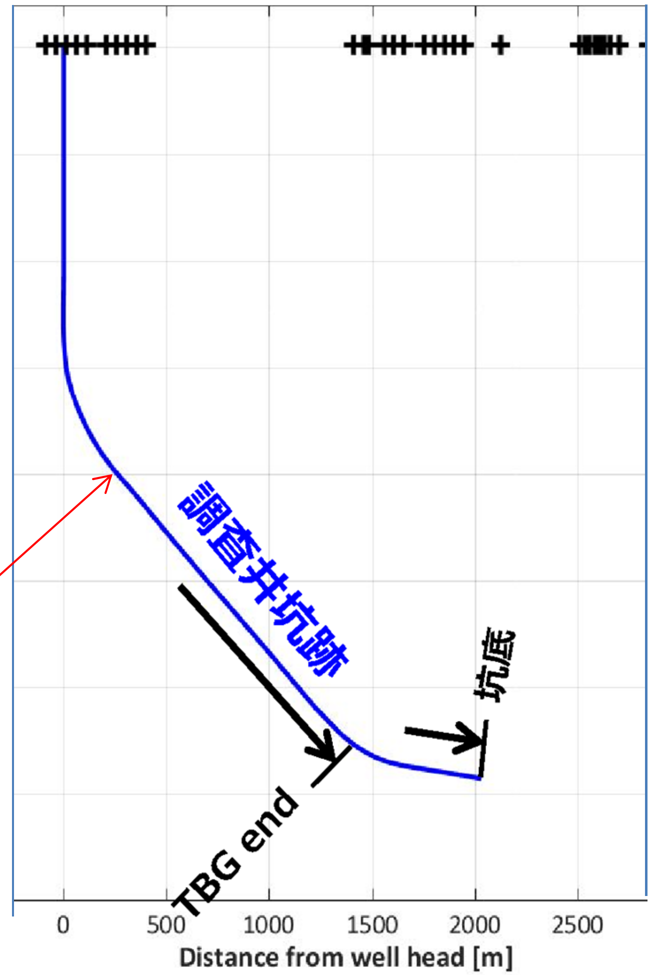
Hovorka et al, 2018

光ファイバーによる音響測定技術開発

DAS/VSP, Natural Earthquake Monitoring



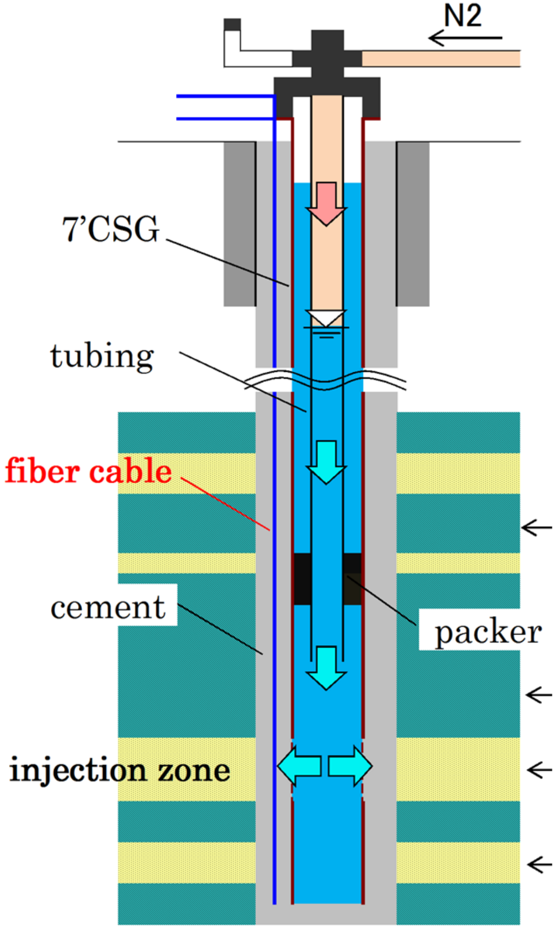
国内初の現場実験@新潟



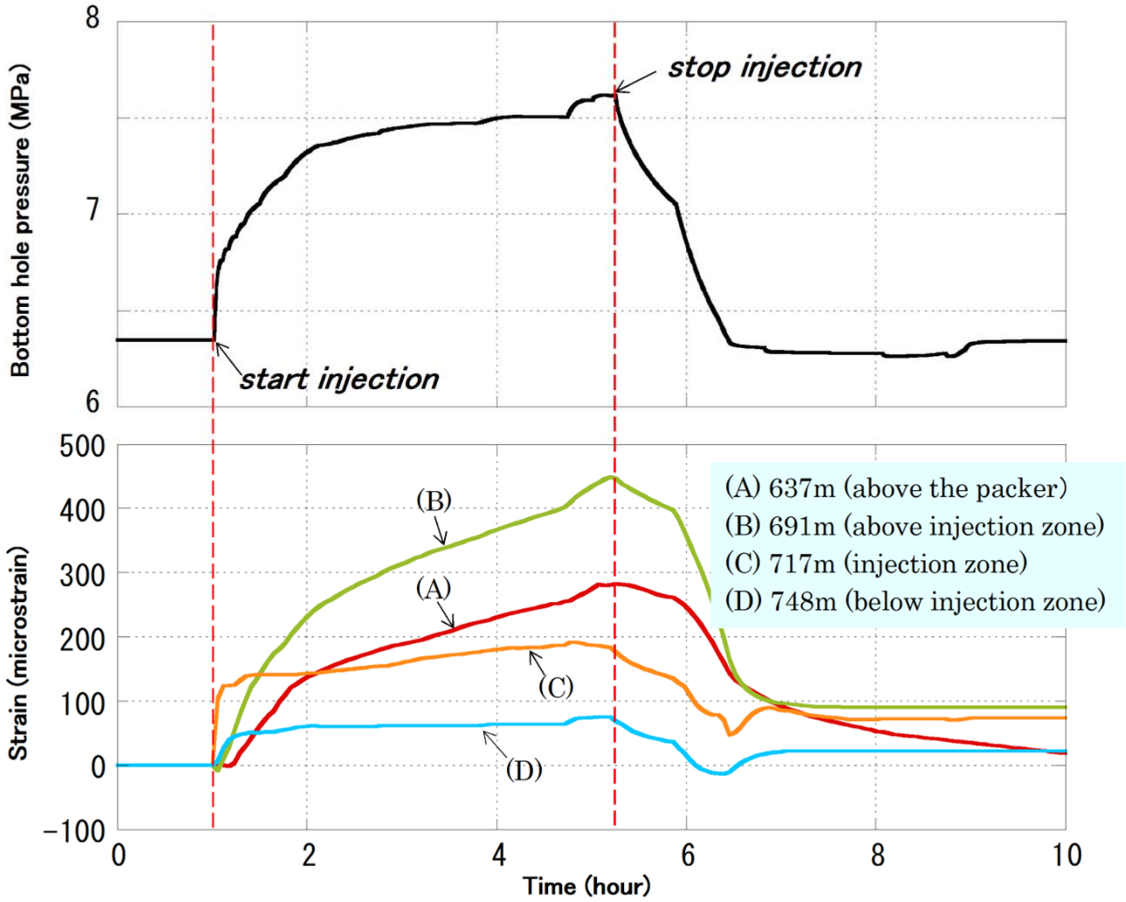
Kobayashi et al., 2018; 2019

DAS/VSP, Earthquake Monitoring at the Deep Well

(Xue et al, in preparation)

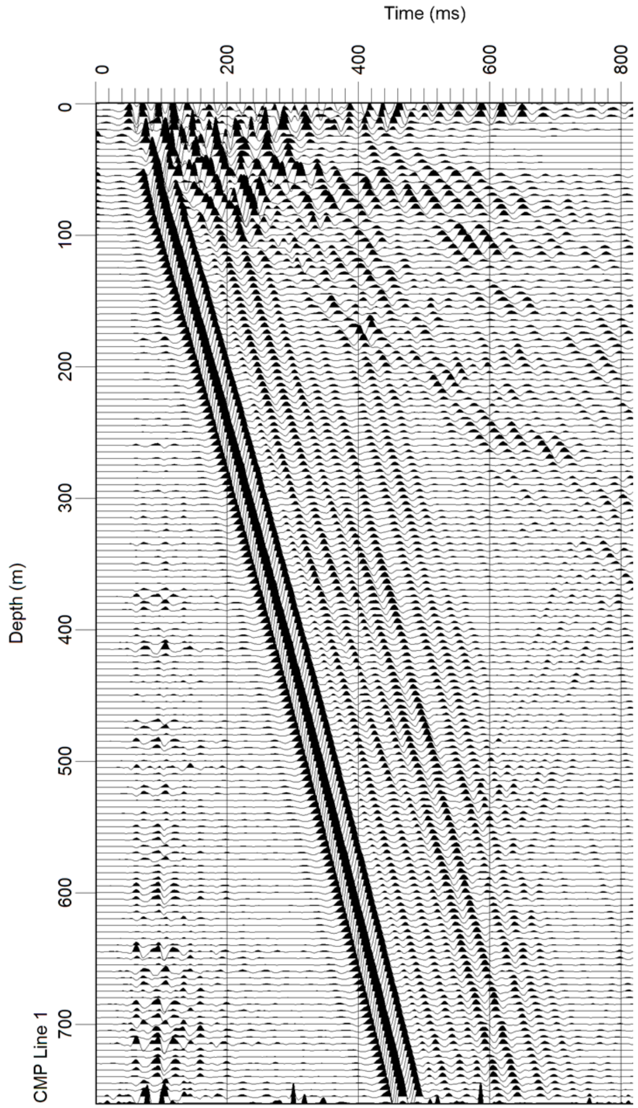


Well depth: 880m

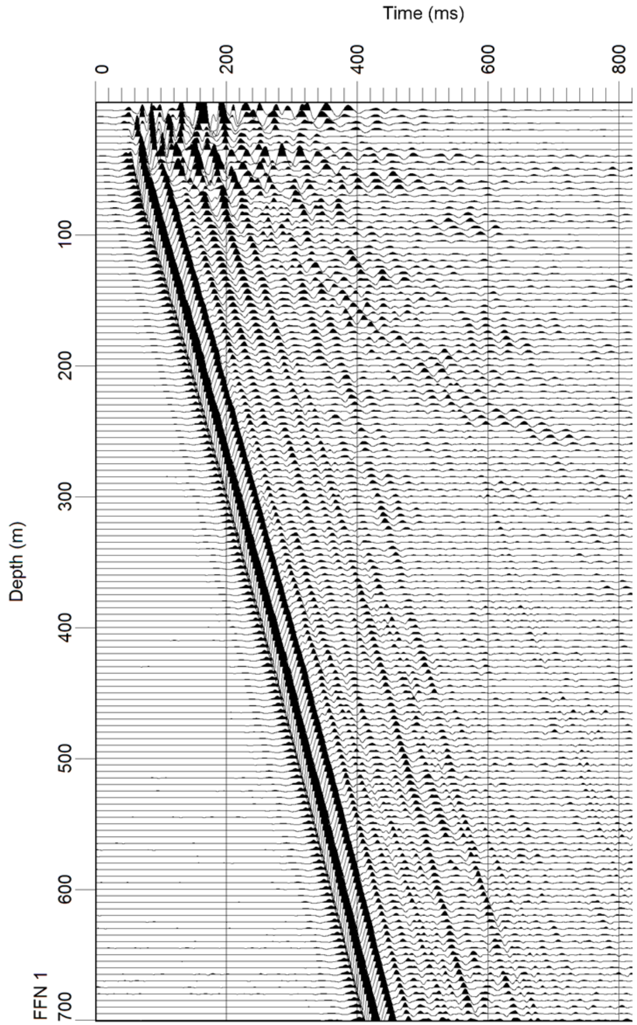


Strains estimated at different depths in N_2 injection

DAS/VSP result comparison at the deep well

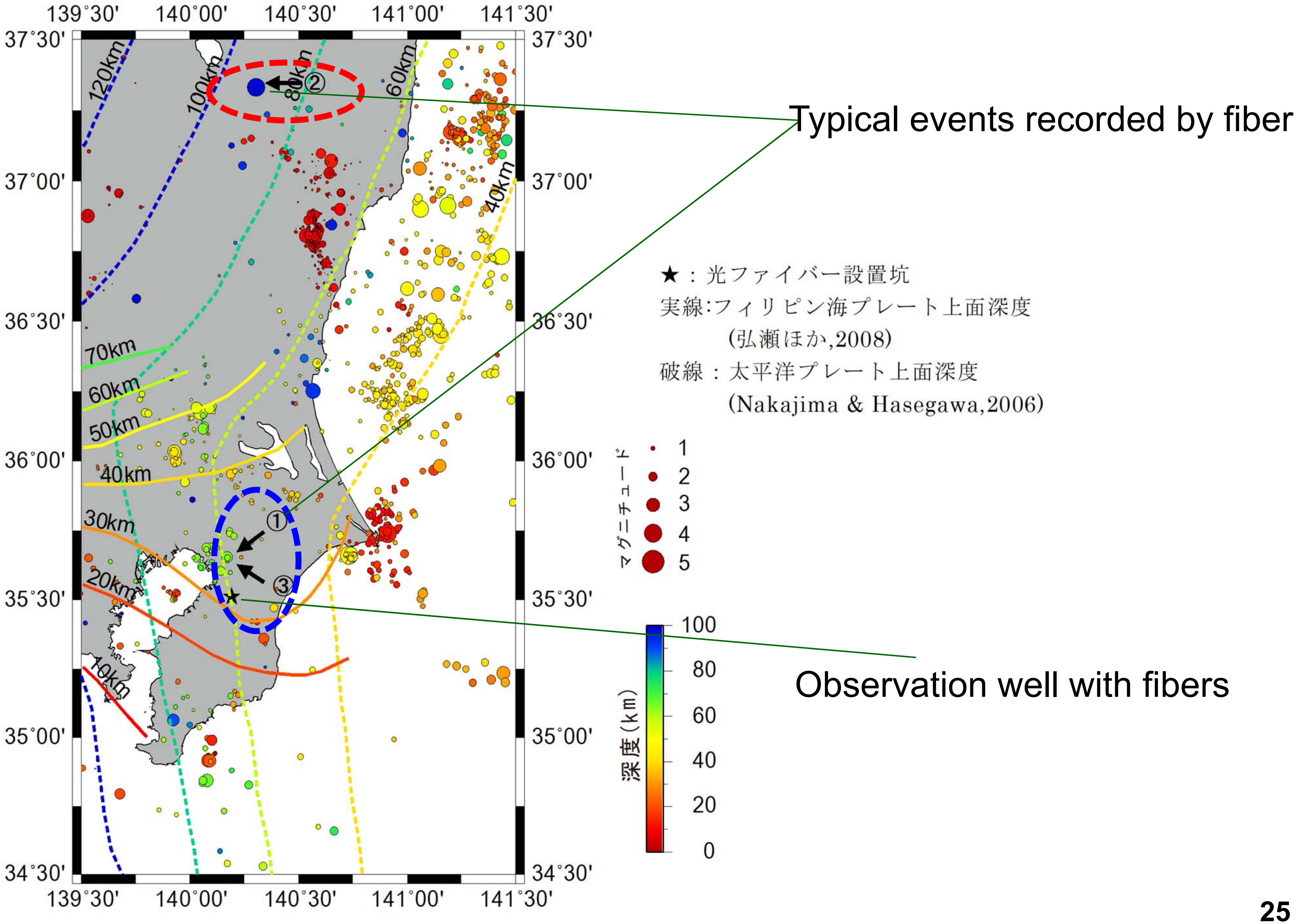


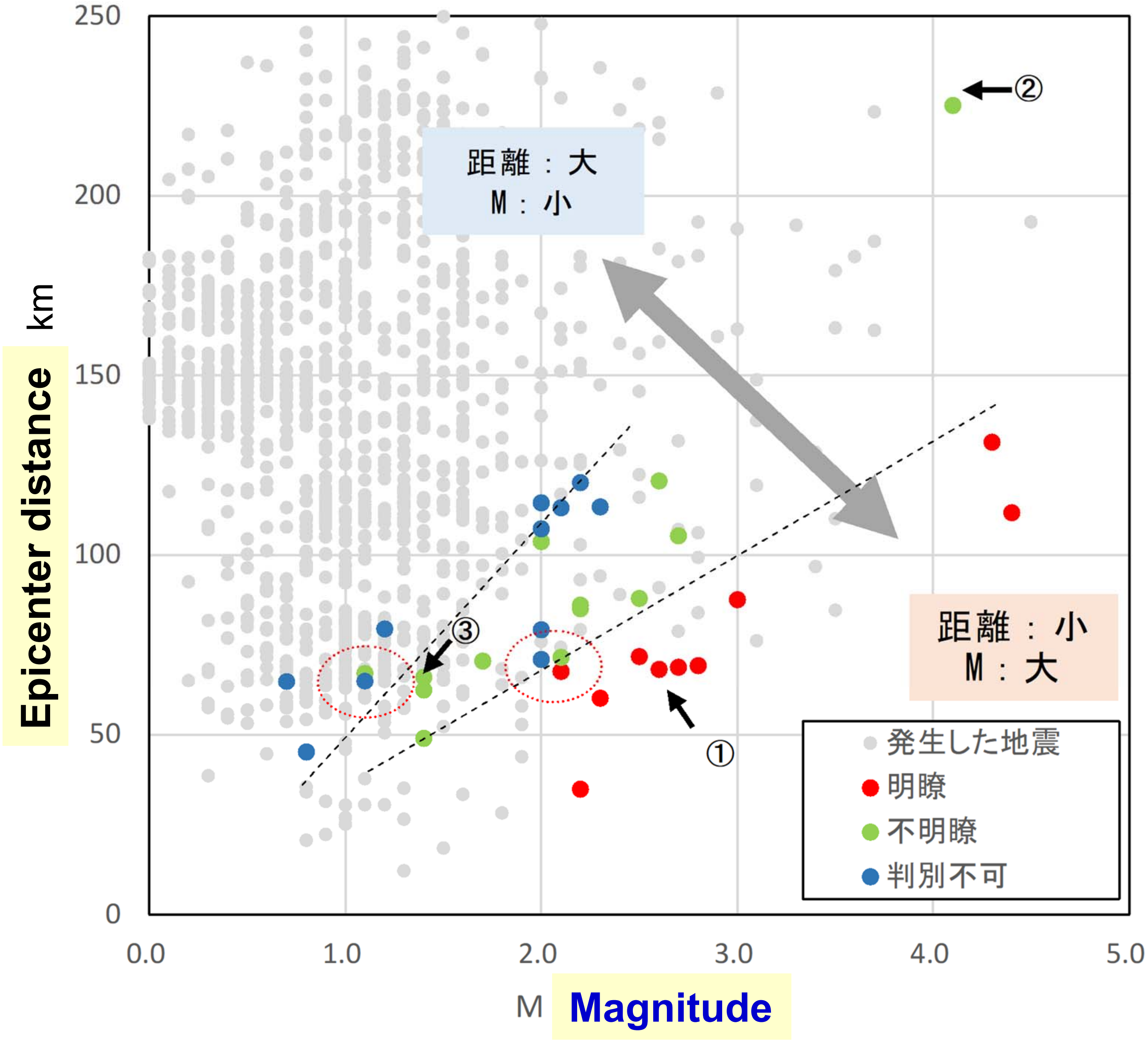
iDAS (35 stacking)



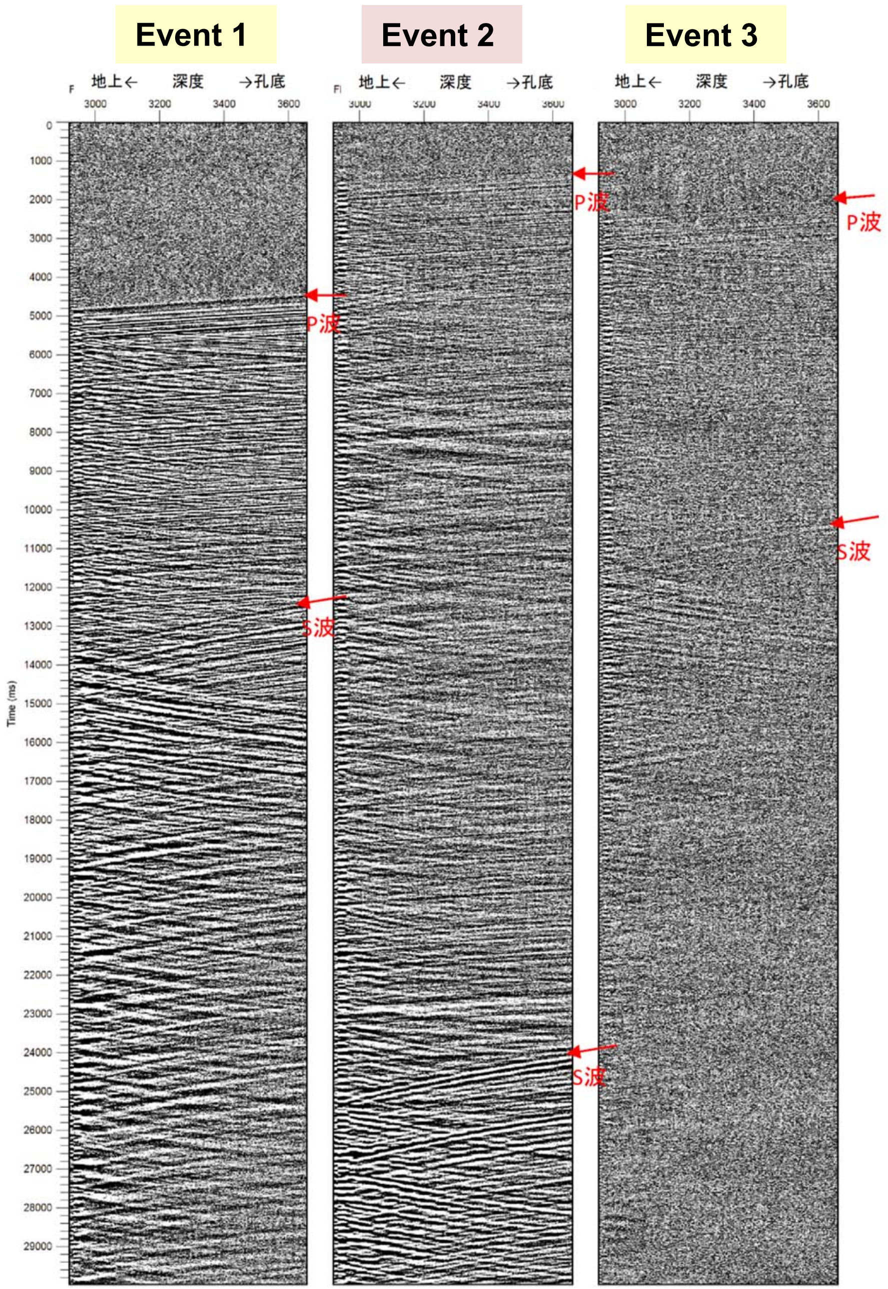
Geophone (1-2 stacking)

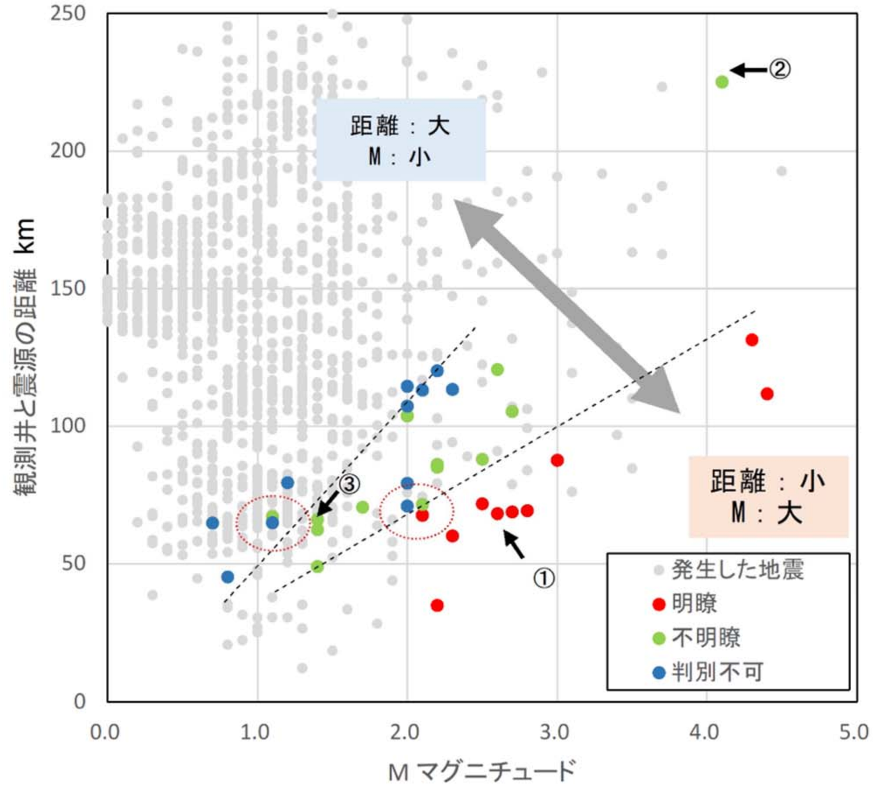
Natural Earthquakes around the test site (March 11-26, 2019)





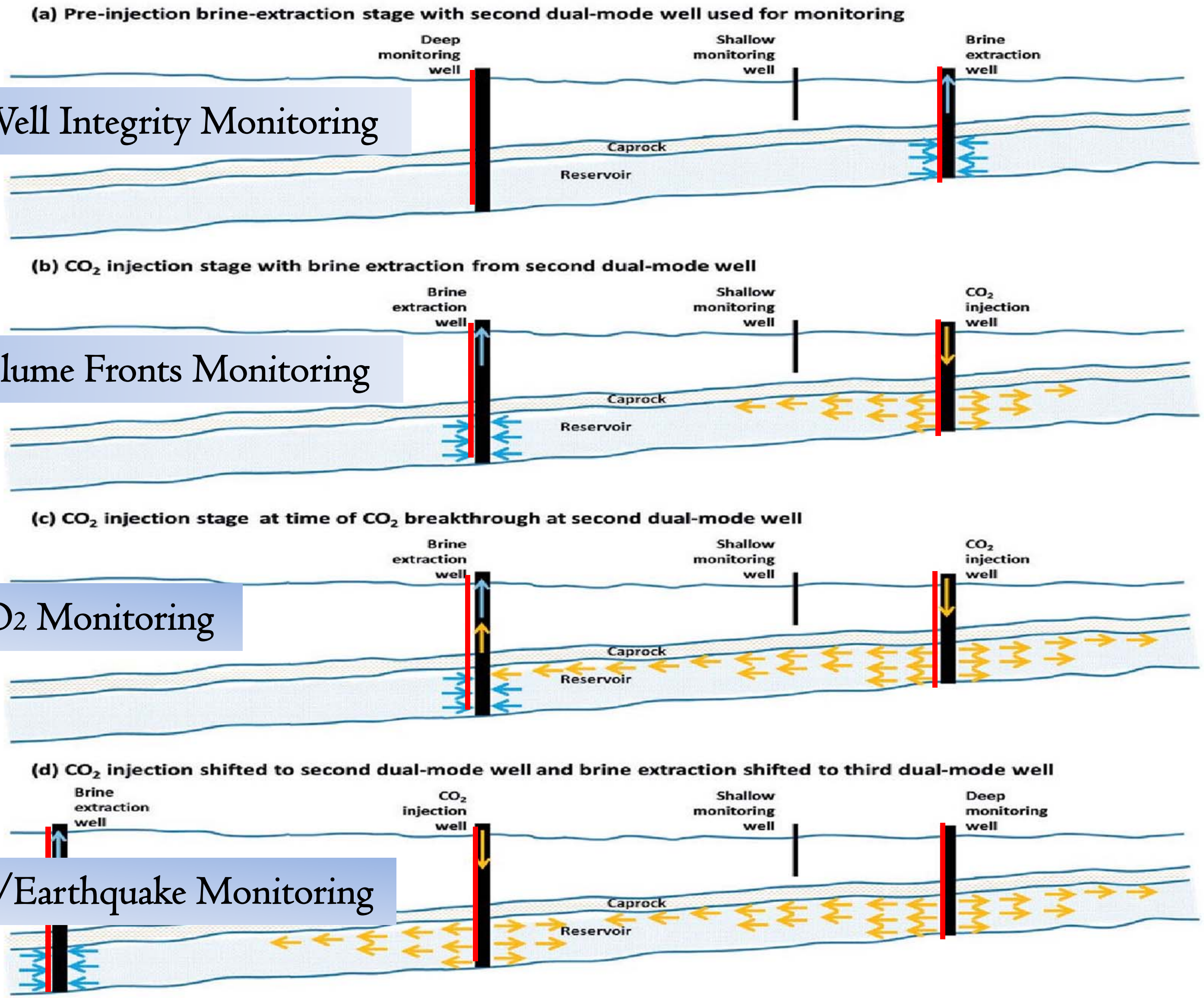
250
200
150
100
50
0
0.0
1.0
2.0
3.0
4.0
5.0
Epicenter distance km
M Magnitude
距離 : 大
M : 小
距離 : 小
M : 大
①
②
③
発生した地震
明瞭
不明瞭
判別不可


Event 1
Event 2
Event 3
地上←
深度
→孔底
P波
S波
Time (ms)

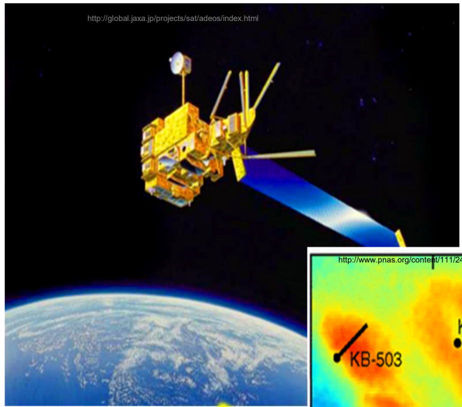

観測井と震源の距離 km
M マグニチュード
距離：大
M：小
距離：小
M：大
①
②
③
発生した地震
明瞭
不明瞭
判別不可

Optic Fiber Sensing in CO_2 Storage

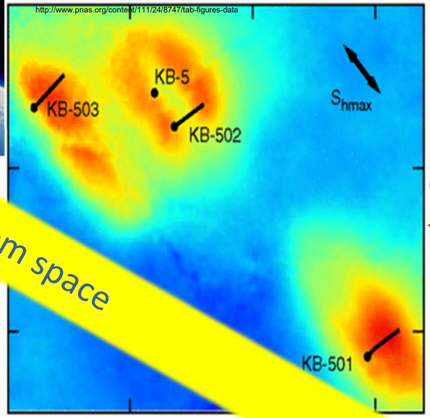
- Caprock and Well Integrity Monitoring
- Pressure and Plume Fronts Monitoring
- DAS/VSP CO_2 Monitoring
- Microseismic /Earthquake Monitoring



International Collaboration on Fiber Optic Sensing



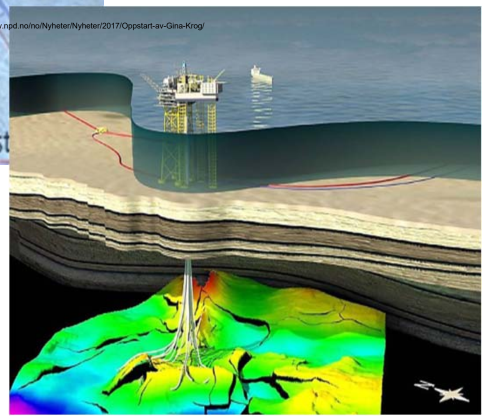
Satellite measurements+ GPS and geodesy for onshore sites



Demonstration of concept and methods: onshore surface heave (e.g. In Salah)

Onshore: North Dakota Univ. /US

Offshore: NGI /Norway



Application to offshore: Seabed monitoring with seafloor geodesy, ROV/AUV, tiltmeter, water pressure, etc.

Simulating deformation of reservoir & overburden, inversion history matching → **overburden management & containment assurance → success of injection/production**

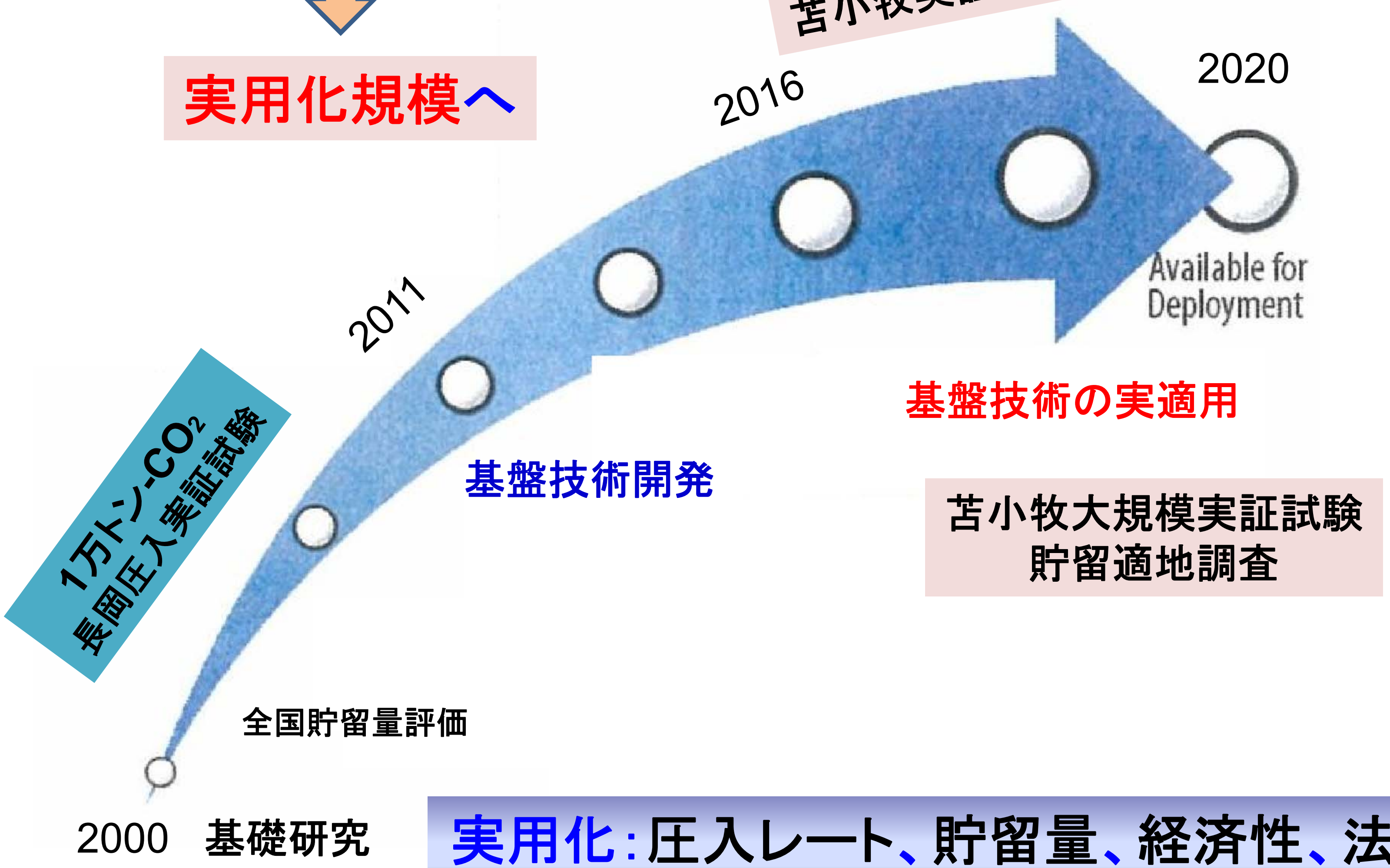
３．CO_2地中貯留技術の実用化への取り組み

Can We Achieve Gigatonne CO_2 Storage?

Norwegian/US CCS collaboration opportunities

長岡サイト →→→ 苫小牧サイト

実用化規模へ



実用化:圧入レート、貯留量、経済性、法整備

Tackling Challenges in CO_2 Geological Storage

- **Gravity Override of the Injected CO_2**

  (**Density difference** between *the injected CO_2 and residual fluids in the reservoir)*

- **Viscous Fingering Caused by the Injected CO_2**

  (typically 0.05-0.1 cp, much lower than oil and brine)

- **Reservoir Geology and Heterogeneity**

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

Carbon Sequestration Leadership Forum
www.cslforum.org

CARBON SEQUESTRATION LEADERSHIP FORUM (CSLF)

TECHNICAL GROUP

TASK FORCE ON

IMPROVED PORE SPACE UTILISATION

Improved Pore Space Utilisation: Current Status of Techniques

The pore space of a CO_2 storage system is the 'resource' to a CO_2 storage site operator. Presently, the efficiency of the storage resource is quite low, with only 1 to 4% of the bulk volume being utilised to store CO_2 in saline formations. A poor utilisation of this pore space resource means that the resource is wasted, and the opportunity to reduce the cost per tonne of CO_2 stored is significantly hindered. Conversely, a resource that is effectively utilised is likely to significantly improve the economics of CCS projects.

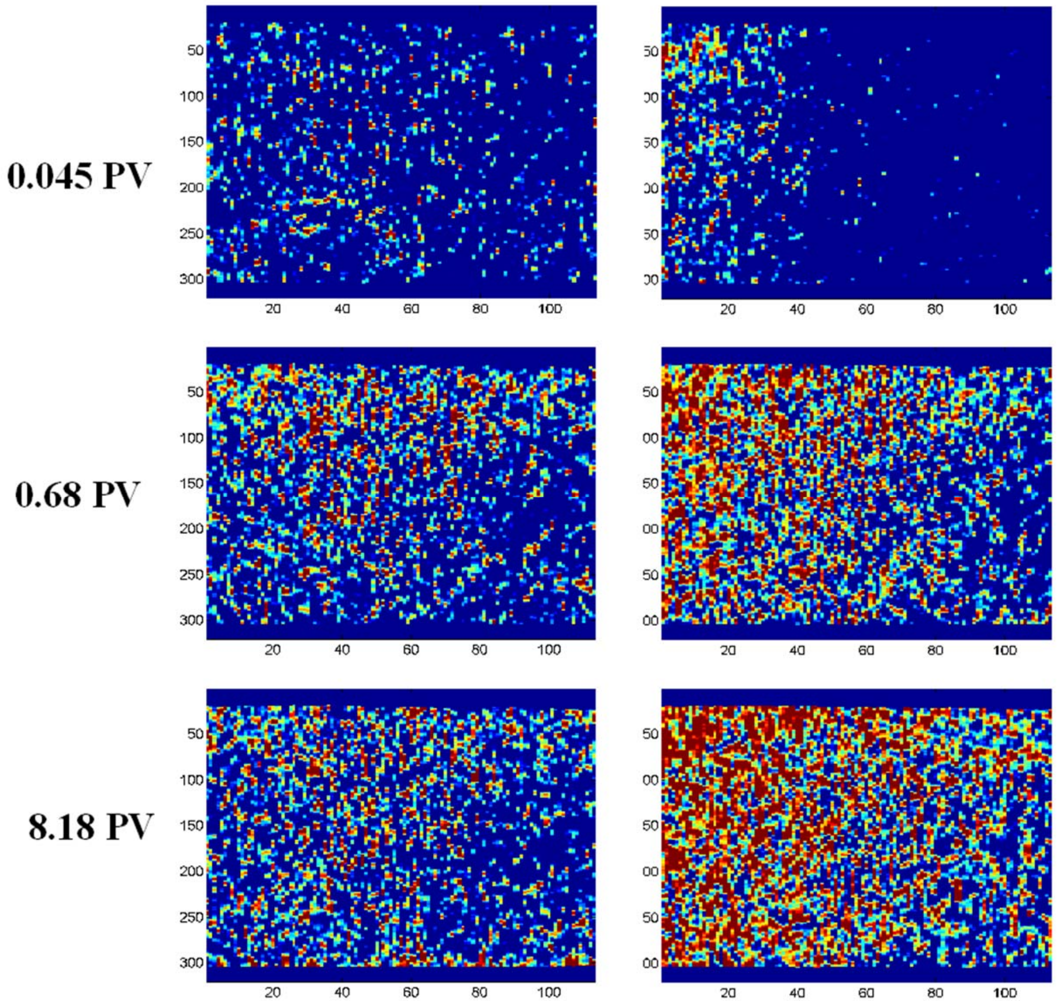
➢ Recommended Technologies for Improved Pore Space Utilisation:

P	Technology Type	Prior R&D and application	Technology Readiness Level (TRL)	Technology Prospectively
1	Microbubble CO_2 Injection	Laboratory and Modelled, prototype	TRL 4	High potential
2	Swing Injection	Laboratory and Modelled	TRL 3	High potential
3	Increased Injection Pressure	Laboratory and Modelled	TRL 3	High potential
4	Active Pressure Relief (increase sweep & reduce lateral spread)	Enhanced Oil Recovery (EOR), planned for Gorgon CO_2 injection project	TRL 6	High potential
5	Foams (block high permeability pathways)	EOR	TRL 6	Reasonably well understood
6	Passive Pressure Relief	Modelled	TRL 4	Limited effectiveness
7	Polymers (increase formation water viscosity)	EOR	TRL 7	Reasonably well understood
8	Surfactants (reduce residual saturation of formation water)	EOR	TRL 7	Reasonably well understood
9	CO_2 saturated water injection & geothermal energy	Laboratory and Modelled	TRL 3	Site specific & lower volume

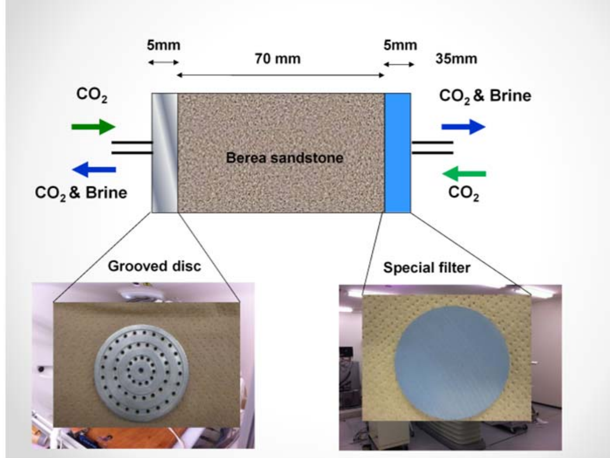
* minor modelling and laboratory investigations may be required prior to commercial scale application

Microbubble CO_2 Injection for Improving *Storage Efficiency*

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

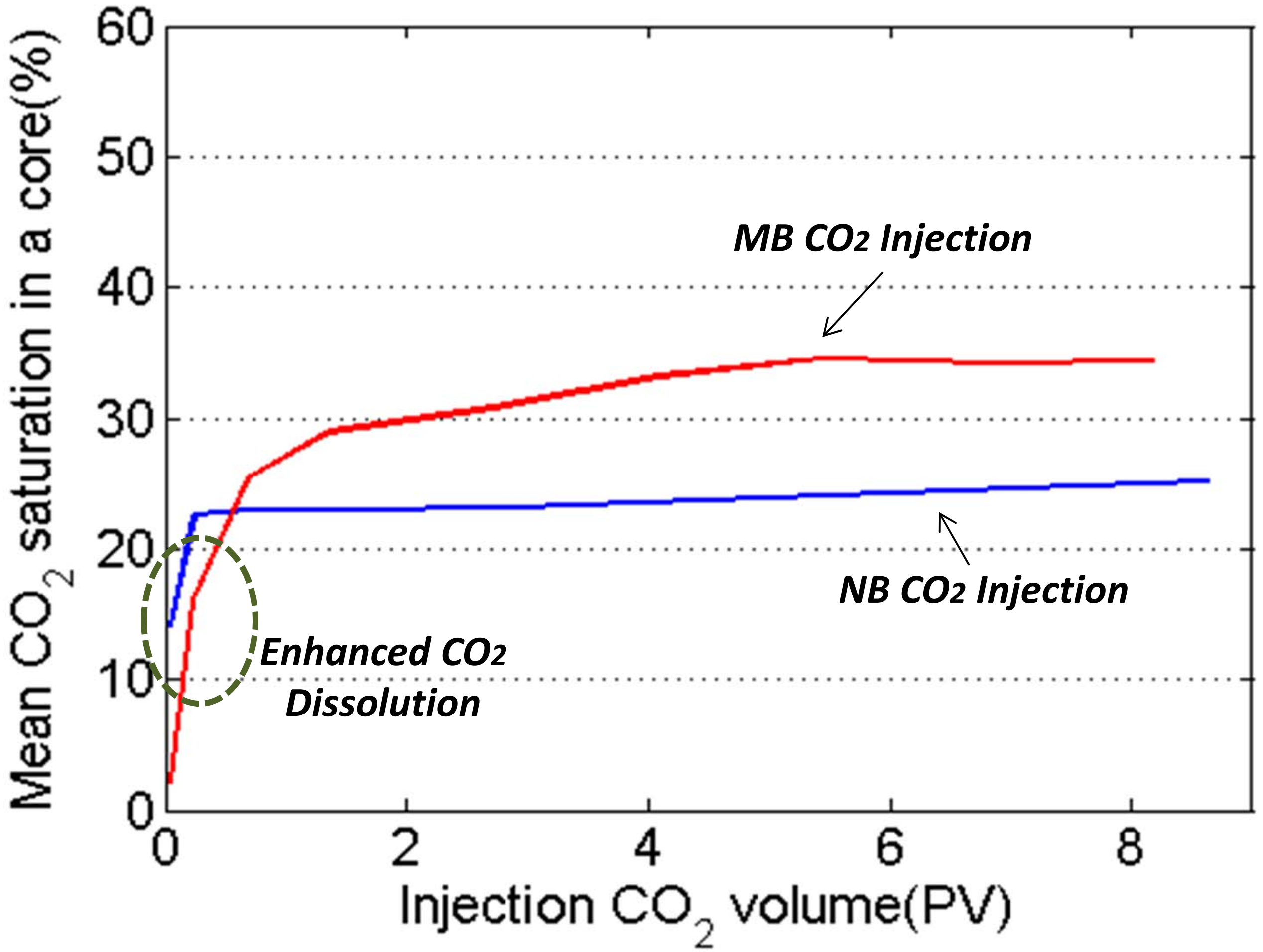


東京ガス(株)／RITEの共同研究



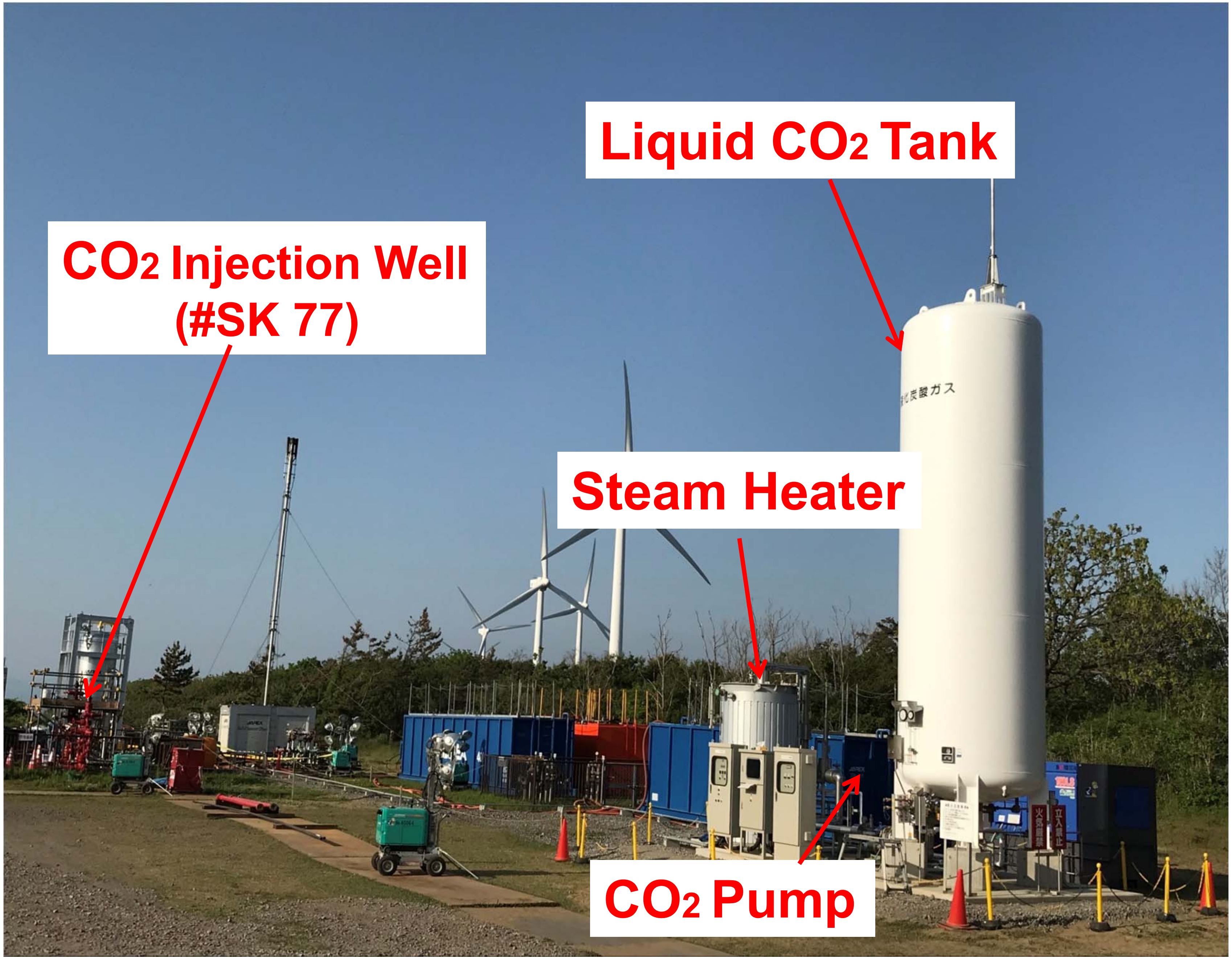
(Patent: PCT/JP2O09/064249)

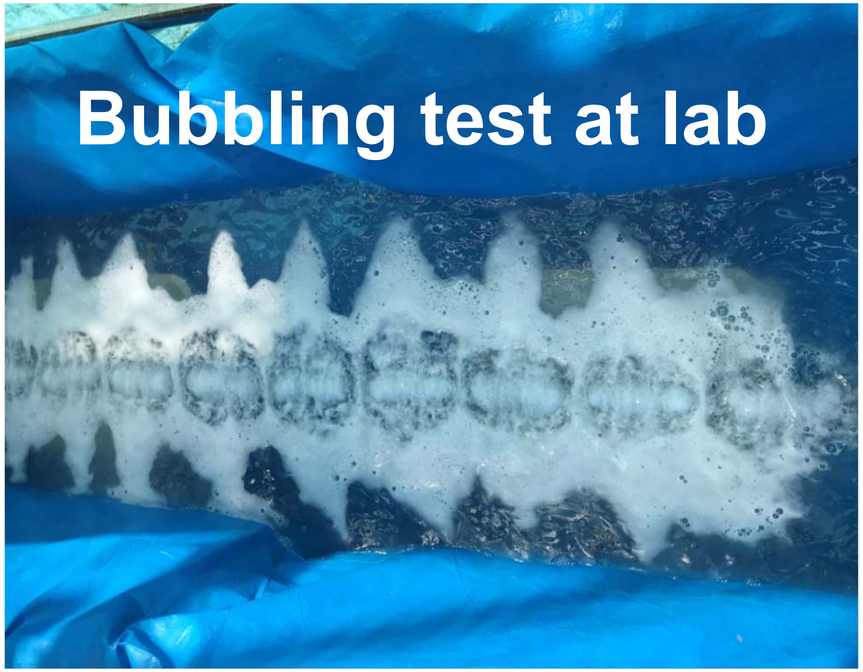
CO_2 Saturation: NB vs MB Injection



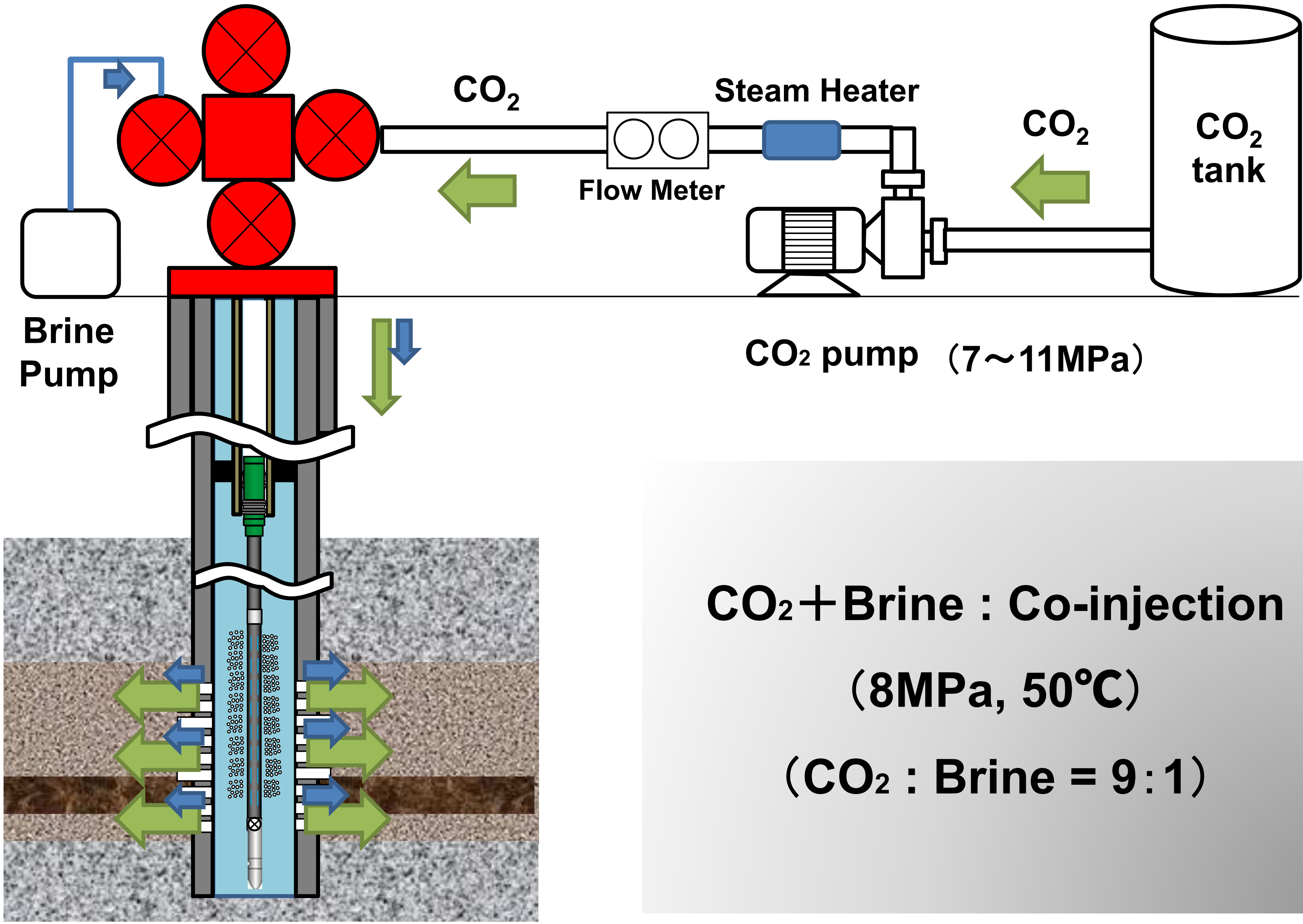
Microbubble CO_2 Injection Pilot Test at the Japex field site

37


Liquid CO2 Tank
CO2 Injection Well
(#SK 77)
Steam Heater
CO2 Pump



Downhole Tool for Microbubble CO_2 Generation



CO_2＋Brine : Co-injection

（8MPa, 50℃）

（CO_2 : Brine = 9：1）

Summary of MB CO_2 Injection Test in May 2019

Injection

CO_2
圧入量：22.2ton（12,100Sm^3）、平均圧入レート：2.2ton/D（1,200Sm^3/D）
Brine
圧入量：4.0kL、平均圧入レート：0.4kL/D
圧入指数（CO_2+ブライン@圧入層条件）
Injection Index ➔➔➔ MB：0.39t/D/MPa

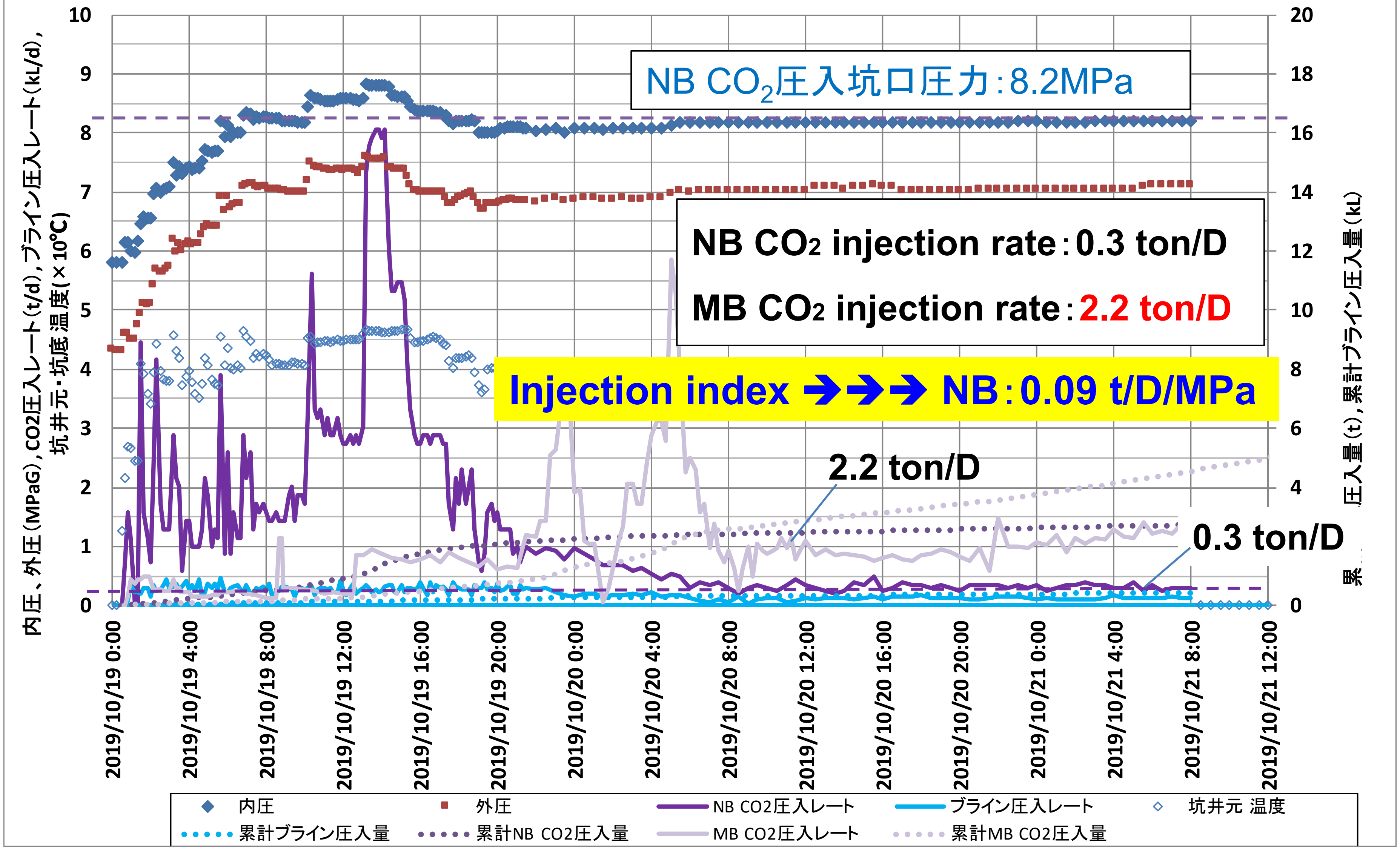
Injected CO_2：22.2 ton; Produced CO_2：5.26 ton

➔➔ 16.94 ton CO_2 Stored !

Production

CO_2
産出量：5.26ton（2,880Sm^3）
Brine
産出量：1.2kL — Pre-CO_2 injection: 140 L/D; 140L/D x 10D = 1.4 KL
Oil
産出量：0.6kL — Pre-CO_2 injection: 10 L/D; 10L/D x 10D = 0.1 KL

Preliminary Result from Normal CO_2 injection (without microbubble filter)



秋田県申川油田実証試験結果（速報）

✓ Normal Bubble CO_2圧入試験実績

ケースNo.		圧入量			産出量				CO2貯留量		
		CO2		水	CO2		水	油	量		率
		（t）	（m³）	（L）	（t）	（m³）	（L）	（L）	（t）	（m³）	（%）
NB実証	予想	22.0	12,000	4,000	9.0	4,900	510	20	13.0	7,100	59.1
	実績	5.8	3,211	1,150	2.1	1,203	351	0	3.7	2,008	62.5

✓ Microbubble CO_2圧入試験実績

ケースNo.		圧入量			産出量				CO2貯留量		
		CO2		水	CO2		水	油	量		率
		（t）	（m³）	（L）	（t）	（m³）	（L）	（L）	（t）	（m³）	（%）
MB実証	実績	20.1	11,033	4,000	3.9	2,189	1,200	600	16.3	8,844	80.2
					試験前生産実績		980	70			

実用化・事業化に向けての課題

◎Technical Gap (技術的課題)

- ✓ Up-scaling(大規模化)技術の確立(実証試験　→→→　事業化へ)
- ✓ IntegrationとDown-scaling(技術の統合と絞り込み)による実用化技術の確立(実証試験から得た知見を基に)
- ✓ 漏出検出・環境影響評価総合システム構築等(海防法への対応)

◎Non Technical Gap (技術以外の課題)

- ✓ 社会受容性の獲得　→　　PO/PA手法の構築
- ✓ CCS実施の仕組み作り　→　法体系の検討、政策的支援
- ✓ 社会的認知度の向上＆人材育成　→　温暖化のリスク認識、長期的視点＆グローバル戦略・対応

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