◆　革新的環境技術シンポジウム 2015　◆

CO_2地中貯留安全性評価技術開発

―海外プロジェクトの最新動向とRITEの取り組み―

(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・主席研究員

せつ　じきゅう
薛　自求

目　次

- CO_2帯水層貯留PJの推移と最新動向
  - ✓陸域・海域／ CO_2ソース／事業者
- 既存＆計画中の貯留PJからの知見
  - ✓貯留層評価＆地質モデリング、地層安定性（とくに遮蔽層）モニタリング
- CO_2帯水層貯留におけるリスク管理
  - ✓リスクマネジメント（リスク低減 →→安全性及び社会的受容性の向上）

Sleipner	In Salah	Snohvit
随伴CO_2 （0.9Mt/y）	随伴CO_2（1.0Mt/y）	随伴CO_2（0.7Mt/y）
Statoil	BPほか	Statoil

2011年より、圧入中止

2004

2008

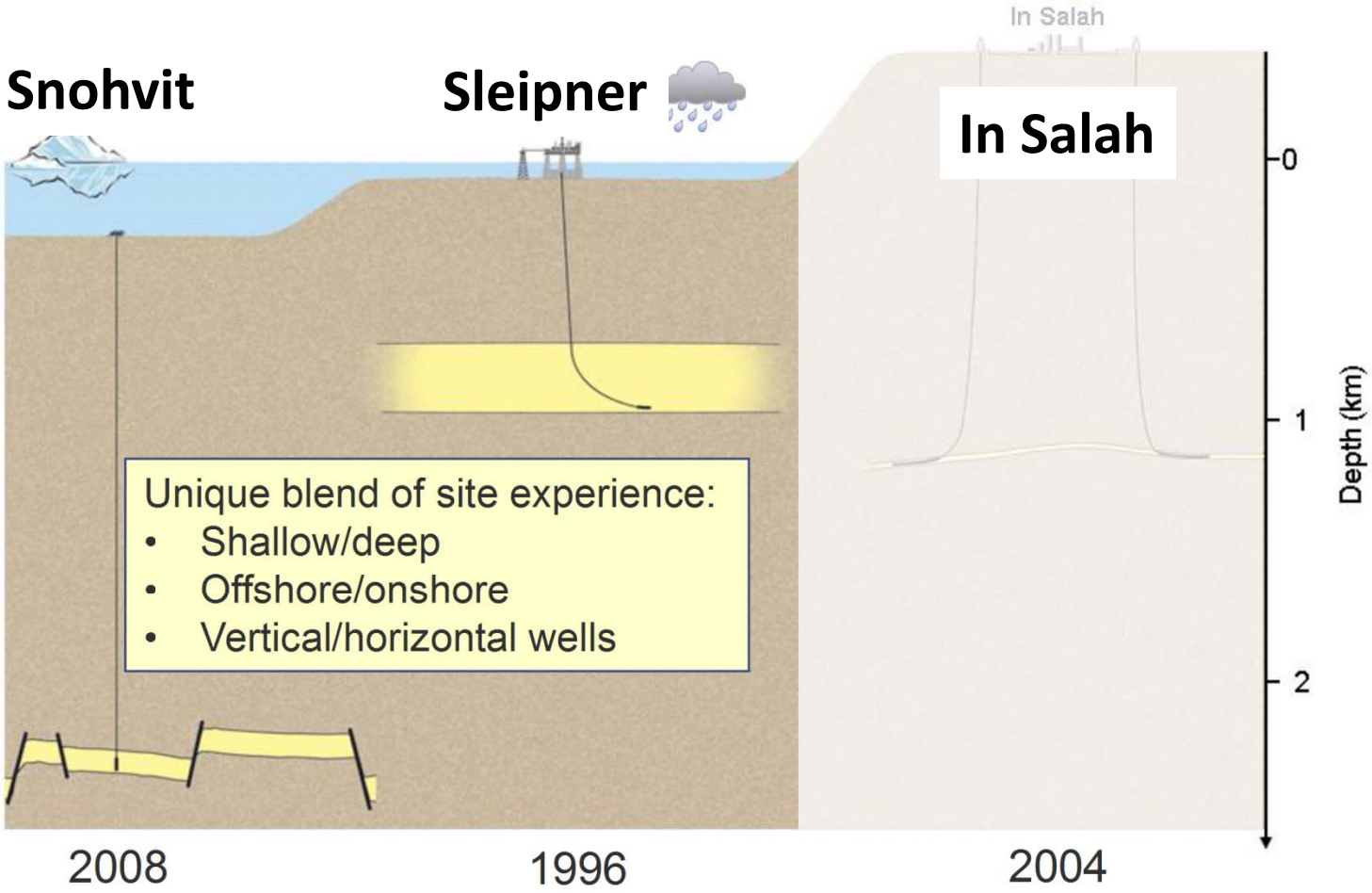
1996

圧入開始、継続中

陸域：In Salah　*vs*　海域：Sleipner, Snohvit

垂直坑井　*vs*　水平坑井，貯留層深度

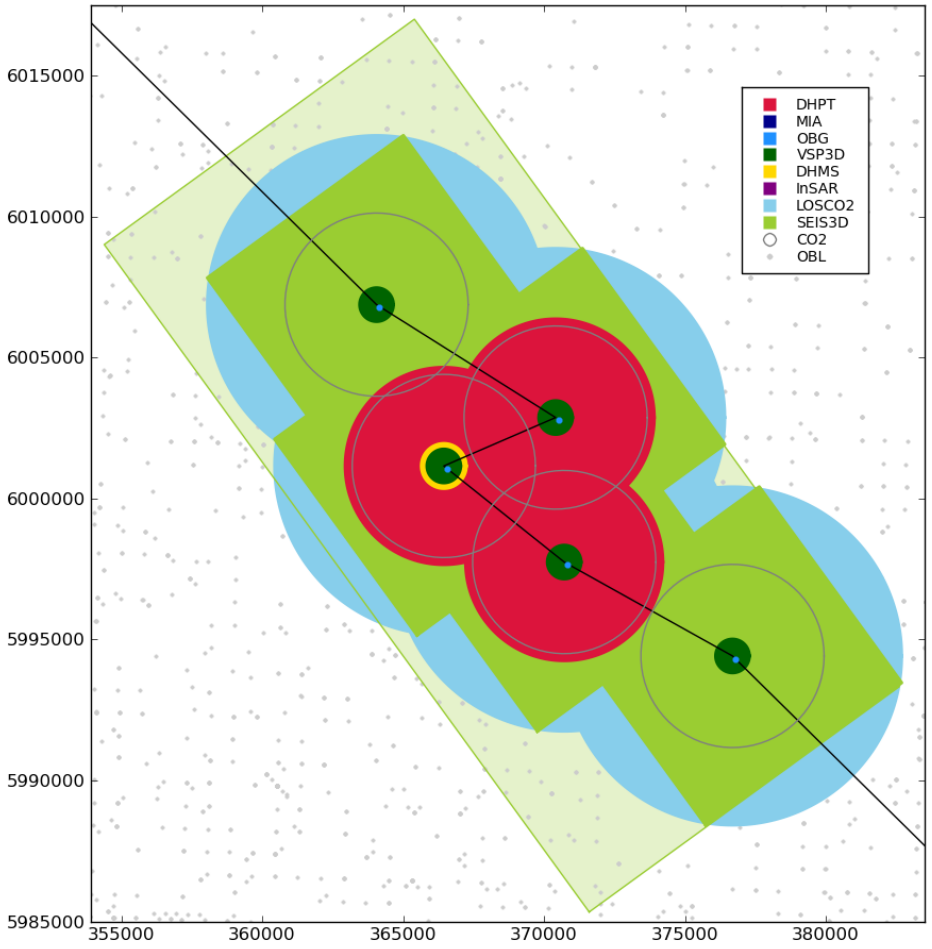
海上プラットフォーム　vs　海底坑口仕上げ



CCSプロジェクトへのSHELLの関与

QUEST プロジェクトの概要

- 1 million tonnes CO_2/year, capacity for 25 years
- 65 km pipeline
- CCS – saline aquifer (BCS)
- DNV – Storage & MMV plans certified



Decatur（米国）： ICCS プロジェクト概要

事業者：エターノル製造会社

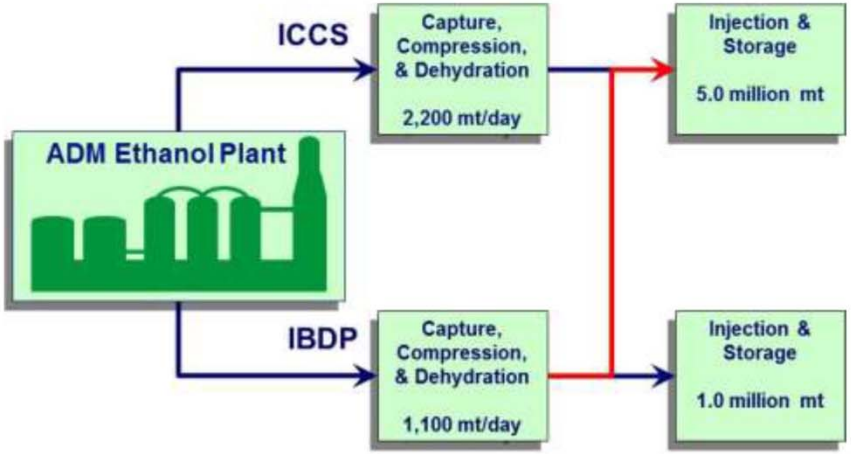
ILLINOIS INDUSTRIAL CARBON CAPTURE & STORAGE

Illinois Basin Decatur Project

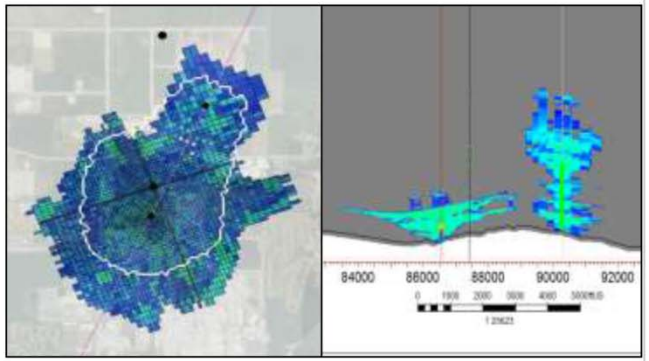
- *Large scale geologic test to inject 1.0 million mt of CO_2 over a three year period (1,000 MT/day).*

Illinois Industrial CCS Project

- *Target & demonstrate advanced CCS technologies at industrial scale facilities.*
- *Inject and store 1.0 million mt CO_2 per year (3,000 tons/day).*
- *Study the interaction of two separate plumes.*



ADM NETL Schlumberger Carbon Services Richland Community College



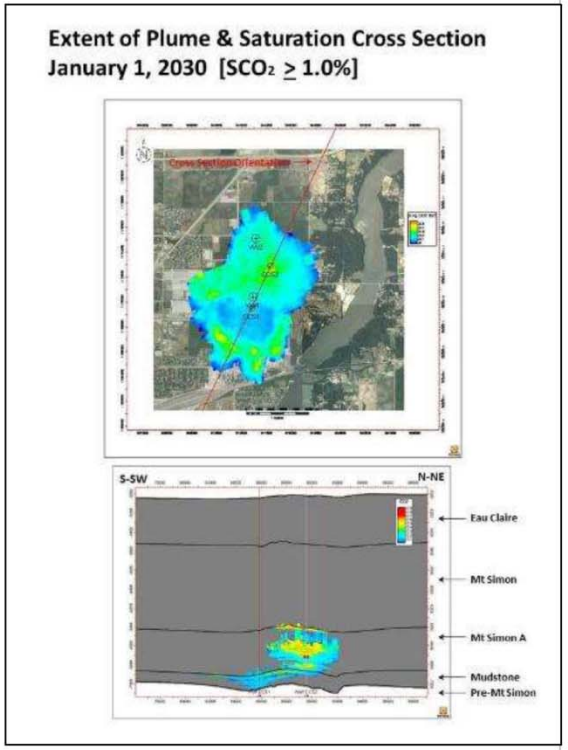
Decatur ICCS の挑戦: 圧入後監視期間

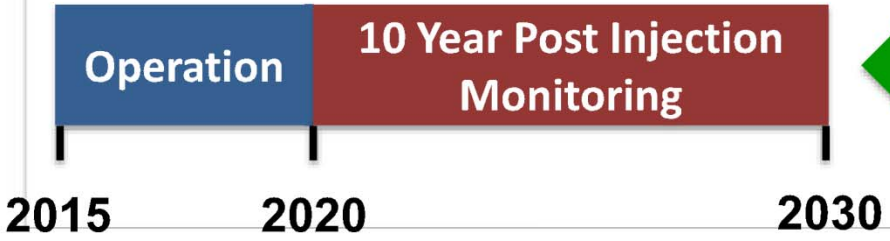
Main Challenges

Alternative PISC Timeframe

ILLINOIS INDUSTRIAL CARBON CAPTURE & STORAGE

- **Default PISC is 50 Years**
- **Applicant allowed to petition for an alternative timeframe**
- **ADM Proposed 10 Year PISC**
  - Reservoir Pressure Decline
  - Plume Stabilization
  - CO_2 Partitioning





Demonstrate Non-endangerment

監視期間：50年から10年に短縮

目　次

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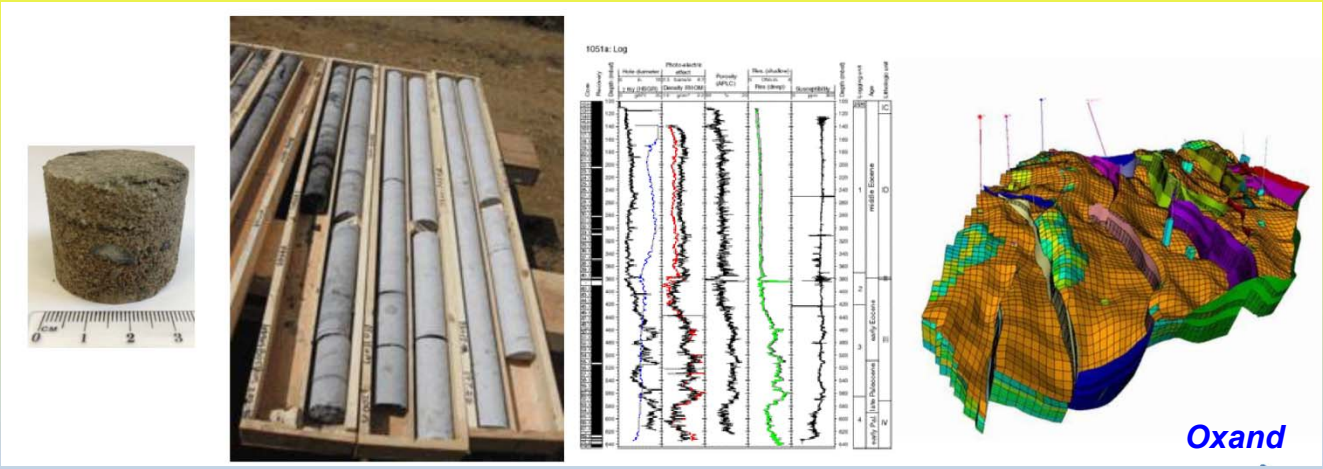
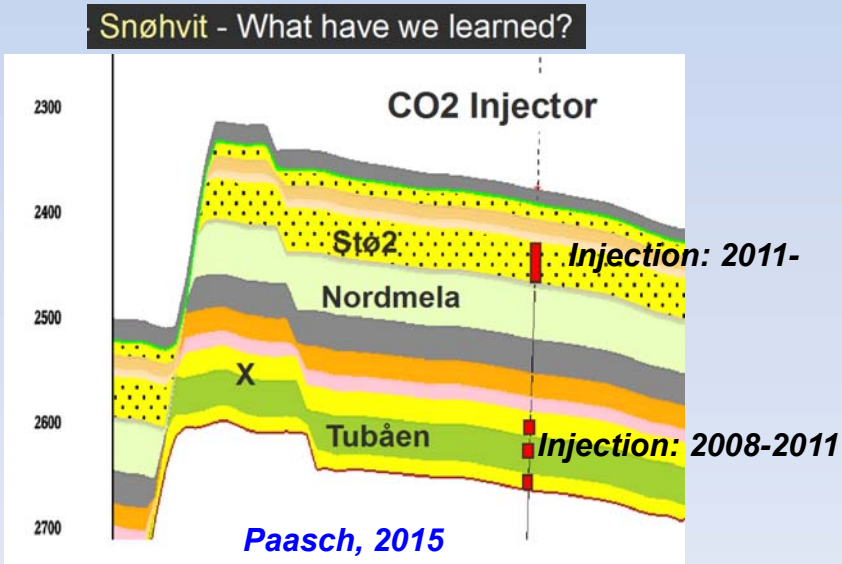
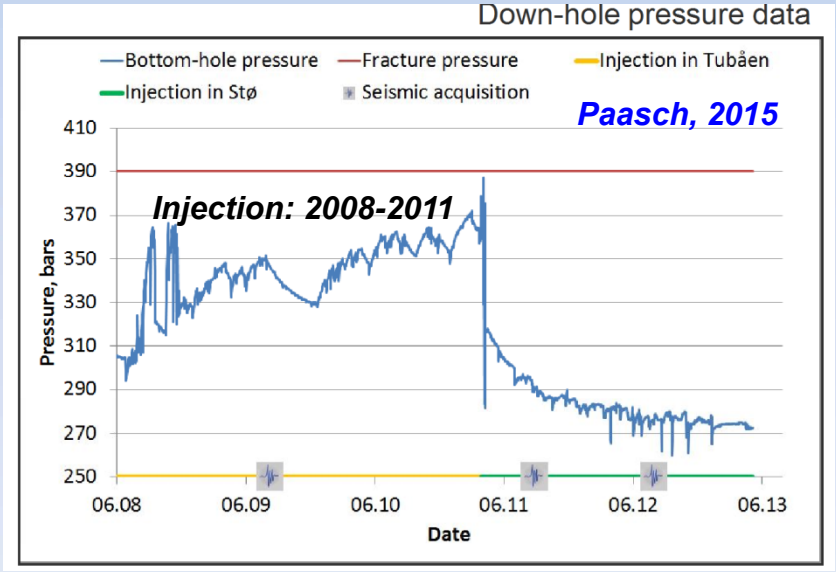
Storage Capacity & Monitoring Tech (1/3)

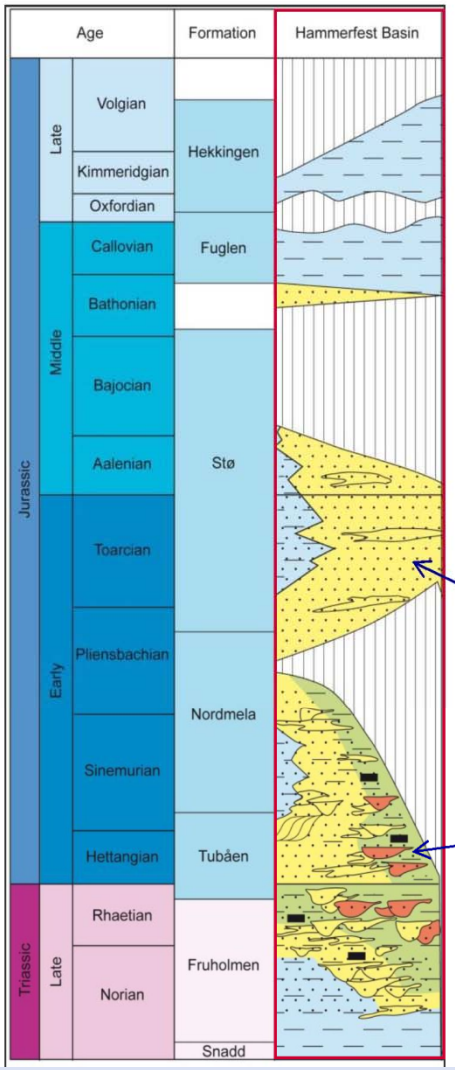


➢ ***Reservoir characterization: Heterogeneity and Injectivity***





Stratigraphy and Depositional Environment



@ Snohvit

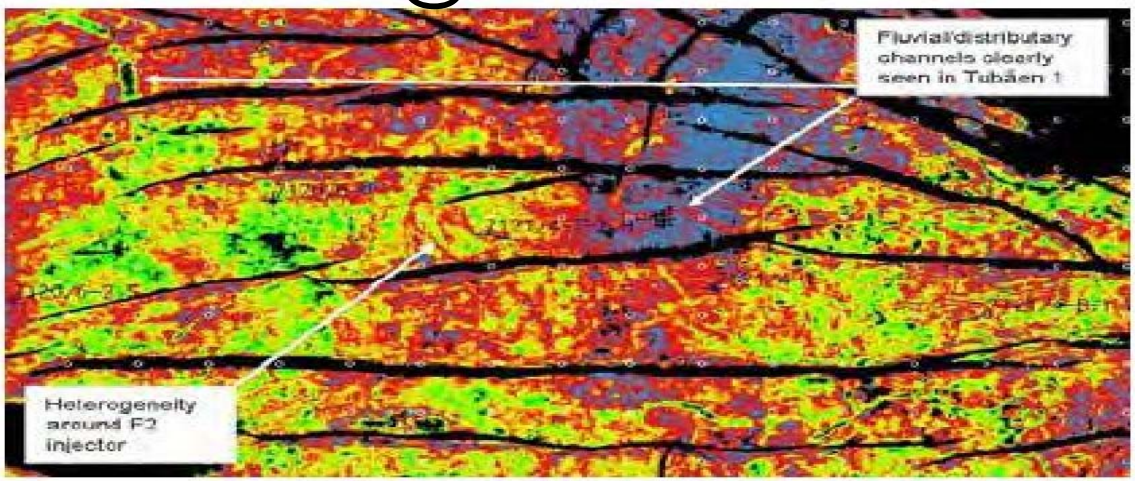


Figure 3: Amplitude map of the base Tubåen Fm reflection. Green colours are high amplitudes and blue colours low amplitudes.

Stø (main reservoir)

- Shallow-marine environment
- Good lateral and vertical communication

Tubåen

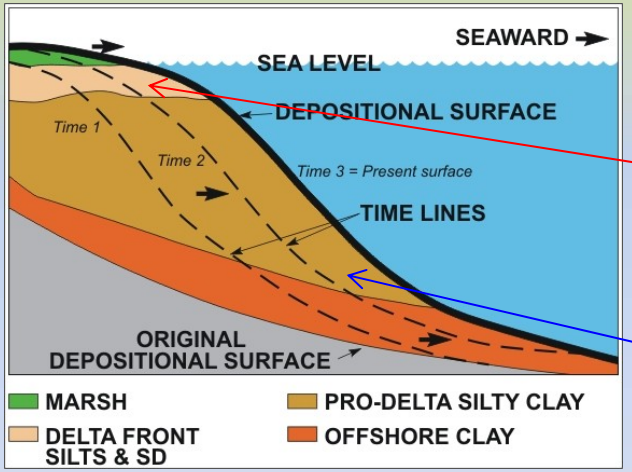
- Densely stacked fluvial channels
- Poor lateral and vertical communication

Paasch, 2015

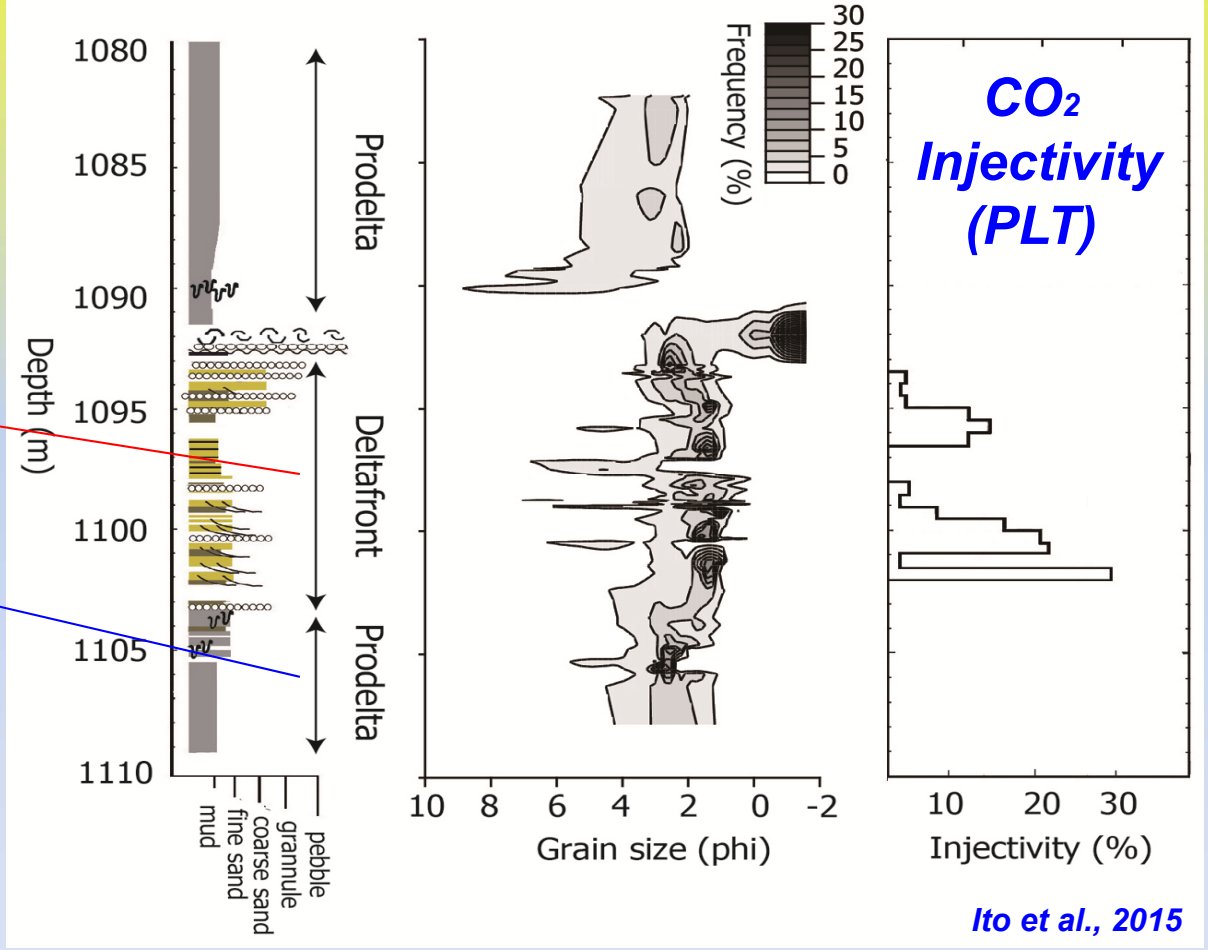
Integrating aspects from both 3D seismic and sequence stratigraphy

Application of Sequence Stratigraphy @ Nagaoka (injection well)

Clay content, γ-ray log



Porosity, Permeability



Ito et al., 2015

Detailed information at wells: Local to Spatial

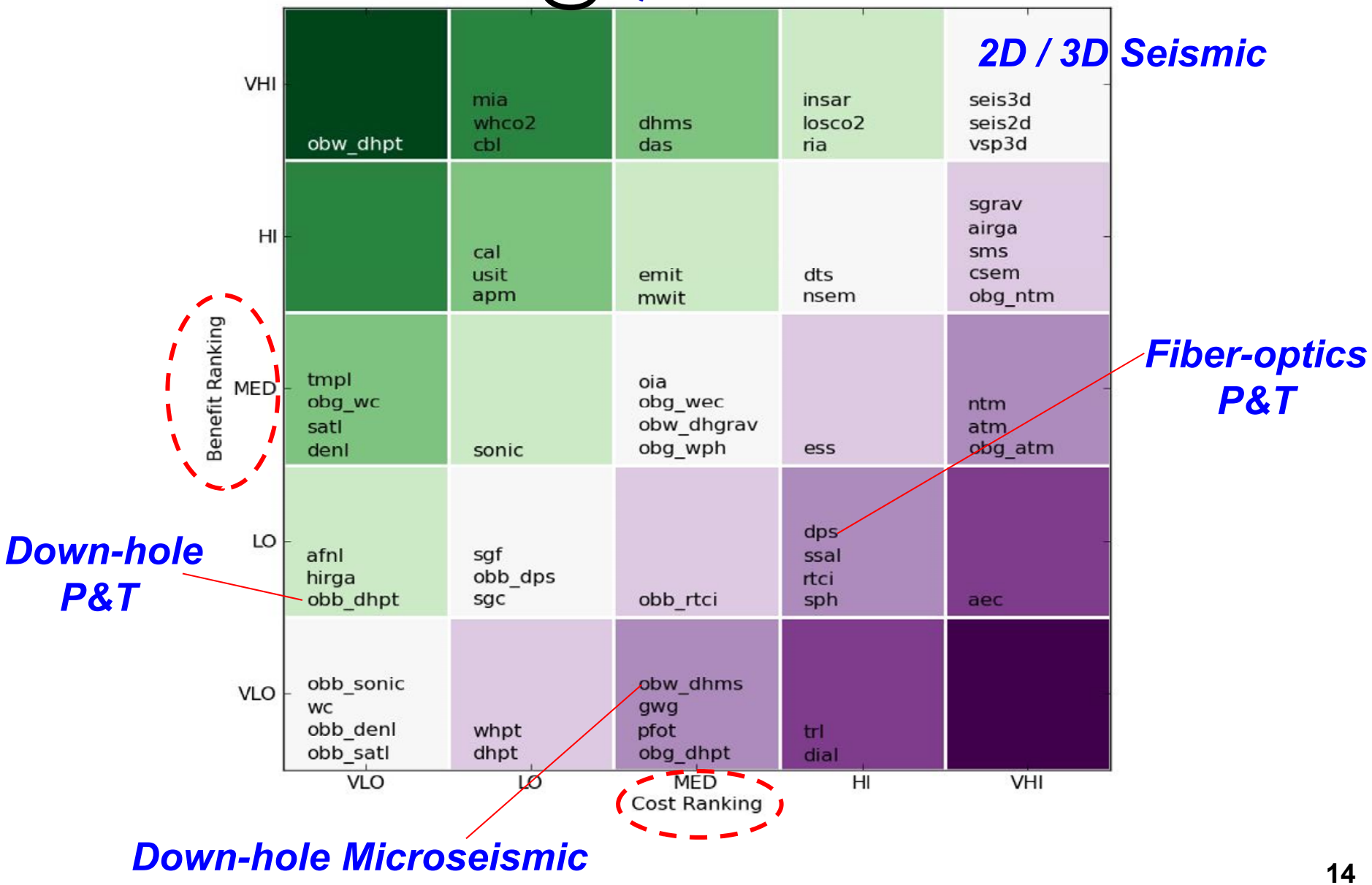
QUESTプロジェクトにおける貯留層評価（地質的不確実性）

Uncertainty

- Insufficient permeability – will only become apparent with the well has been drilled
- Insufficient connectivity – the further away the greater the exposure to this risk

貯留層の浸透率（圧入性）：坑井掘削後に判明
貯留層の連結性：遠くほどよりリスクに現れる

Measurement, Monitoring & Verification @QUEST



AQUISTORE（Boundary Dam）: MMV

Designed for: (1) project/plume monitoring; (2) public assurance; (3) research objectives

Surface-based:

- Regional 3D seismic survey
  - Geological characterization
  - Baseline & time-lapse
- Permanent seismic array
  - Time-lapse imaging
- Electrical/electromagnetic
- Gravity

PLUME

- Passive seismic (broadband & short period array)
- InSAR
- GPS
- Tiltmeters

DEFORMATION

- Groundwater & Soil gas monitoring
- Carbon Isotope profile

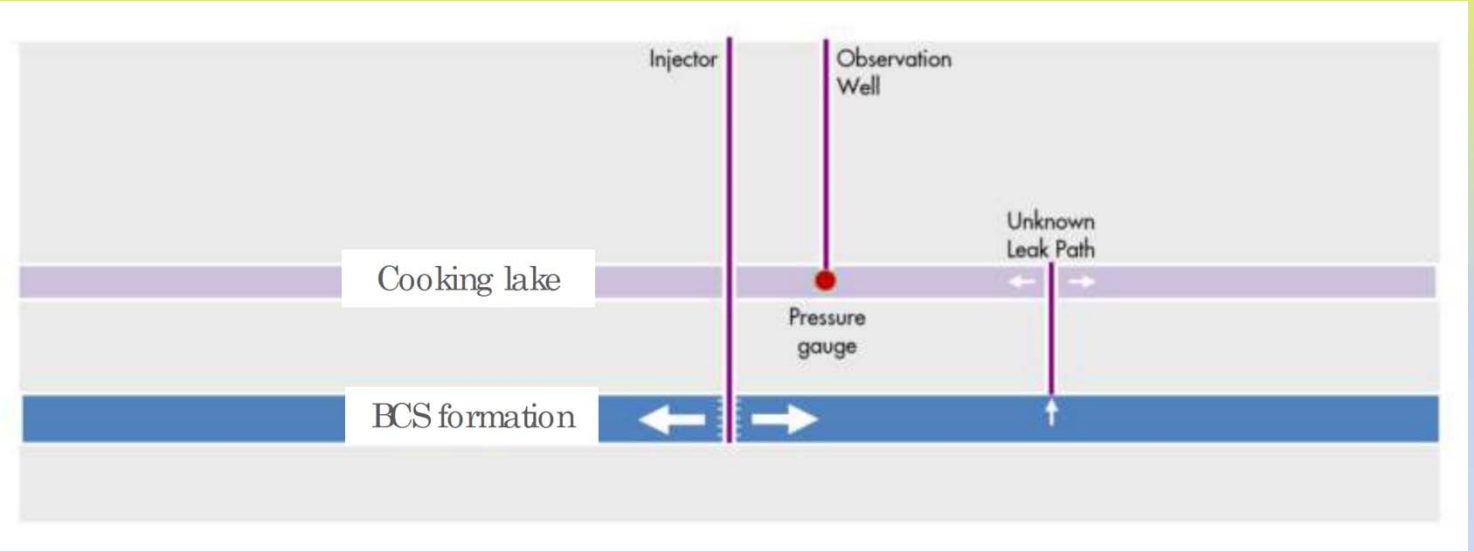
LEAKAGE

Down-hole

- Cross-well seismic & VSP
- Cross-well & surface-to-downhole electrical monitoring
- Real-time P & T
- Passive seismic
- Fluid sampling
- Time-lapse logging
- Distributed Acoustic/Temperature Sensors (DAS/DTS)
- Heater cable
- Gravity

IN SITU

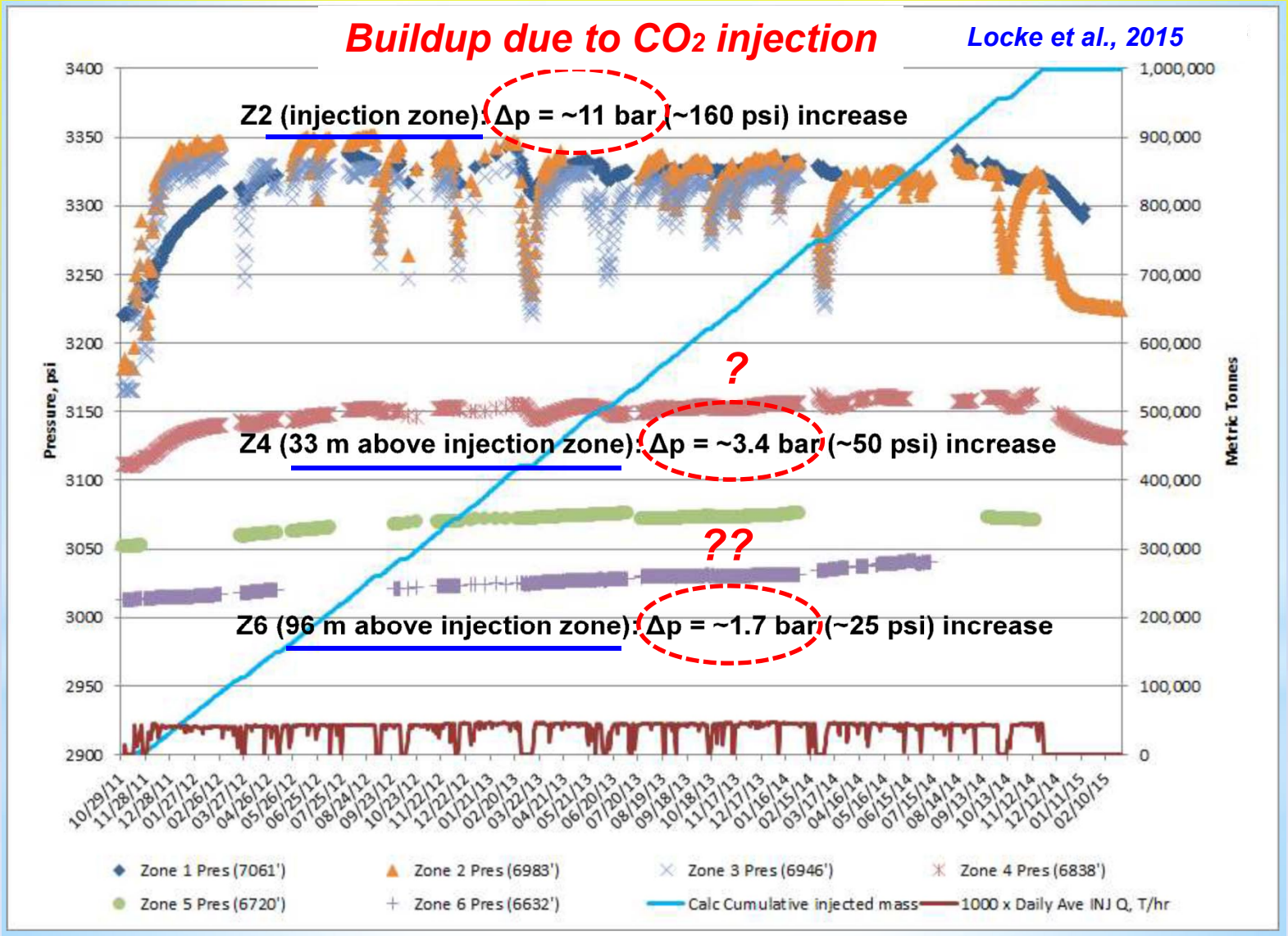
米国やカナダにおける地下水保護
貯留層からのCO_2漏洩検知：上位層の圧力測定



QUESTのCO_2漏洩検知シミュレーション

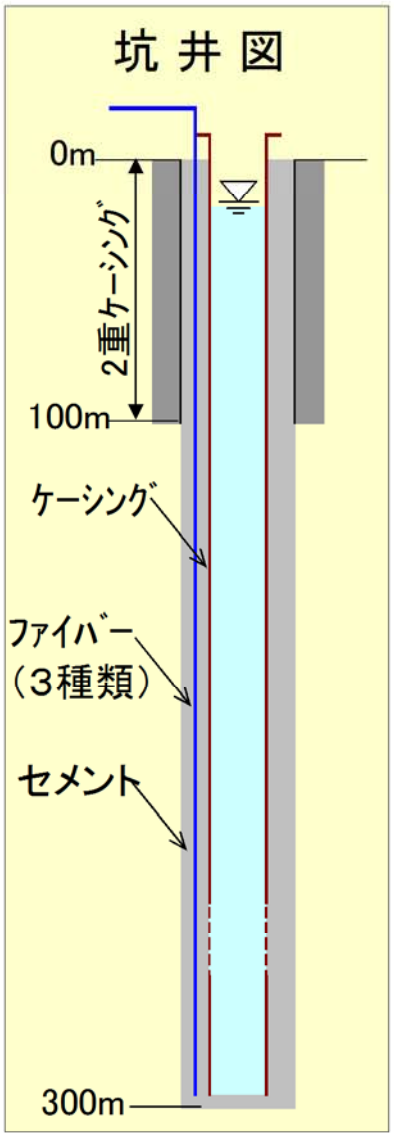
Modelled two hypothetical leak rates, 6 kg/day and 600 kg/day. For reference we inject 2700 tonnes/day: 4000 years to leak 1 day's injection at 600kg/day

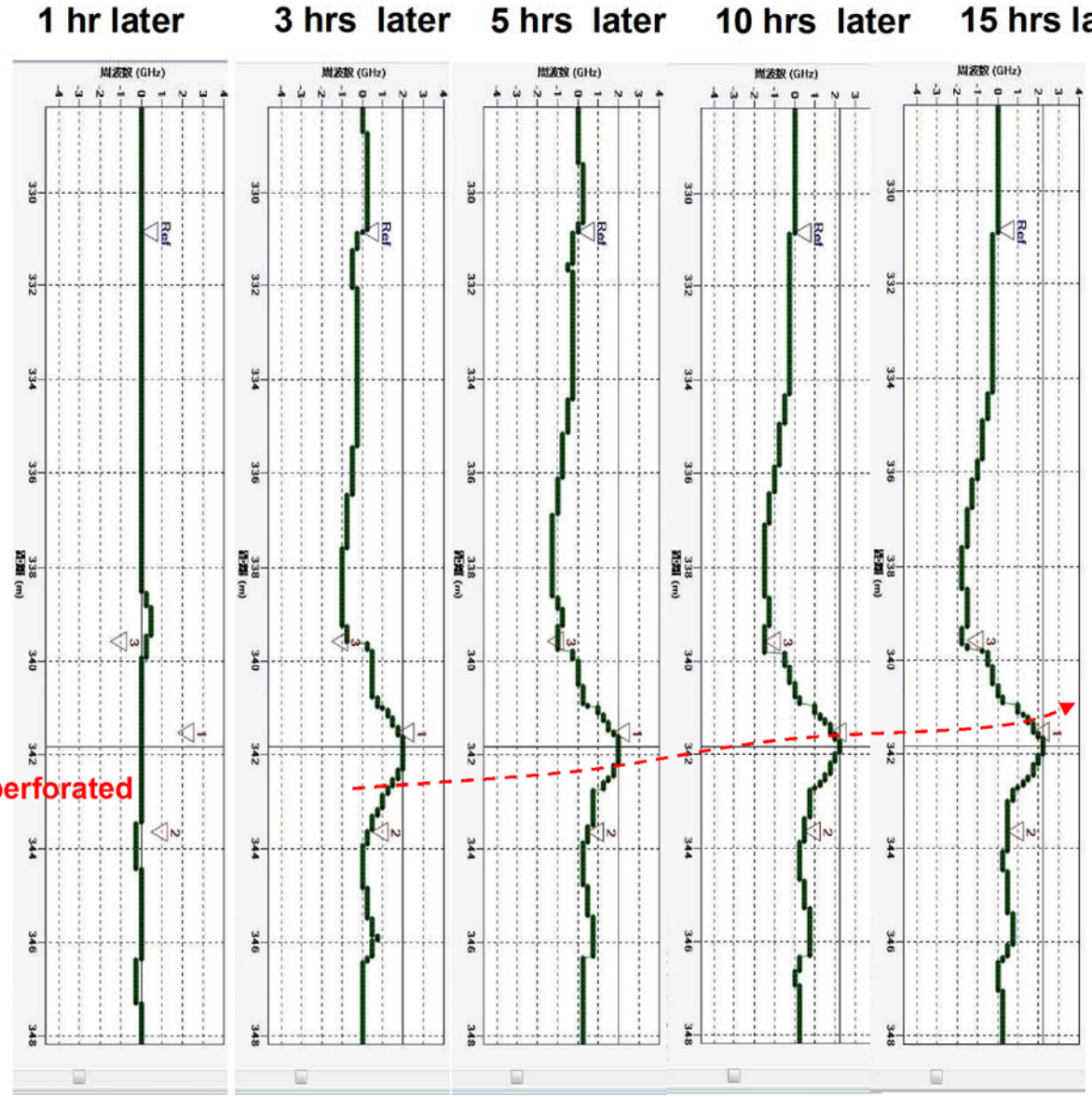
圧力モニタリング@ Decatur (Illinois)



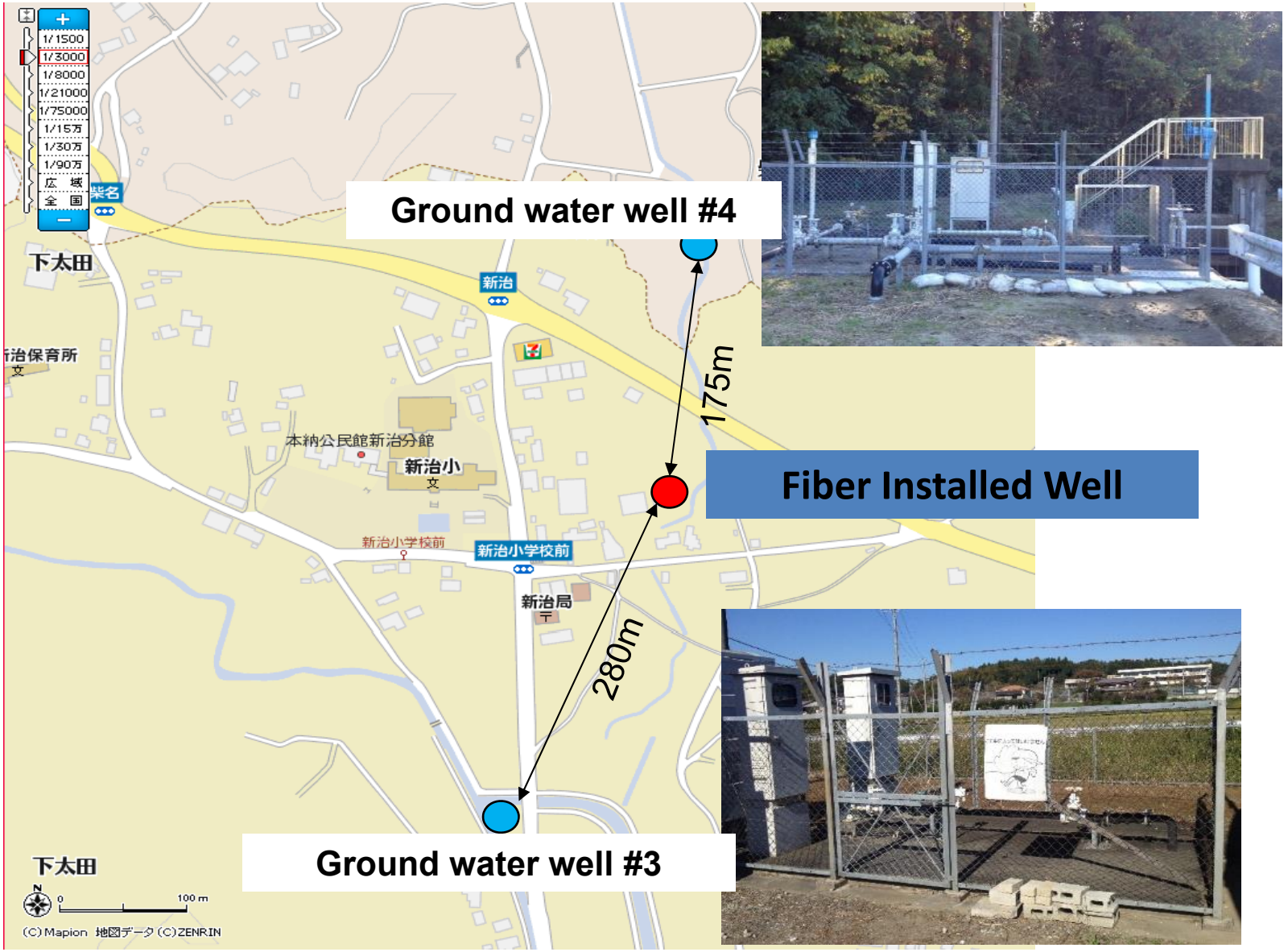
Geomechanics: Pressure change →→→ Deformation

光ファイバーによって検出できた流体圧入時の地層変形

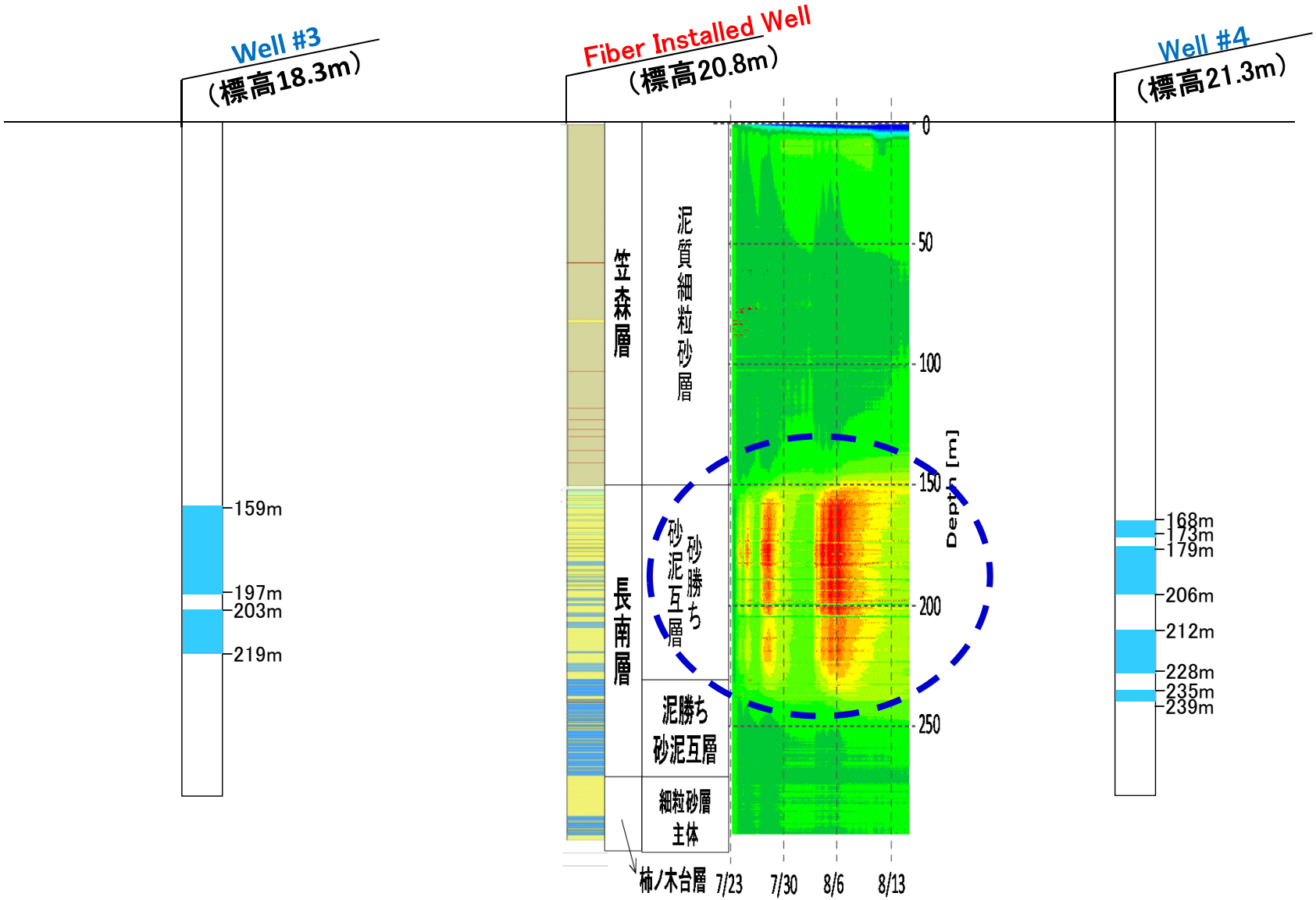




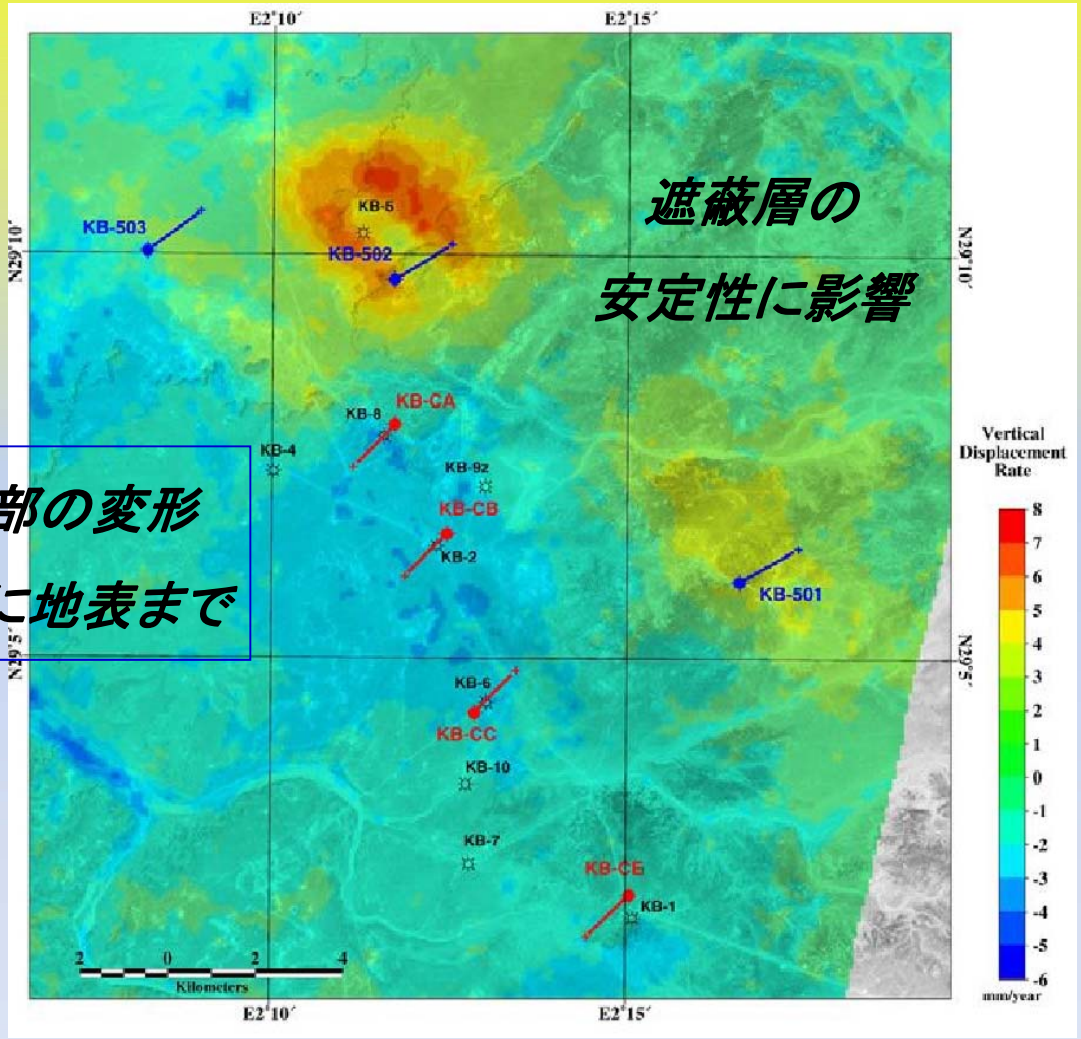
近傍坑井からの揚水に伴う地層変形 (1/2)



近傍坑井からの揚水に伴う地層変形 (2/2)



貯留層＆遮蔽層の力学的安定性評価



遮蔽層の

安定性に影響

地下深部の変形

どのように地表まで

InSAR解析結果

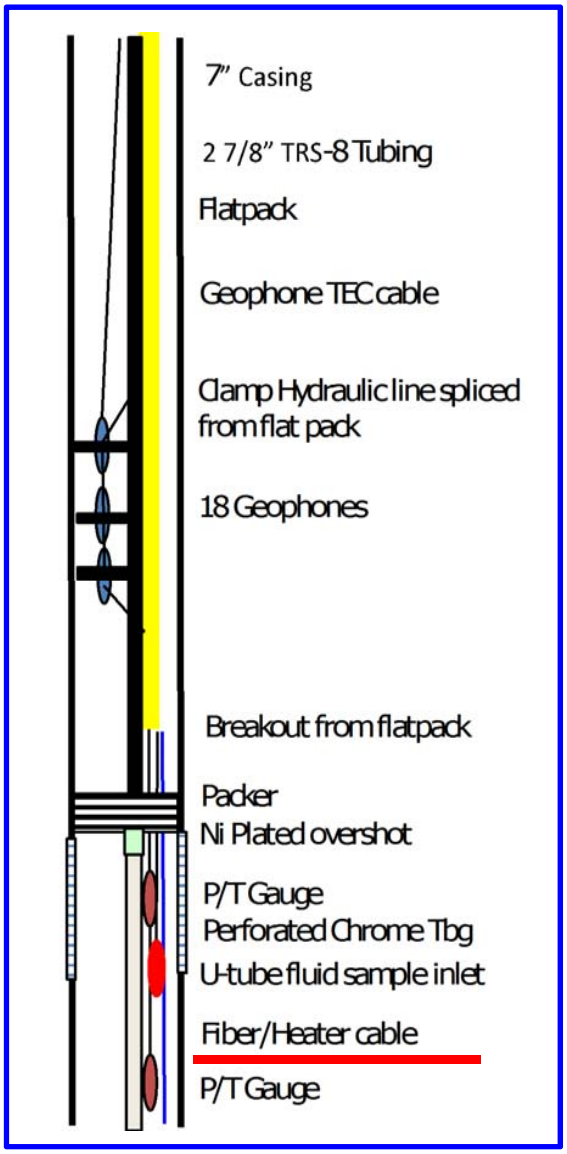
CO_2圧入井付近の
地表隆起

CO_2圧入による

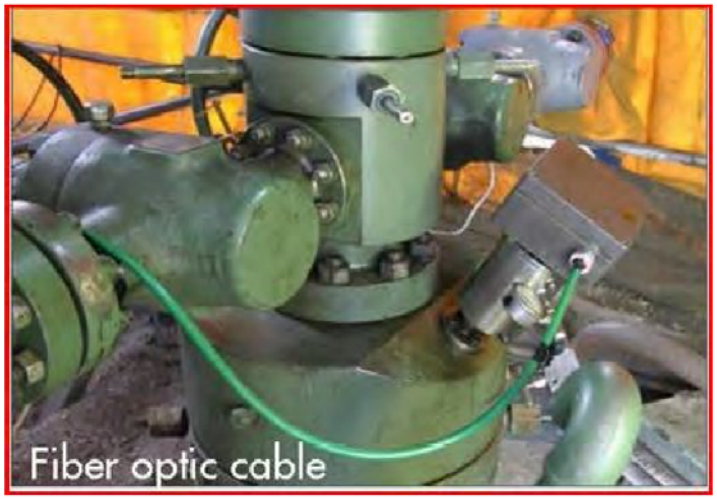
地層圧の増加

深度方向に連続的なデータ取得方法？

光ファイバーセンシング技術@CCS

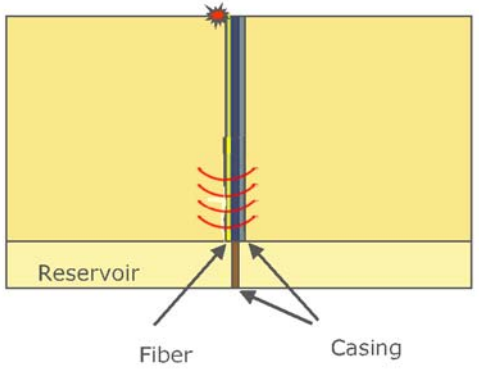


QUEST Project



Zero-Offset Source for CO2 Leak Detection

Velocity change in overlying formations



CO2漏洩検知

DTS - Distributed Temperature System ***温度***

DAS - Distributed Acoustic System ***音波***

坑井健全性監視

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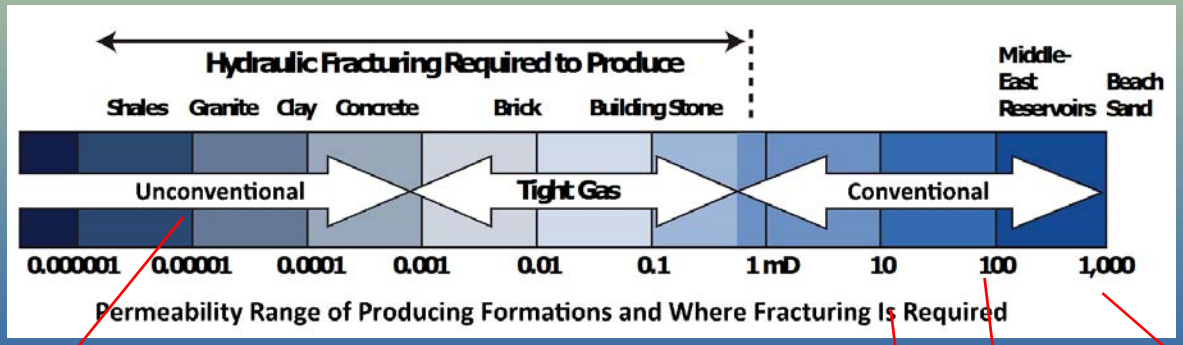
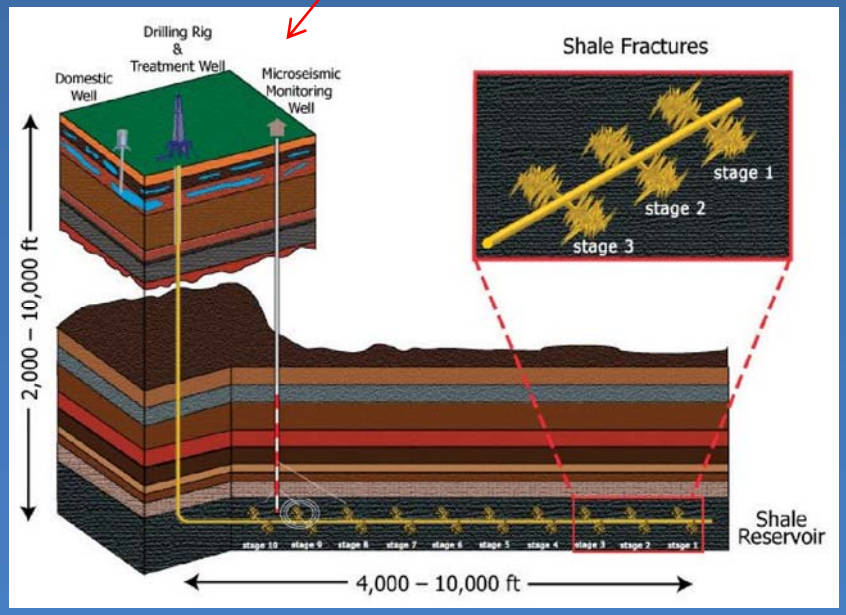
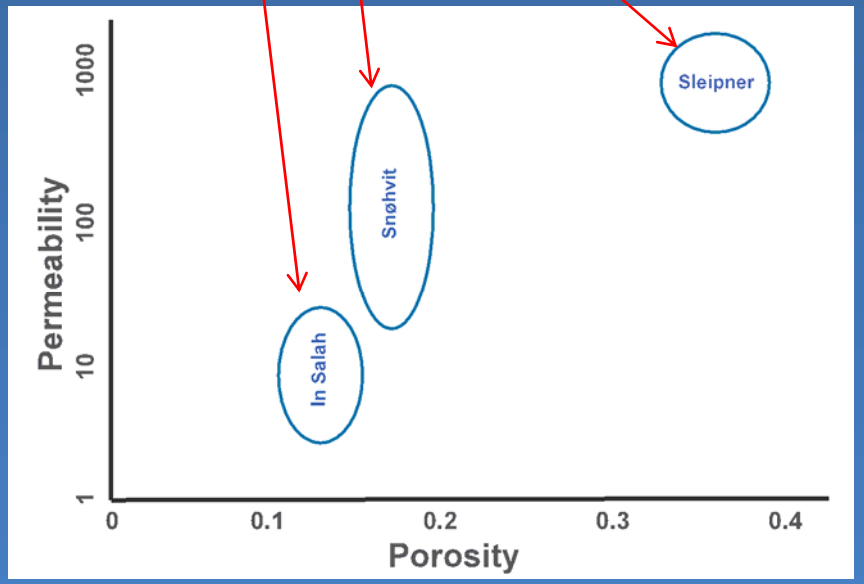
地熱、非在来型油ガス、CO_2地中貯留における流体圧入







National Academy of Sciences, 2013

米国内のエネルギー開発分野における有感地震の報告

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

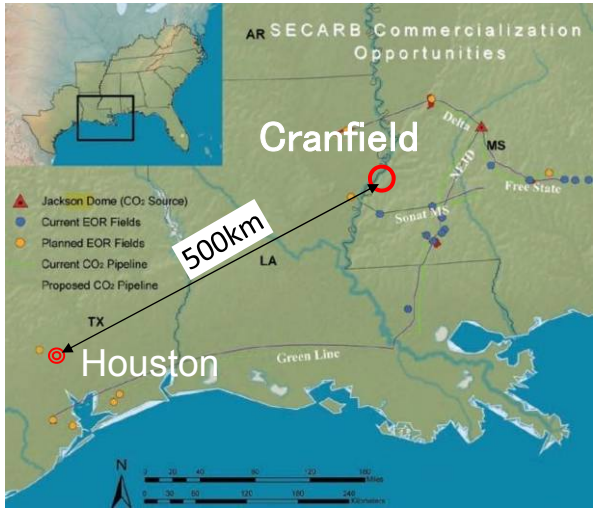
Weyburn（CO_2-EOR）からの現場観測報告

Magnitude	Equivalent TNT Radiated Energy	Energy Comparison
+3	480 kilograms	Large potash mine earthquake
+2	15 kilograms	Small potash mine earthquake
+1	480 grams	10 ton trucks collide
0	15 grams	Jump off a tall building
-1	0.5 gram	30-30 rifle bullet
-2	15 miligram	Drop a large dictionary
-3	0.5 miligram	Break a small stick

微小振動

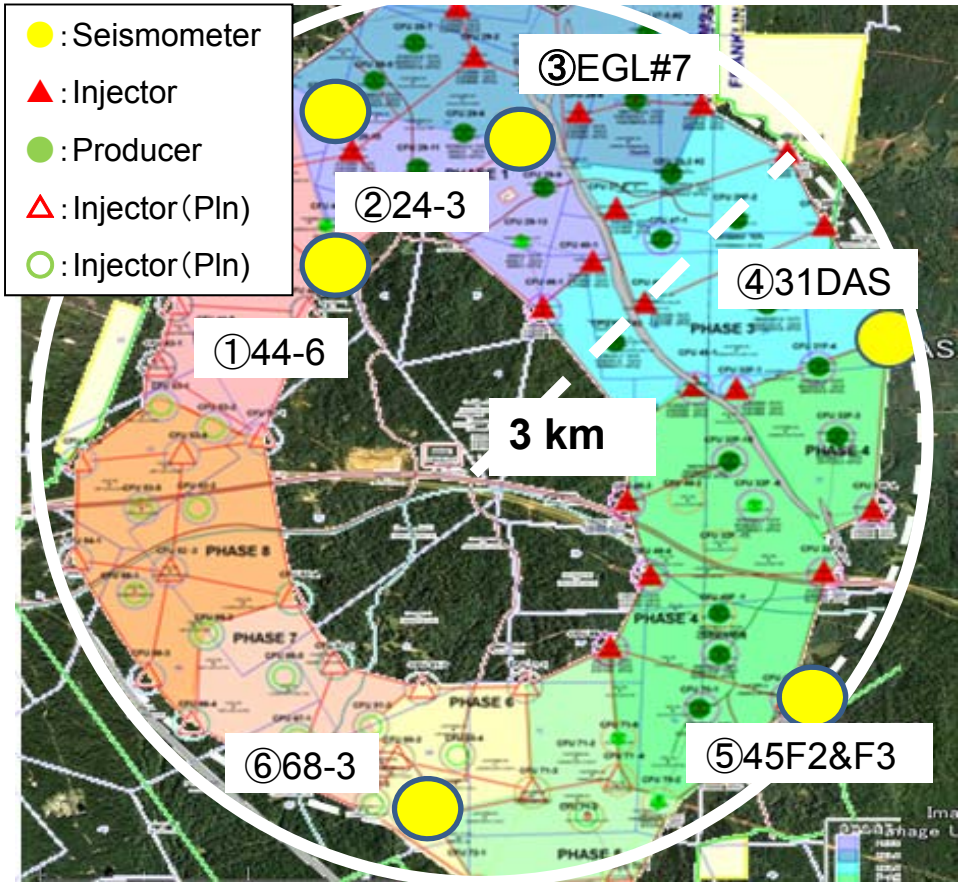
Red = Weyburn CO_2 injection micro-earthquake sizes

米国の大規模CO_2圧入サイトでの微小振動観測（1/2）



試験サイト(ミシシッピ州Cranfield油田)

微小振動観測点（全6点）



2012年7月Denbury社より提供

・2007年～圧入開始。既に400万t圧入済（100万t/年）
・2011年12月より観測開始； 2015年3月観測終了

CO_2圧入量が多い、地震活動性が低い → **CO_2圧入と微小振動との関連性**

米国の大規模CO_2圧入サイトでの微小振動観測（2/2）

2011/12～2015/3の観測データ

↓

ノイズ状況の確認

↓

①処理・解析ツール、および
②目視確認による
微小振動イベント抽出作業

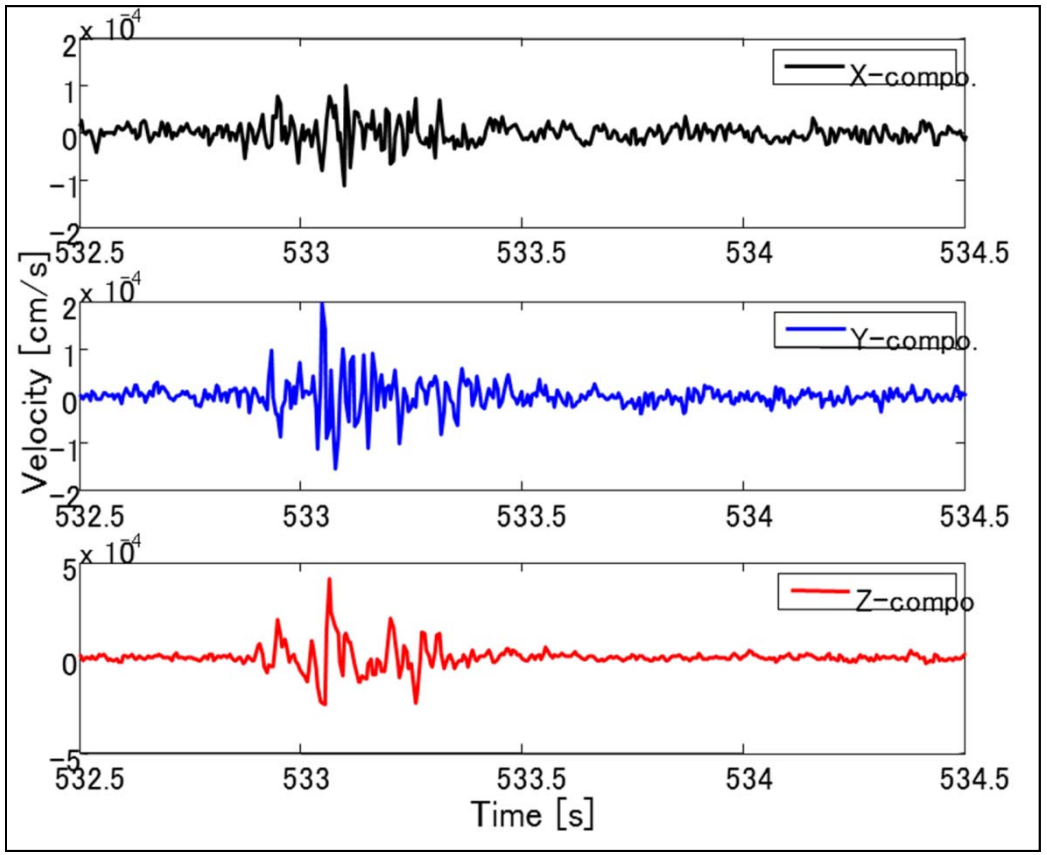
↓

観測データ中に高周波・ごく低周波ノイズ、落雷によるノイズ、遠地地震などを確認

↓

期間中に微小振動イベントは認められなかった

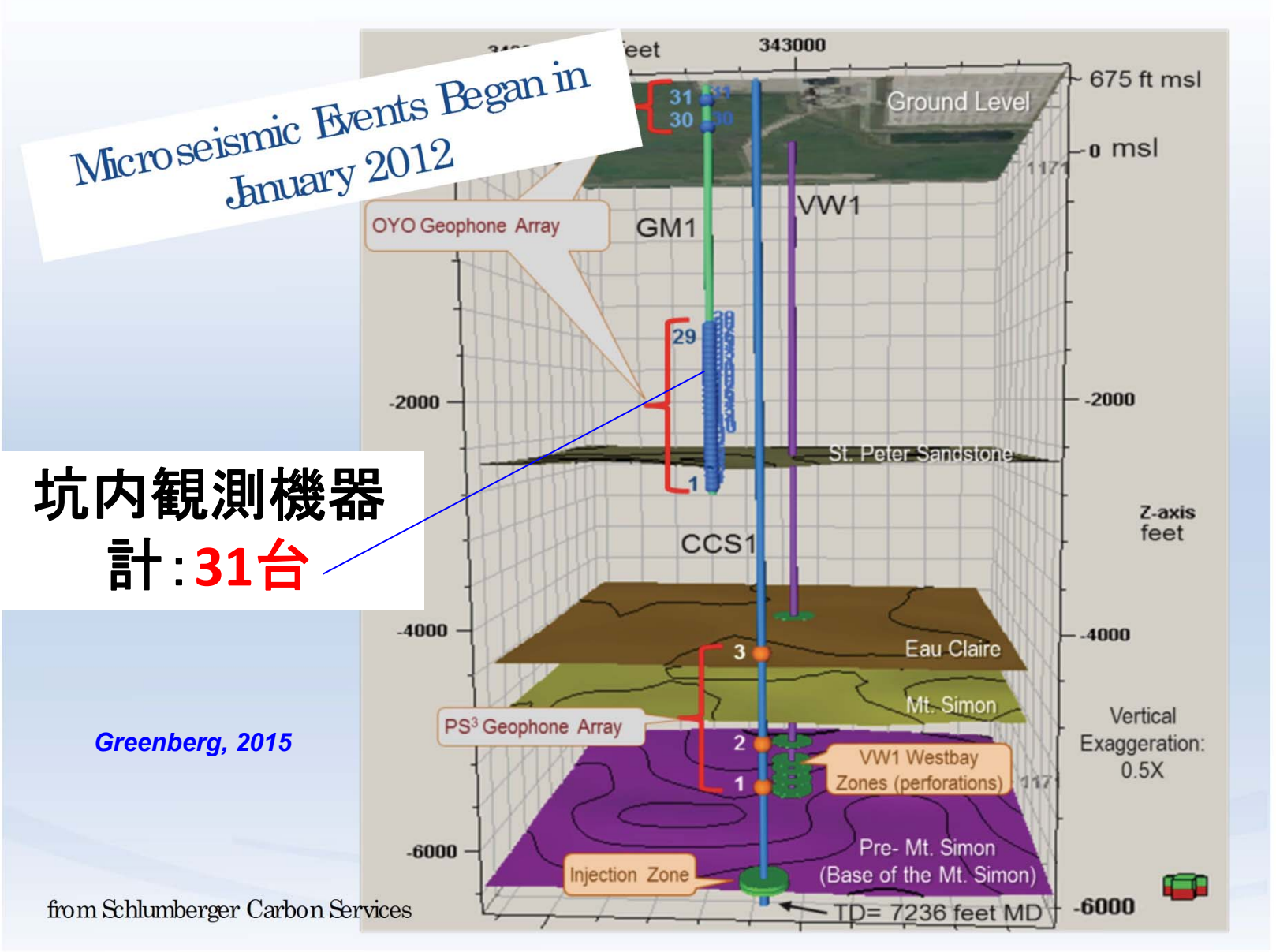
✓Z成分の最大振幅より、M-0.2と推定



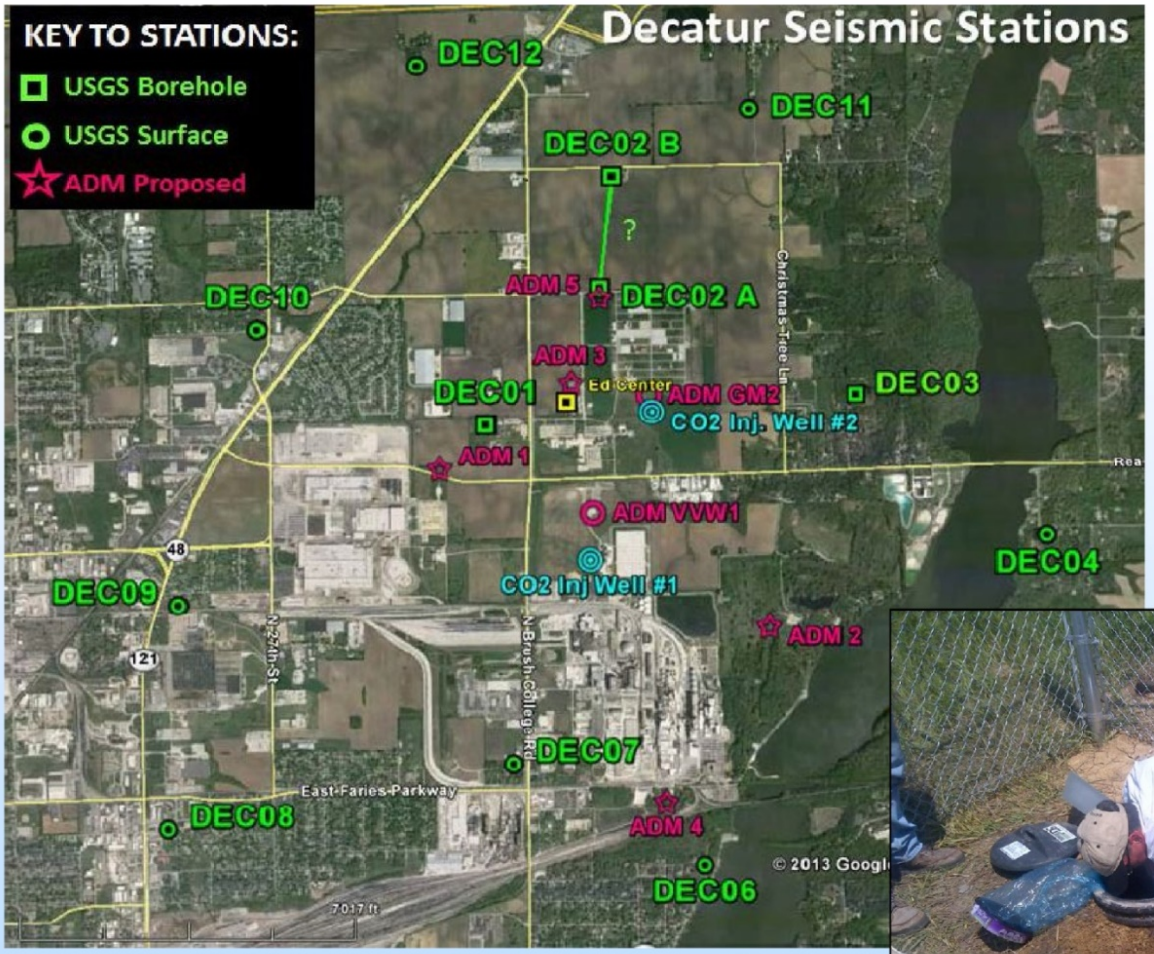
発破地点から 最も近いDAS31サイトのみ観測された！

→ 大規模実証試験や実用化への知見提供（システム構築、解析手法）

米国Decaturサイトの微小振動観測事例（1/5）



米国Decaturサイトの微小振動観測事例（2/5）

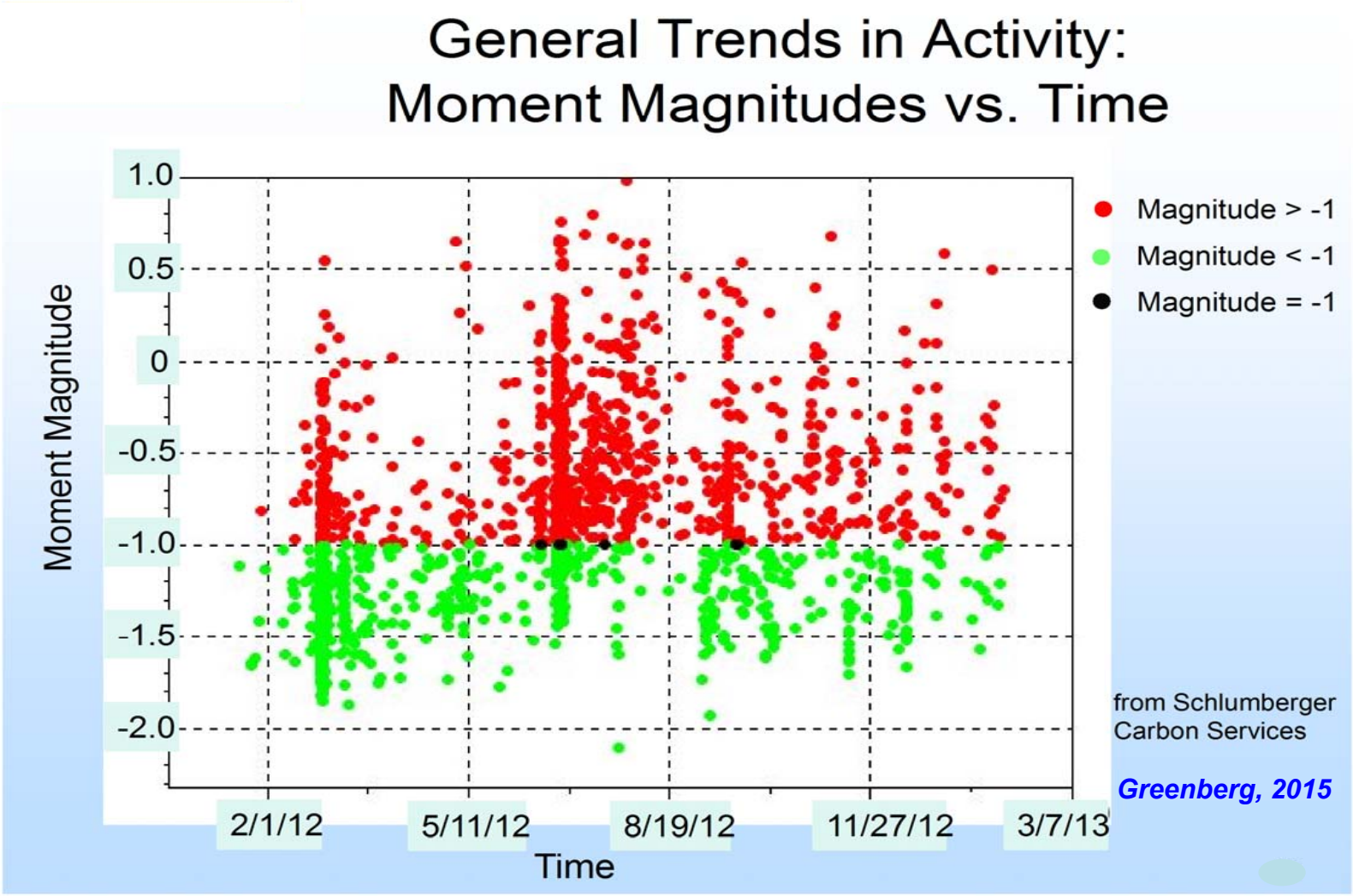


MGSC Installed Five Surface seismic Stations: ADM1-5

Finley, 2013

地上＆地表浅部の観測機器計：17台

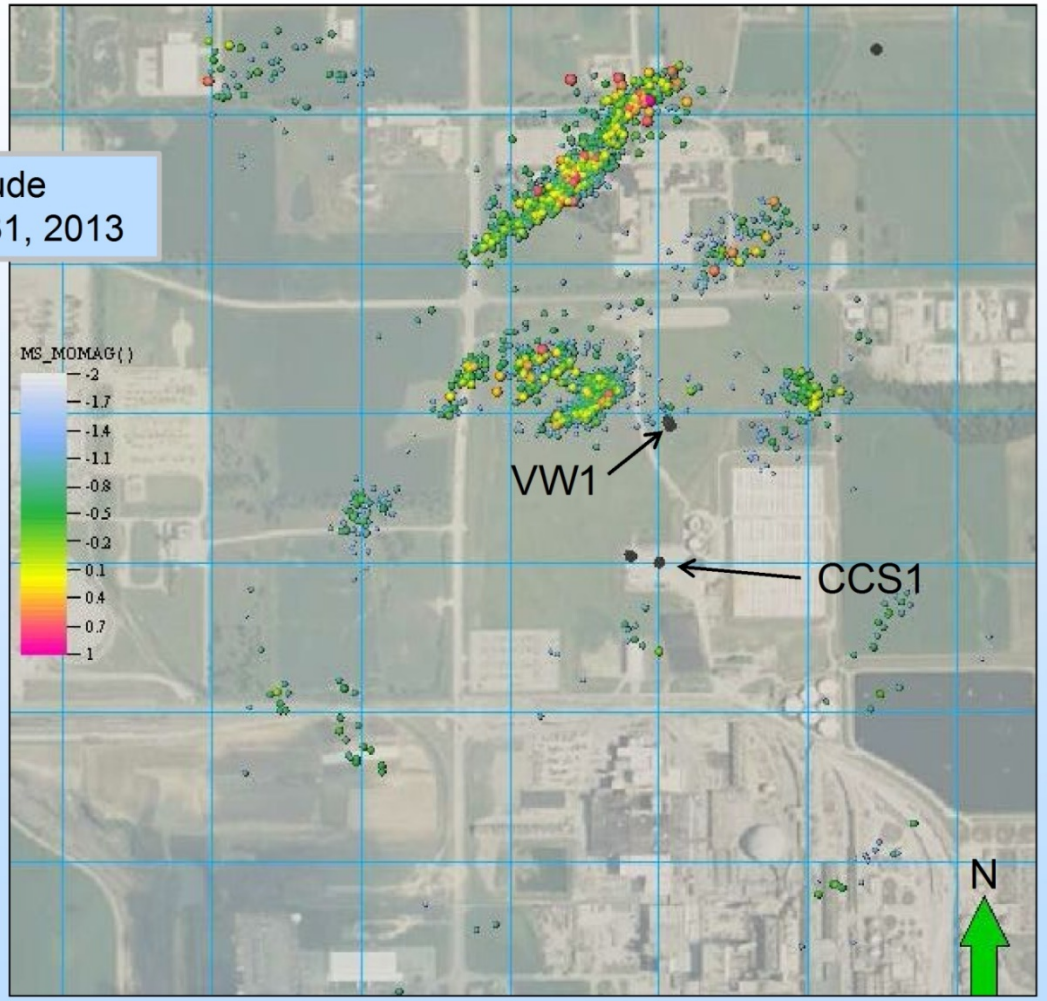
米国Decaturサイトの微小振動観測事例（3/5）



米国Decaturサイトの微小振動観測事例（4/5）

Microseismic Cluster Activity: Cluster Locations with Relation to Surface

Moment Magnitude
Jan 18, 2012 – July 31, 2013

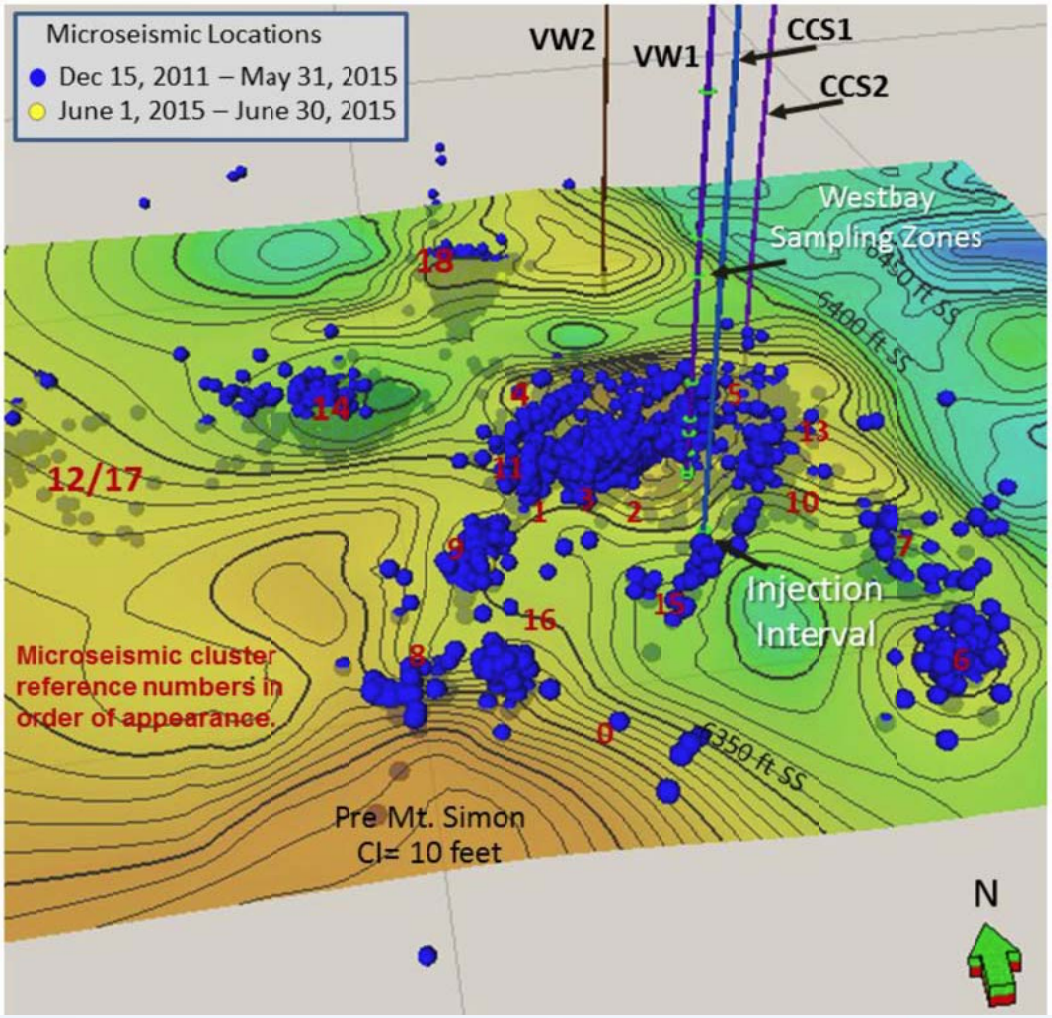


Inject, Monitor, and Model

Greenberg, 2015

from Schlumberger Carbon Services

米国Decaturサイトの微小振動観測事例（5/5）

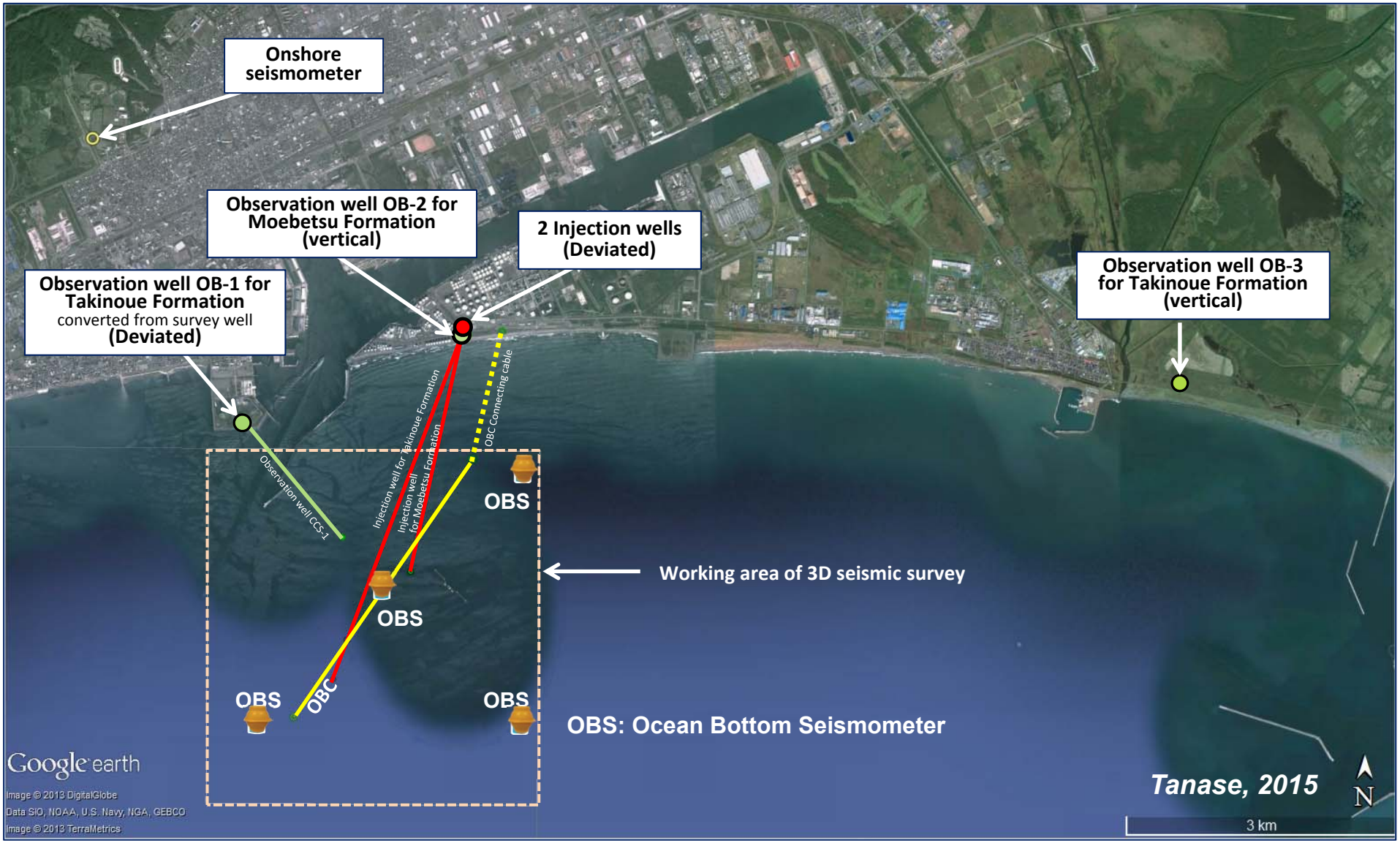


Microseismic Cluster Activity: Relationship to Basement Structure

Greenberg, 2015

from Schlumberger Carbon Services

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

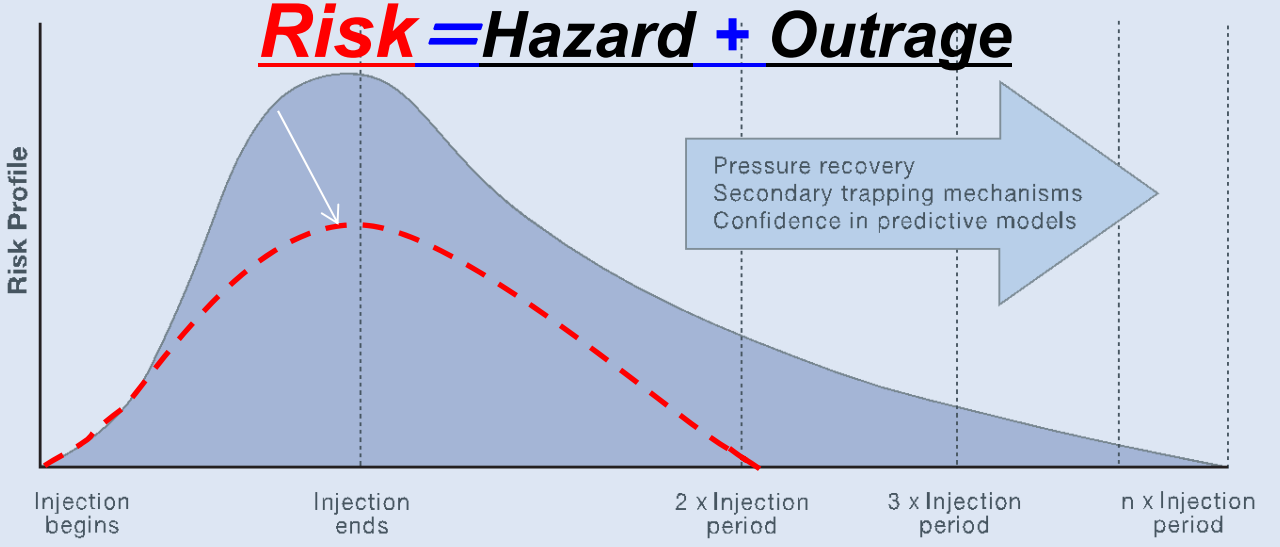


CO_2圧入実証試験より、不確実性への理解を深め、リスクマネジメントを学ぶ

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 !