◆ 革新的環境技術シンポジウム 2018 ◆

CO_2地中貯留技術の実用化に向けての安全管理技術開発の取り組み

(公財)地球環境産業技術研究機構（RITE）
CO_2貯留研究グループリーダー

二酸化炭素地中貯留技術研究組合・技術部長

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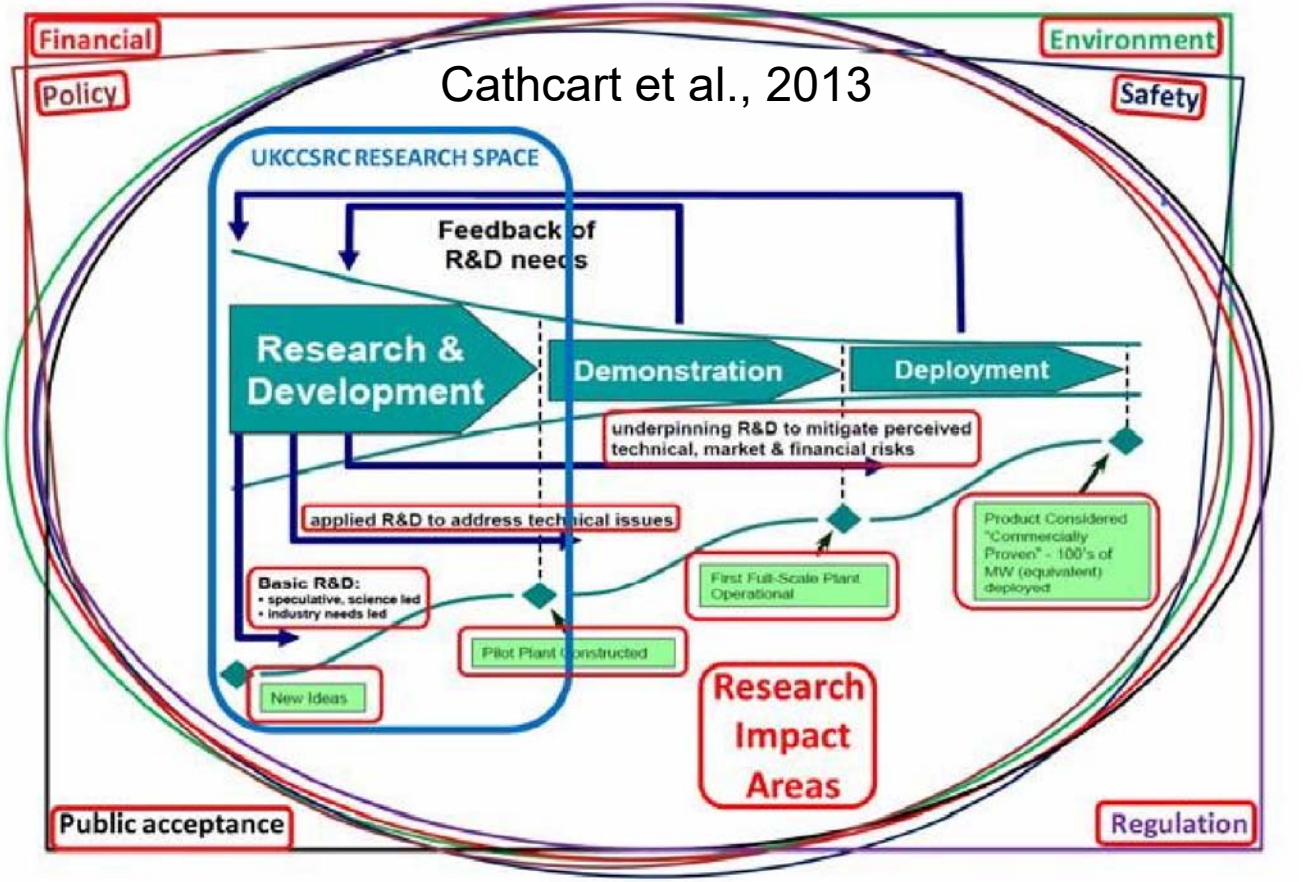
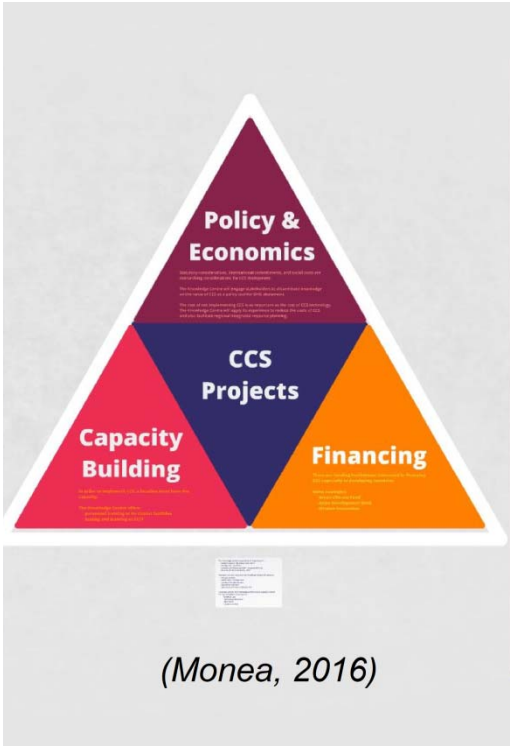
地中貯留技術の実用化・事業化へ





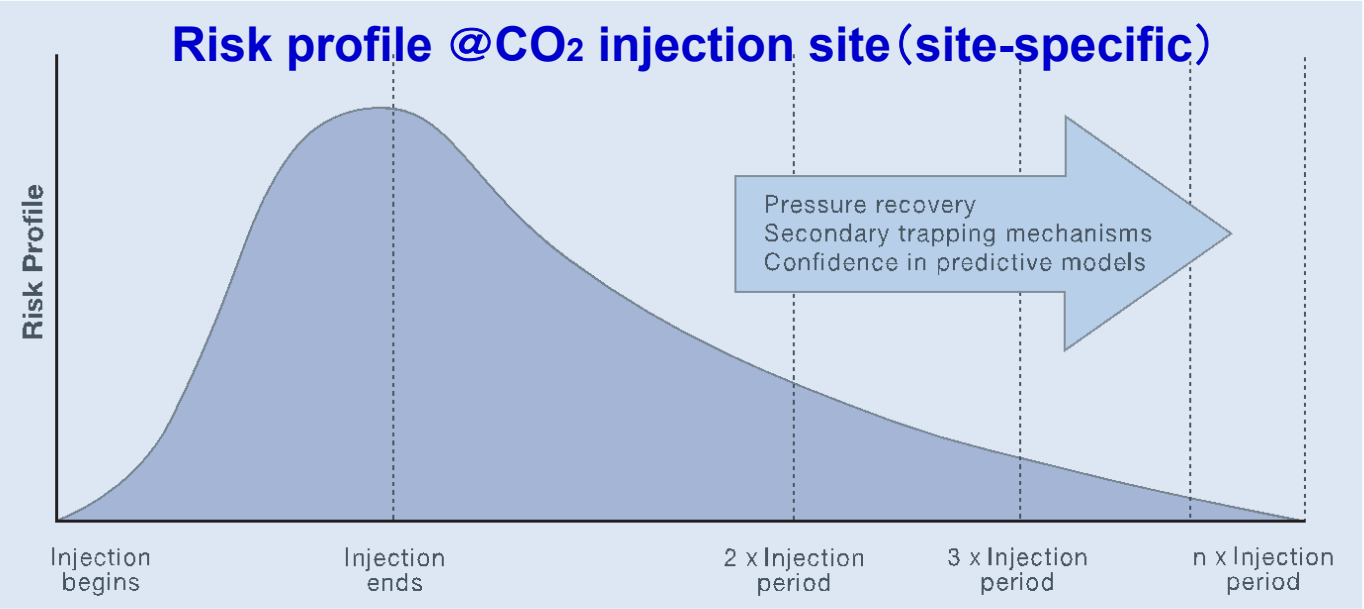
(Monea, 2016)

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

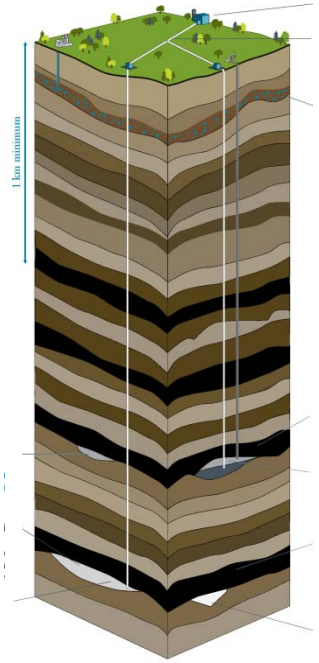
（コスト）　　（安全性）

➢Safety/Risk Assessment in CO_2 Storage

·*Potential Risks*

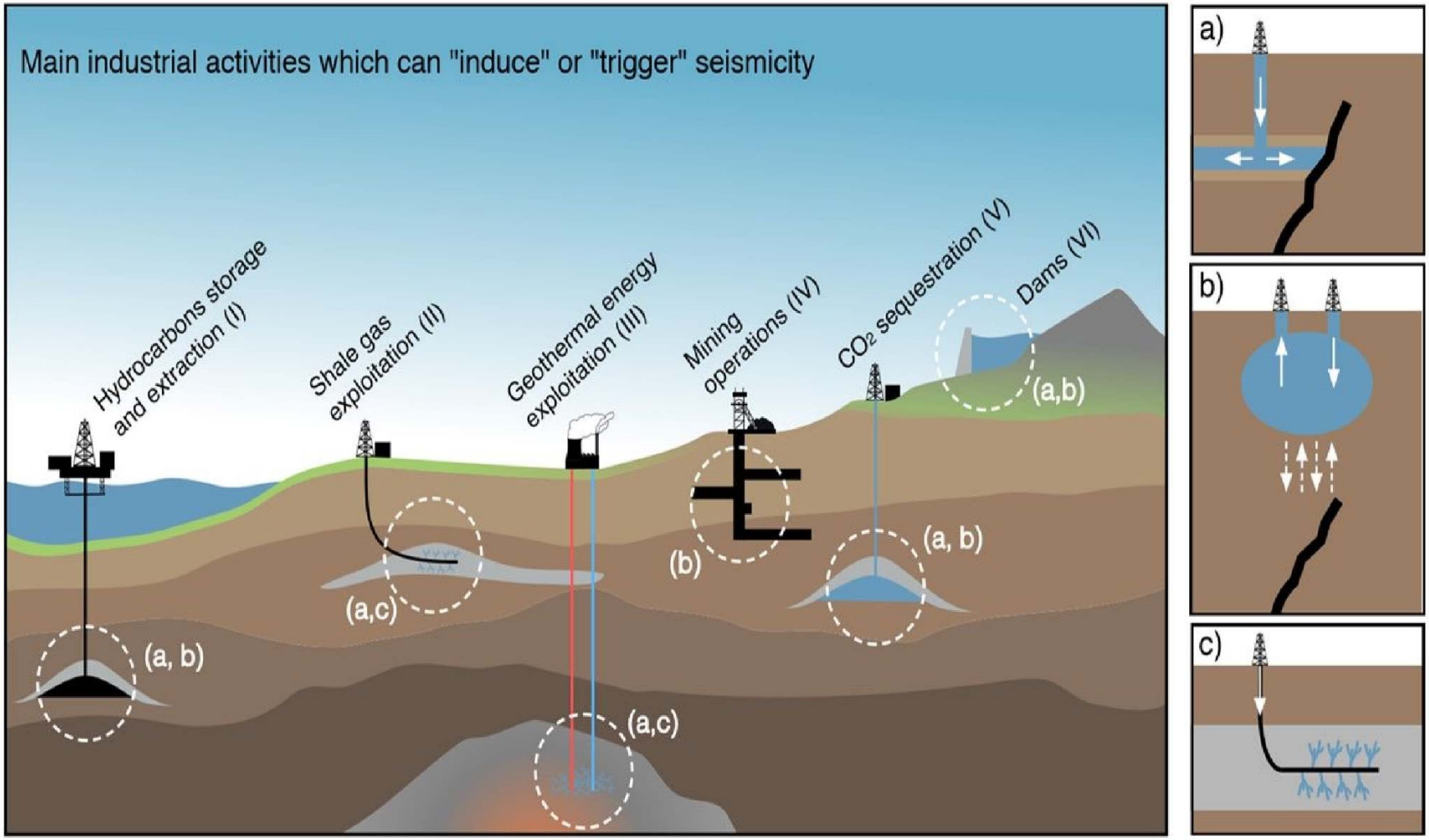


[Illustration source: Benson, 2007]



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

人類の産業活動に係わる minor earthquakes and tremors



A variety of anthropogenic activities can trigger minor earthquakes and tremors.

地下への流体圧入

（地熱開発、水圧破砕、非在来型資源開発）

地層の間隙水圧力（pore pressure）増加、

有効応力（effective stress）減少

Injection-Induced Seismicity

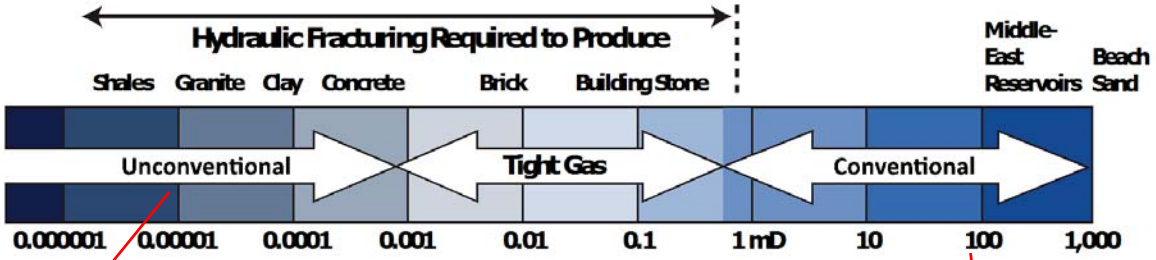
地下資源開発、CO_2地中貯留

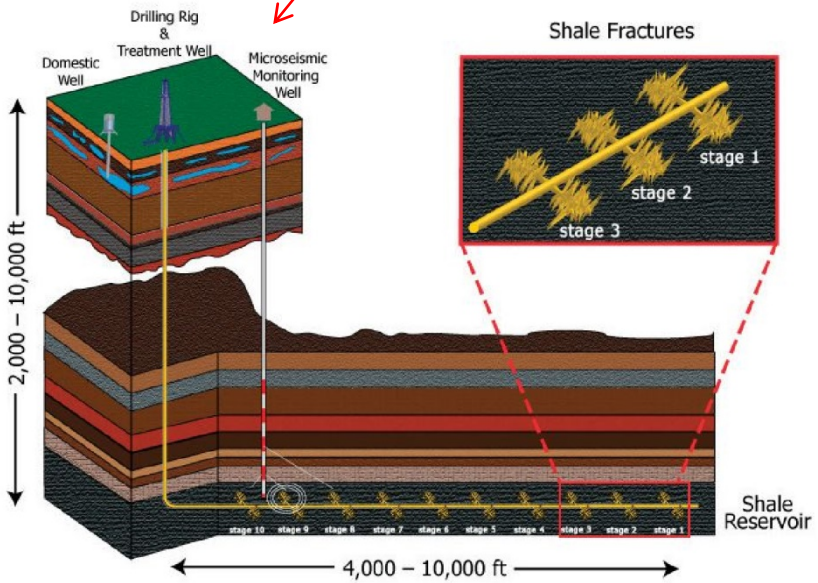
米国内のエネルギー開発分野における有感地震の報告

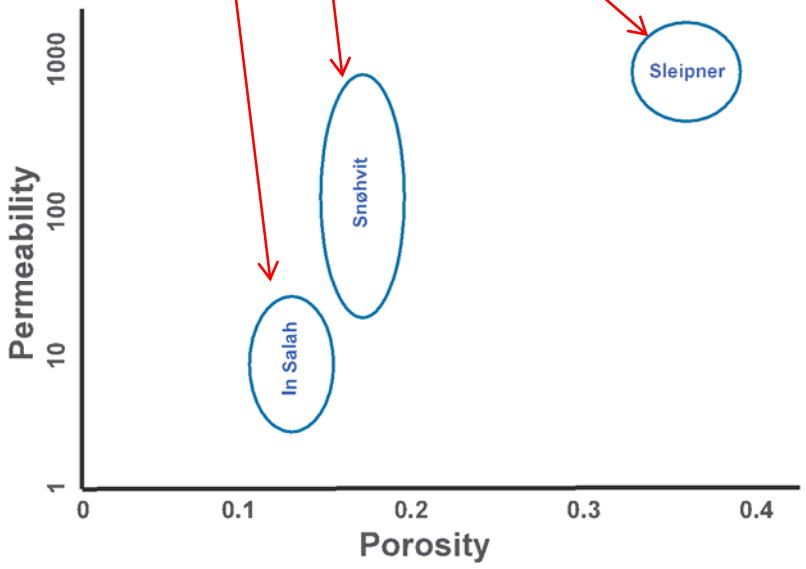
Energy Technology	Number of **Current** Projects	Number of **Historical** Felt Events	**Historical** Number of Events M≥4.0	Locations of Events M≥2.0
Geothermal				
Vapor-dominated (The Geysers)	1	300-400 per year since 2005	1 to 3	CA
Liquid-dominated	23	10-40 per year	Possibly one	CA
EGS	~8 pilot	2-10 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

地熱開発、非在来型資源開発、CO_2地中貯留における貯留層の差異（浸透性）







National Academy of Sciences, 2013

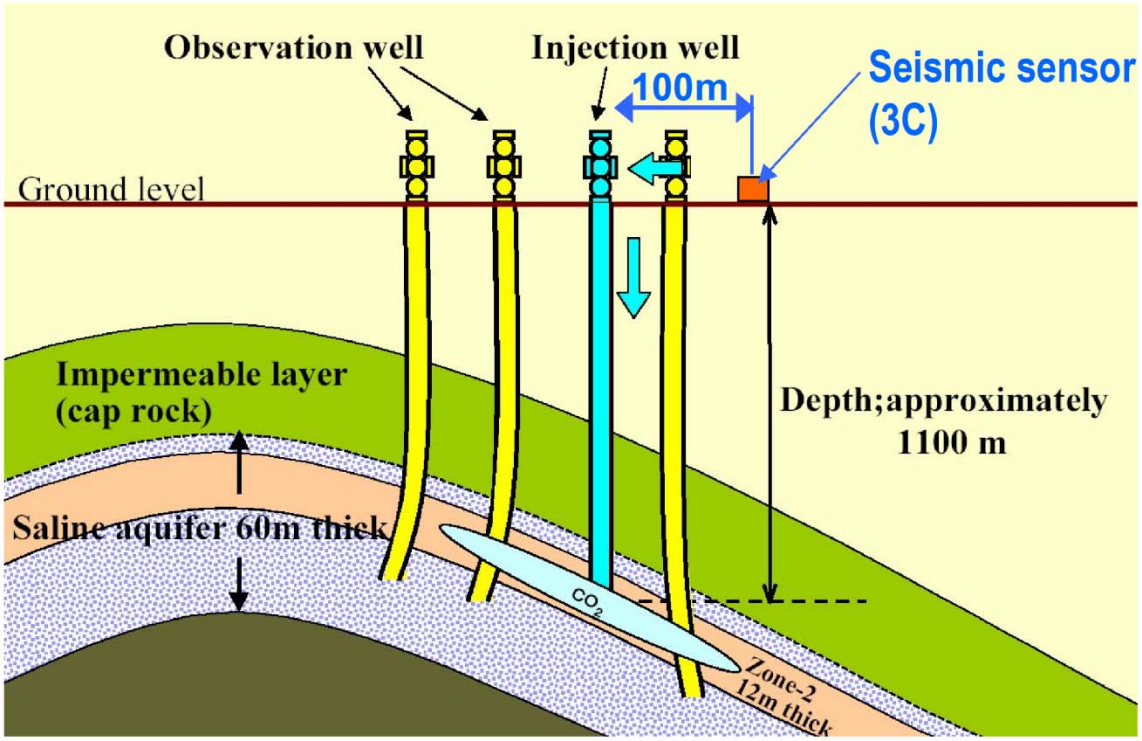
Earthquake and Micro-Earthquake Comparison

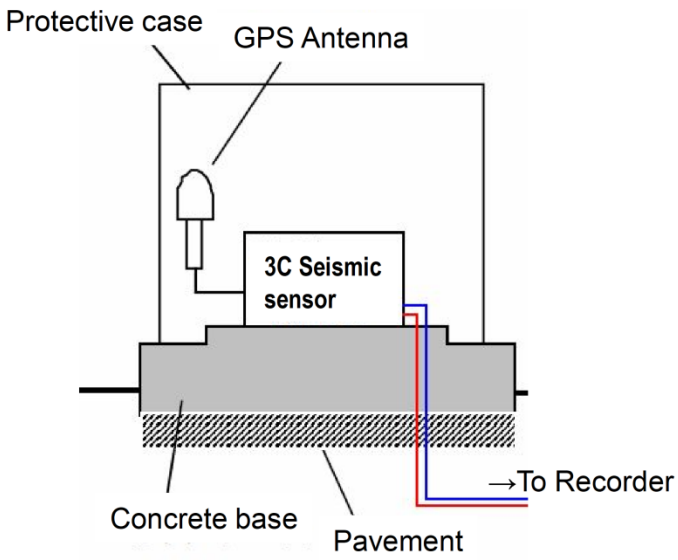
（微小地震/微小振動）

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

Red = Weyburn CO_2 injection micro-earthquake sizes

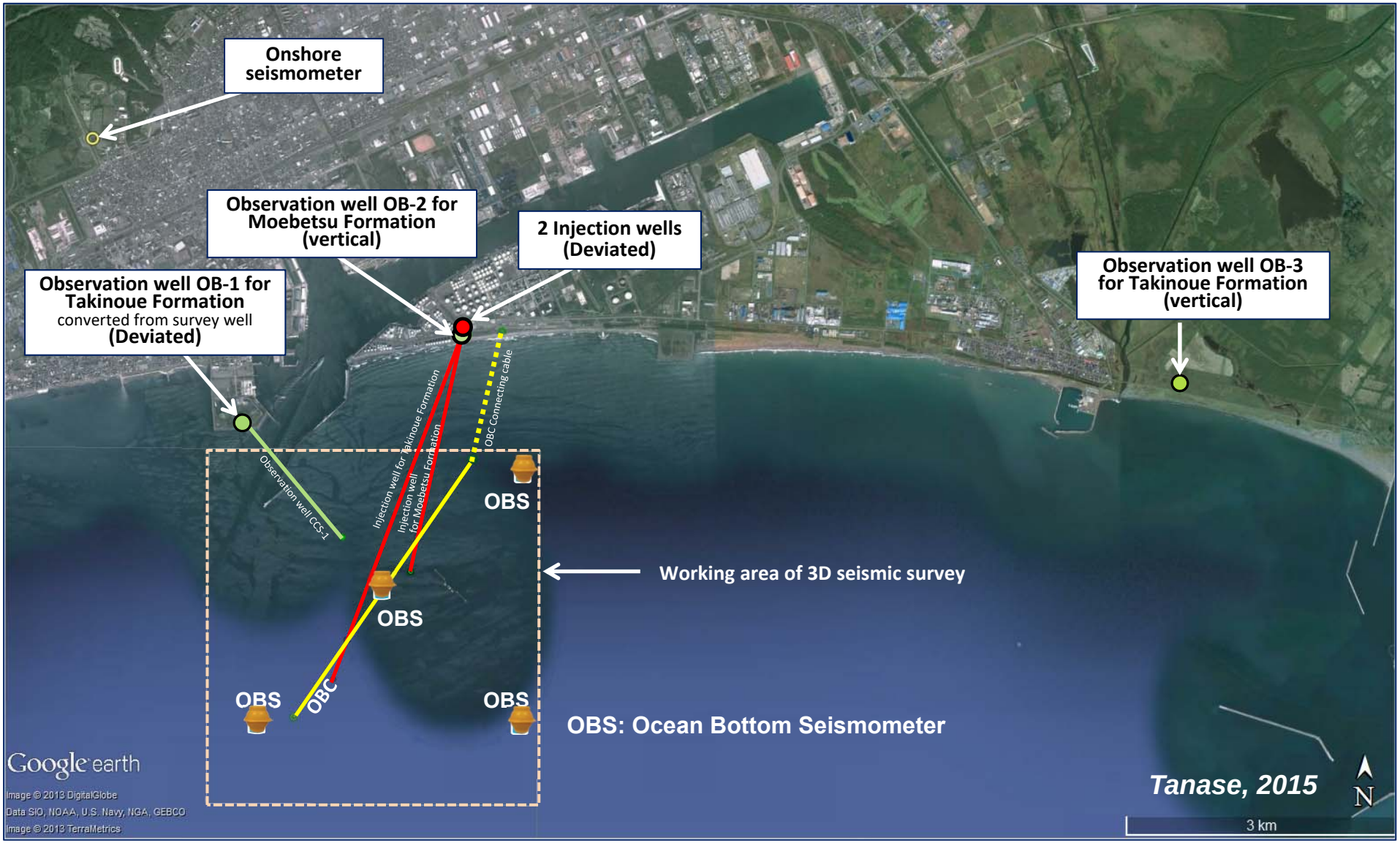
Microseismic Monitoring at Nagaoka Site



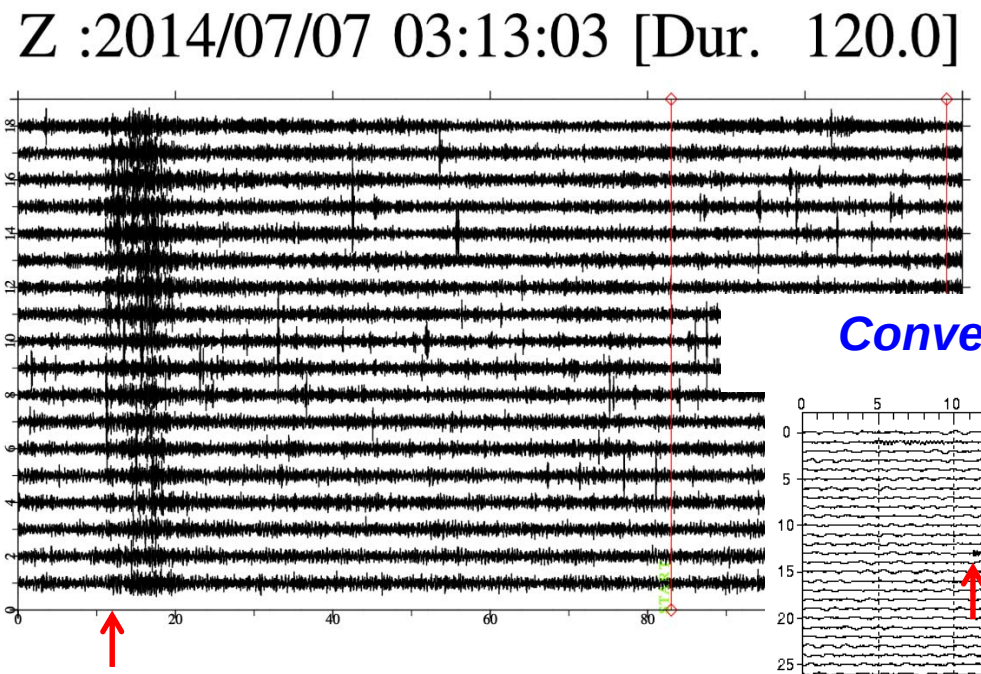


長岡実証試験サイトにおける微小地震観測
（CO_2圧入：2003.7 – 2005.1、約1万トン）

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

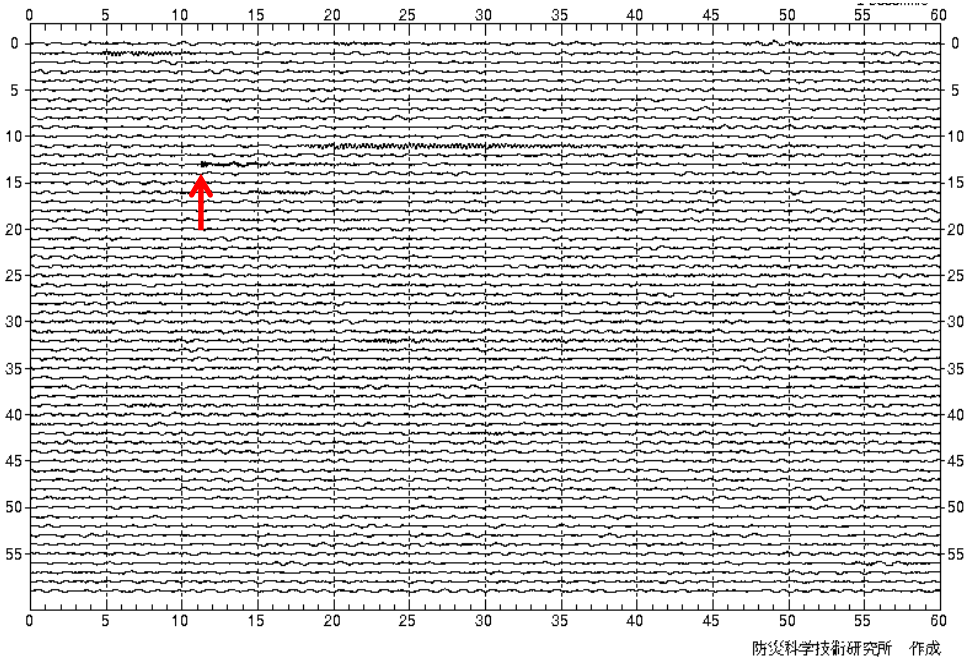


Microseismicity (M<1) detected by OBC and Conventional seismometer @ Tomakomai



OBC Record

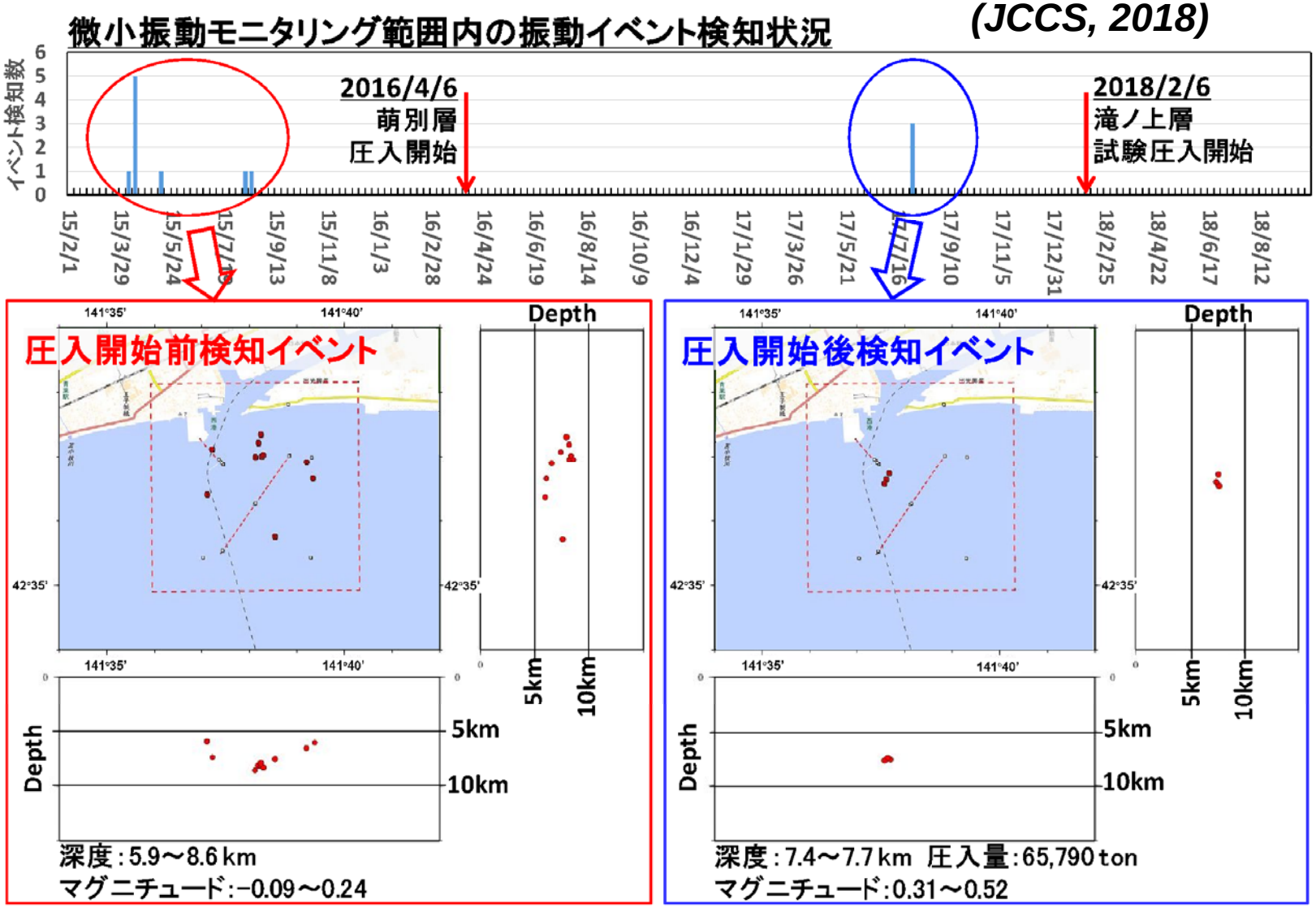
Conventional Seismometer Record



"Two birds (2D/3D Seismic, Microseismic) with one stone (OBC)"

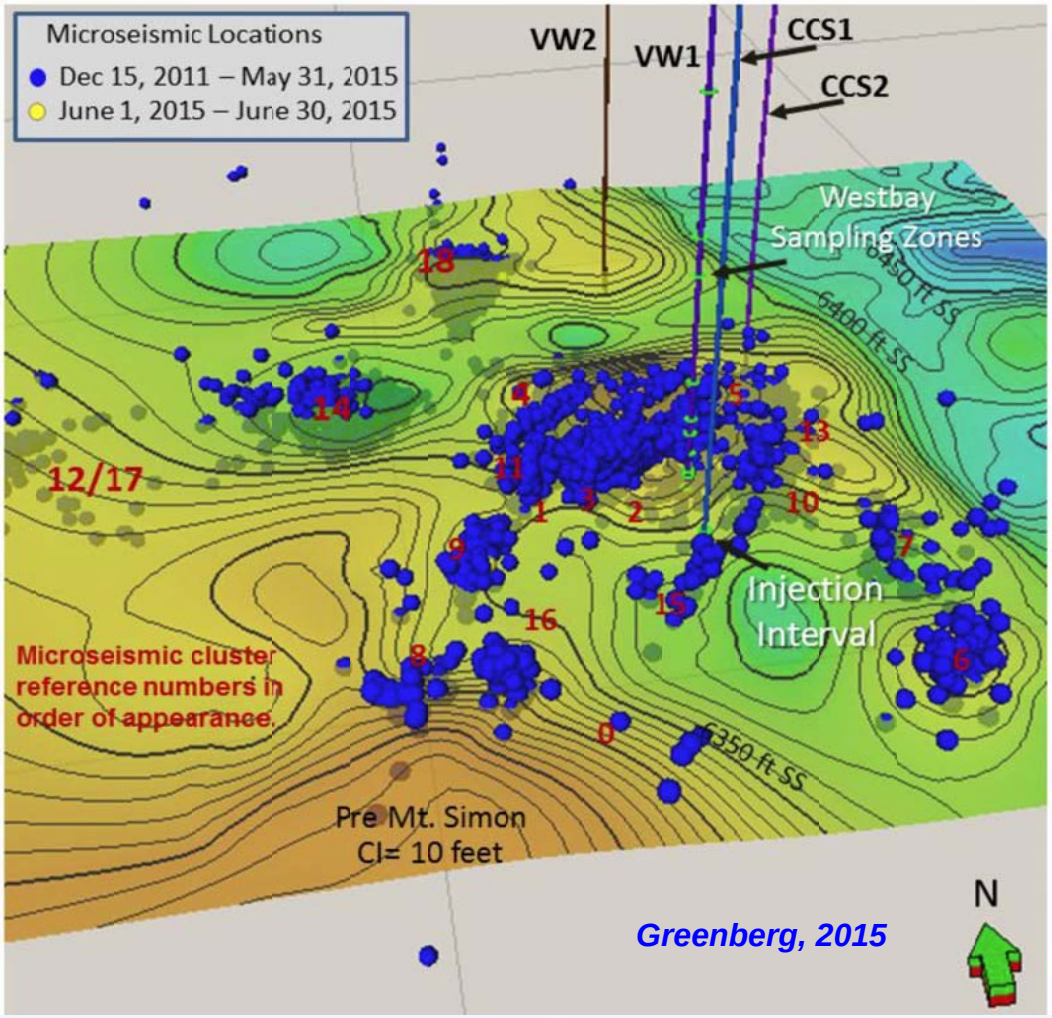
微小振動観測事例@苫小牧サイト

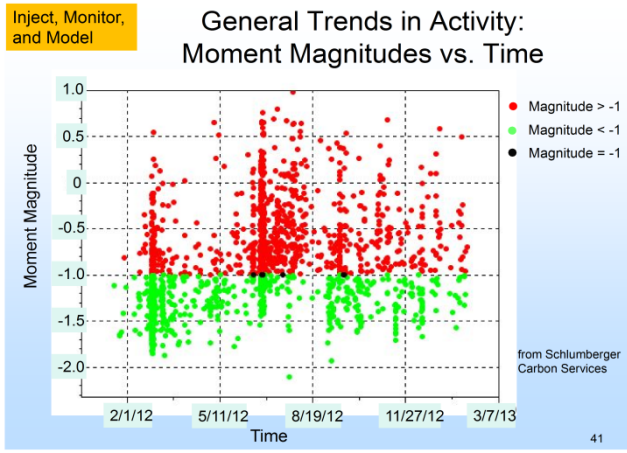
(JCCS, 2018)

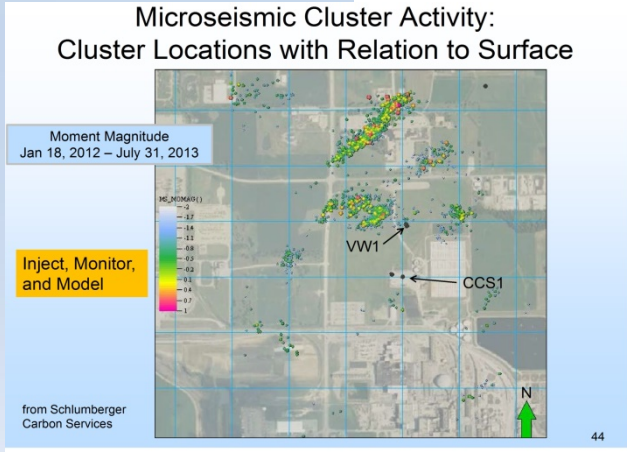


（地図背景： 国土地理院 電子地図（地理院地図）に加筆）

米国Decaturサイトの微小振動観測事例







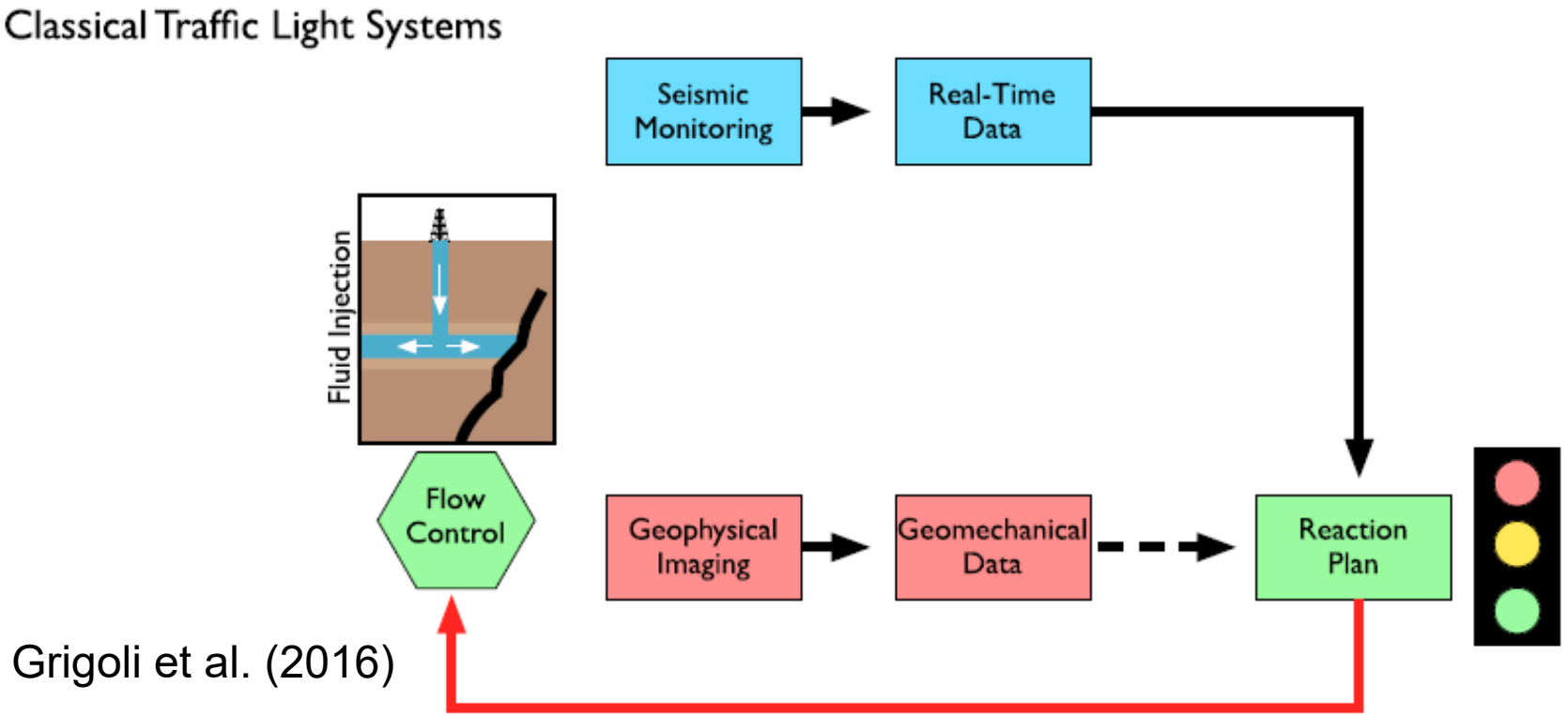
約100万トン／3年間

圧入安全管理システム（ATLS）の開発

ATLS（Advanced Traffic Light System）の役割：

CO_2圧入サイト周辺の自然地震や微小振動の常時観測、社会的受容性の向上（観測結果の公開による不安解消）、他の観測結果との総合判断によるCO_2圧入安全管理

- 自然地震と微小振動の自動検知、震源決定の精度向上
- 海外サイトとの連携、シェールガス開発等他分野の知見収集



より進んだ安全管理：圧入データ、モニタリングデータ、地震発生傾向変化に注目（地震カタログとの比較）

日本特有の事情：自然地震が多い。人為的活動が活発（ノイズが大きい）。

地下への流体圧入におけるリスクマネジメント

◆ It is of critical importance that fluid injection-induced seismicity be better understood so that any potential hazards can be mitigated.

(1) the site-specific factors which can lead to induced seismicity, e.g., why some wells trigger earthquakes and the vast majority do not;

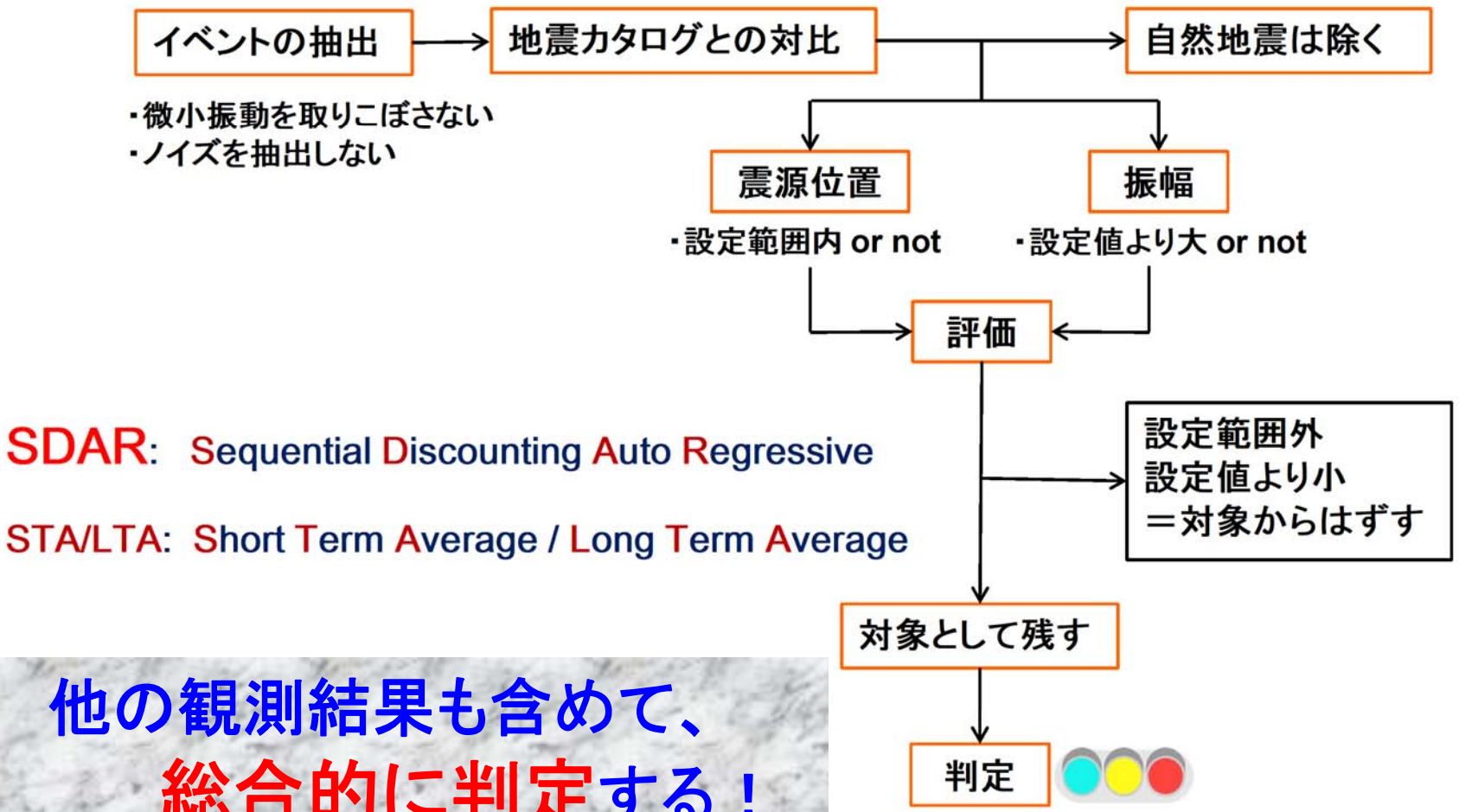
(2) how to predict the maximum magnitudes and rates of potential induced seismicity;

(3) how can fluid injection-induced earthquakes be controlled;

(4) how to mitigate the impacts of induced earthquakes.

"traffic light", a calibrated control system : One approach for direct mitigation of induced seismicity!

ATLSにおける観測データ解析フロー

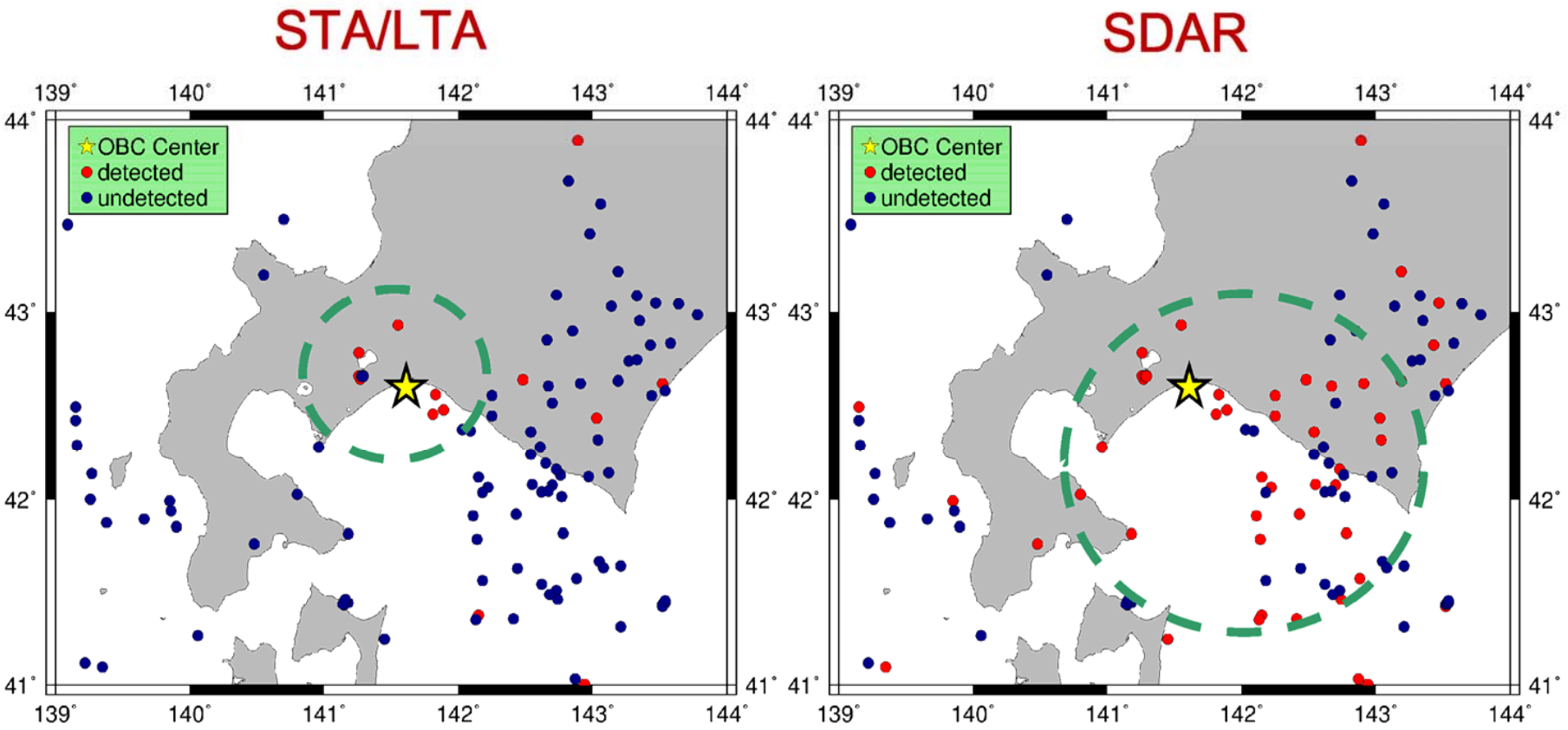


SDAR: Sequential Discounting Auto Regressive

STA/LTA: Short Term Average / Long Term Average

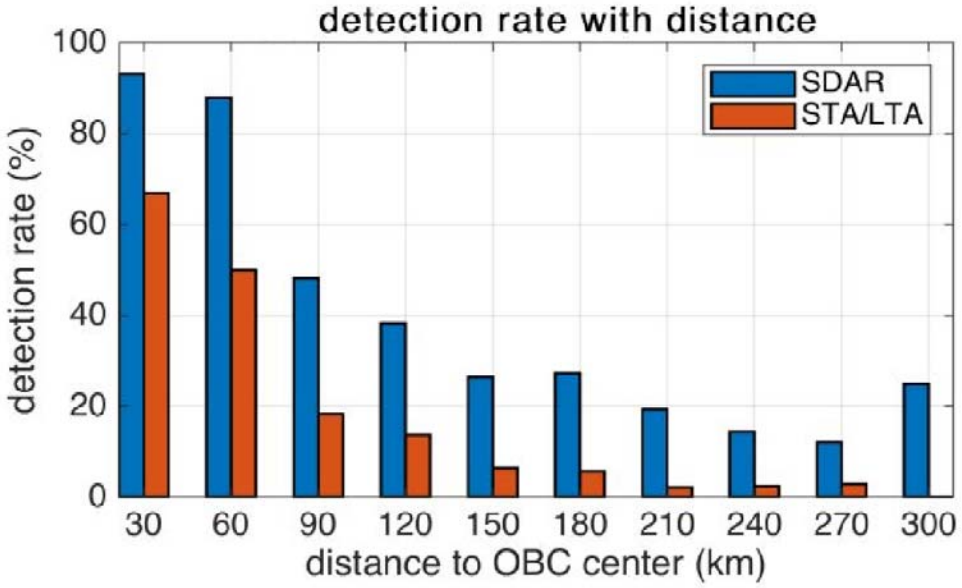
他の観測結果も含めて、
総合的に判定する！

従来のSTA/LTA法と新しいSDAR法の有効性の検証



圧入前の自然地震の観測データ：　2015.02.01 -- 2015.02.28

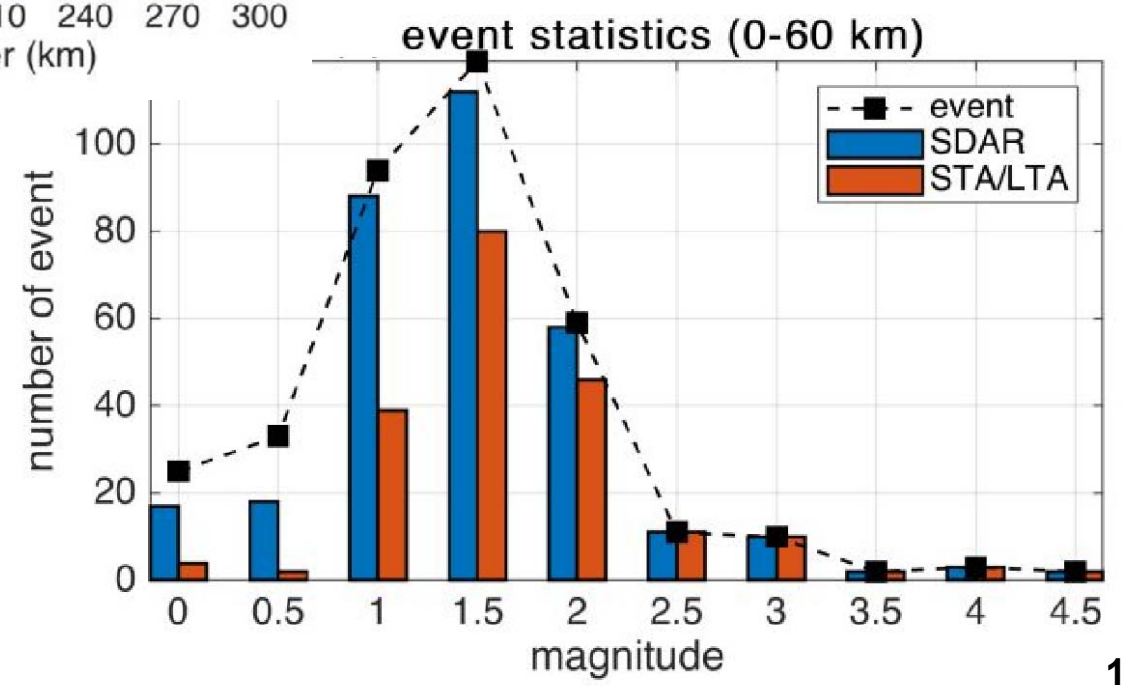
SDAR and STA/LTA on OBC data (2015.02-2016.01)



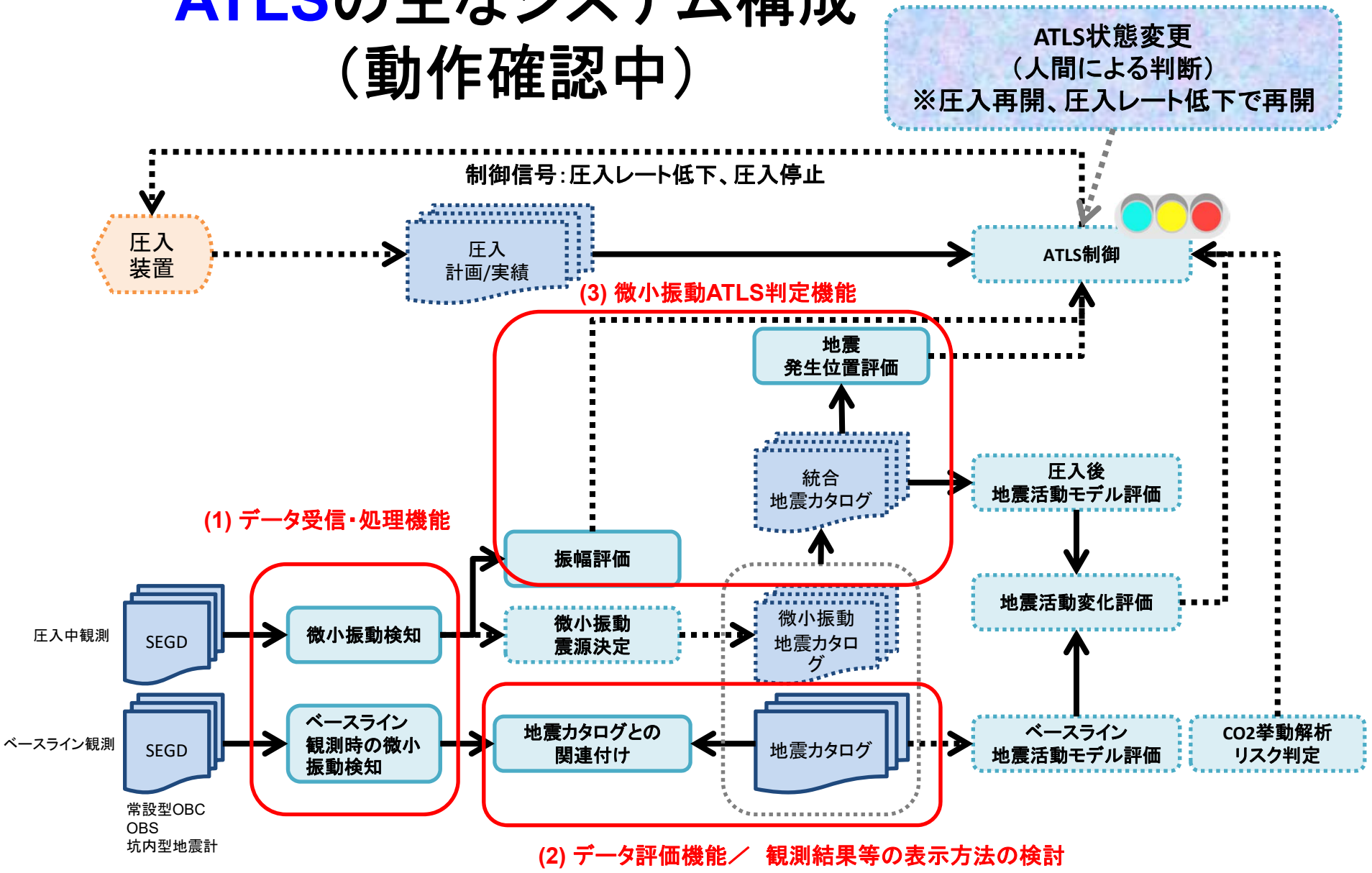
Natural earthquake hypocenters come from:
Japan Meteorological Agency (JMA)

http://www.data.jma.go.jp/svd/eqev/data/bulletin

震源距離、
マグニチュード



ATLSの主なシステム構成（動作確認中）



Micro seismicity monitoring

Performances of the network, Alarms thresholds

- Very good performance of whole network

Detection sensitivity map
-3 : near the injection wellbore
-2 : near the shallow wells

フランスの警報・警告の運用事例
（閾値設定）

In 2010, with subsurface network
Very near seismic event : 6

Magnitude : -1.1 to -0.2

Since April 2011, micro-seismic events detected by the deep seismic array in the injection well

Magnitude : -3.1 to -1.4

- French administration asked for alarms thresholds

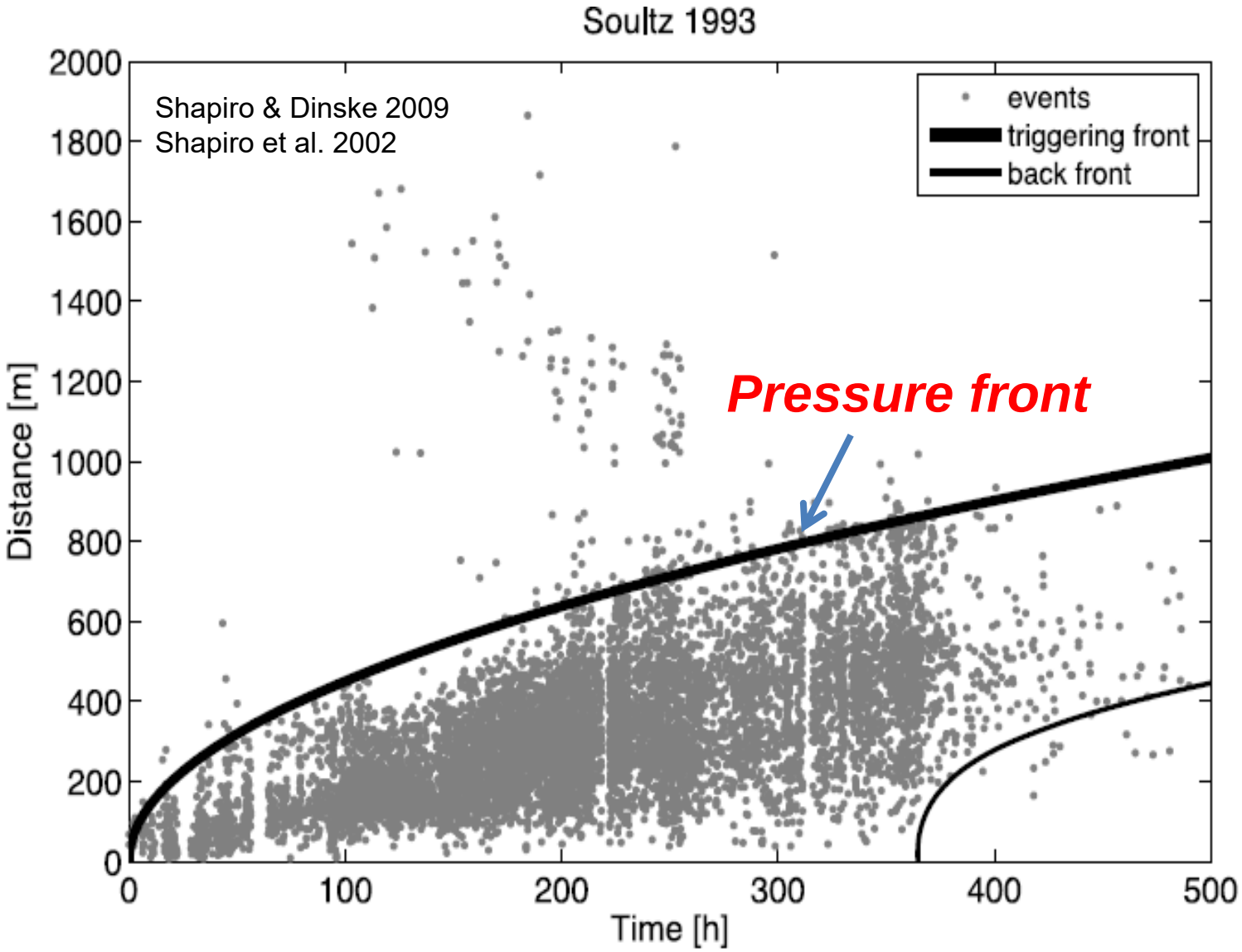
Official alarms thresholds

According to magnitude and number of events, alarm procedure is activated

- For seismic events with magnitude above 2, in the circle given by the subsurface network
- For magnitude above -1, if there is evidence of propagation in space and in time of seismic events external to the reservoir

Billiot (2011)

事例：地熱開発における微小地震eventとpressure frontの関係



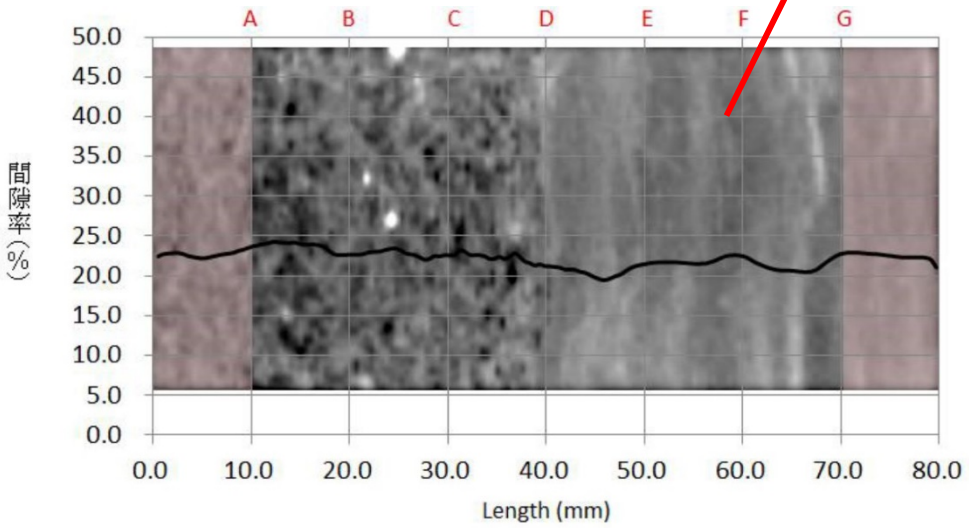
不均質砂岩試料を用いた流動と変形の同時測定実験

貯留層（粗粒）

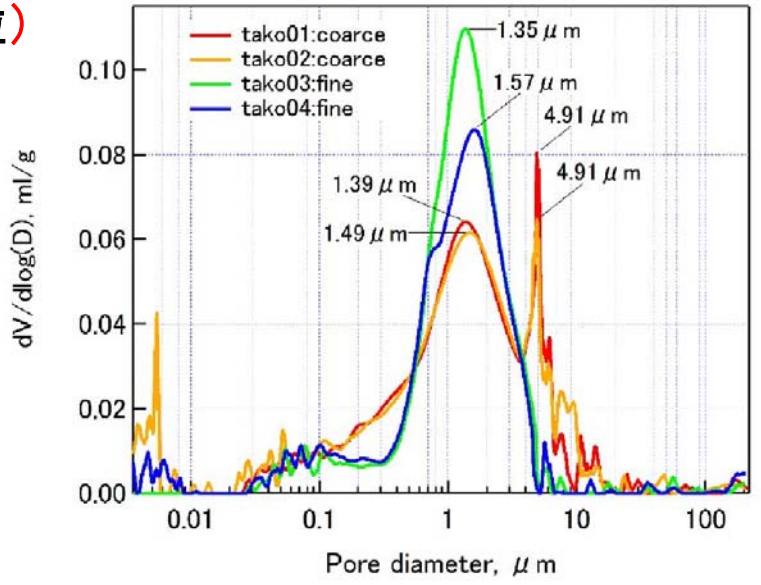
巻き付けた光ファイバー

遮蔽層（細粒）

X-CT画像



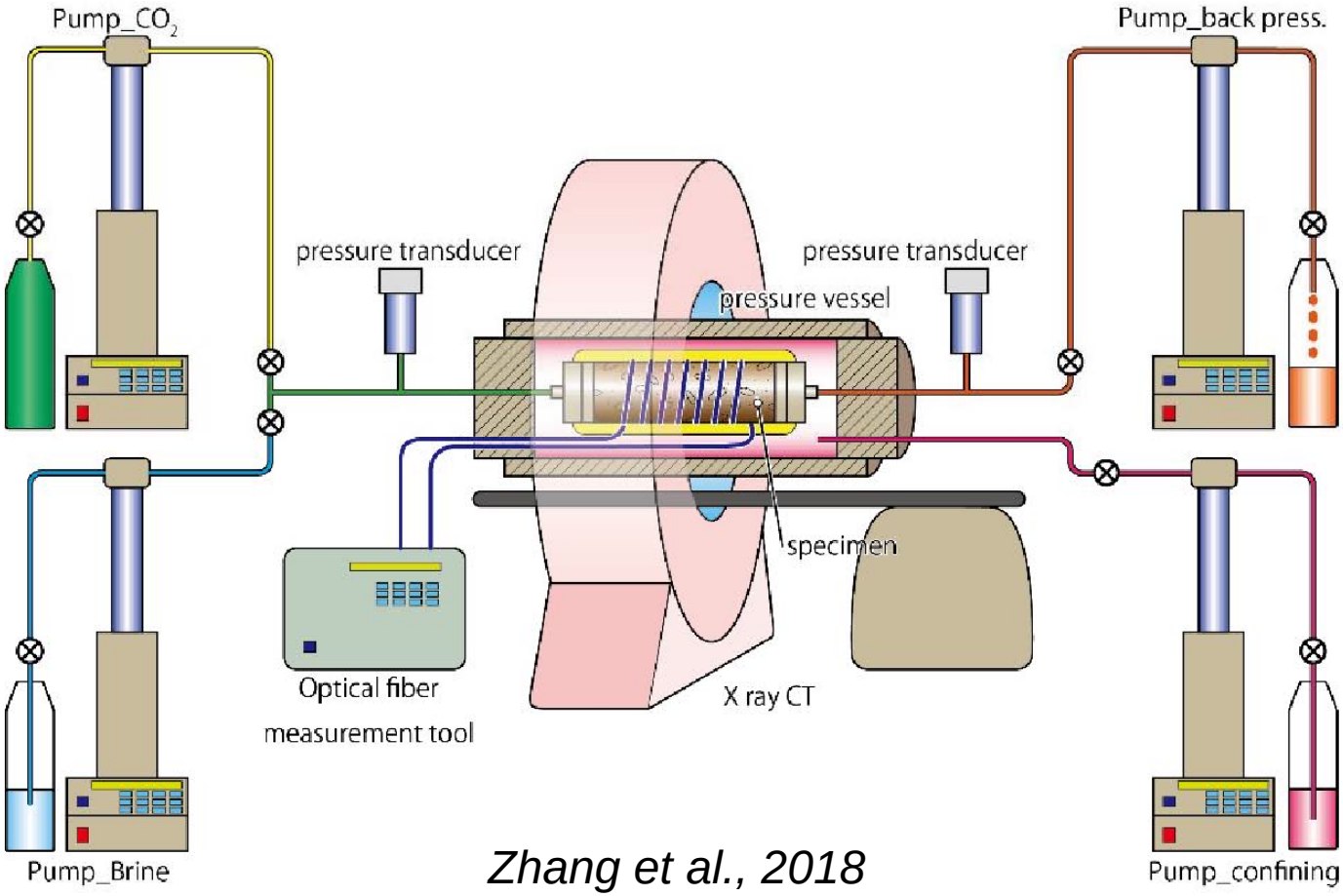
細孔分布



遮蔽層の安定性監視、圧力フロントの観測

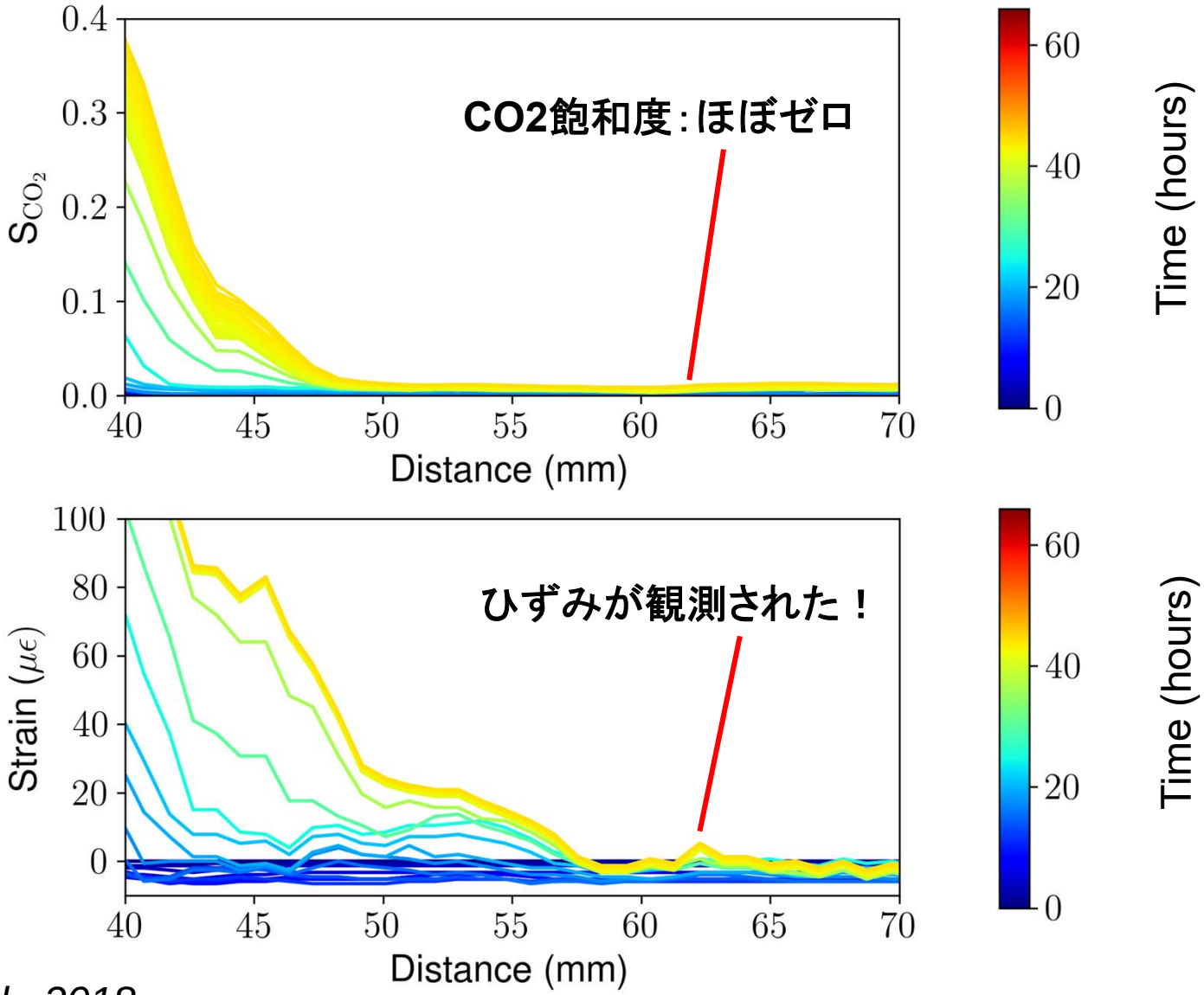
CO_2 Plume Front and Pressure Front

-- *Insights from a lab experiment* --



Zhang et al., 2018

粗粒部のCO2飽和度が増える過程で、細粒部のひずみ発生状況



Zhang et al., 2018

ATLSシステムの完成に向けて

- 気象庁の地震観測情報（データベース）を活用して、解析対象イベントを絞込み
- 信号機の色（判断基準）や圧入再開条件等の検討
  （他分野の事例や知見を参照）
- 圧入サイトにおいて、どの範囲（Area of Review）まで重点的に監視するか
- 圧入時の観測データを有する海外機関との協力
- Science-basedのリスクコミュニケーション
  （社会的受容性向上の手法論からの転換）

謝 辞

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