CCSにおける微小振動観測技術開発

Microseismic Monitoring at the CCS fields

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Contents

- Previous studies of fluid injection
  - Geothermal and oil fields
- Seismicity at CO_2 injection fields
  - Weyburn (Canada), Lacq (France)
- Microseismic monitoring tech developments
  - Offshore potential CO_2 storage sites

➢Fluid Injections:

Stimulation & Production at geothermal and oil fields

Site	Activity	Rock	Sensors	Wells
Austin Chalk	stimulation	clastic sediment/lime stone	2, plus reflection	2
Lower Frio	stimulation	clastic sediment	50	2
Cotton Valley	stimulation	clastic sediment	6	2
Clinton Co.	production	massive limestone	3	2
Fenton Hill	stimulation	crystalline	4	4
Soultz	stimulation	crystalline	4	4

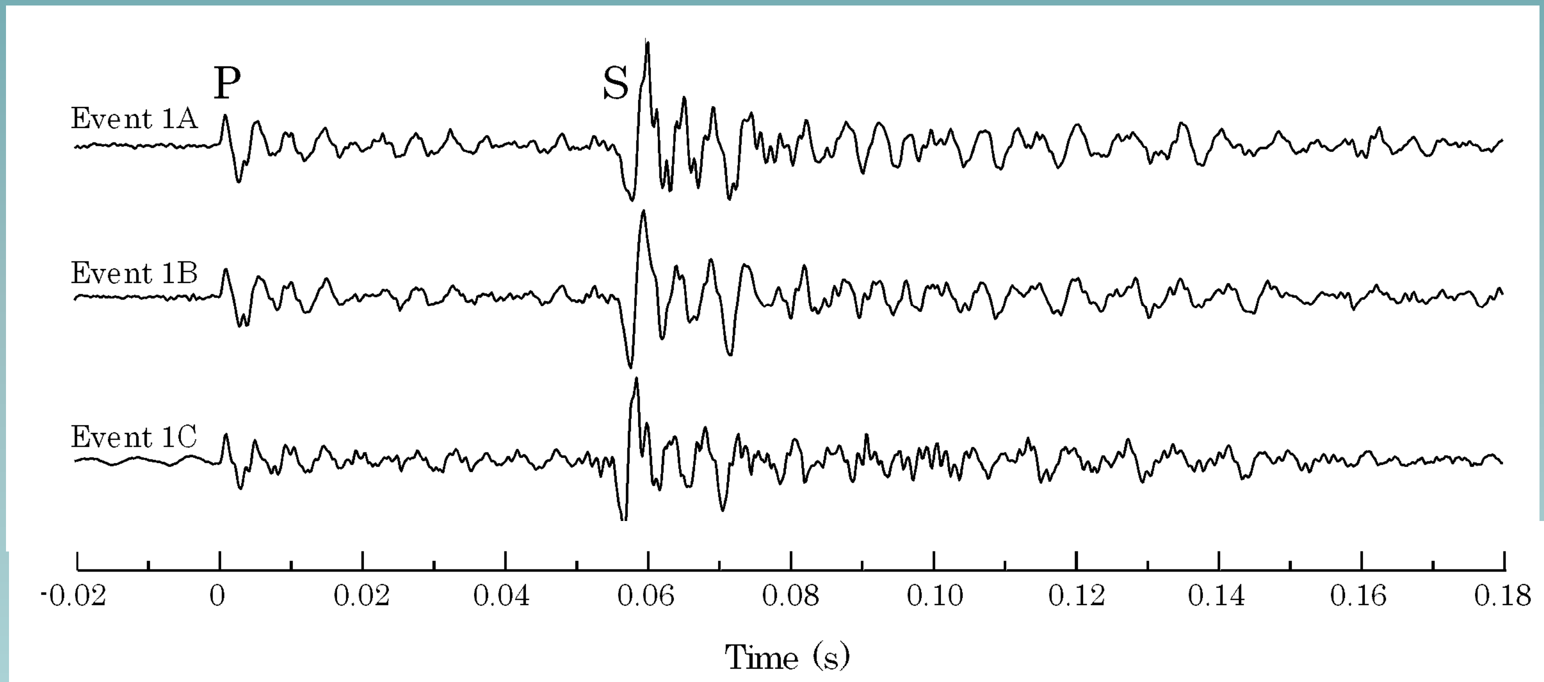
Phillips et al, 2001

Unconsolidated sandstone

Low porosity carbonate

Hot-Dry Rock Granite

Examples of Seismogram Recorded at Fenton Hill, New Mexico



Over 21,000 m³ of water were injected into deep HDR in 61 hours.

Lessons from Previous Fluid Injections

- ***Microseismic monitoring must be performed by <u>downhole</u> instruments due to the small size***

- ***Most events fall in the magnitude - 4 to -2 range, formed surrounding the injection point.***

- ***Microseismic techniques equally useful if sufficient events observed in sedimentary reservoirs.***

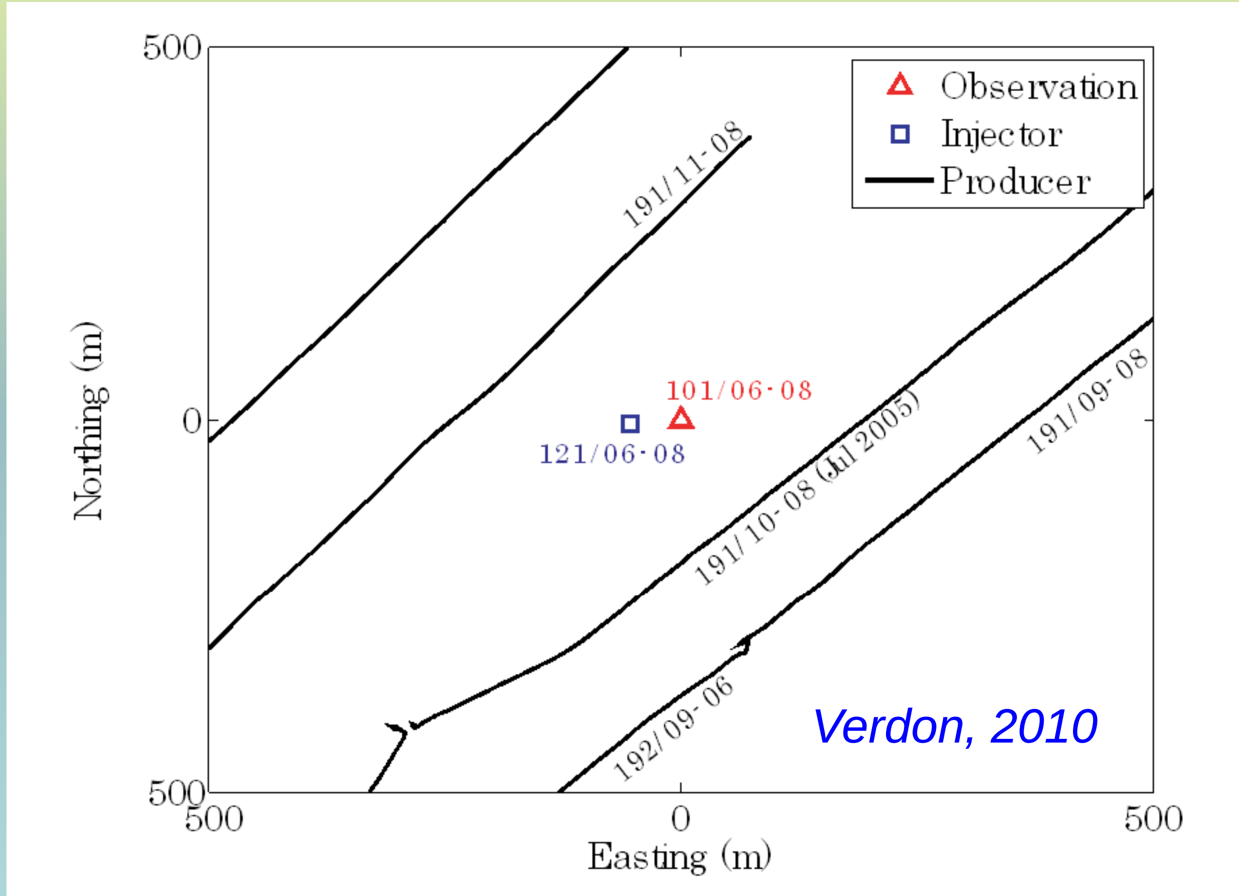
- **Lower Frio: 54 located from 2900 events (too small for location).**

- **Clinton Co.: 3200 events recorded clearly associated with production rate, with time lag.**

- **Fenton Hill: over 11,000 locatable events recorded in a volume of 1 km x 1 km x 300m.**

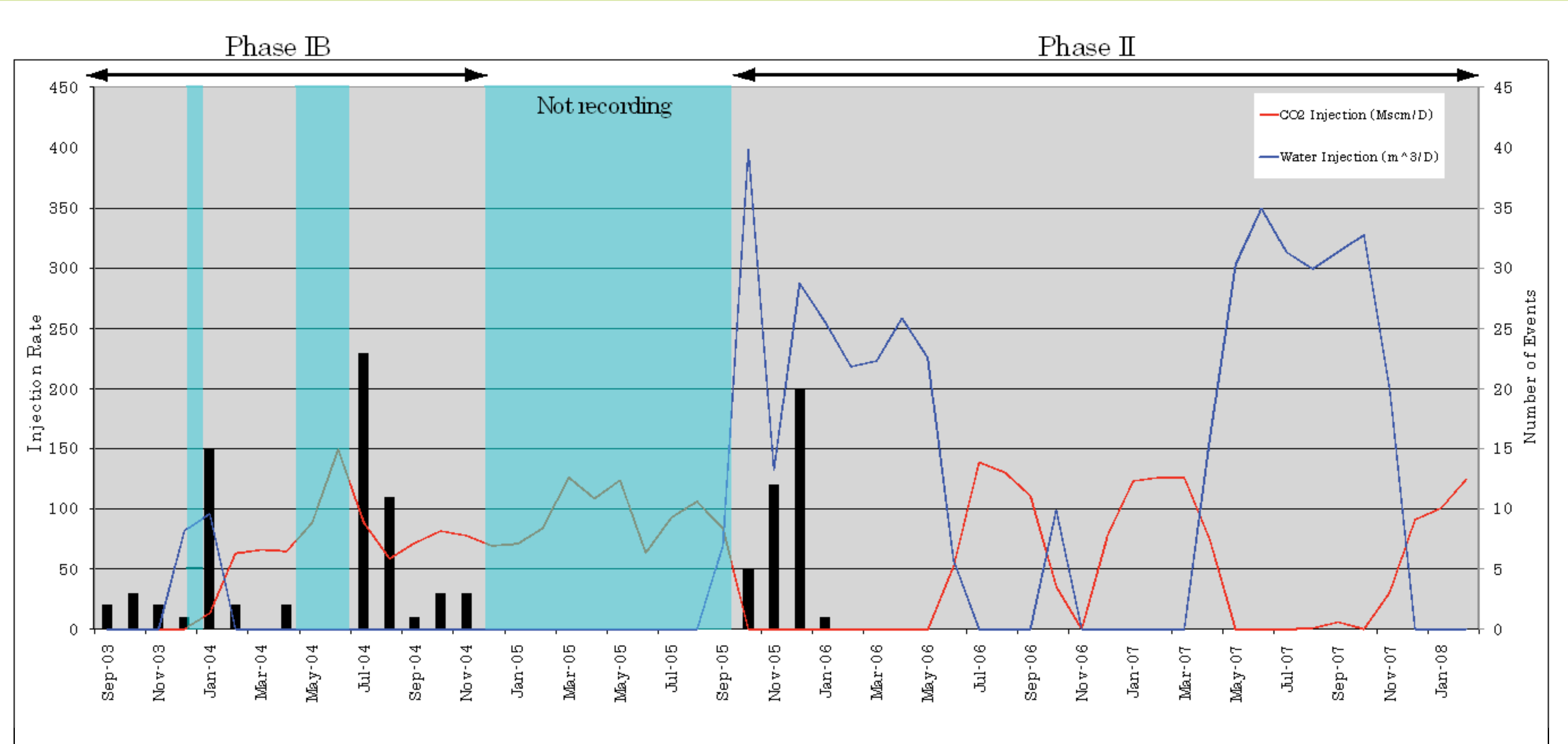
Contents

➢Microseismic Monitoring at Weyburn CO2-EOR field



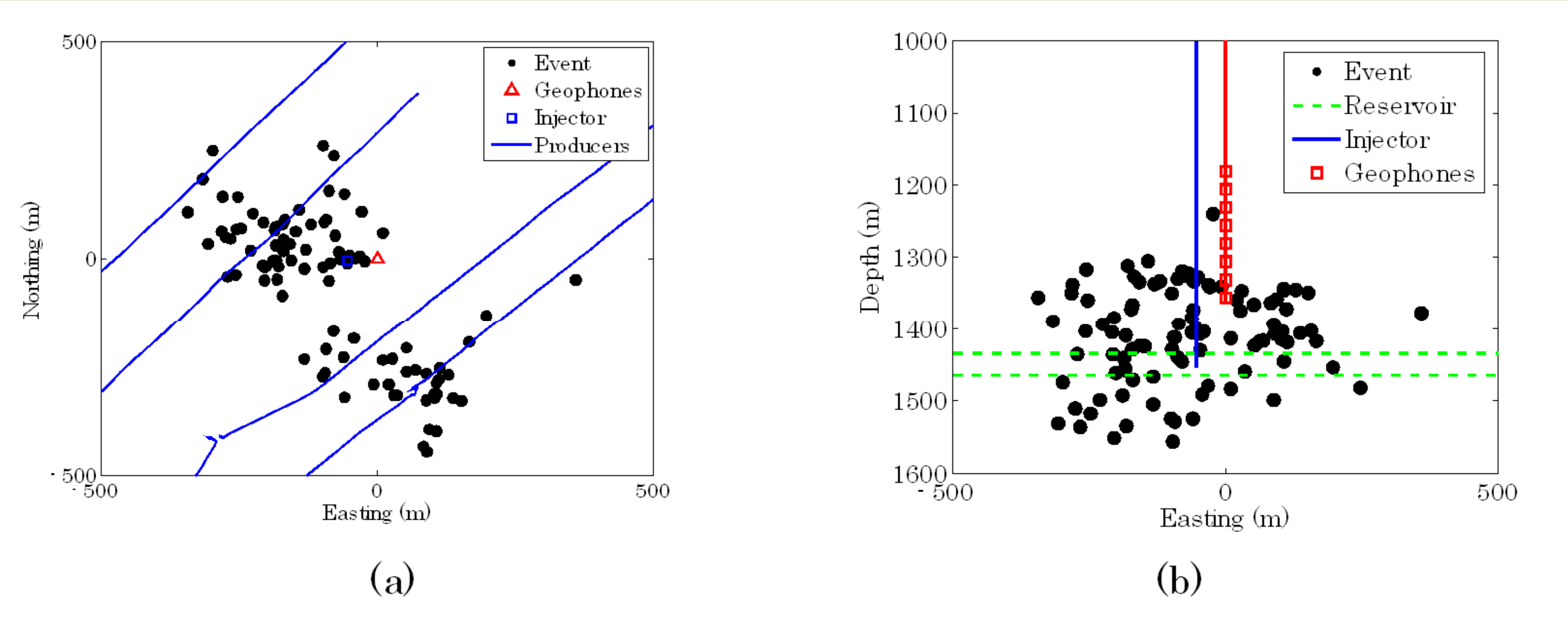
8-level, 3-components geophones installed in well 101/06-08, about 50 m away from injection well 121/06-08, CO_2 injection rate 100-500 ton/day, 2003.8 – 2004.11

Monthly event rates during CO_2 & water injection



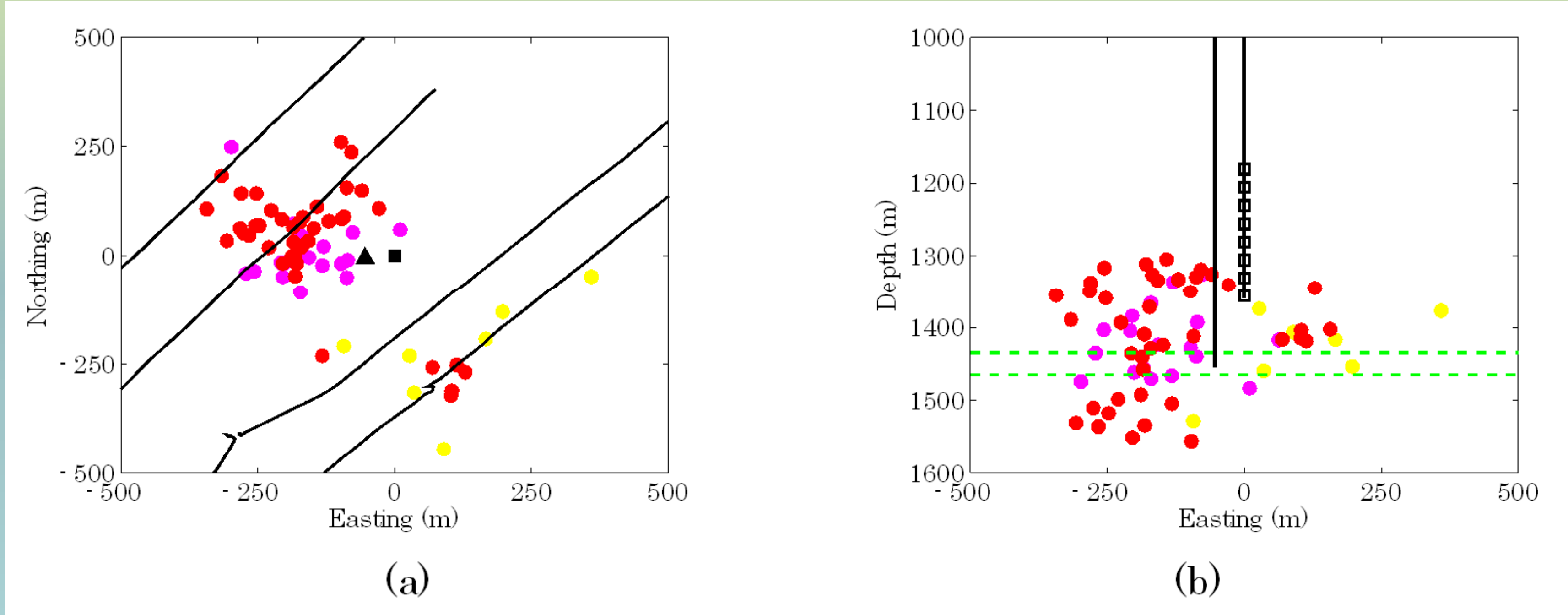
Most days have no events, sometimes as many as 7 events and no events at all for Over 2 years from 2006 (*Verdon, 2010*).

Map (a) and East-West cross-section (b) view of Phase 1B events plotted by ESG



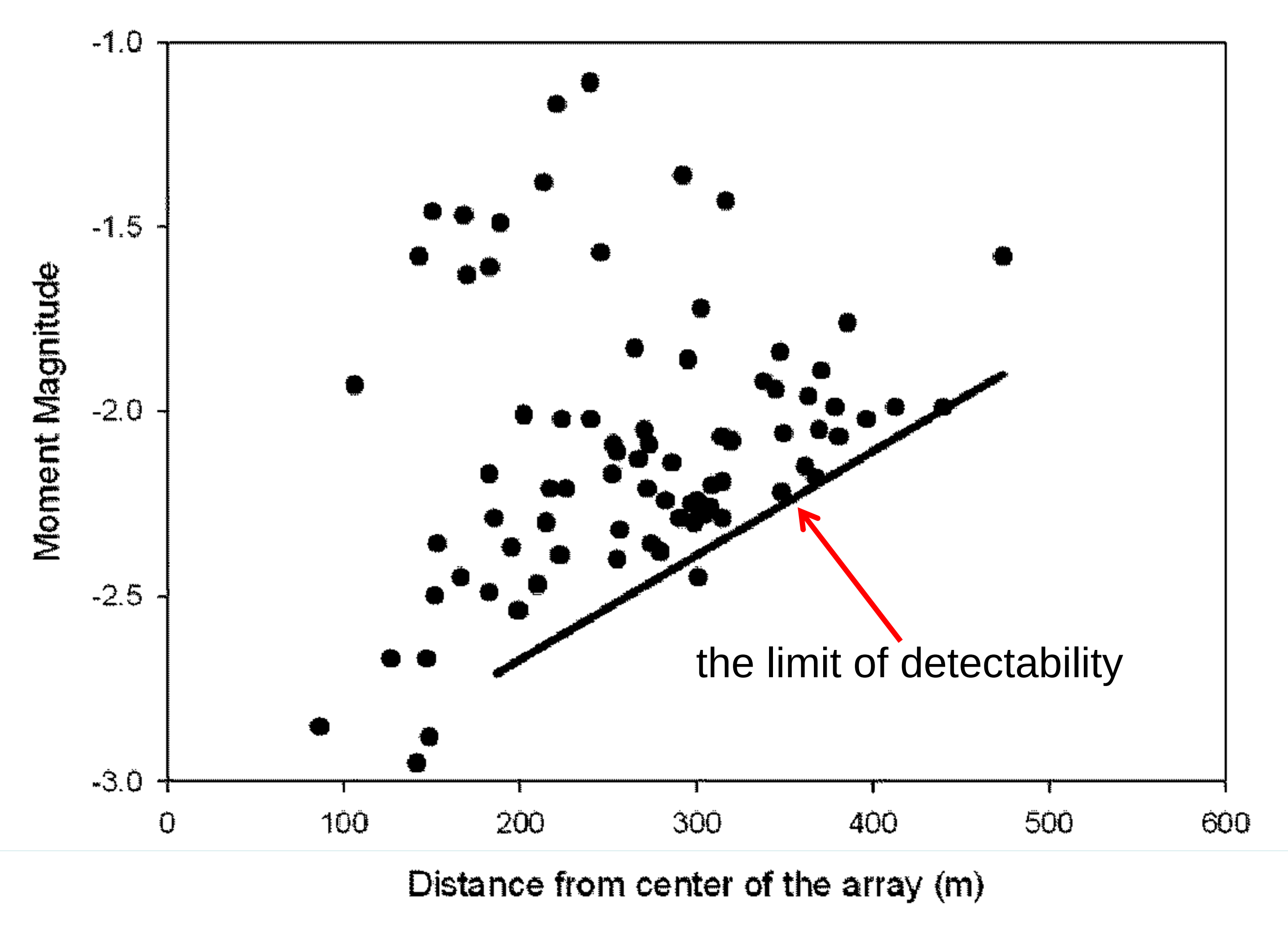
This plot includes some events caused by completion and drill activities pointed out by *Verdon (2010)*.

Map (a) and East-West cross-section (b) view of Phase 1B events plotted by Verdon (2010)



Yellow: pre-injection (Aug-Dec 2003); Magenta: initial injection period (Jan-Apr 2004); Red: during elevated injection rate period (Jul-Nov 2004) by *Verdon (2010)*.

Event magnitudes plotted as a function of distance from the array by Verdon (2010)



➢Summary of Microseismic Monitoring at Weyburn CO2-EOR field

- Event magnitudes ranged between -3 to -1, event magnitudes of -2 are still detectable over 400 m away.

- Comparison with production data, the timing of events located in and just above the reservoir correlates with periods temporarily stopped production.

- Microseismicity occurs at the onset of CO_2 injection, and also appears to correlate with periods of increased injection.

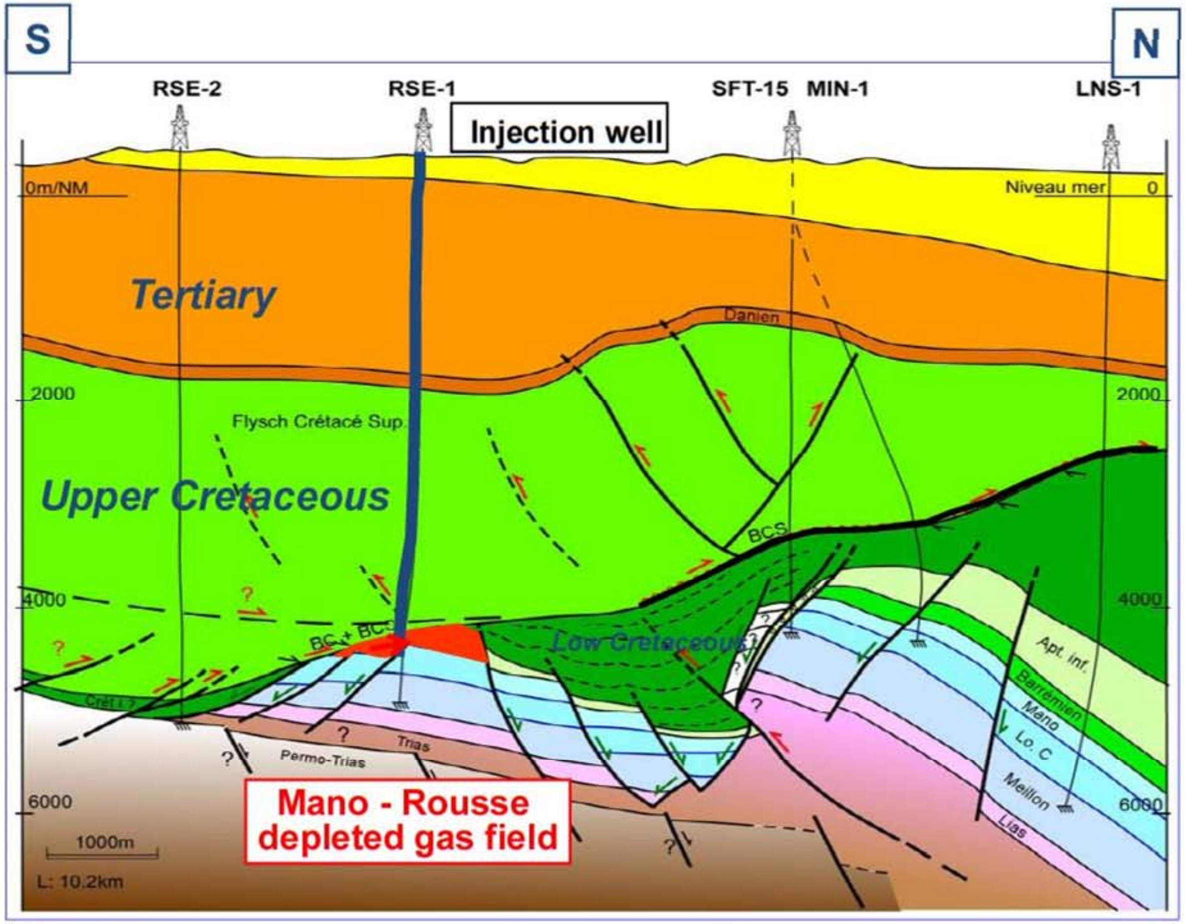
- Events are characterized by a low dominant frequency (15 - 80 Hz) and poor signal-to-noise ratio.

CCS pilot, Lacq, France

CO_2 storage into Rousse

- Depleted gas reservoir producing from 1972 to 2006
  - ✓ Depth = 4500m,
  - ✓ Temperature = 150°C,
  - ✓ Initial Pressure = 485 bar
- Fractured dolomitic reservoir
- No aquifer support
- A tightly sealed cap rock
- Maxi injection : 100 ktonnes, pressure@endinjection:100 bar

Billiot (2011)

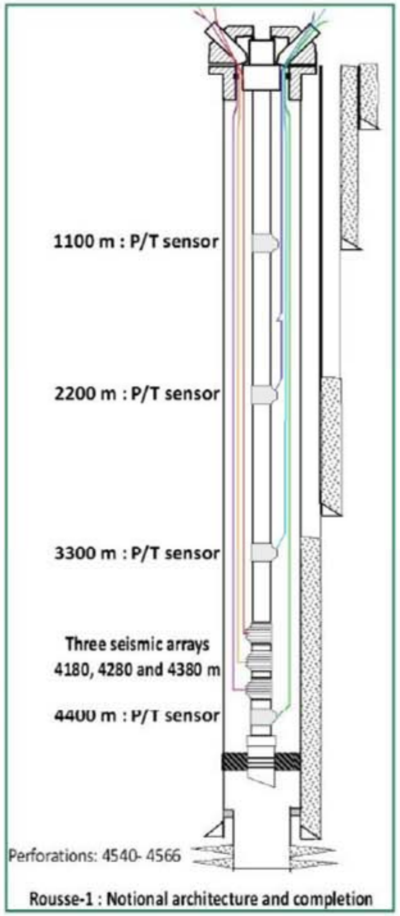


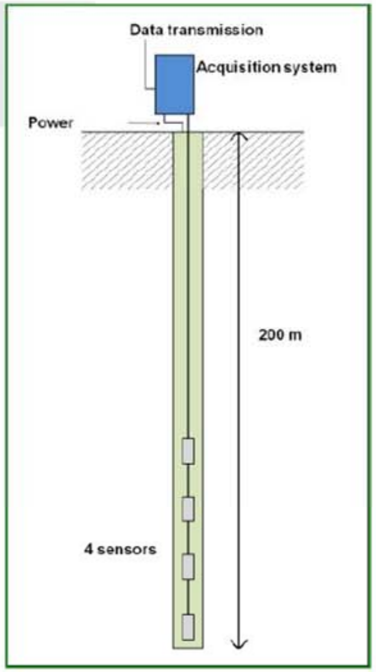
Geological cross – section (S – N)

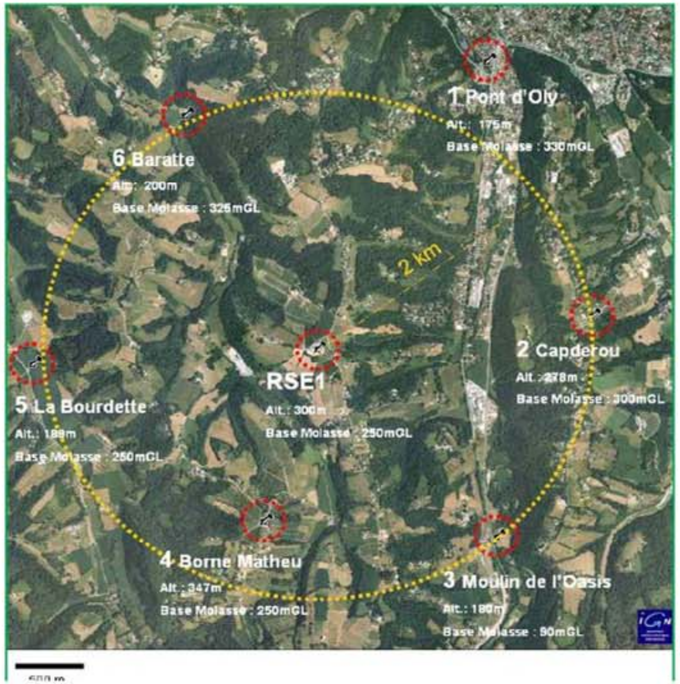
Micro-seismicity monitoring

Network description

- Network is composed of
  - One deep array in injection well - Injection completion inside well
  - Seven subsurface arrays in shallow wells
  - One surface seismometer







Billiot (2011)

Micro-seismicity monitoring

Data during injection in 2010 and 2011

- January 10 to July 10 : non continuous injection
- August 10 to December 10 : continuous
- January to March 11 : no injection
- Since April 2011: 100 ton/day

- Velocity model : very detailed
  - ✓ 7 layers with velocity law
  - ✓ Evolution of the ratio Vp/Vs
  - ✓ Calibration and orientation of the deep array in June 11

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

Billiot (2011)

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

- 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)

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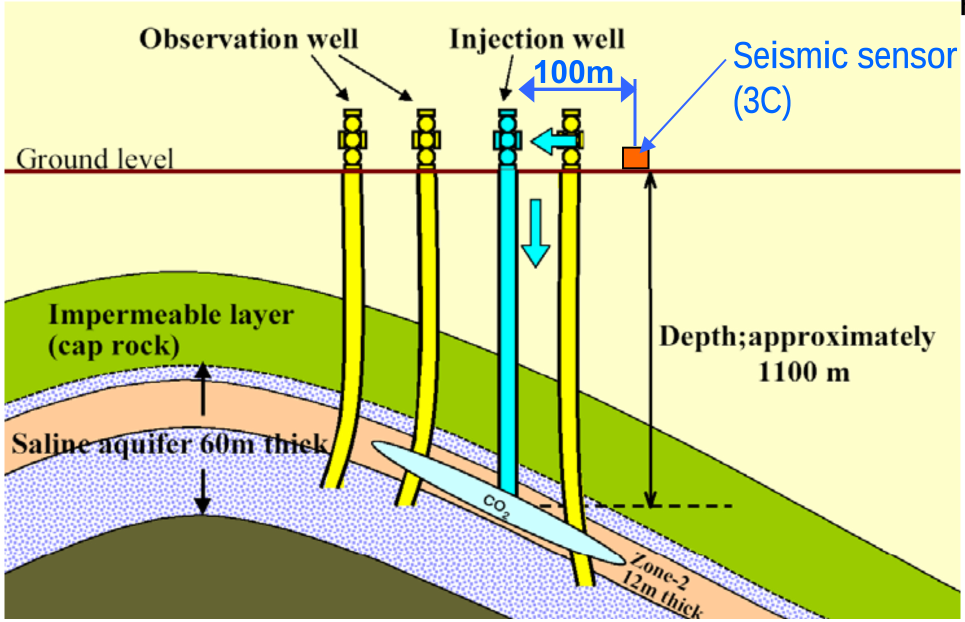
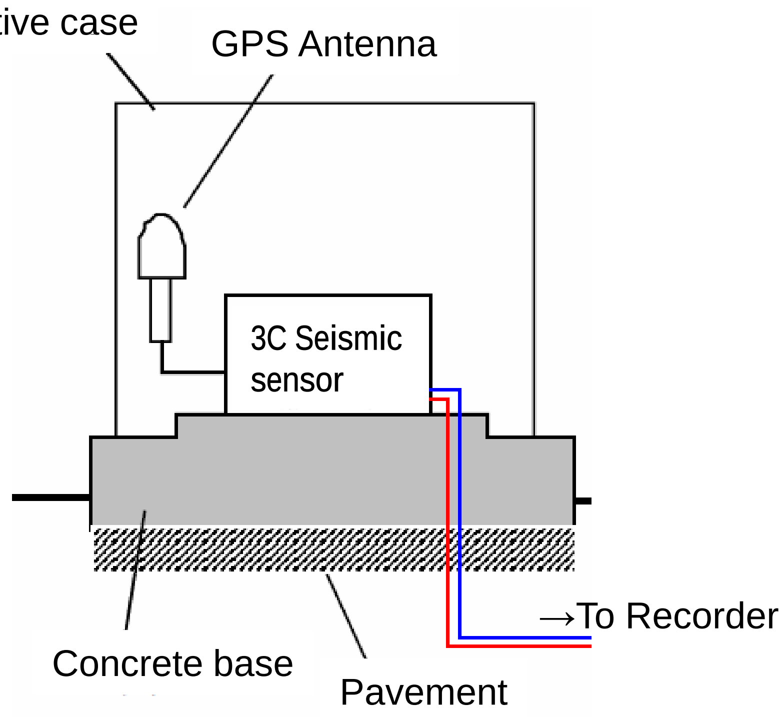
- **Microseismic monitoring tech developments**
  - ✓Offshore potential CO_2 storage sites

Microseismic Monitoring at Nagaoka Site

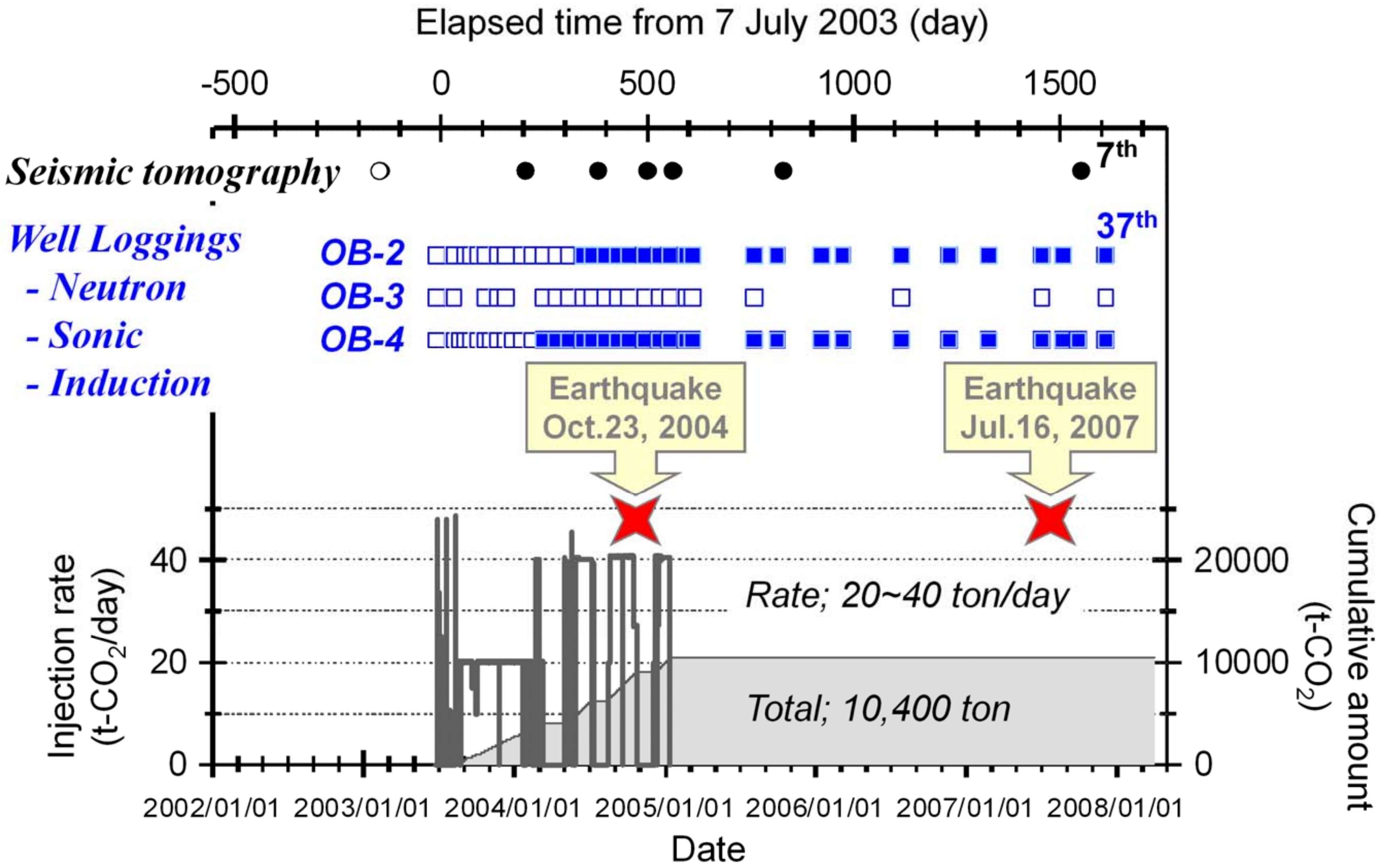




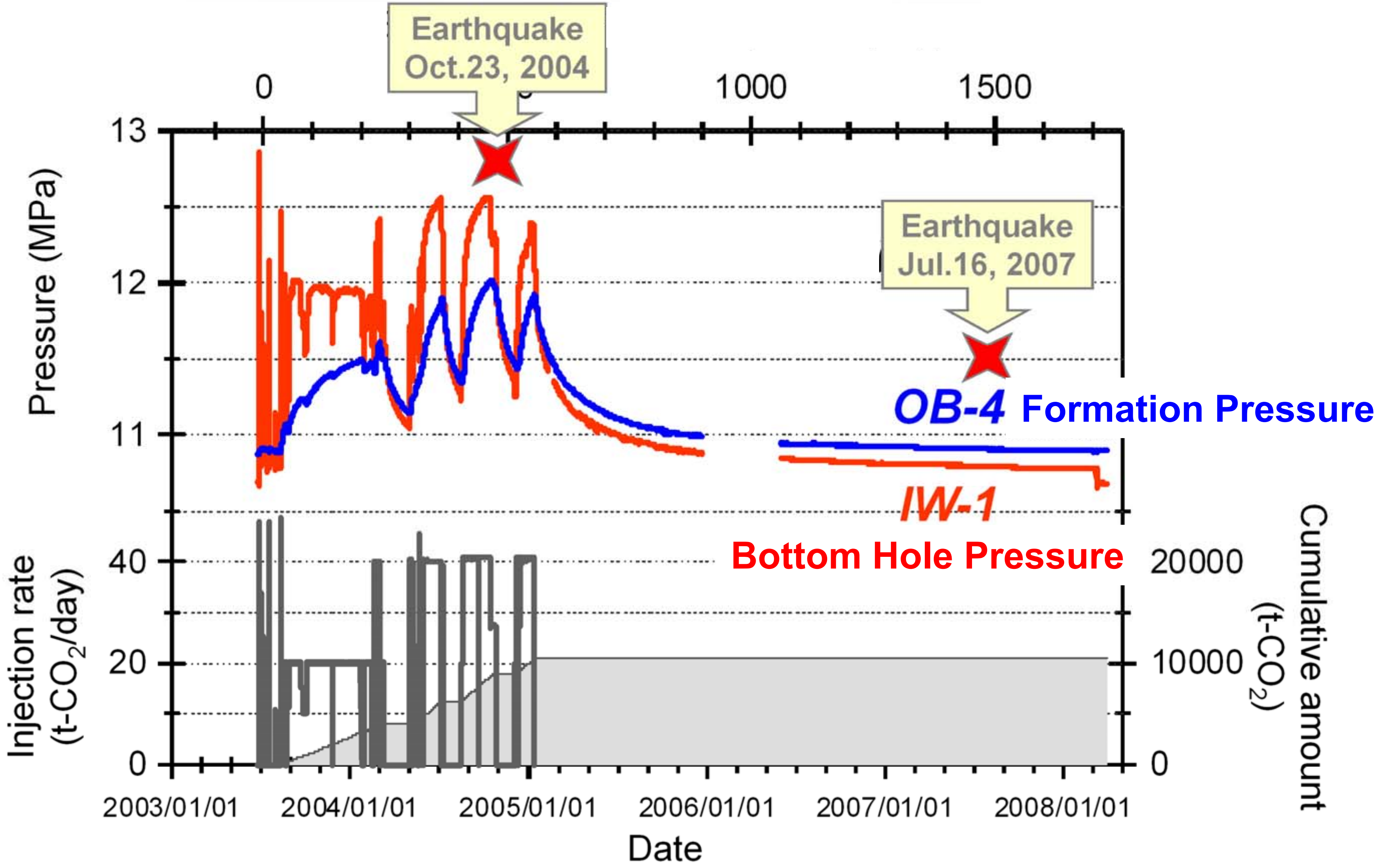
Seisimic sensor specifications

Item	specification
Seismic Sensor (ALTUS Enta; Kinemetrics)	Sensor type: triaxial EpiSensor force balance accelerometer Full scale: ±2G Frequency range: DC～100Hz Dynamic range: 135dB
Seismic Recorder (ALTUS –K2; Kinemetrics)	Number of channels: 6ch Sampling time: 20, 40, 50, 100, 200, 250Hz Frequency range: DC～40Hz（in 100Hz sampling case） Dynamic range: 114dB（19Bit） Power supply: Internal battery 12V, 12Ah

Geophysical Monitoring (incl. earthquake safety surveys)



Pressure Changes at Injection and Observation Wells



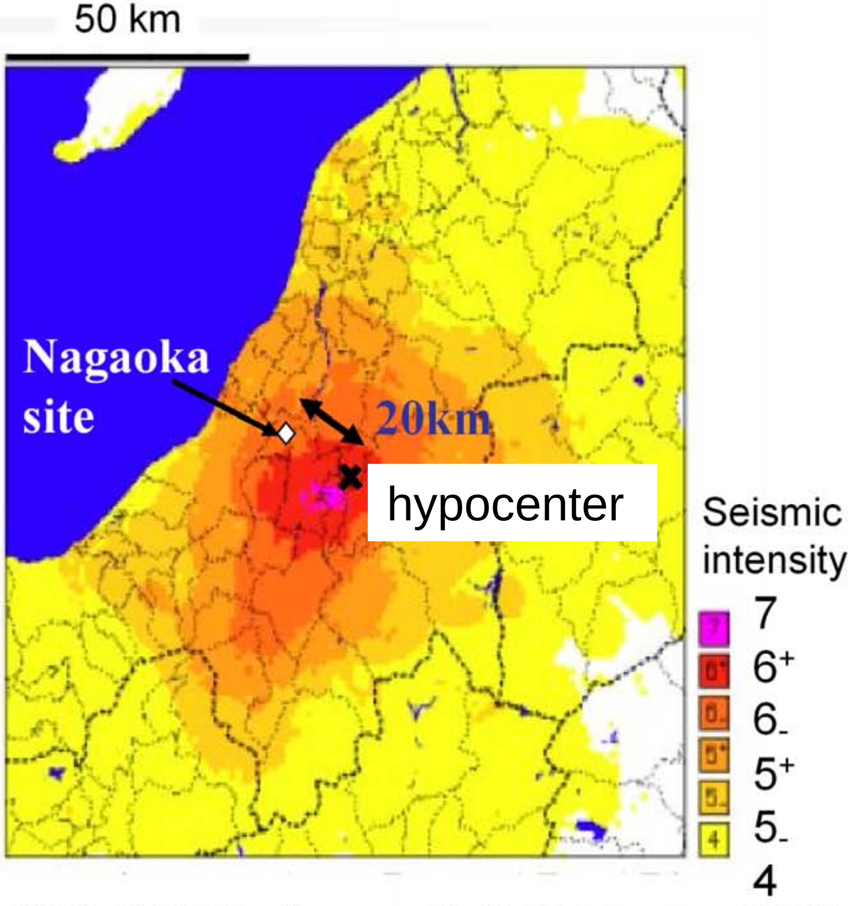
The Mid Niigata Prefecture Earthquake in 2004

Main shock: 23 Oct 2004
M6.8 at 10km depth
Seismic intensity: 7
→Injection was automatically stopped at the main shock.

Access road was damaged.

CO_2 detector (No leak)

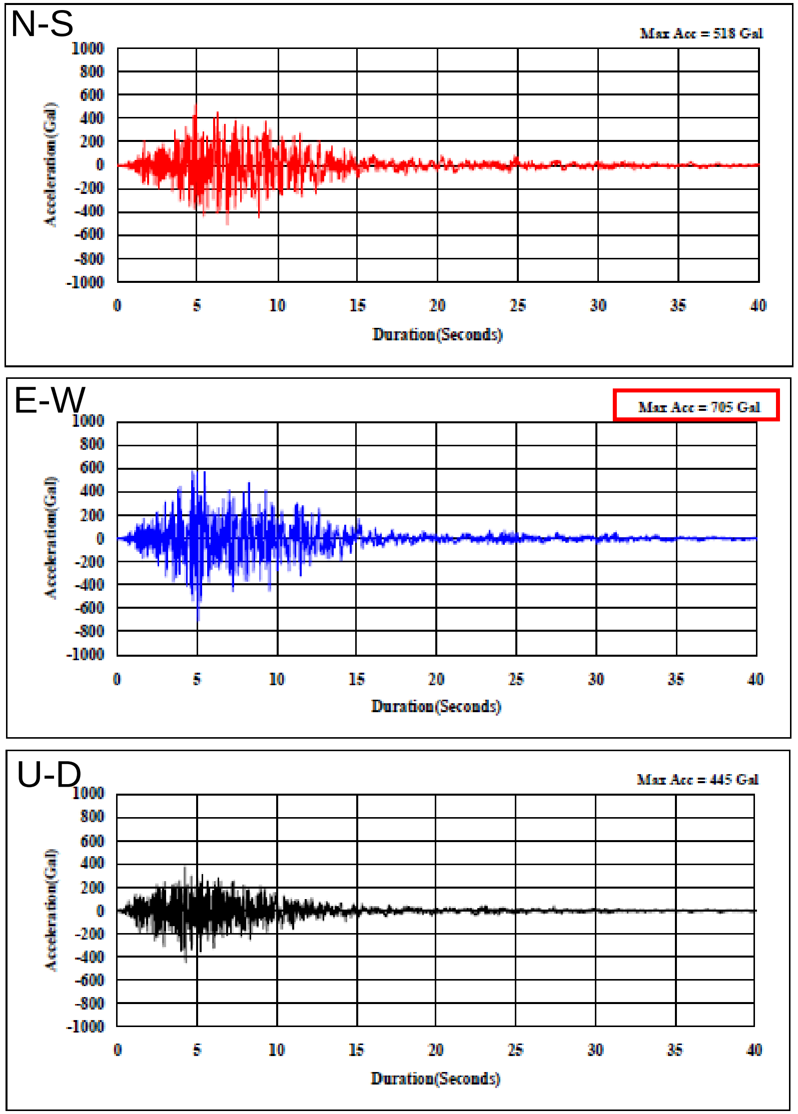
Injection was carefully resumed after confirming safety (6 Dec 2004)
injection rate: 40t-CO_2/day



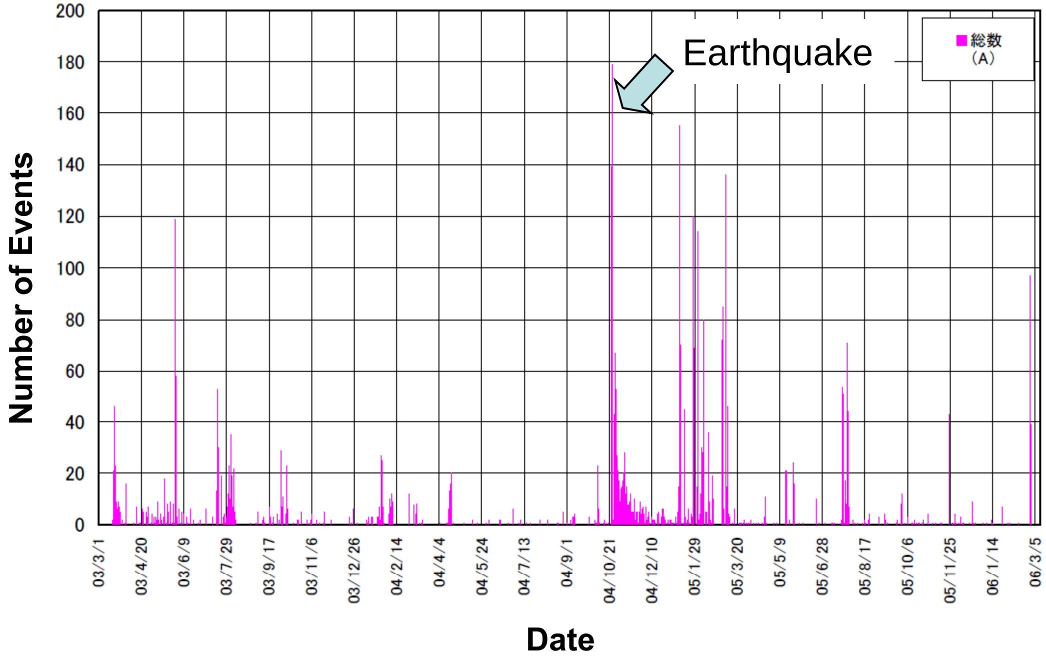
(GSJ, 2004 http://www.gsj.jp/jishin/chuetsu_1023/)

For detail: Xue et al. (2006)
3rd Monitoring Network Meeting (Melbourne)

The Mid Niigata Prefecture Earthquake in 2004



Earthquake Wave-forms observed by the seismic sensor of Nagaoka site

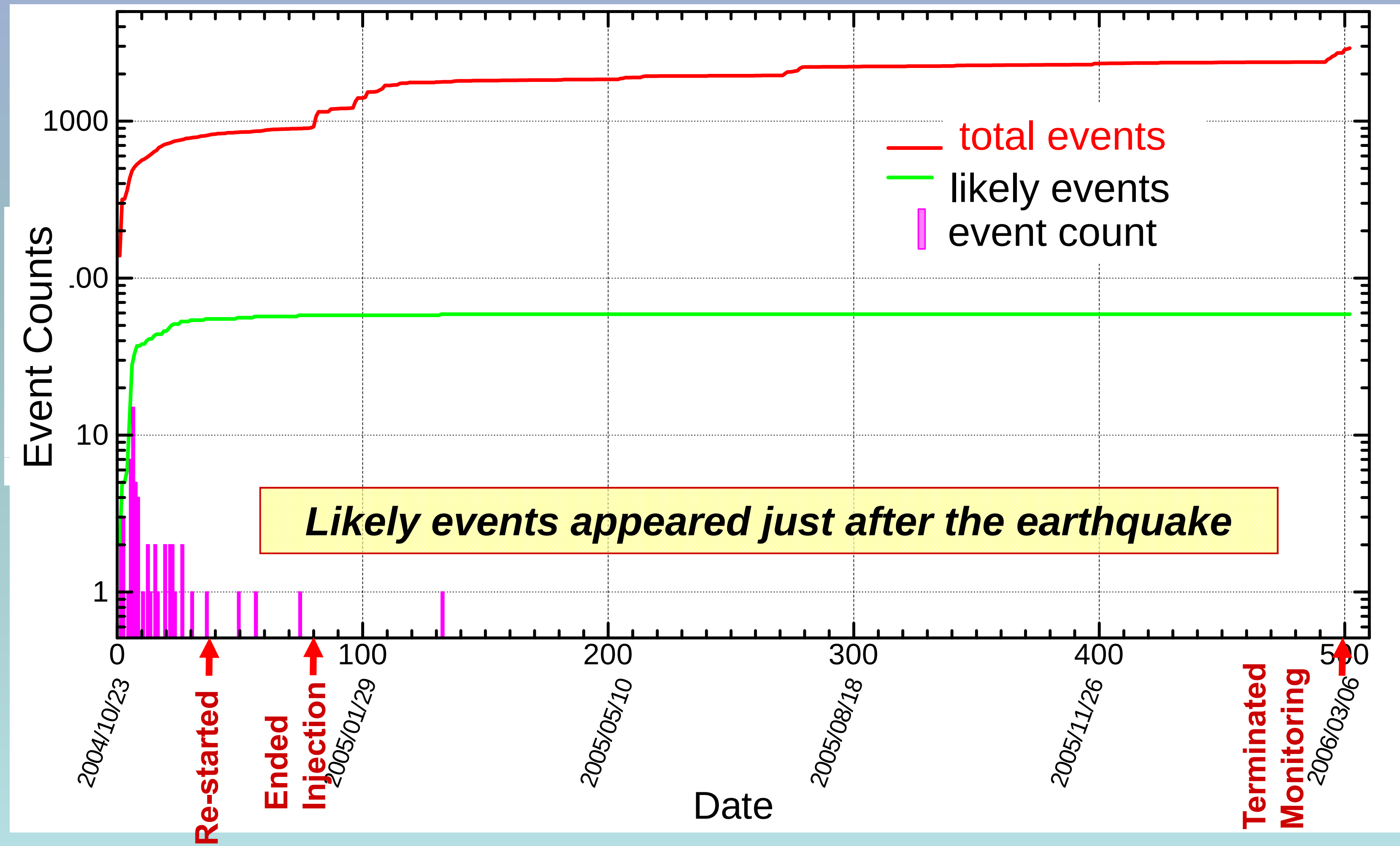


Histogram of microseismic events by the seismic sensor of Nagaoka site. Injection period is July 2003 to January 2005.

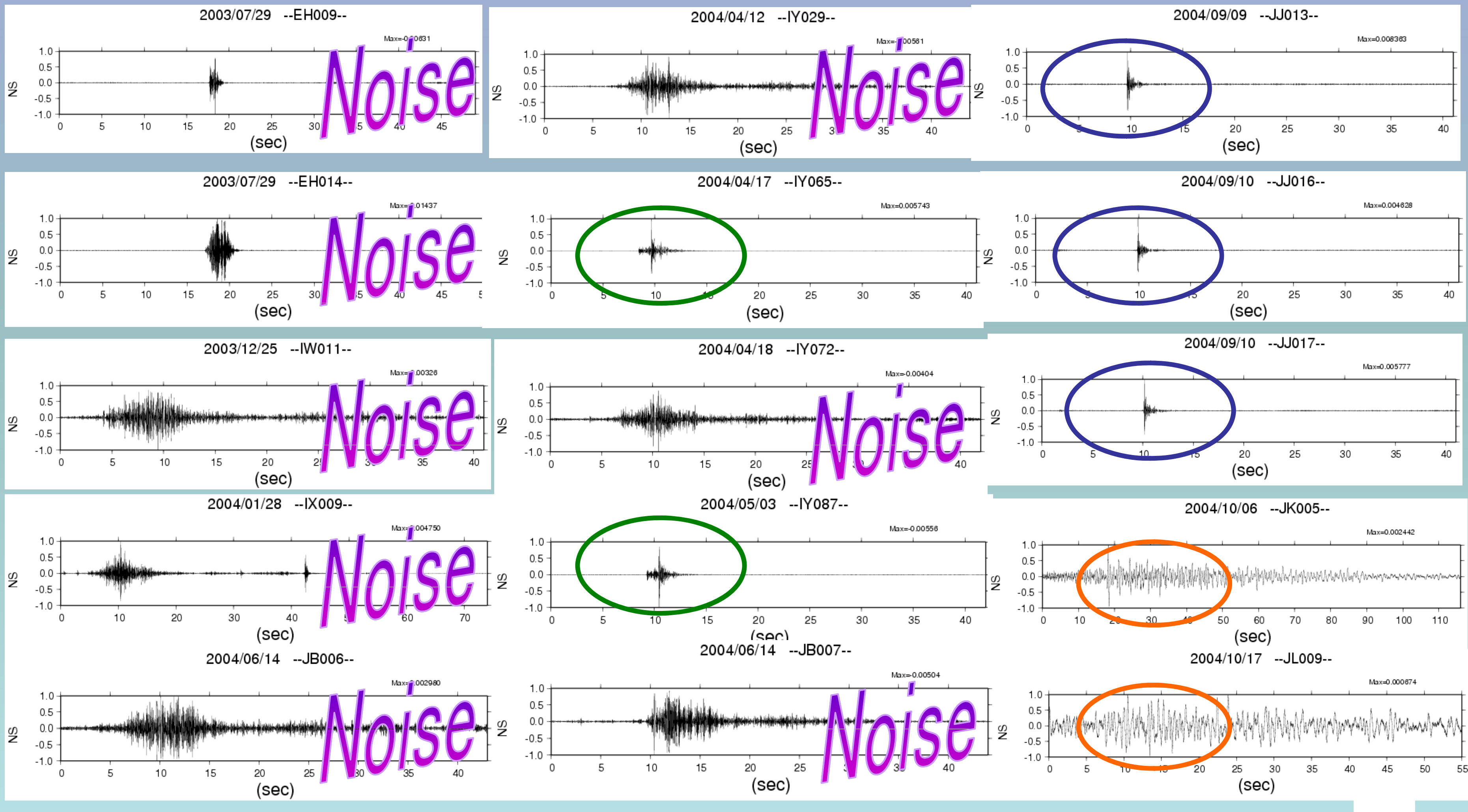
Natural earthquakes and surface noises are included in these events.

Likely Events Recorded at Nagaoka Site

(2004.10.23-2006.3.6)

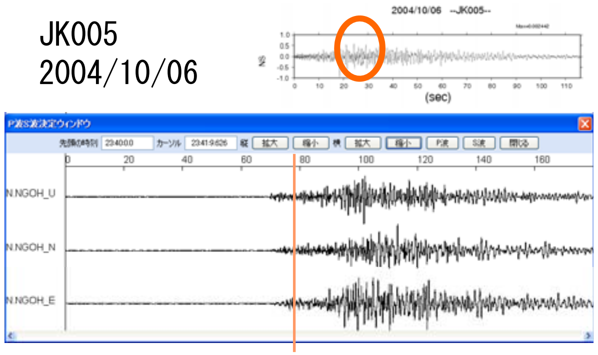


Likely Events Observed from starting injection to Mid-Niigata Earthquake

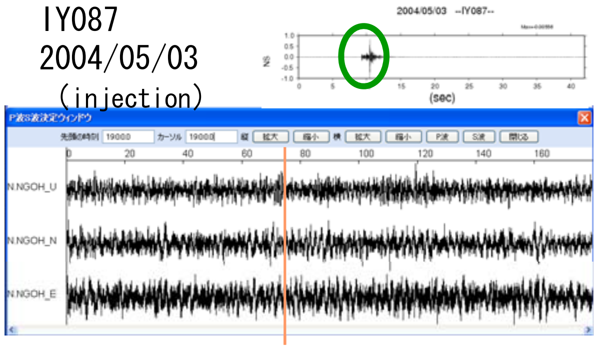


Comparison with Hi-net data

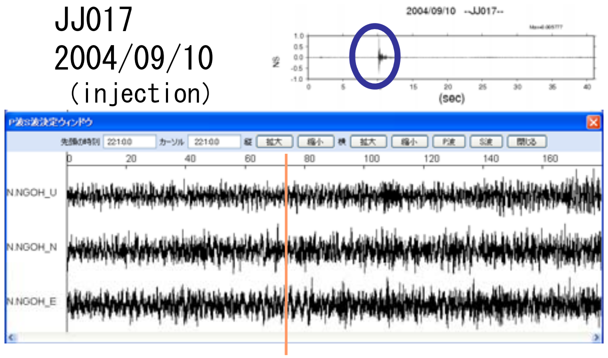
JK005
2004/10/06



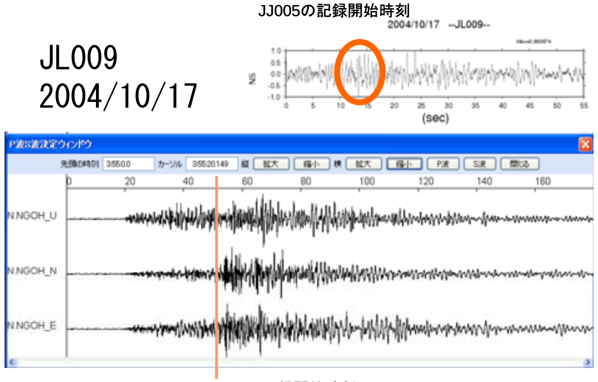
IY087
2004/05/03
(injection)



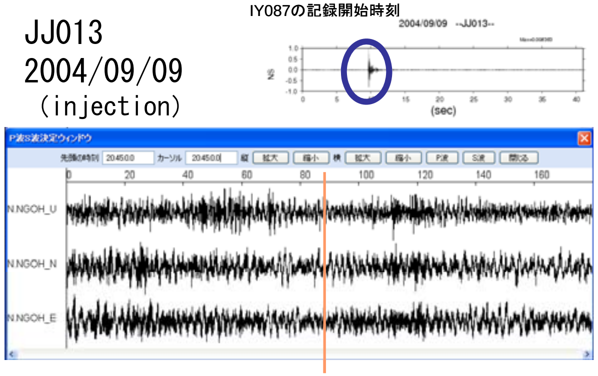
JJ017
2004/09/10
(injection)



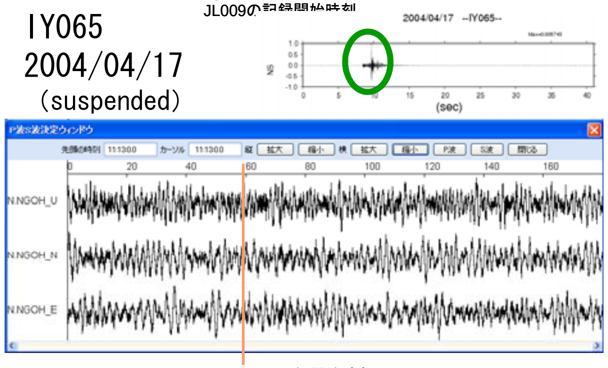
JL009
2004/10/17



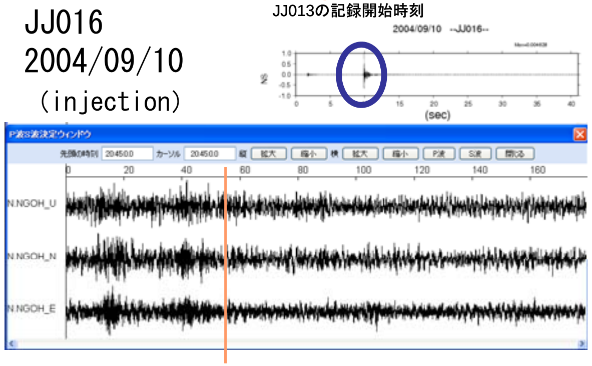
JJ013
2004/09/09
(injection)



IY065
2004/04/17
(suspended)

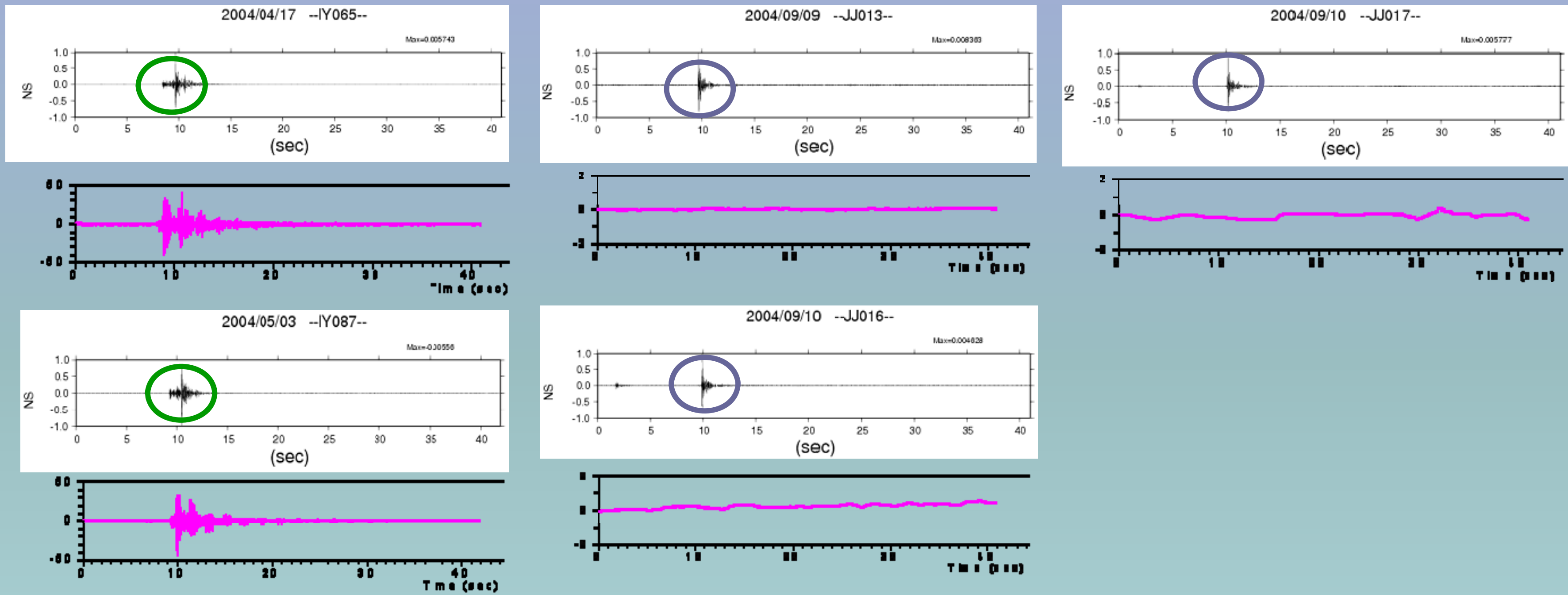


JJ016
2004/09/10
(injection)



: matched event

Comparison with Hydrophone data



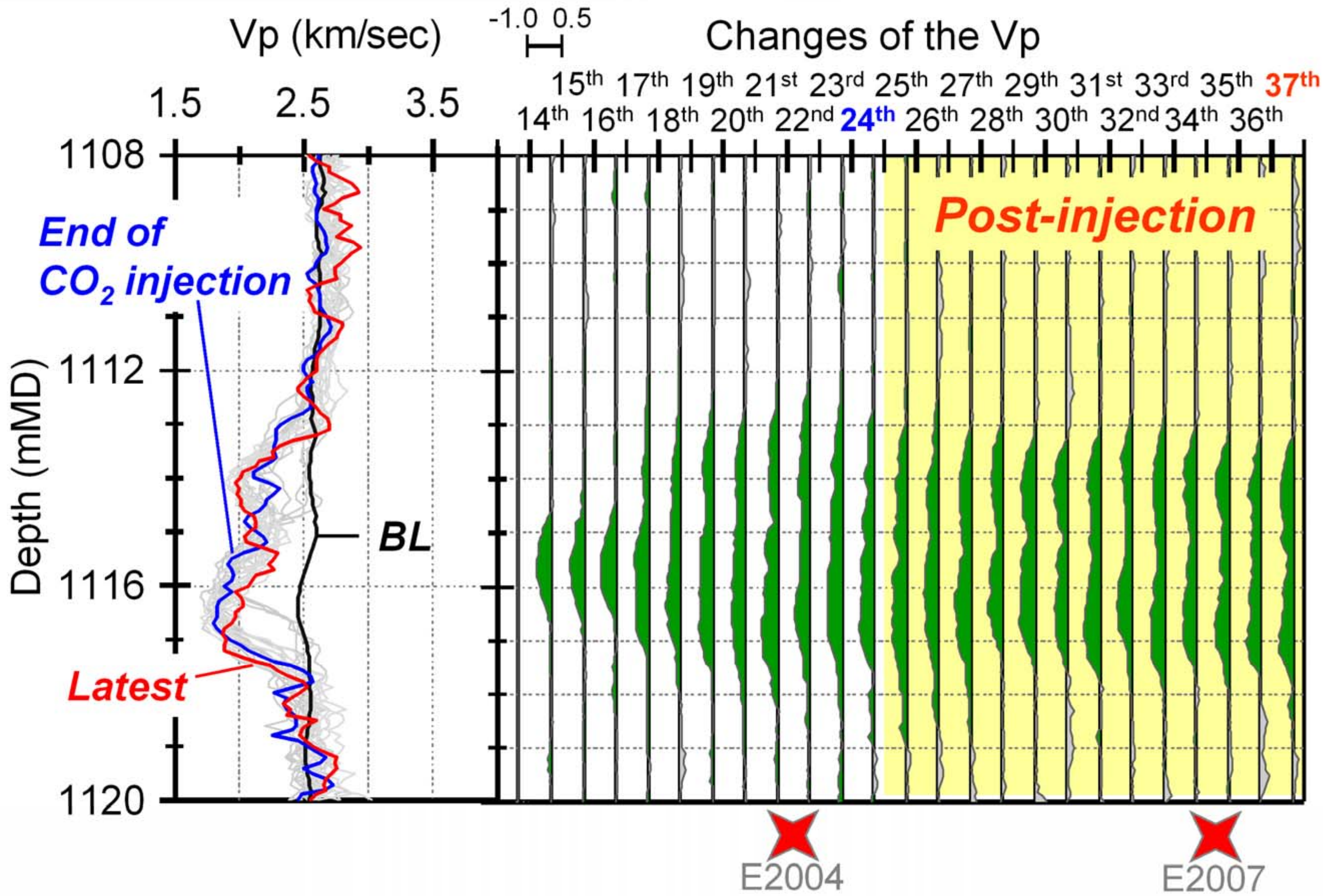
: matched with Hydrophone record, phase lag in P, S-waves

→ *possibly seismic event*

: no record in Hydrophone data, no phase lag in P, S-waves

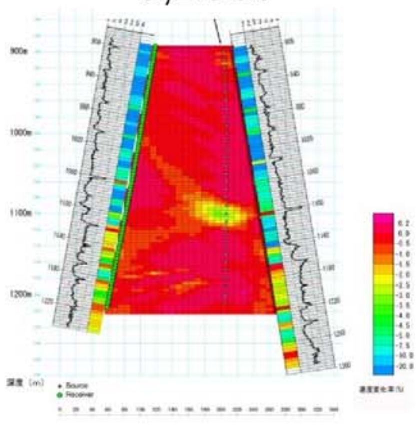
→ *Noise*

Sonic Logging (Vp) @ OB-2

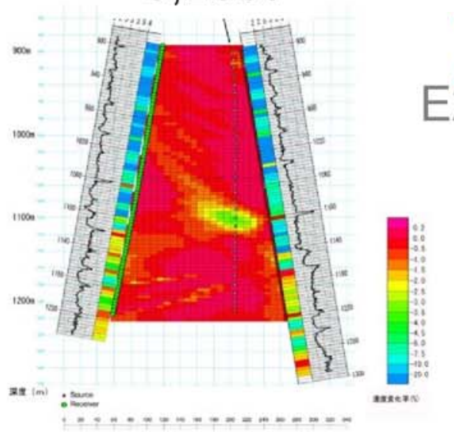


Results of Crosswell Seismic Tomography

MS1/BL
3,200t

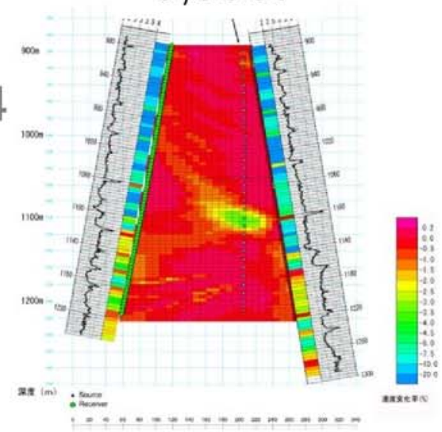


MS2/BL
6,200t

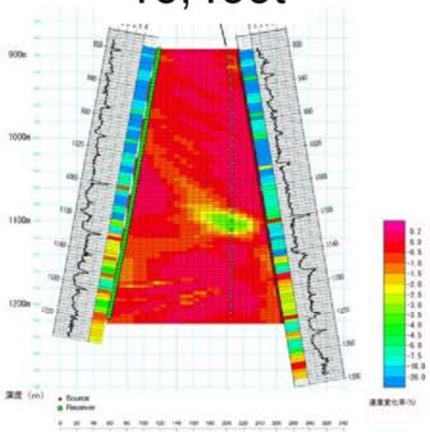


E2004

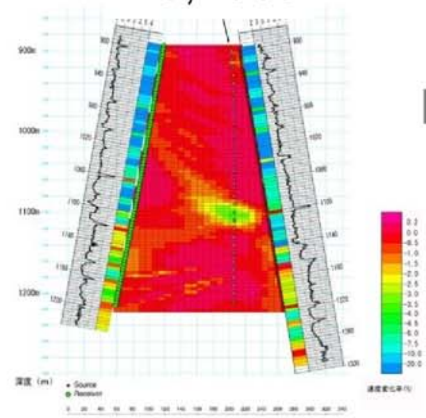
MS3/BL
8,900t



MS4/BL
10,400t

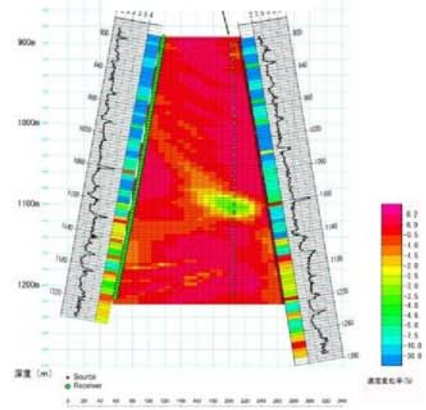


MS5/BL
10,400t

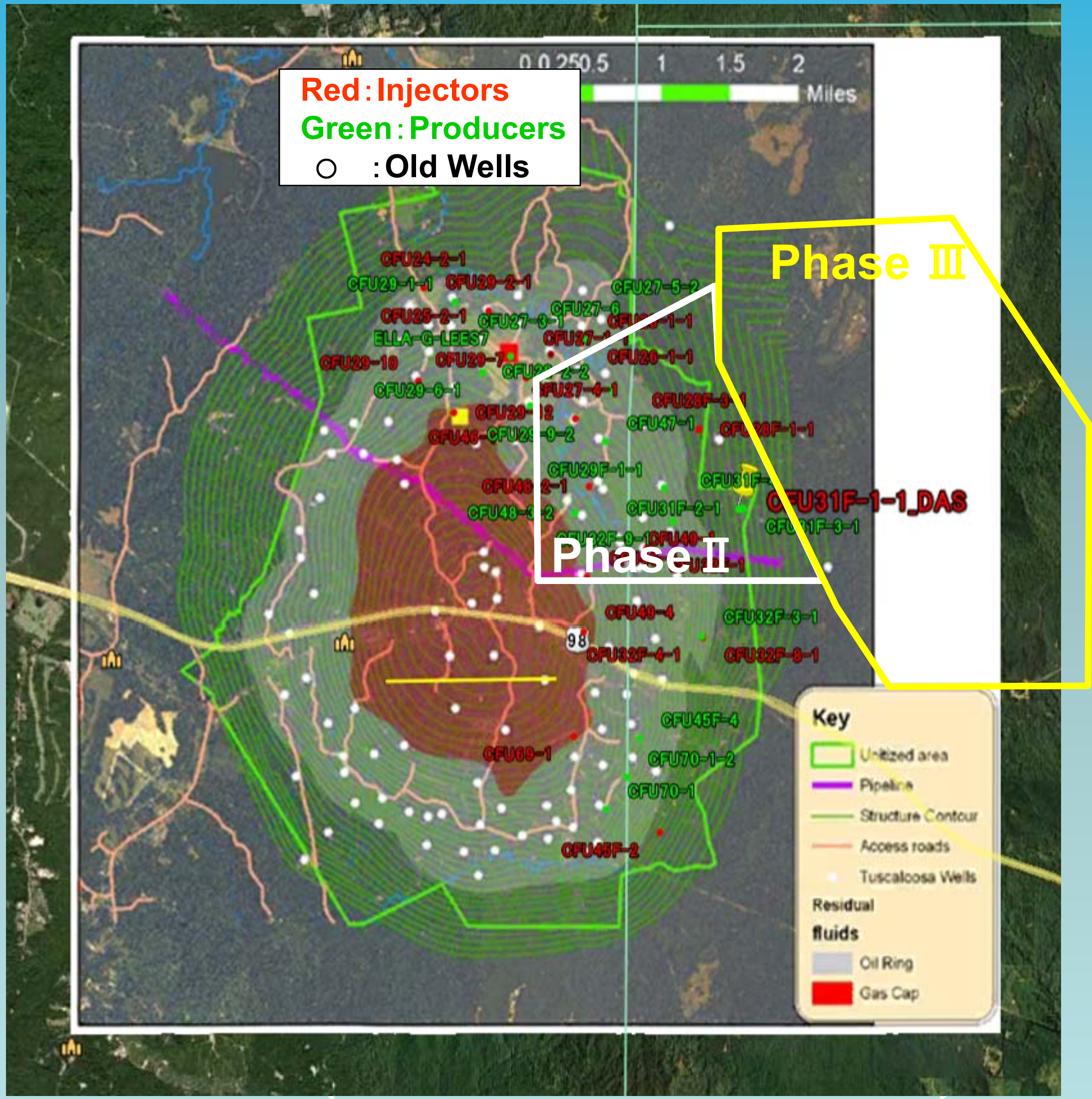


E2007

MS6/BL
10,400t



Japan-US Collaboration with LBNL-SECARB on Microseismic Monitoring at Cranfield



Depleted Oil Field

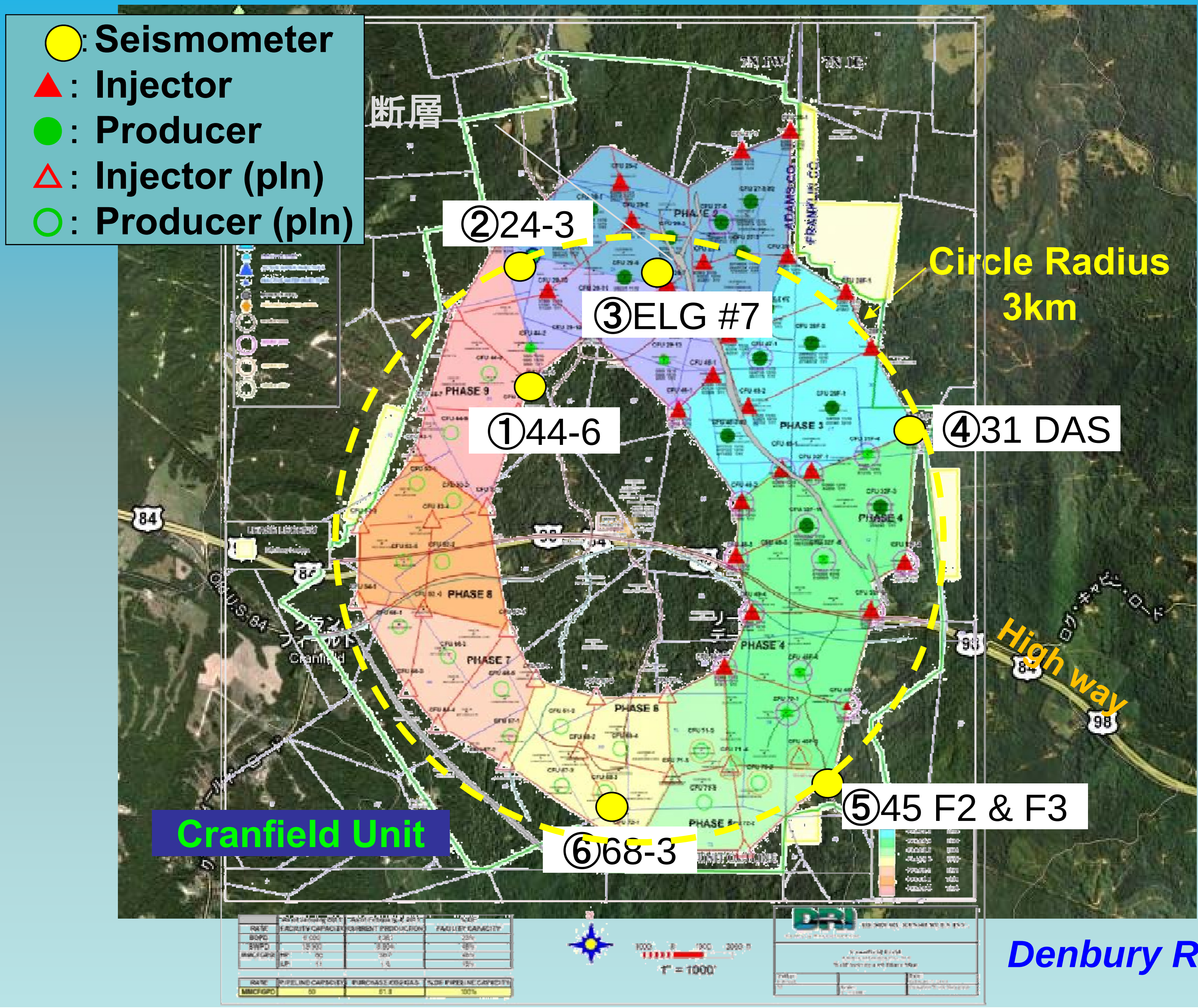
Tuscaloosa formation (3100 m depth)

Large-scale Injection

Low Seismic Activity

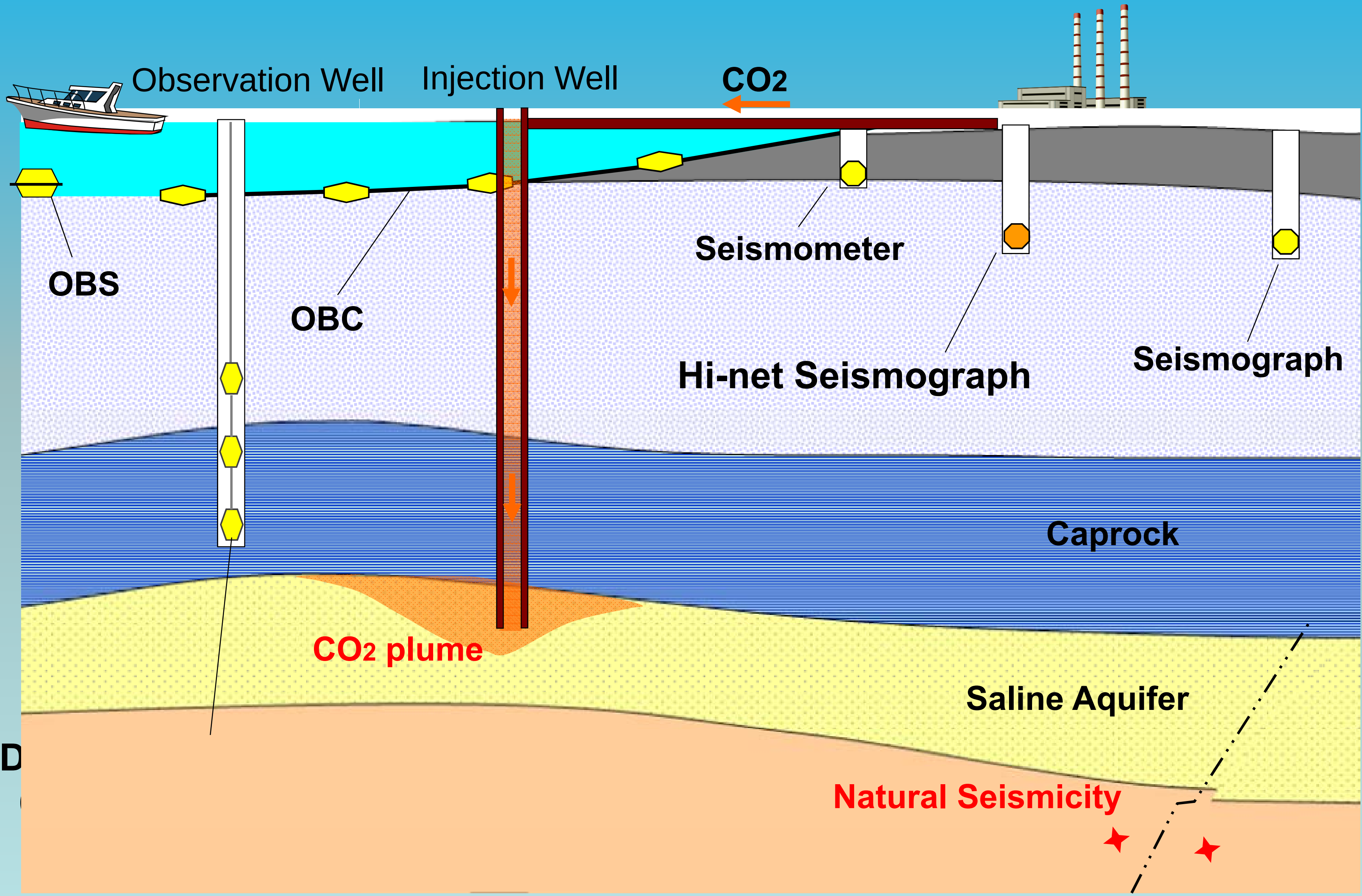
Denbury Resource Int.

Locations of RITE Seismometer at Cranfield



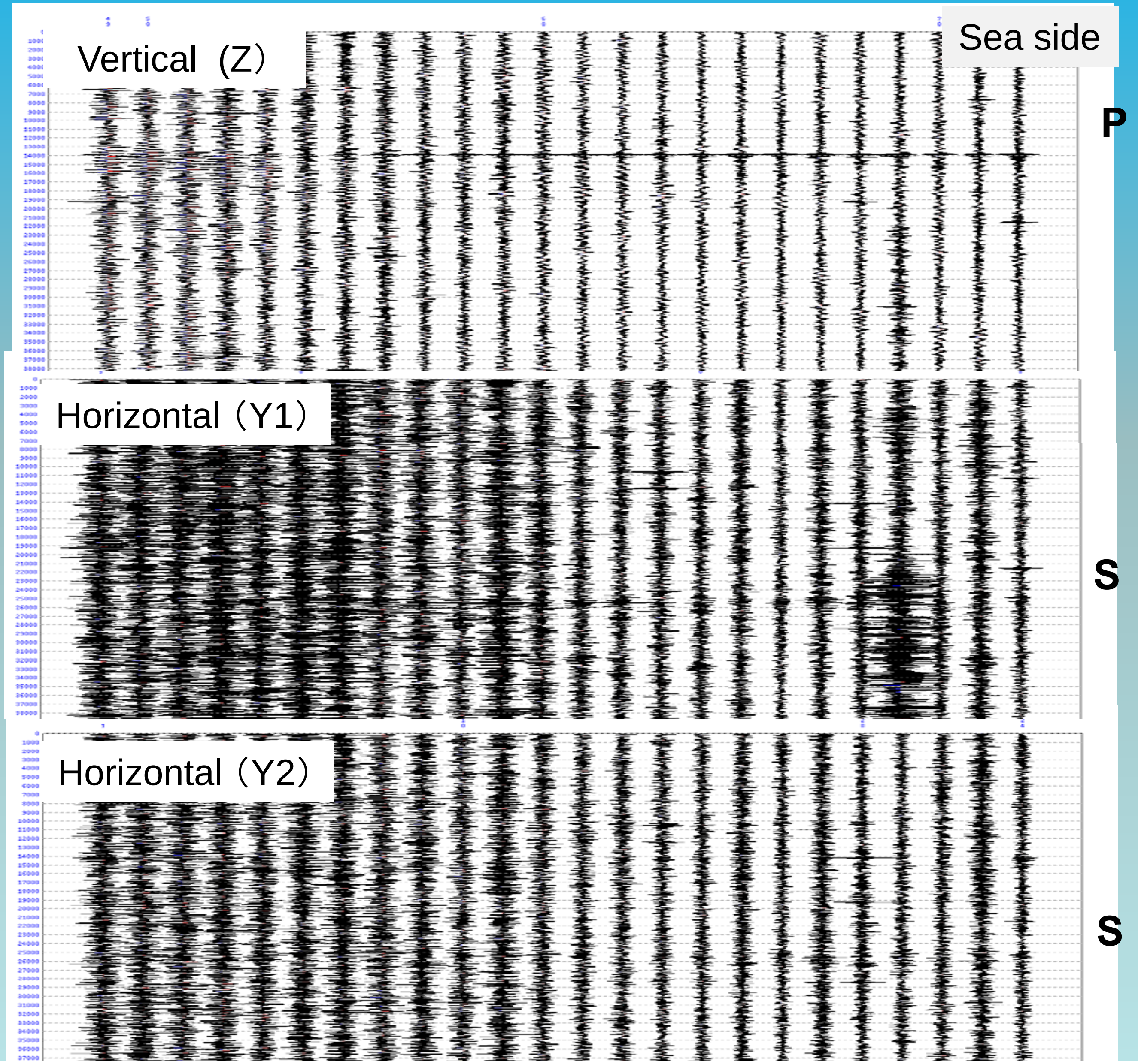
Denbury Resource Int.

Microseismic Monitoring at the Offshore Potential Storage Sites in Japan

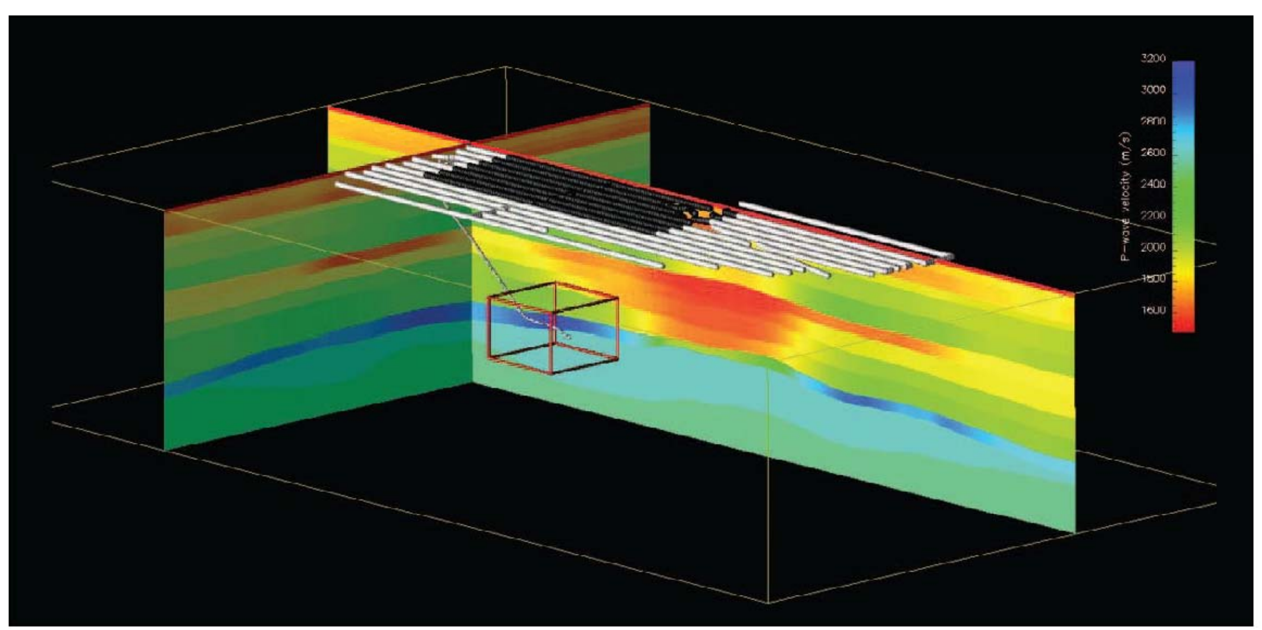


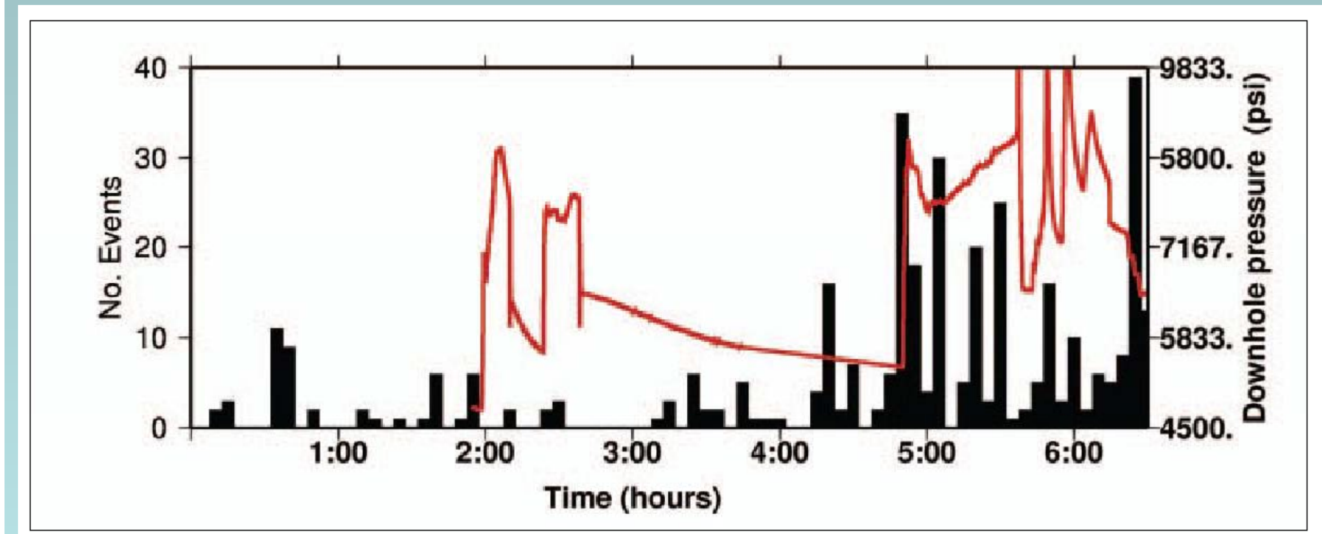
Waveforms of a Natural Seismicity by OBC

M=0.6
(depth: 100km)



Induced Microseismic Measurement at Valhall Using OBC





Permenent OBC
(2008-2048)

120 km length, 45 km^2
(2500 4C Sensors)

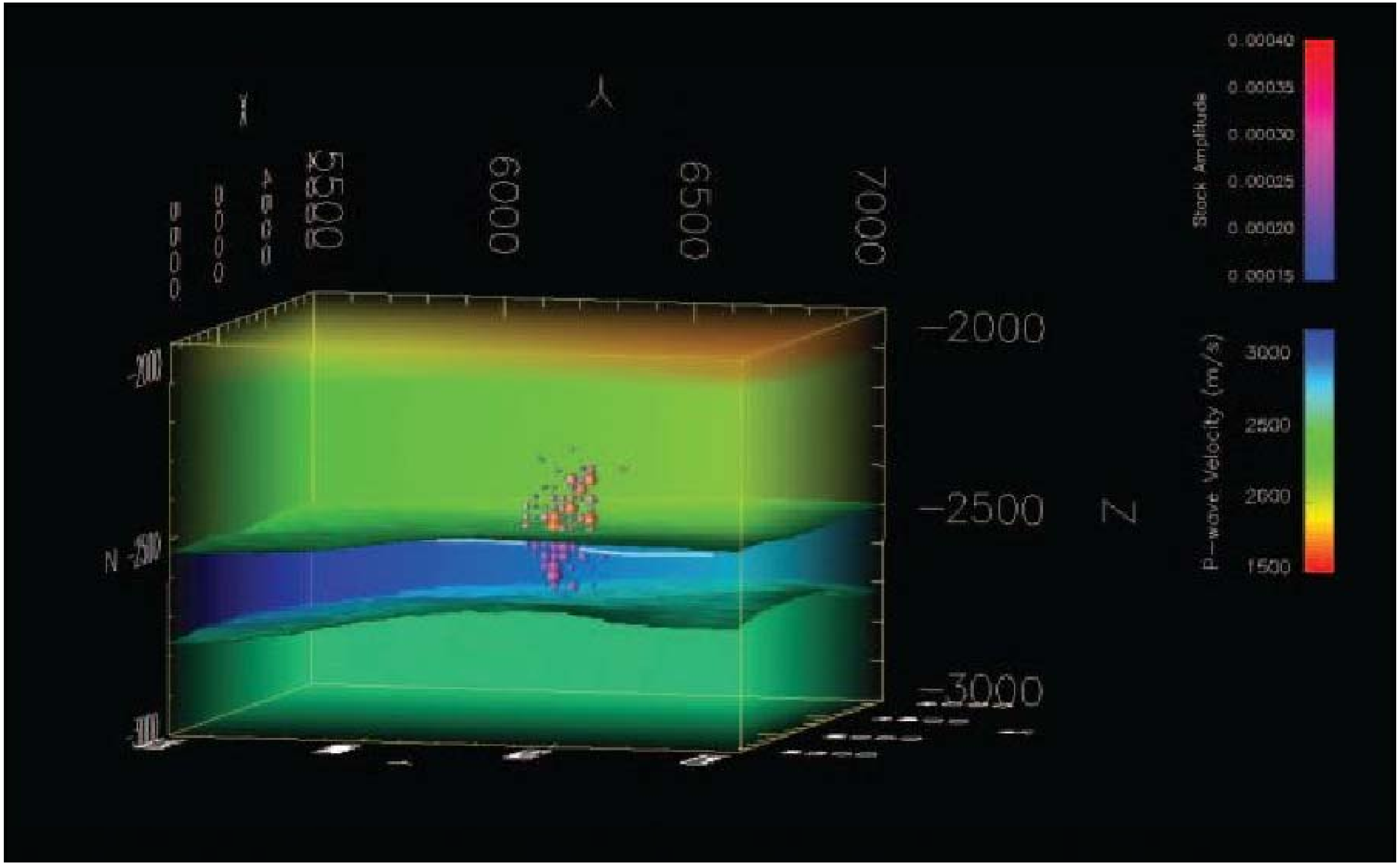
4D Seismic Survey

Microseismic Monitoring
(hydraulic fracturing)

Magnitude: -3.0

Chambers et al., 2010

Event Locations for the Major Cluster in Hydro-fracturing



Chambers et al., 2010

➢Summary of Microseismic Monitoring

◆Events with low signal-to-noise ratio can be grouped and stacked to enhance these signals in OBC system.

◆Integrating OBC with OBS and Hi-net systems to remove events not correlating with CO_2 injection at the offshore storage sites.

◆Building geomechanical models to interpret events outside of reservoir (fluid migration or stress transfer).

◆Field survey results after the Mid-Niigata Earthquake confirmed the safety of CO_2 storage at Nagaoka site.

Acknowledgements

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