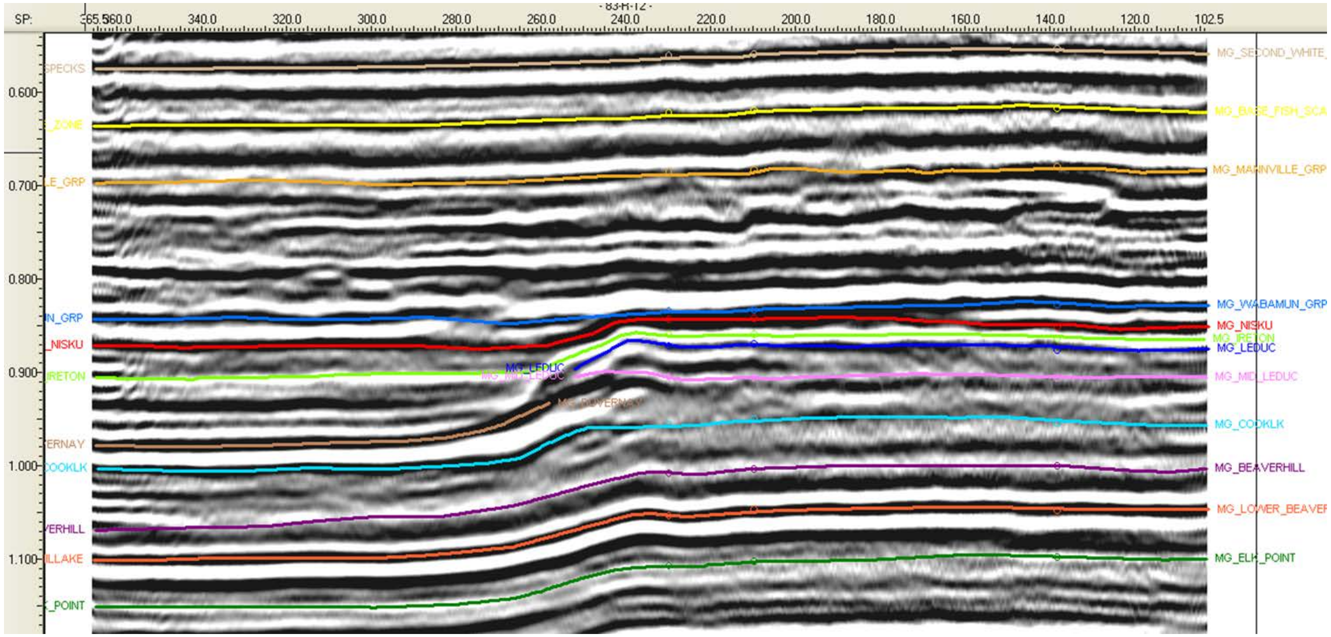
Comparison of seismic technologies for monitoring versus exploration

Don Lawton

Oct 9, 2015



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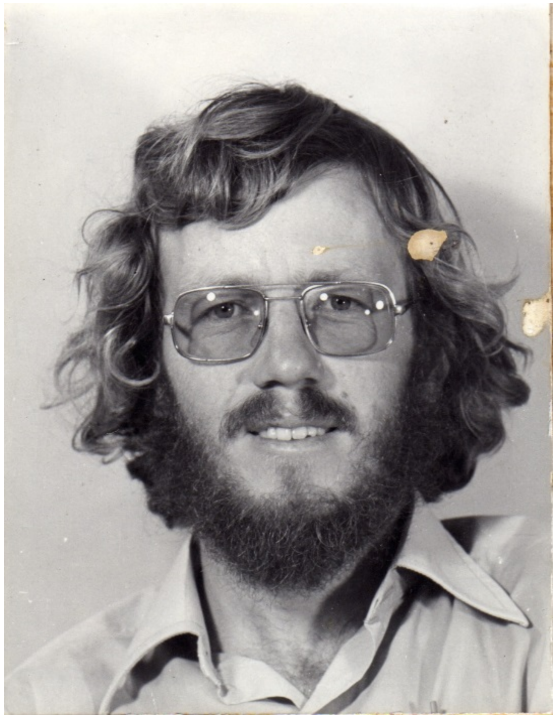
Comparison of seismic technologies for monitoring versus exploration



Exploration

Monitoring

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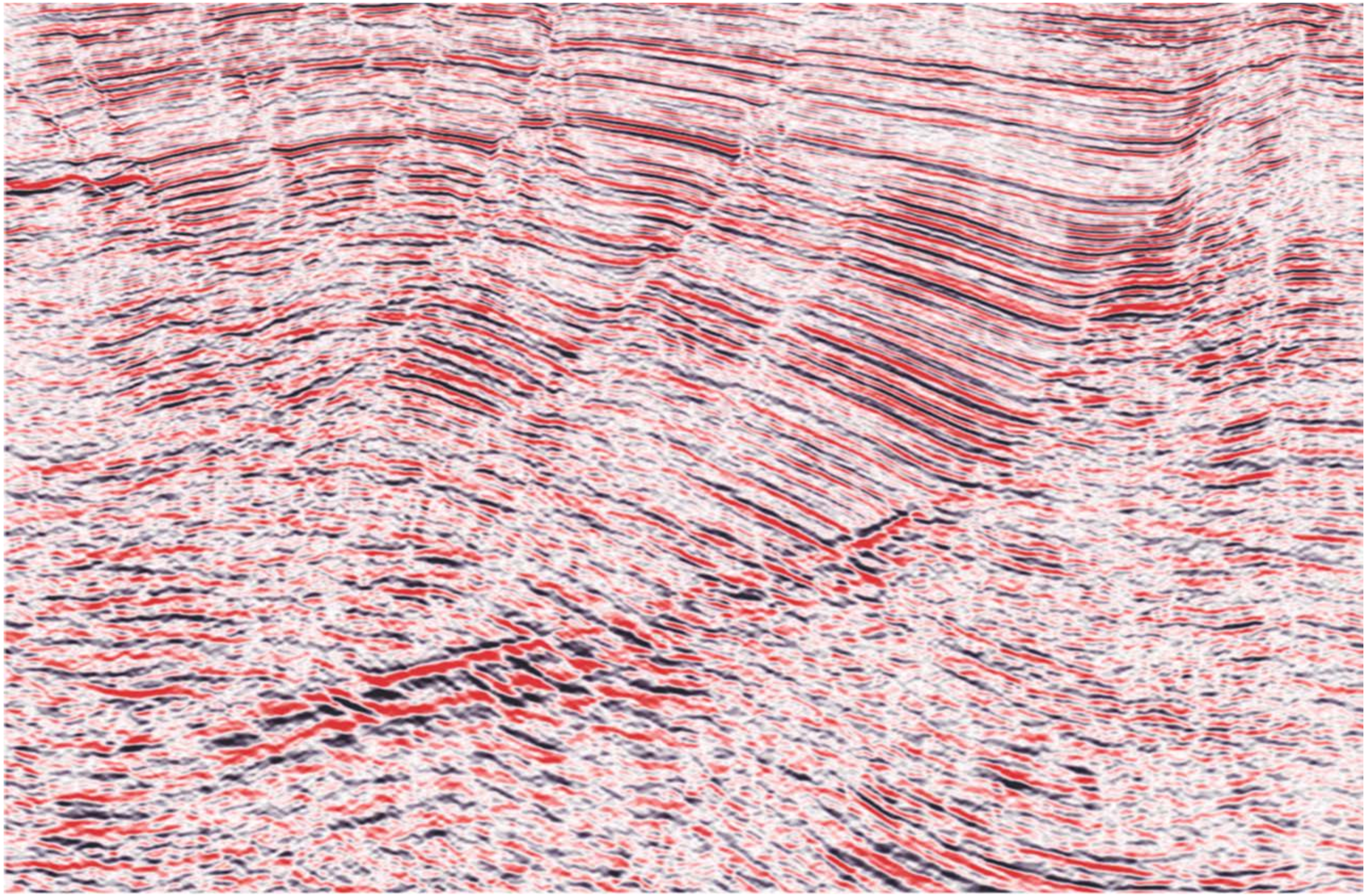
Exploration

Identifying and mapping targets of interest



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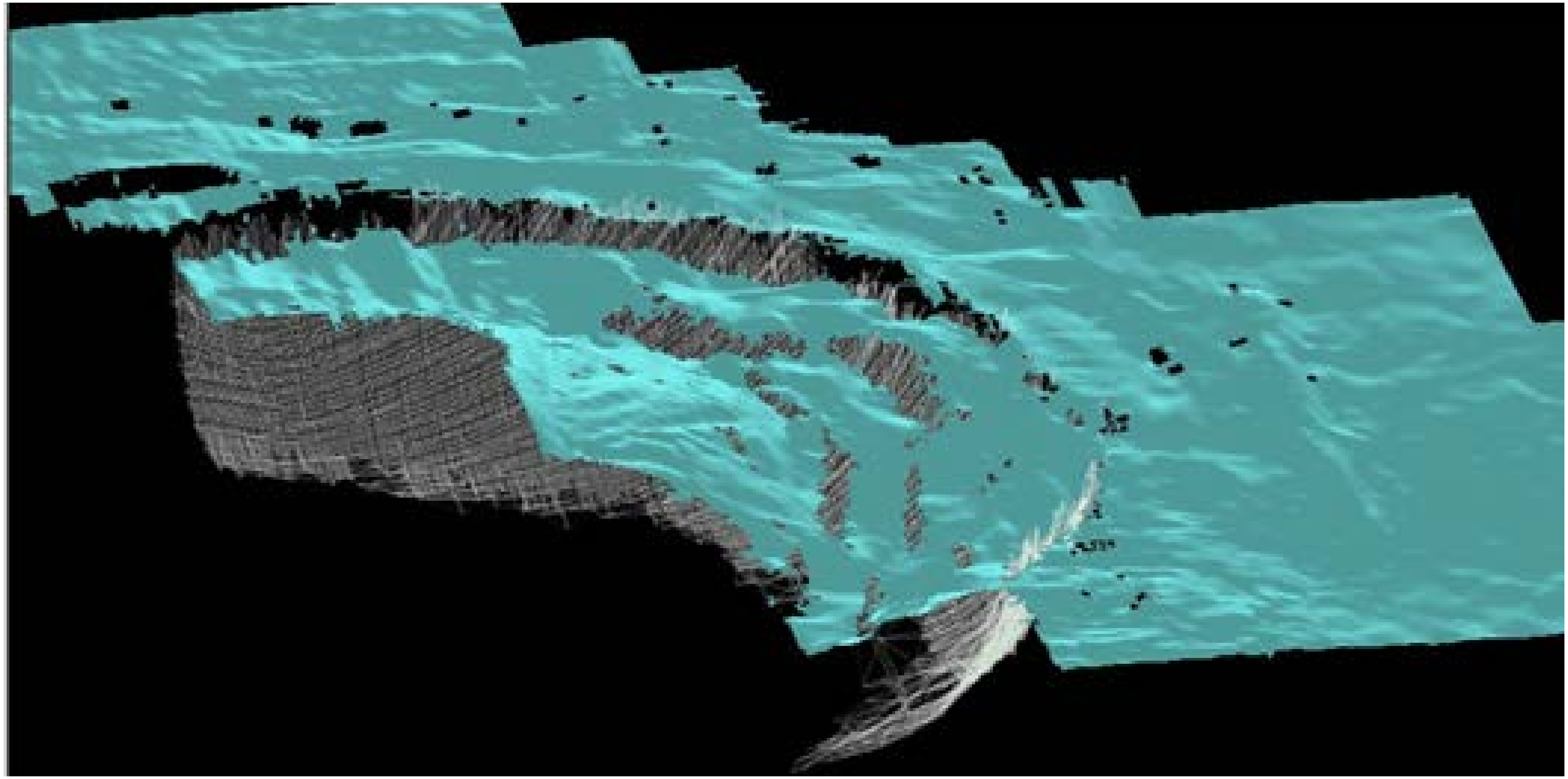
Exploration

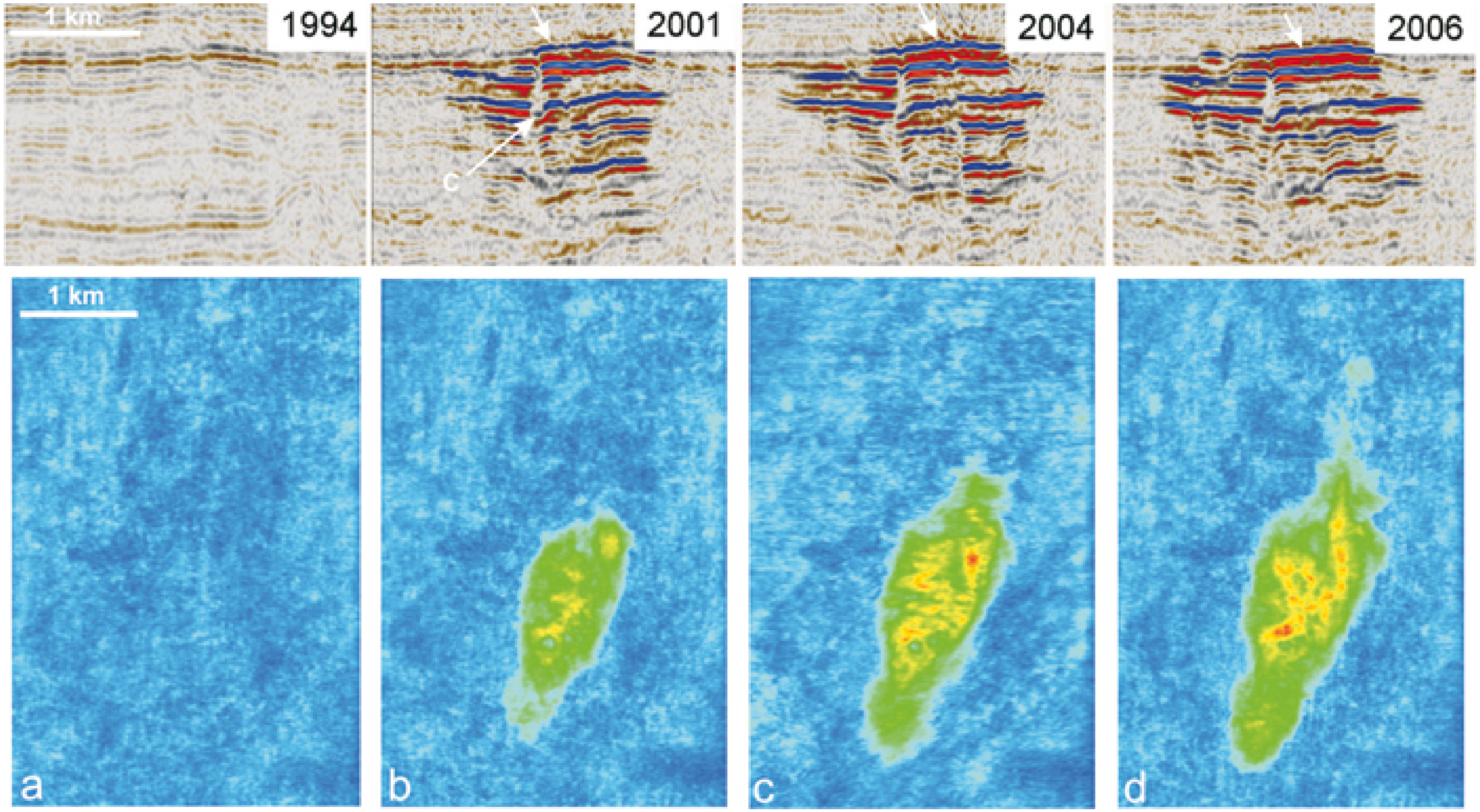
Identifying and mapping targets of interest



Hanova, 2004

Monitoring

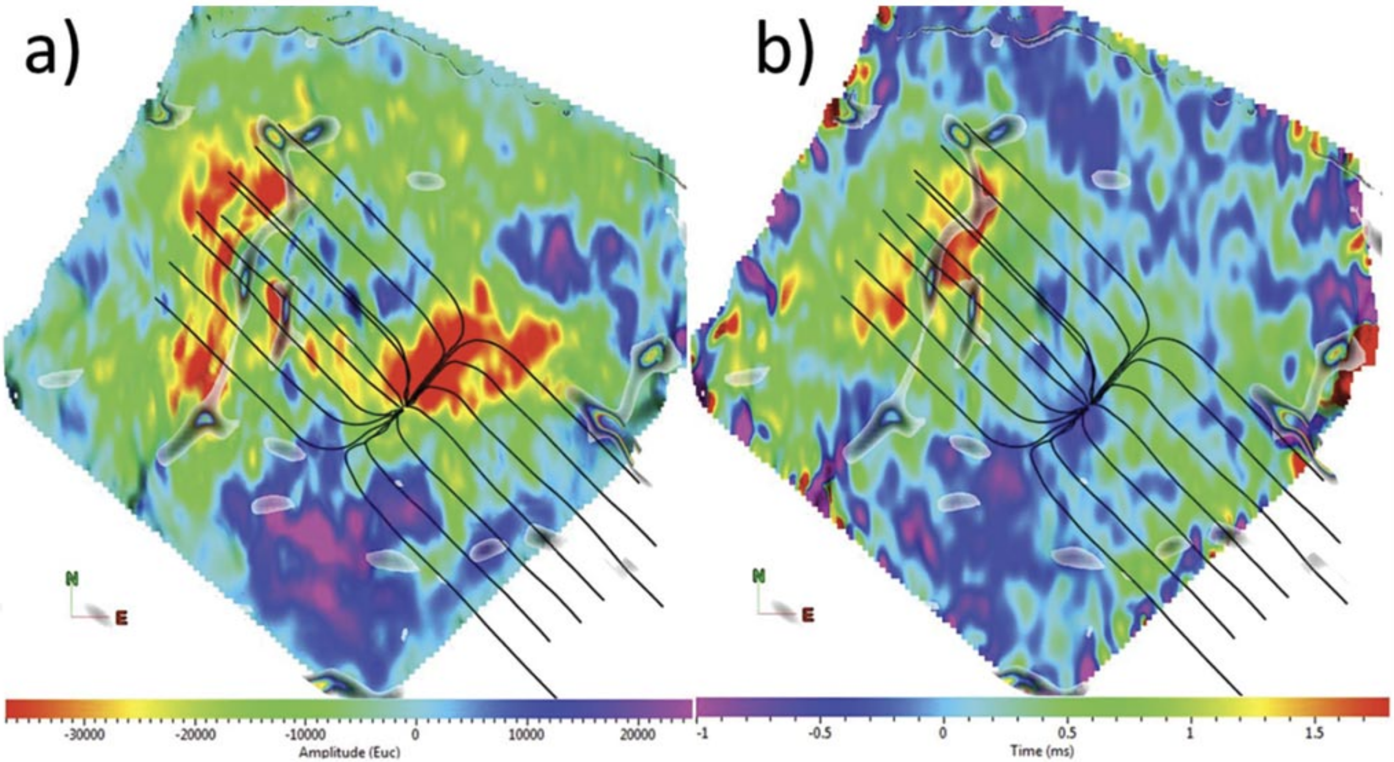
Behaviour of reservoirs over time and space



Sleipner; Chadwick et al, 2010

Monitoring

Behaviour of reservoirs over time and space

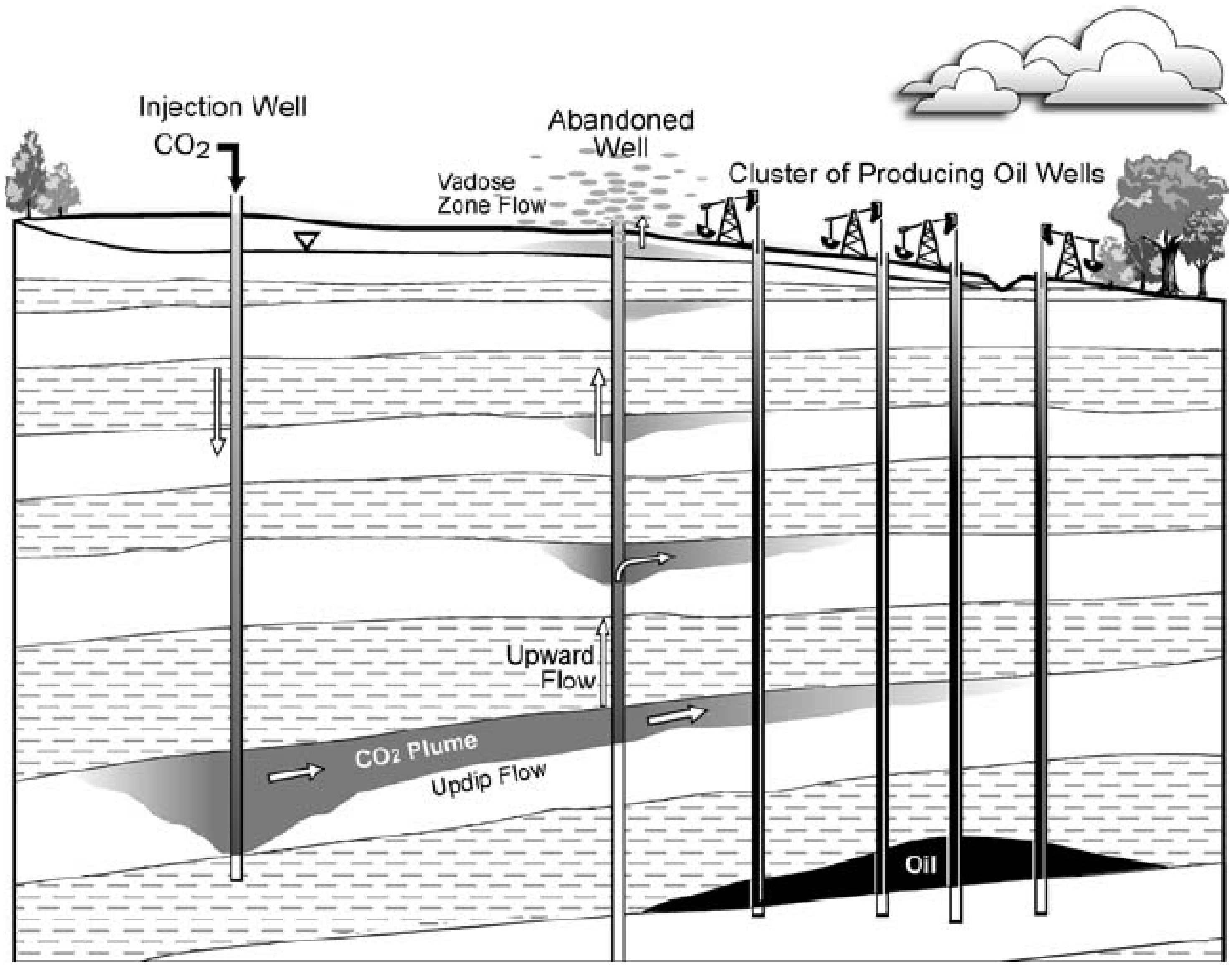


Goodway et al., 2012

Monitoring opportunities

- Secure carbon storage (CCS)
- Steam chamber containment and conformance
- Enhanced petroleum recovery
- Fugitive methane emissions
- Well integrity
- Shale gas and tight oil (hydraulic fracturing)
- Acid gas disposal
- Produced water disposal
- Induced seismicity risk analysis

Containment risk



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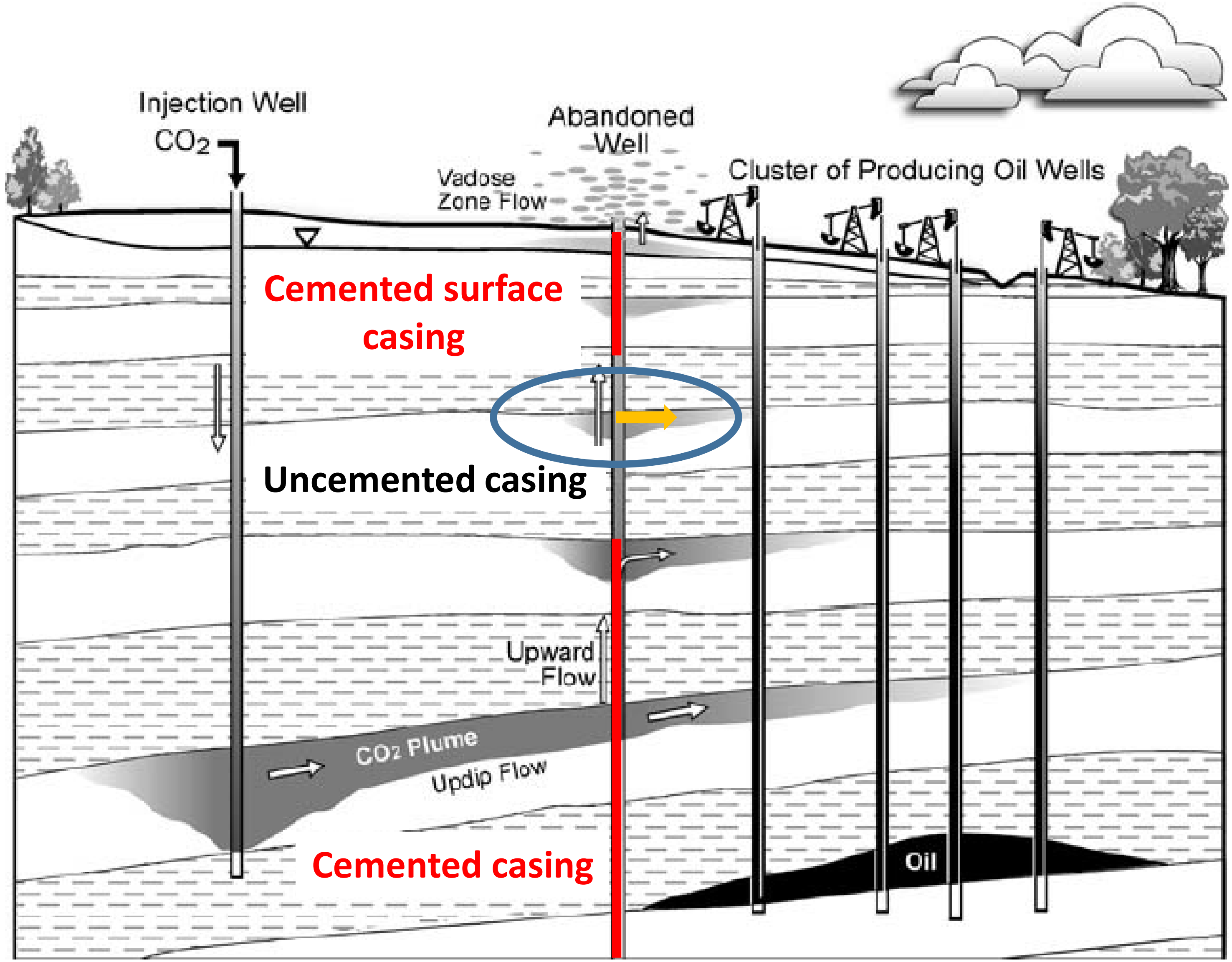
Containment risk



After Celia et al., 2004

Containment failure

ERCB

ERCB

Credit CNRL/Emma Pullman

www.montrealgazette.com

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Monitoring technologies

- 3D-3C surface seismic surveys/3D vertical seismic profiles
- Cross-well seismic surveys
- Microseismic surveys
- Electrical and electromagnetic geophysical surveys
- Fibre-optic monitoring technologies (DAS, DTS)
- Microgravity surveys
- Muon density tomography
- Tilt-meters & DGPS surveys
- InSAR imaging and interpretation

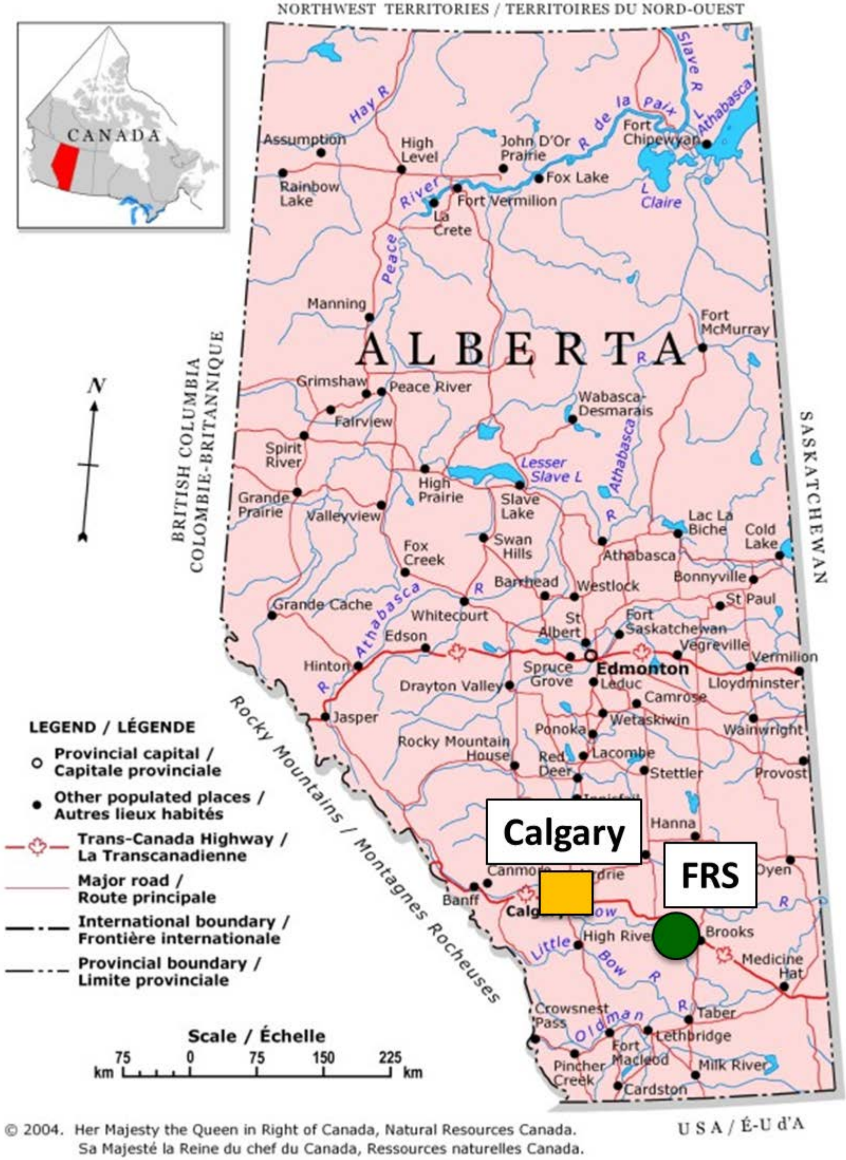
- Geomechanics
- Geochemical sampling/tracers (isotopes, noble gases)
- Groundwater monitoring surveys
- Casing gas, soil & atmospheric surveys
- Flow engineering

Monitoring challenges

Verification of conformance and containment

- Thin reservoirs (saturation-thickness)
- Resolution from monitoring methods, tuning
- High rock matrix K and μ values
- Fluid migration through legacy wells
- Cap rock integrity
- Impacts on groundwater
- Pressure vs. CO_2 saturation
- Pressure interference with adjacent hydrocarbon pools

CaMI.FRS



Land leased from Cenovus Energy

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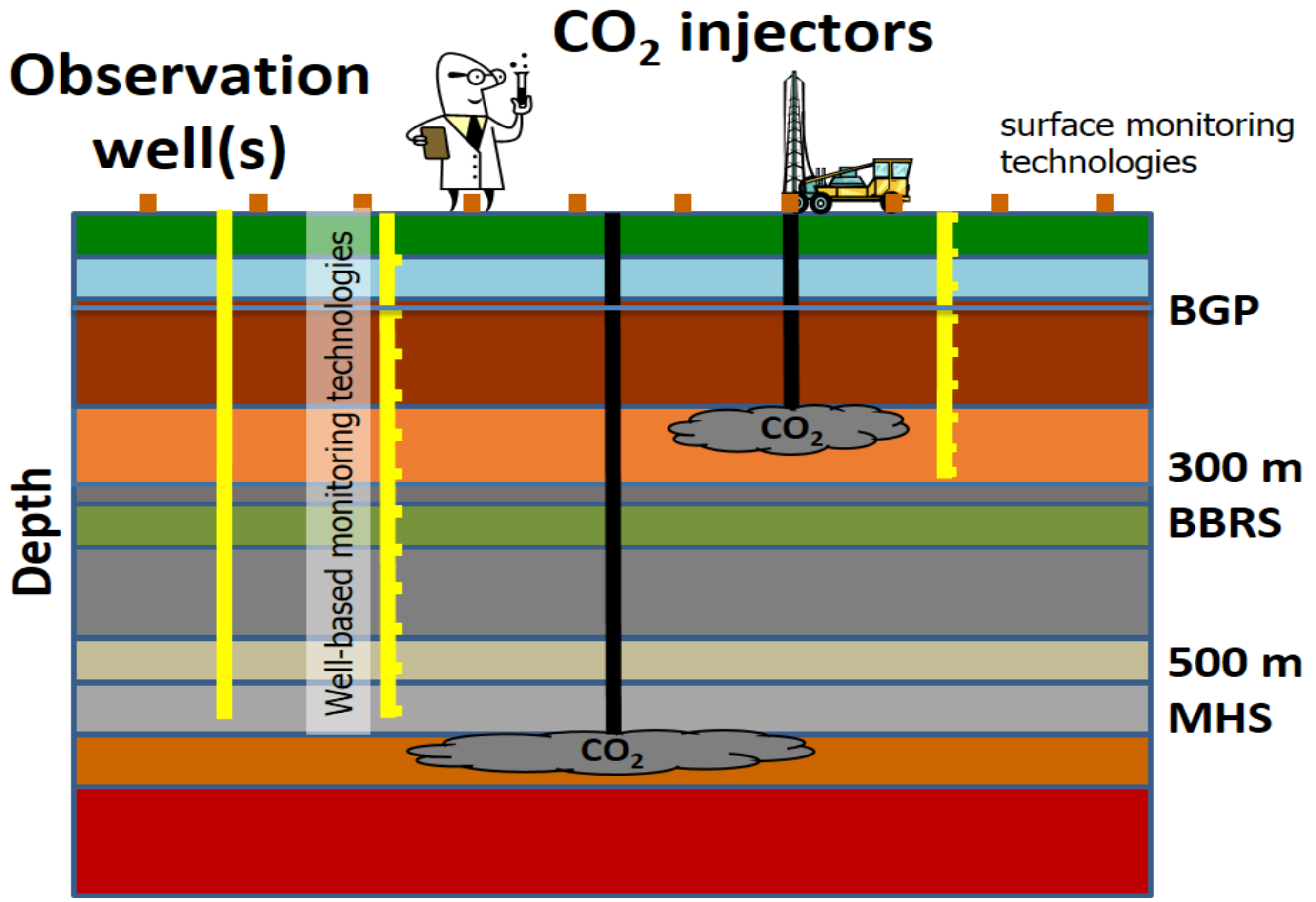
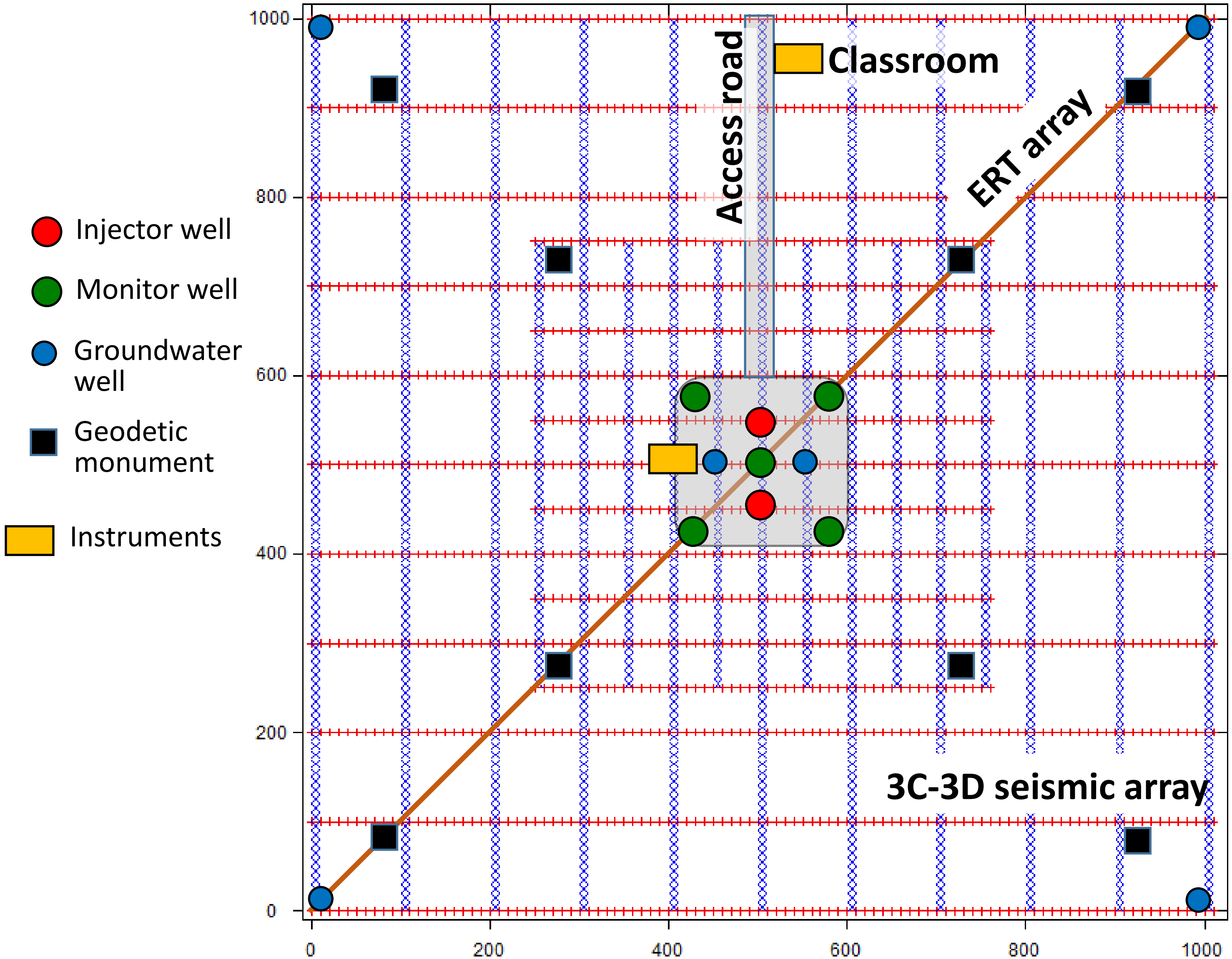
CaMI.FRS



- BGP : Base of Groundwater Protection
- BBRS : Basal Belly River Sandstone
- MHS : Medicine Hat Sandstone

CaMI.FRS monitoring layout

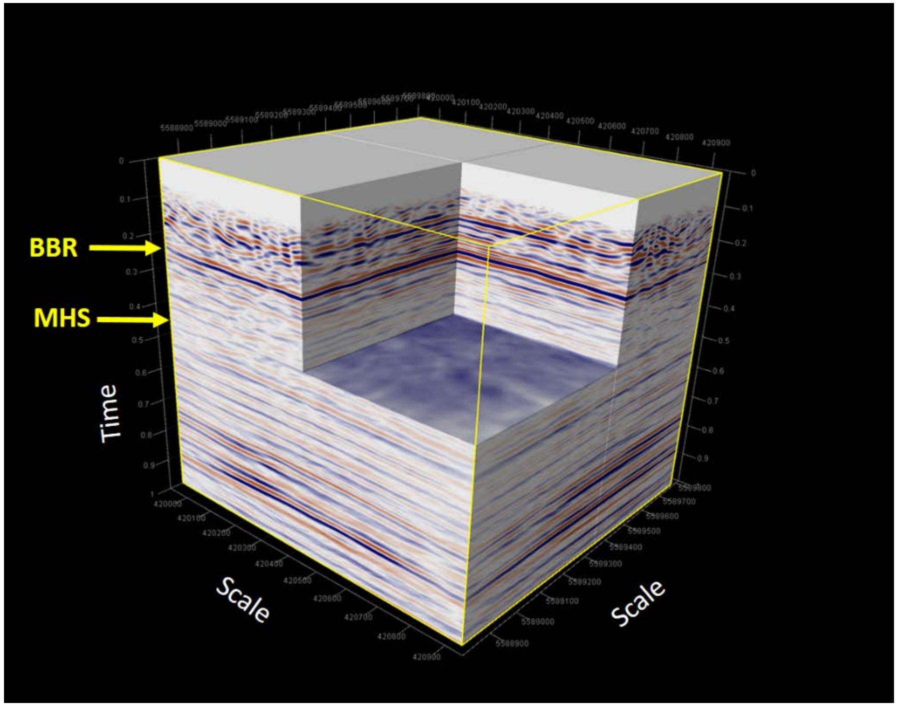


Monitoring needs (seismic)

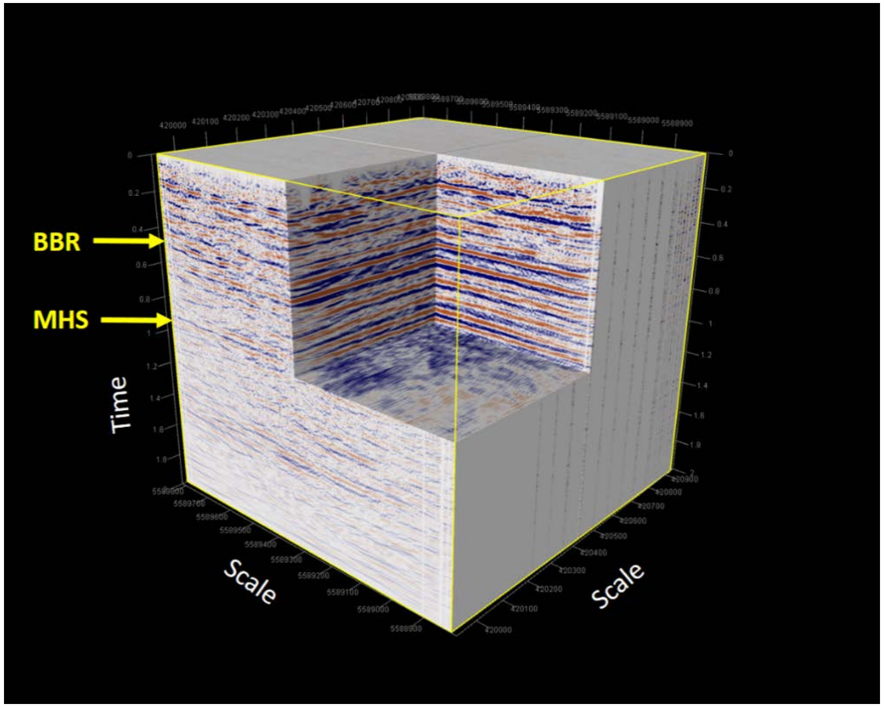
- Excellent P and S seismic volumes (baseline)
- Sensors close to reservoir
- Robust and slim sensors
- Preservation of well integrity
- Repeatable seismic source
- Rapid response to trigger
- Temporally unaliased images (high repeat rate)

CaMI.FRS seismic volumes

PP

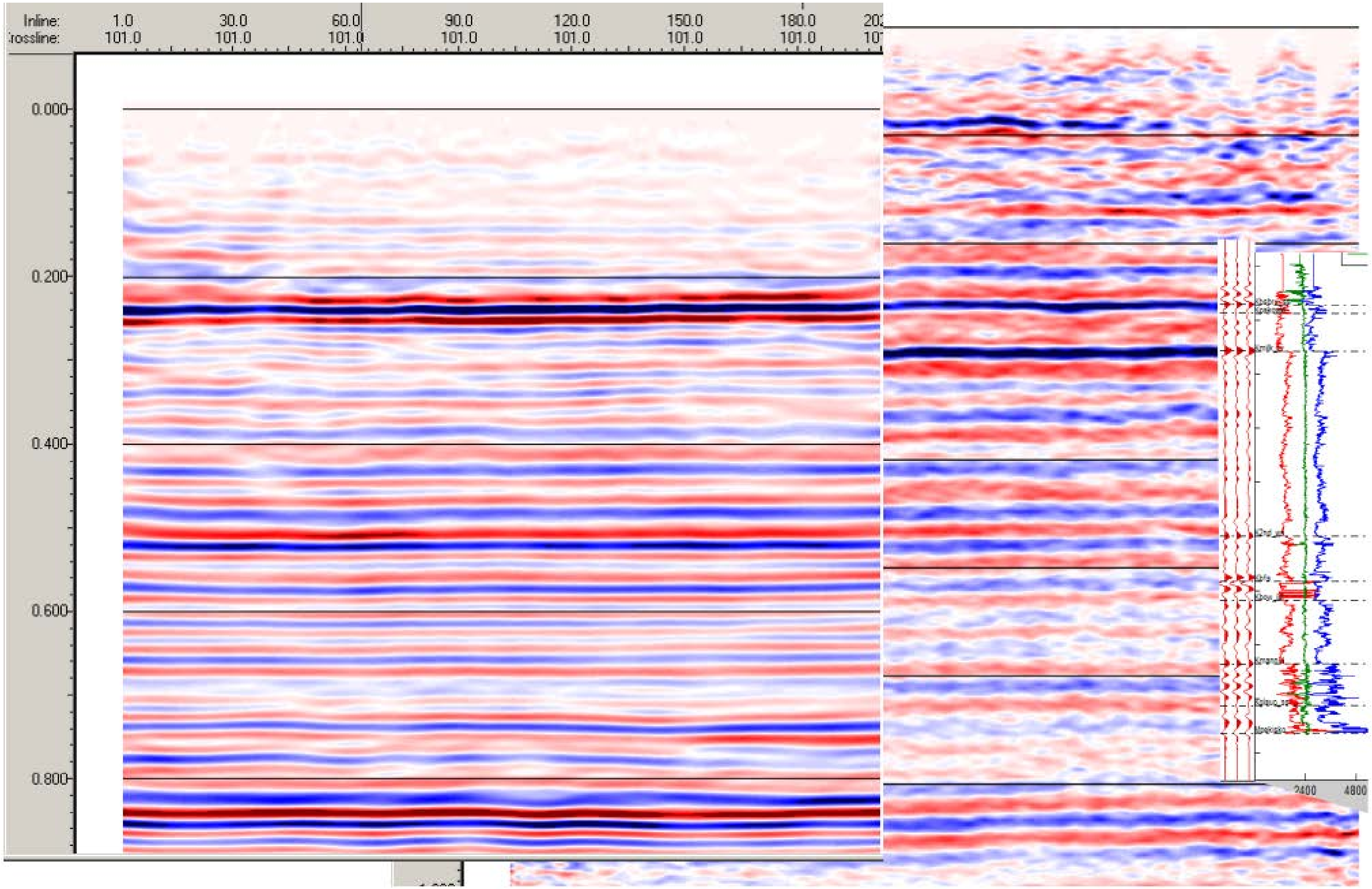


PS



CaMI.FRS PP-PS correlation

PP - inline **PS - inline**



Helen Isaac

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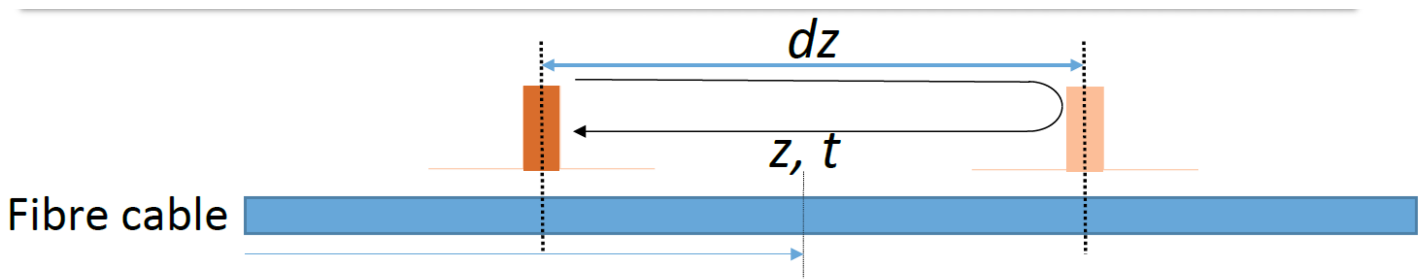
Borehole sensors

3C geophone

Distributed acoustic sensing (DAS)

DAS fibre longitudinal strain rate



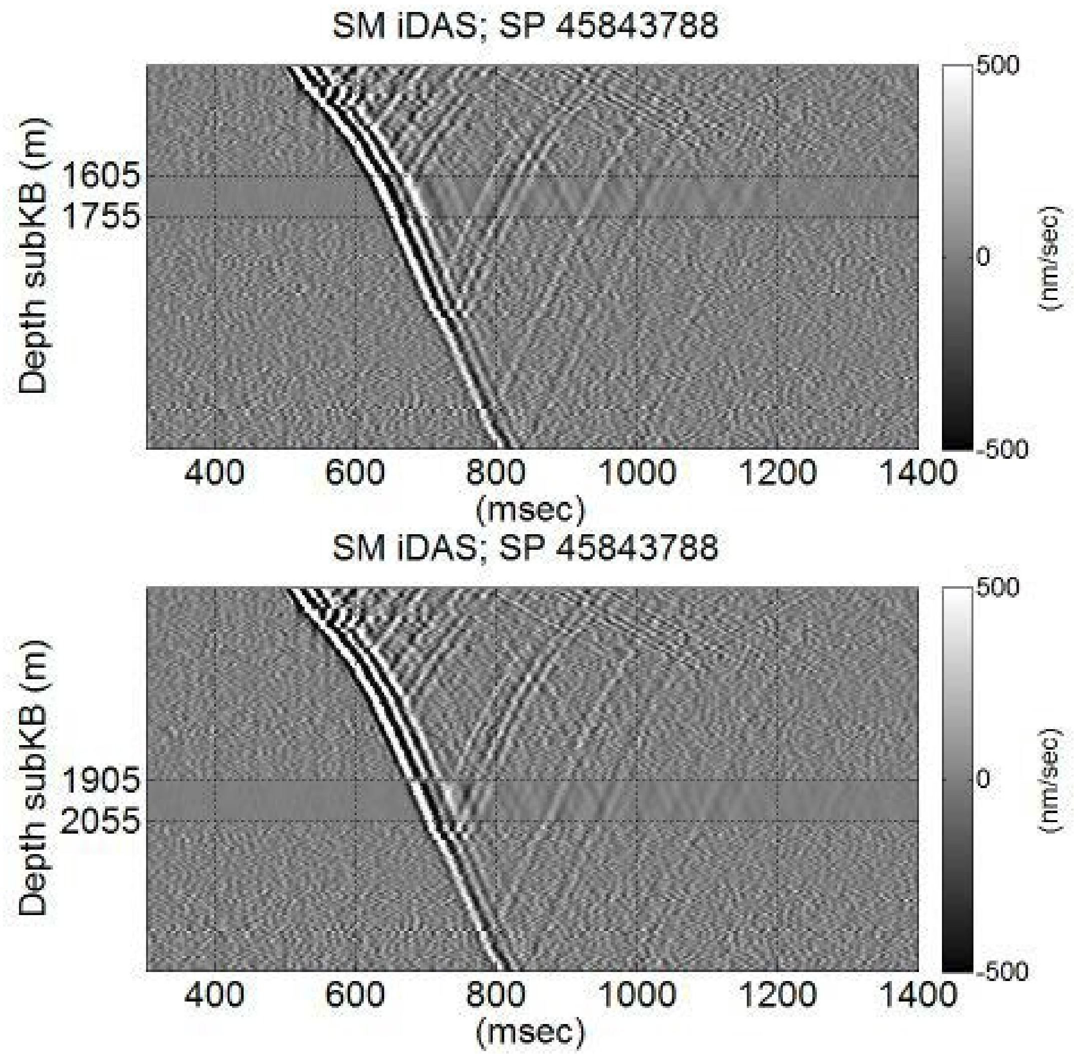
fibre elongation at location z and time t, u(z,t), is measured over a reference distance dz

time difference (t, t + dt) of elongation spatial difference (dz)

$$\left[u\left(z+\frac{dz}{2},t+dt\right)-u\left(z-\frac{dz}{2},t+dt\right)\right]-\left[u\left(z+\frac{dz}{2},t\right)-u\left(z-\frac{dz}{2},t\right)\right]$$

Courtesy Tom Daley, LBNL

DAS vs geophones



(after Daley, 2014)

Continuous acquisition

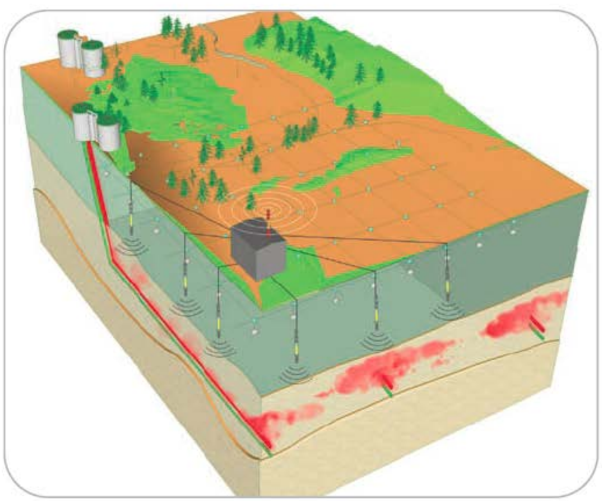
SeisMovie

Continuous High-Resolution
Reservoir Monitoring

ACQUISITION - LAND

CGGVERITAS

SeisMovie is CGGVeritas' solution to high-resolution onshore reservoir monitoring. Using buried sources and buried receiver arrays, data is acquired continuously and autonomously to provide a seamless, high-resolution movie of your reservoir. The system offers unparallelled sensitivity and can capture subtle and rapid reservoir variations which conventional 4D techniques fail to resolve. SeisMovie is both versatile and environmentally friendly, with a wide range of applications.



FEATURES

- Continuous automated seismic data acquisition
- Remote operation and data recovery
- Buried source and receiver installations for high sensitivity and optimum 4D repeatability
- Versatile and flexible design can target vertical and/or spatial reservoir variations
- Applications for monitoring:
  - Subsurface gas storage
  - Steam and water injection enhanced production
  - Reservoirs with small 4D signatures.

BENEFITS

- Captures subtle reservoir variations
- Enables monitoring of previously unsuitable reservoirs

http://www.cggveritas.com/data/1/rec_docs/1886_Seismovie.pdf

ACROSS source 0 – 40 Hz

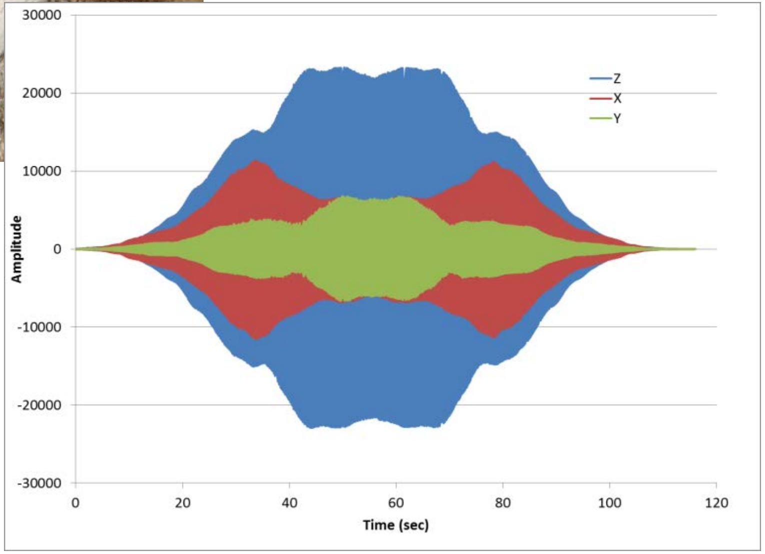
Courtesy Mamoru Takanashi JOGMEC

LBNL rotary source 0 – 80 Hz

After Barry Freifeld, LBNL

10 T-force rotary source sitting on a 1 m x 2 m x 2 m deep foundation

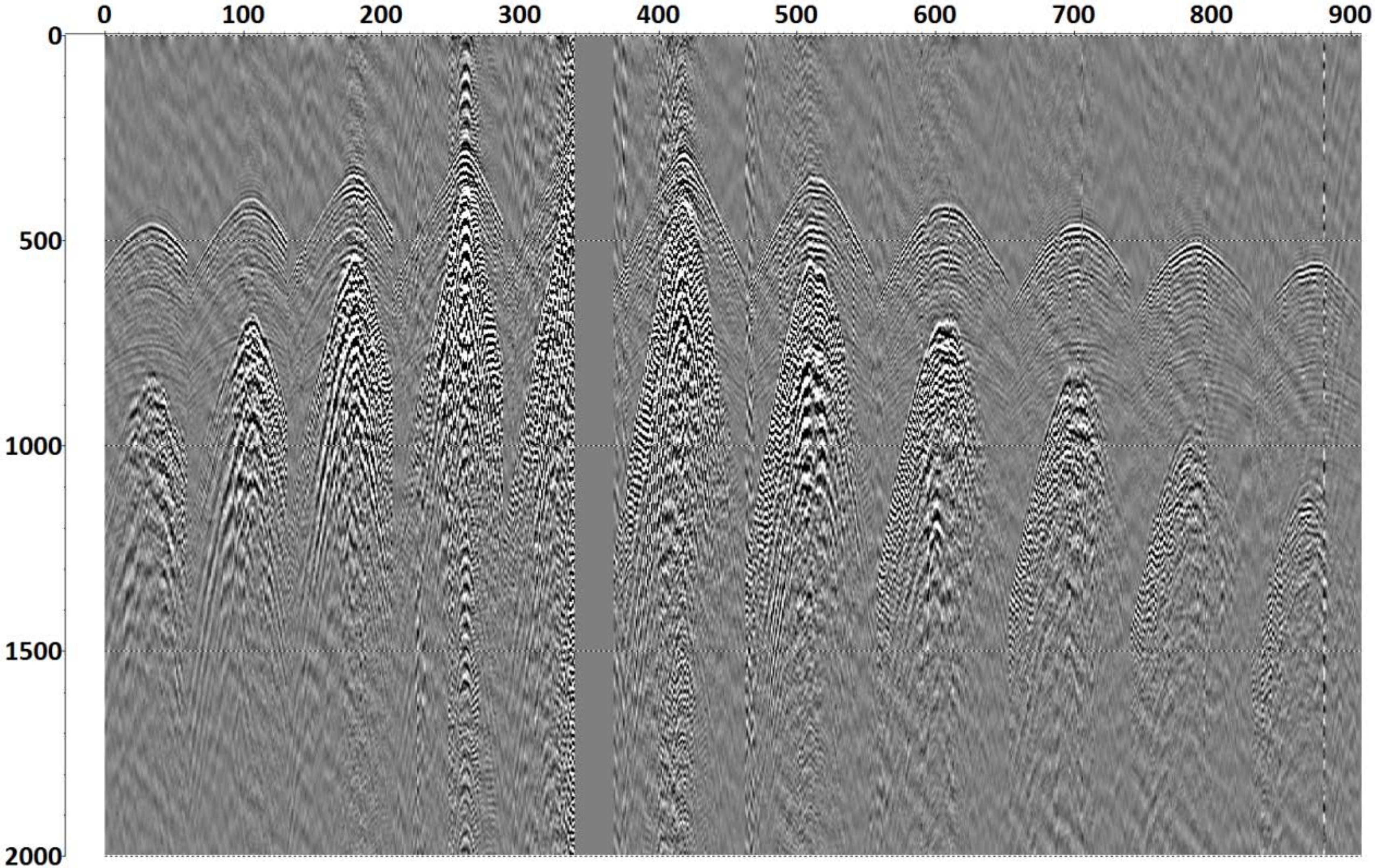
$$F = Mr\omega^2$$



Reference geophone amplitude during a 0-80 Hz sweep, 1 minute up, 1 minute down

Australian Otway Project images courtesy of LBNL, Curtin University and the CO2CRC

LBNL rotary source 0 – 80 Hz



Australian Otway Project images courtesy of LBNL, Curtin University and the CO2CRC

Conclusions

- We need a multiphysics approach to invert for more then velocity and density (or moduli).
- We need snapshots often enough to monitor all of the changes in the reservoir and cap rock
- Ideally we would like semi-continuous acquisition, which will require permanent sources and receivers for active-source methods
- We need permanent, robust, small sensors that preserve integrity of the geology
- How do we deal with ‘big data’?

Go forth and monitor!

Courtesy Dave Eaton

Acknowledgements

CREWES sponsors
CREWES staff and students
CMC Research Institutes Inc.
Colleagues

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