Australian Government

Geoscience Australia

Risk Evaluation and Monitoring

Rick Causebrook – Geoscience Australia

CO2 Geological Storage and Technology
Summer School of CAGS
Sanya City, Hainan Island, PRC
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cags
China Australia Geological Storage of CO_2
中澳二氧化碳地质封存

Acknowledgements

Contributions from presentations by

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Monitoring & Verification

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Principal Geochemist

British Geological Survey (BGS)

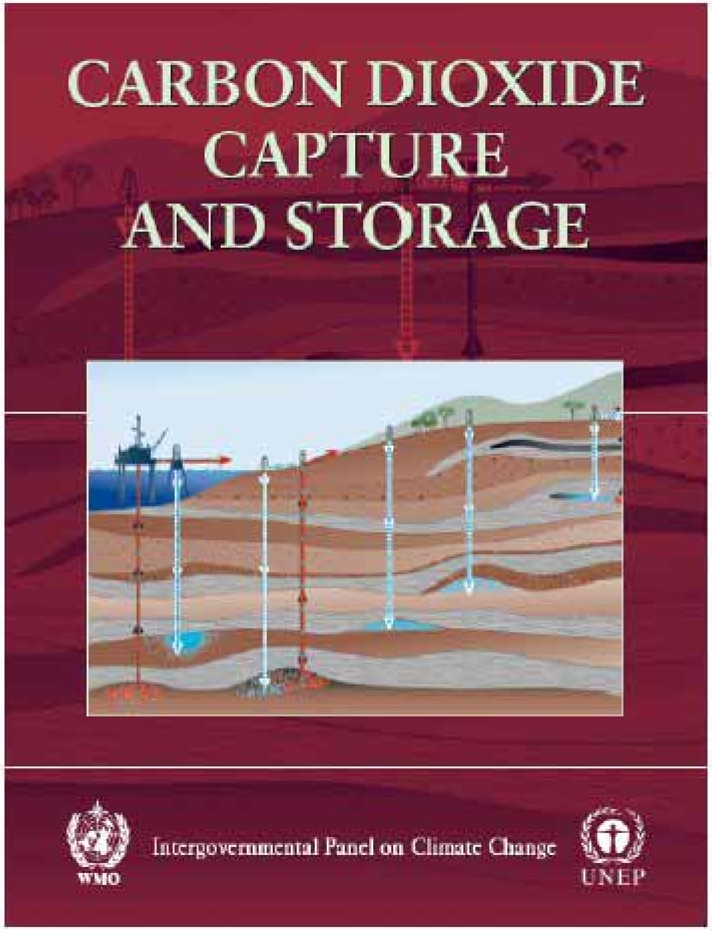
Introduction

- The deployment of carbon dioxide capture and geological storage requires policy and regulations to ensure that the technology can be safely deployed, and will require reliable monitoring technologies

- Monitoring will aim to demonstrate that the carbon dioxide is safely contained within the primary storage formation, and/or to detect leakge out of that formation into other formations or to the surface.

IPCC Special Report

- “22. With appropriate site selection based on available information, **a monitoring programme to detect problems**, a regulatory system and the appropriate use of remediation methods to stop or control CO_2 releases if they arise the local health, safety and environmental risks of geological storage would be comparable to the risks of current activities such as natural gas storage, EOR and deep underground disposal of acid gas.”


CARBON DIOXIDE
CAPTURE
AND STORAGE

WMO
Intergovernmental Panel on Climate Change
UNEP

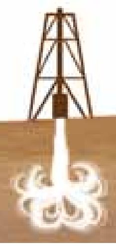
Concerns about Carbon Capture and Storage

- Safety
  - Transportation safety
  - Well control
  - Human health
  - Seismicity
  - Occupational safety

Concerns about Carbon Capture and Storage

- Local Environmental Impacts
  - Groundwater
  - Ecosystems

- Storage Effectiveness
  - Leakage out of the reservoir
  - Seepage back to the atmosphere



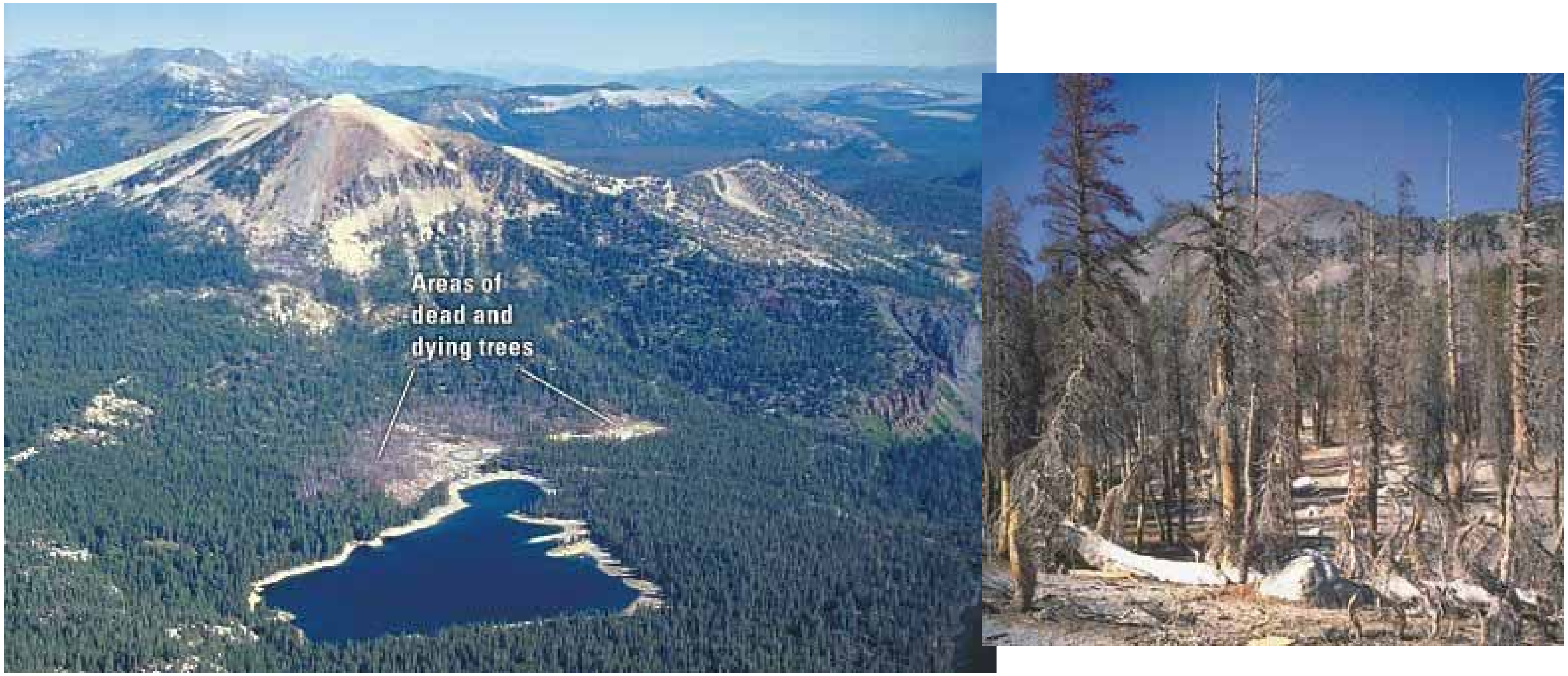
Potential CO_2 leakage pathways

- Leakage from storage complex through subsurface into atmosphere
- Alteration of groundwater chemistry
- Displacement of fluids previously occupying pore space

Natural leaks demonstrate risks

- CO_2 seeping from vents near in volcanic regions have been known to cause human injury and death.
- >5% CO_2 in air can be toxic
- It is important that we are able to monitor the CO_2 that we inject to ensure it remains safely under ground.

Potential environmental damage Mammoth Mountain California



CO_2 seepage from natural volcanic source results in tree kill

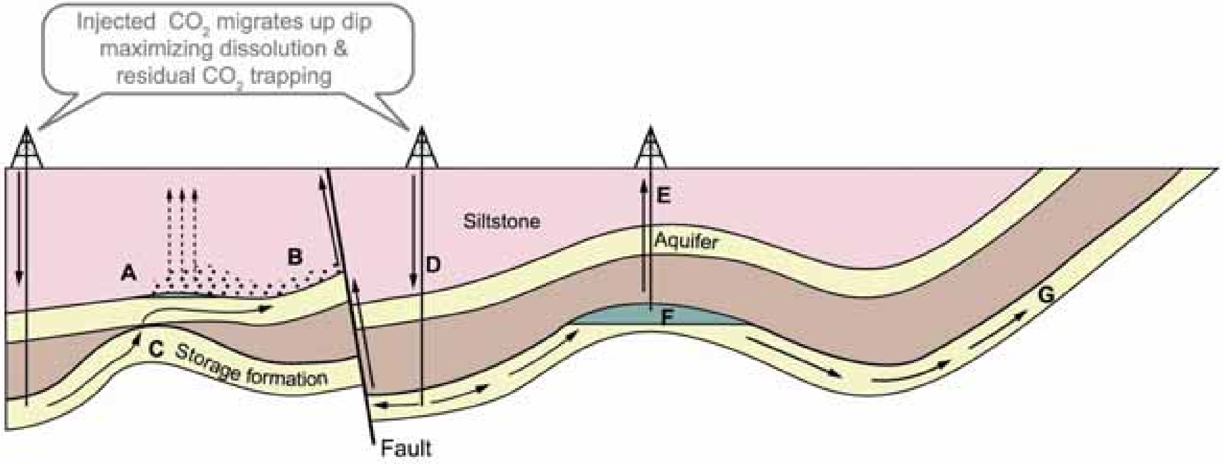
Potential ecological health hazards

- Damage or death from elevated CO_2 concentrations
- Acidification of soils and enhanced weathering
- Alteration of groundwater chemistry
- Induced seismicity or ground heave
- Impacts to off-shore benthic environments

Risk Assessment

- Risk is the chance of injury, damage, or loss
- Risk assessment evaluates the potential for adverse effects resulting from carbon dioxide exposure
- To evaluate these risks, the potential hazards associated with a specific event must be considered in conjunction with the likelihood of the event happening
- Risk= Impact x probability

Potential leakage pathways

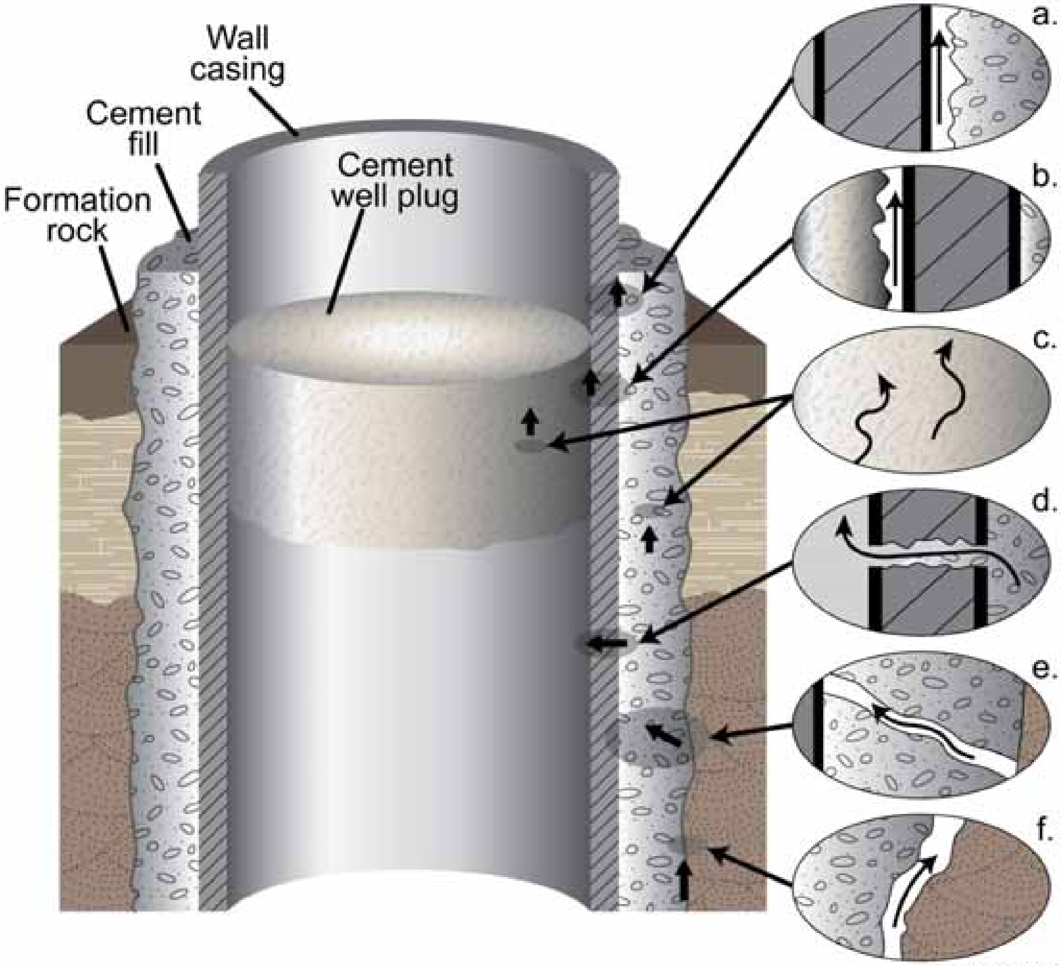


Potential Escape Mechanisms

Remedial Measures

Potential Escape Mechanisms	Remedial Measures
A. CO_2 gas pressure exceeds capillary pressure & passes through siltstone	***A.*** *Extract & purify groundwater*
B. Free CO_2 leaks from A into upper aquifer up fault	***B.*** *Extract & purify groundwater*
C. CO_2 escapes through 'gap' in cap rock into higher aquifer	***C.*** *Remove CO_2 & reinject elsewhere*
D. Injected CO_2 migrates up dip, increases reservoir pressure & permeability of fault	***D.*** *Lower injection rates or pressures*
E. CO_2 escapes via poorly plugged old abandoned well	***E.*** *Re-plug well with cement*
F. Natural flow dissolves CO_2 at CO_2 / water interface & transports it out of closure	***F.*** *Intercept & reinject CO_2*
G. Dissolved CO_2 escapes to atmosphere or ocean	***G.*** *Intercept & reinject CO_2*

Well leakage



After Gasda *et al.*, 2004

What Experience do we have?

- Only one long running CO_2 storage project in the world: Sleipner
- But also younger projects, In Salah and Snovit
- Research projects CO2CRC Otway basin, Frio, Weyburn
- EOR - 50 yrs experience in Permian basin- excellent safety record.
- Acid gas storage in Canada

What Experience do we have?

- Natural Analogues - numerous CO_2 accumulations worldwide but difficult to know how good the analogies are. Do we know when one has leaked?
- Underground Gas storage: extensive experience over 90 years.

Experience from Underground Gas storage (UGS)

- First underground gas storage in 1915 in Ontario
- 470 natural gas storage facilities in US & Canada
- Only nine incidents of significant leakage
- Five related to well bore issues
- Three due to cap rock seals
- UGS storage puts greater stress on rock than GHG storage – pressure and recycling
- UGS experience low chance of major GHG leaks

What Do we know?

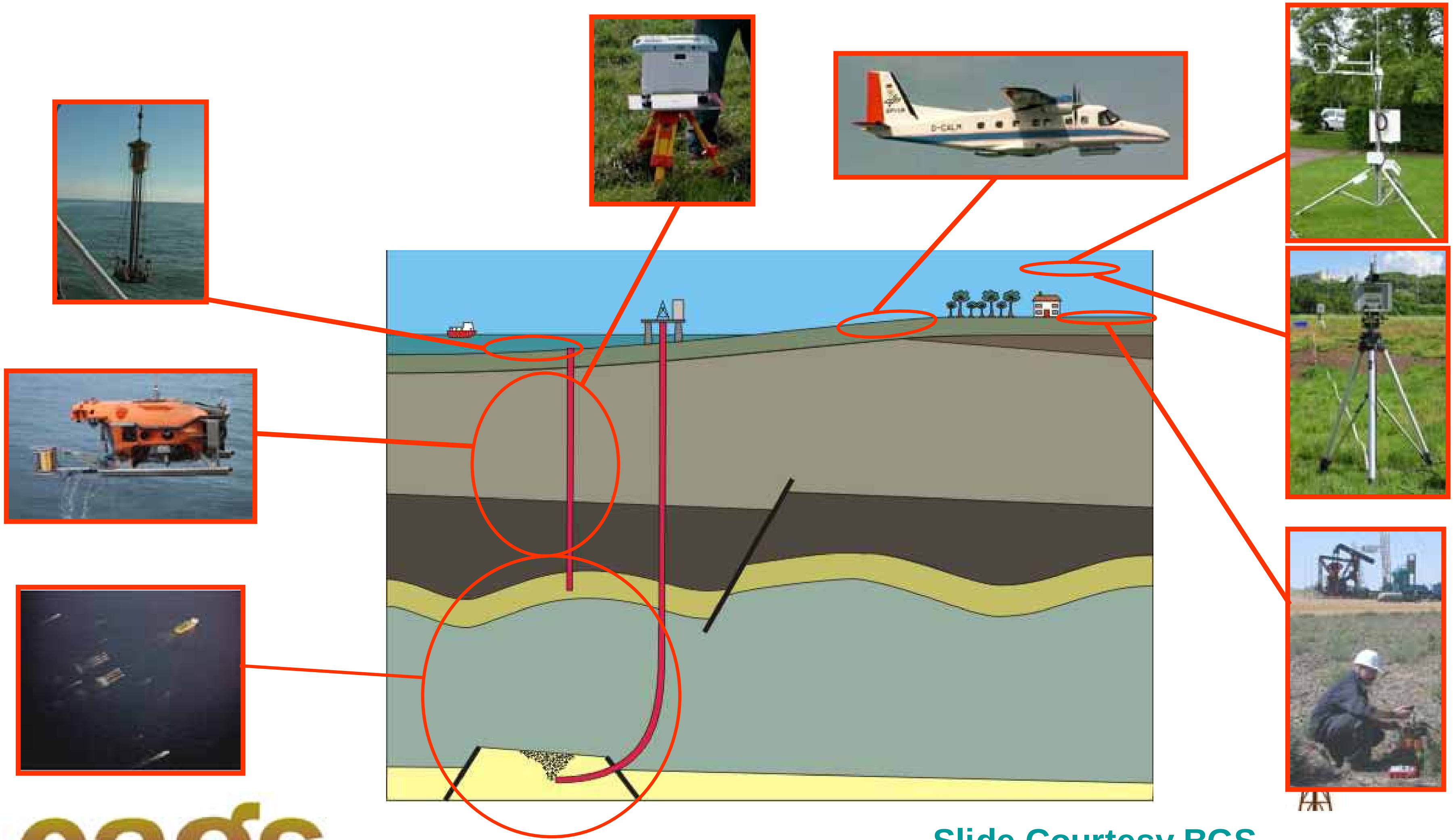
- We know a great deal, although much of it is by analogy and little of it is quantitative.
- Therefore not much of it can be easily turned into probabilities.
- Risk assessments used must rely on industry experience in other areas to allow expert panels to make some estimate of the risks of specific projects.

Carbon dioxide storage risks summary

- Experience with naturally occuring geologically stored carbon dioxide implies that leakage from well-designed carbon dioxide storage reservoirs will be very small

- Current estimate is that >99% of geosequestered CO_2 will be retained in the subsurface for over 1,000 years

Monitoring and Verification



Slide Courtesy BGS

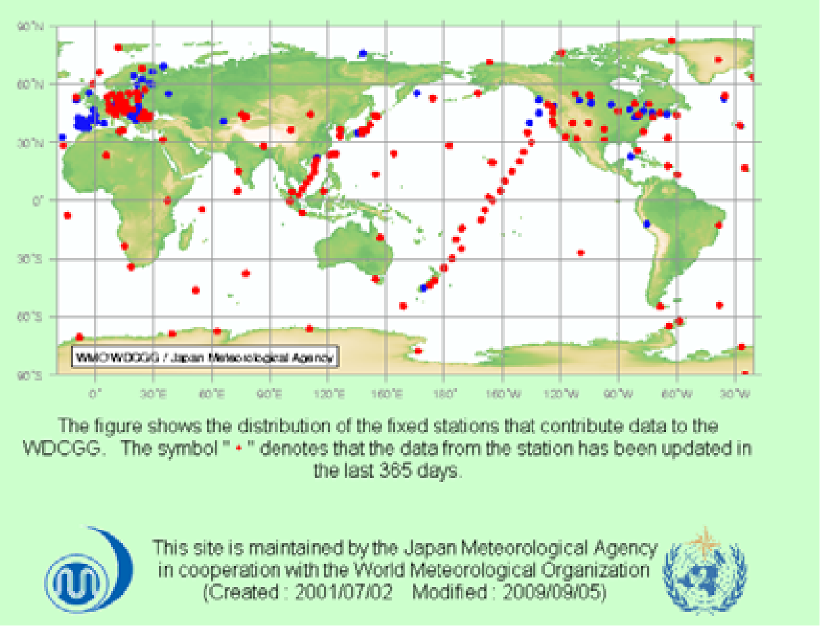
What is “monitoring”?

- Definition
  - Making measurements which locate, and possibly quantify, CO_2 in the deep subsurface
  - Making measurements which give assurance that near-surface assets (water, soil, air) are unaffected
  - Making measurements which verify that any leakage does not affect the climate abatement value of the storage

Two types of monitoring

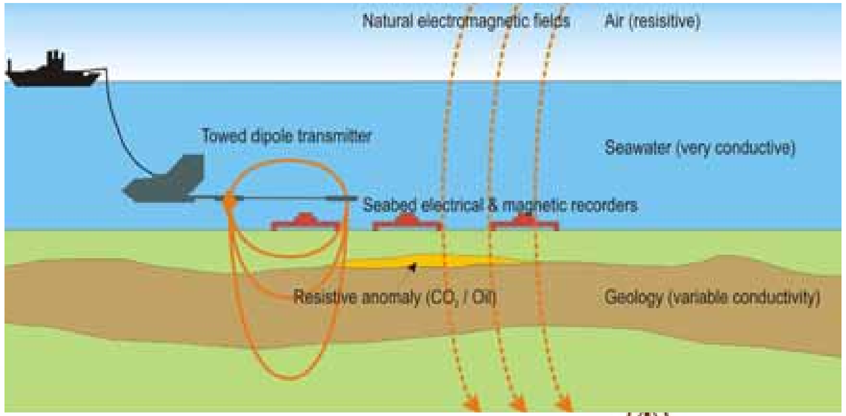
- Baseline monitoring
  - Need to establish natural conditions to be able to detect changes that may be caused by leakage from storage

- Project monitoring
  - Monitoring the behaviour of the plume in the subsurface and monitoring groundwater and atmosphere for traces of leakage



The figure shows the distribution of the fixed stations that contribute data to the WDCGG. The symbol "•" denotes that the data from the station has been updated in the last 365 days.

This site is maintained by the Japan Meteorological Agency in cooperation with the World Meteorological Organization (Created : 2001/07/02 Modified : 2009/09/05)



Selection of monitoring tools

- Location of site:
  - Offshore/onshore
  - Access (land use, topography, wells…)
  - Volume to monitored (depth, footprint)
- Monitoring aims
- Timing
  - Project stage (baseline, injection, post-injection, closure)
  - Mass of CO_2 injected (detection limits, plume migration)
- Cost and benefits
- Environmental impacts of monitoring technologies

Baseline Monitoring

- Atmospheric

- Soil Gas

- Groundwater Chemistry

Remote

Hyperspectral imaging INSAR

Surface

Conventional seismic surveys
VSP (hybrid)
Gravity surveys
Some electromagnetic techniques

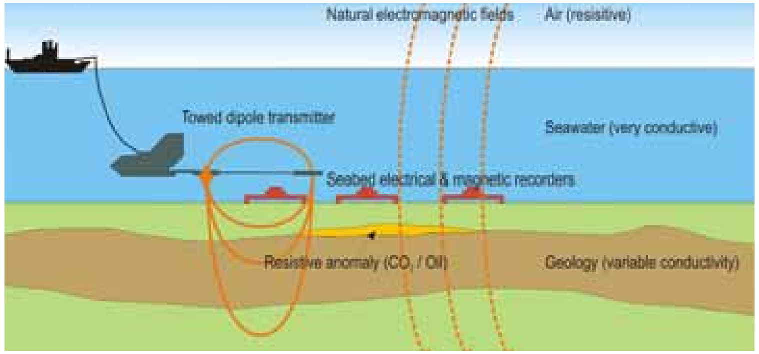
Downhole

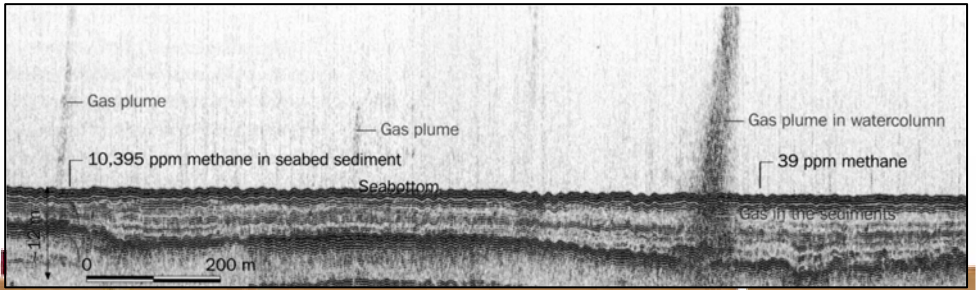
Saturation logging
Borehole gravity
Cross-well seismic
Cross-well electromagnetic
Pressure
Fluid sampling (tracers)
Thermal effects

Monitoring the plume within the formation

Containment monitoring at depth- measuring the CO_2 plume from the surface

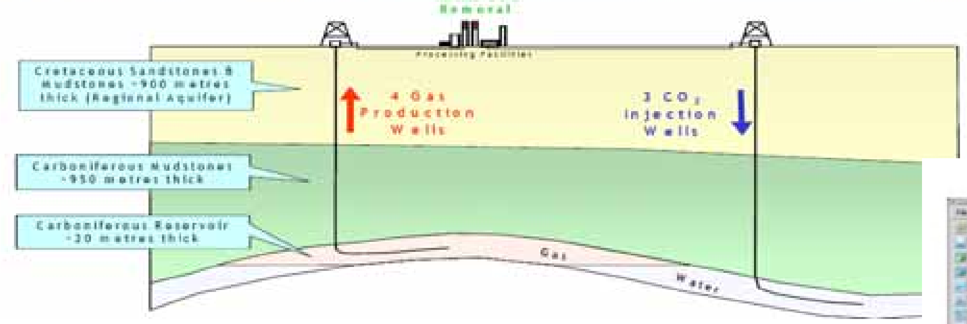
- Surface
  - – Conventional seismic surveys
  - – VSP (hybrid)
  - – Gravity surveys
  - – High-res acoustic
  - – Some electromagnetic techniques





Remote Sensing

Satellite imaging monitoring surface deformation at the In Salah Project in Algeria



Surface deformation detected by synthetic aperture radar.

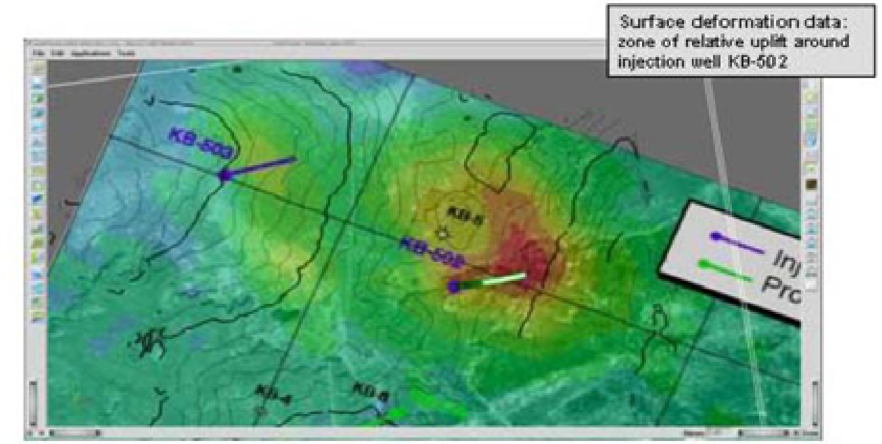
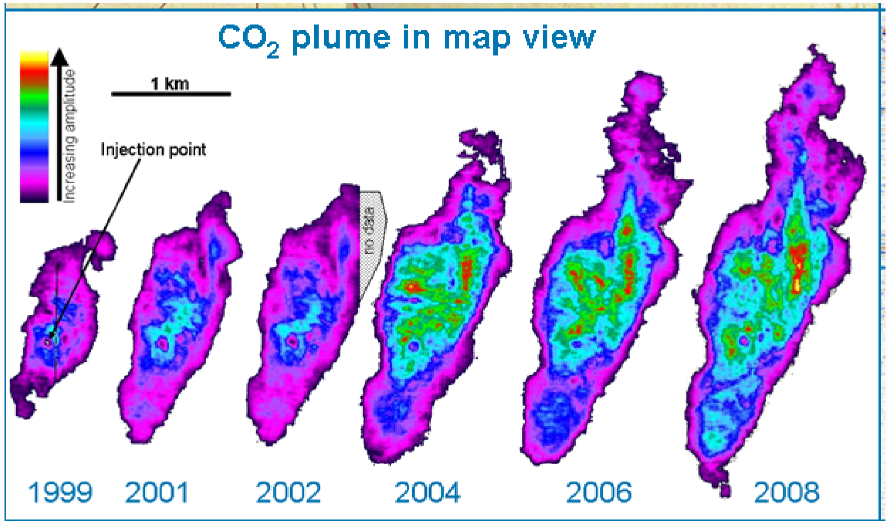


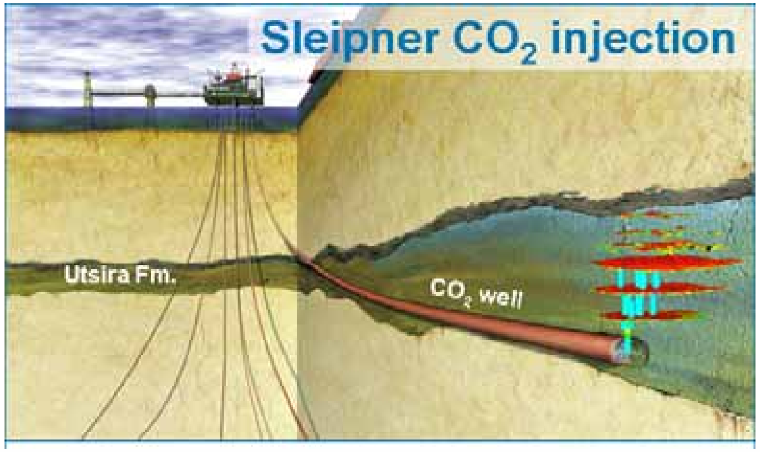
Figure 8: JAPEX/BGS Satellite Image August 2007

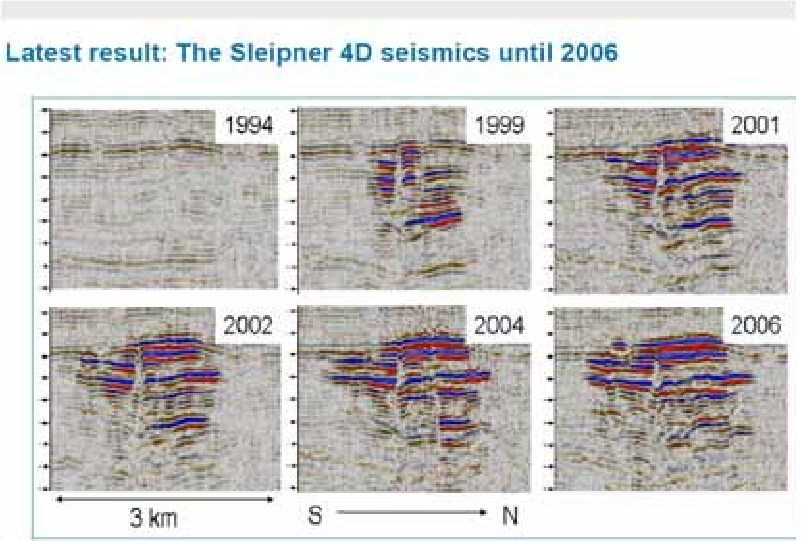
Injection of around 1 million tonnes CO_2 per annum since 2004

Seismic monitoring

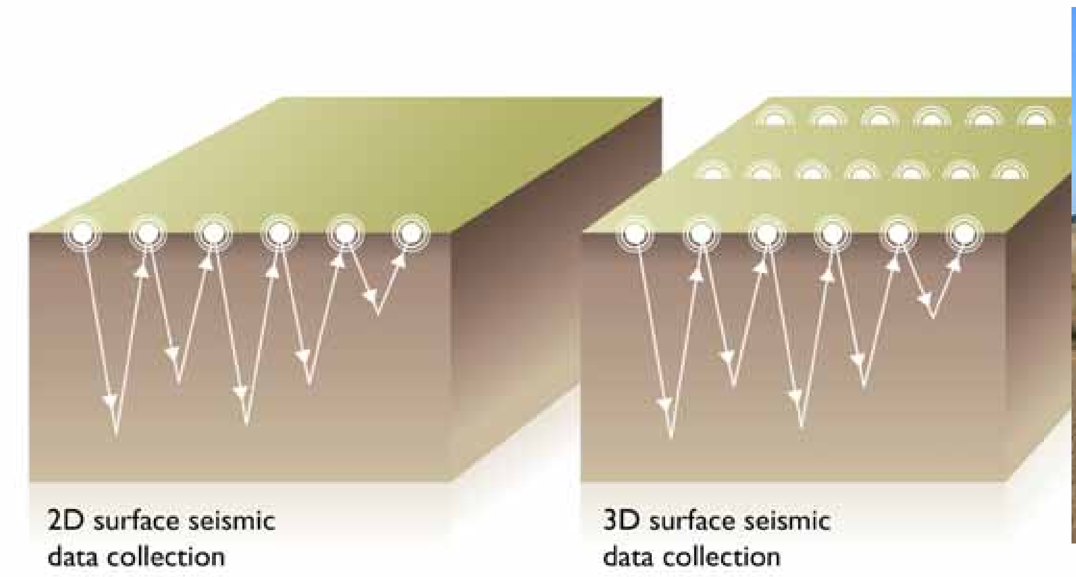


The Sleipner Project 15 years of Experience

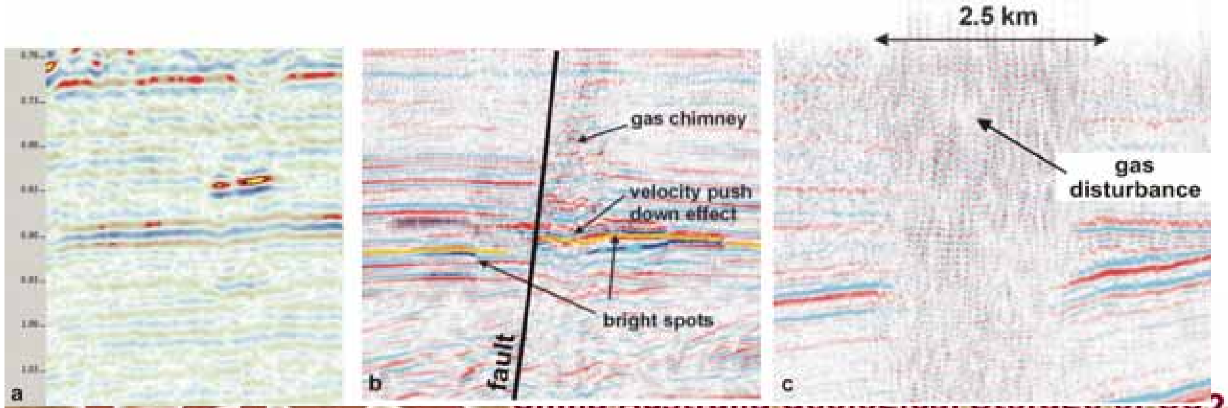


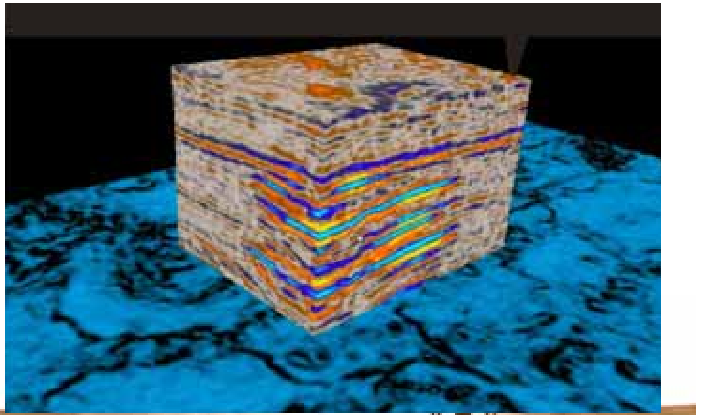


Surface seismic monitoring



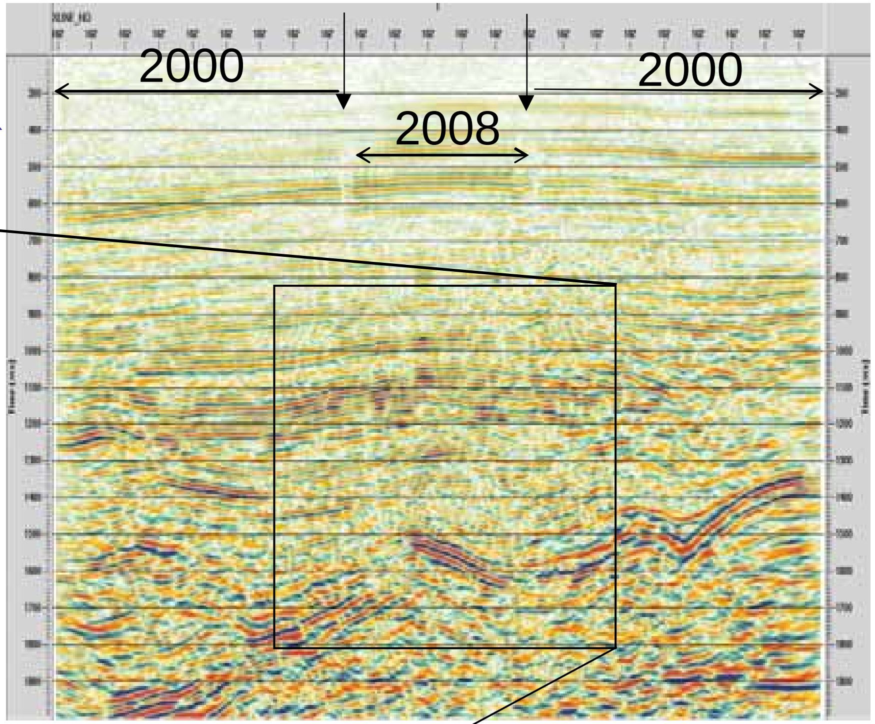
CO2CRC



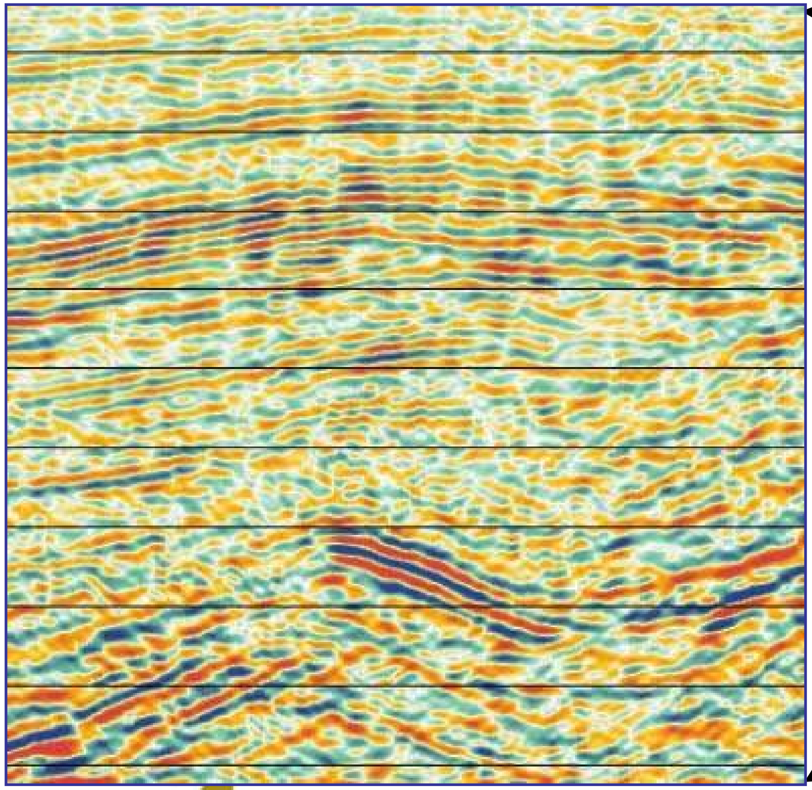


Time-lapse studies – CO2CRC Otway Project

Updating previous seismic data with new data from reservoir to provide baseline data



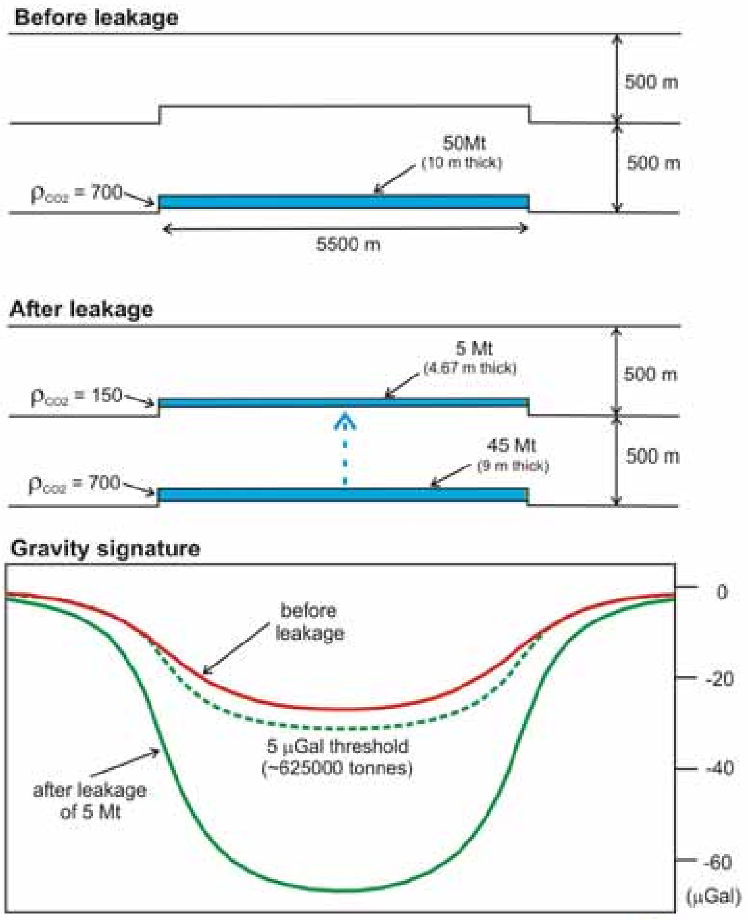
Pevzner & Shulakova, 08



Images, CO2CRC

Gravimetric techniques

- Measure gravitation acceleration due to mass distributions within the earth
- Can be used to detect variation in subsurface rock or fluid density
- Potential to detect mass changes induced by the storage and migration of CO_2 into the overburden
- Ability to detect mass variations may enable estimates of amount of CO_2 going into solution (invisible on seismic)



Slide Courtesy BGS

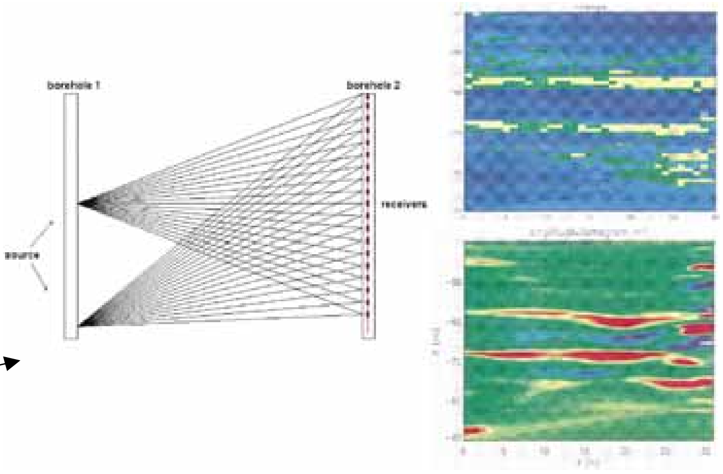
Gravity models to illustrate gravimetric signature caused by leakage of 5MT of CO_2 from a putative storage reservoir to shallower depth.

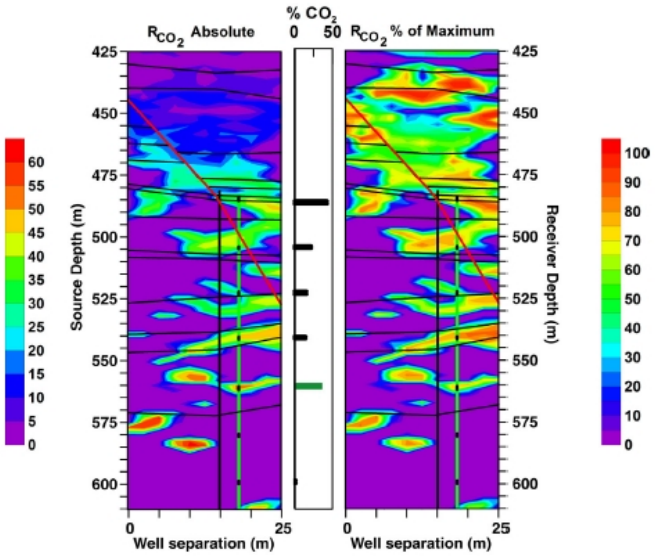
Surface techniques: advantages (pro) and disadvantages (con)

- Time-lapse seismic
  - Pro: conventional TL seismic is well understood and sensitive
  - Con: expensive, intrusive and may be impractical
- Vertical seismic profile (VSP)
  - Pro: VSP is very sensitive
  - Con: intrusive, large surface footprint
- Other methods
  - Pro: other methods respond to other properties of CO_2 plume
  - Con: insensitive, untried

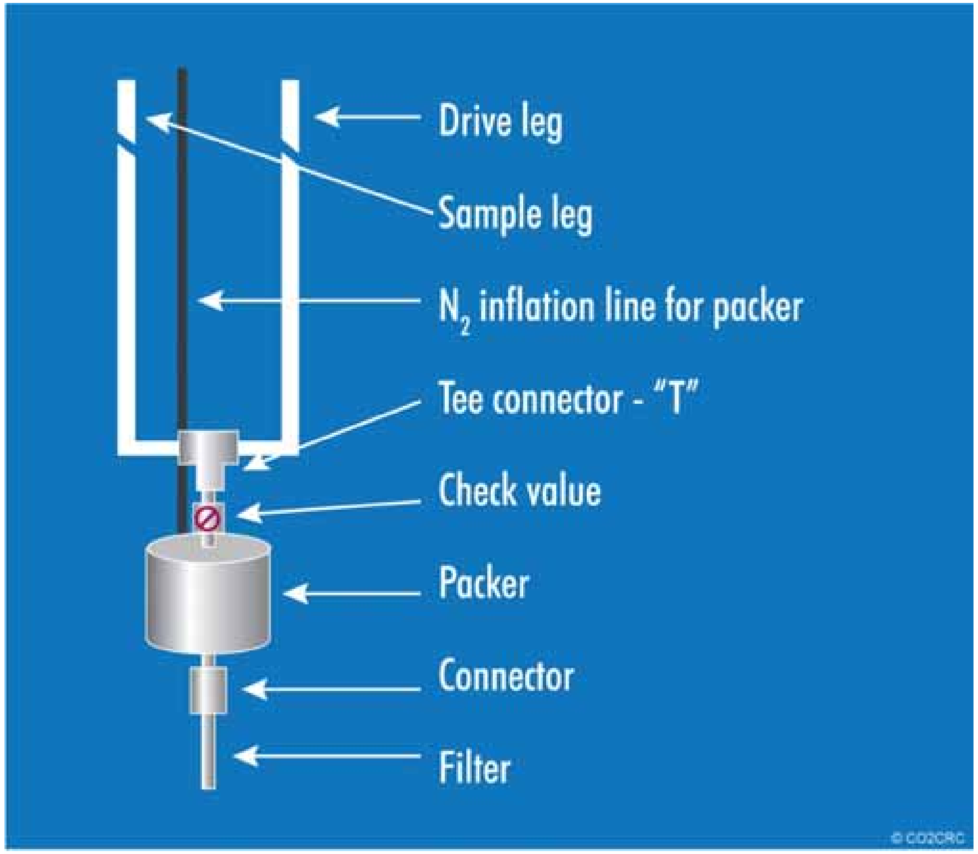
Containment monitoring at depth- measuring the CO_2 using downhole techniques

- Downhole
  - Saturation logging
  - Borehole gravity
  - Cross-well seismic
  - Cross-well electromagnetic
  - Pressure
  - Fluid sampling (tracers)
  - Thermal effects





Containment monitoring at depth- measuring the CO$_2$ using downhole techniques



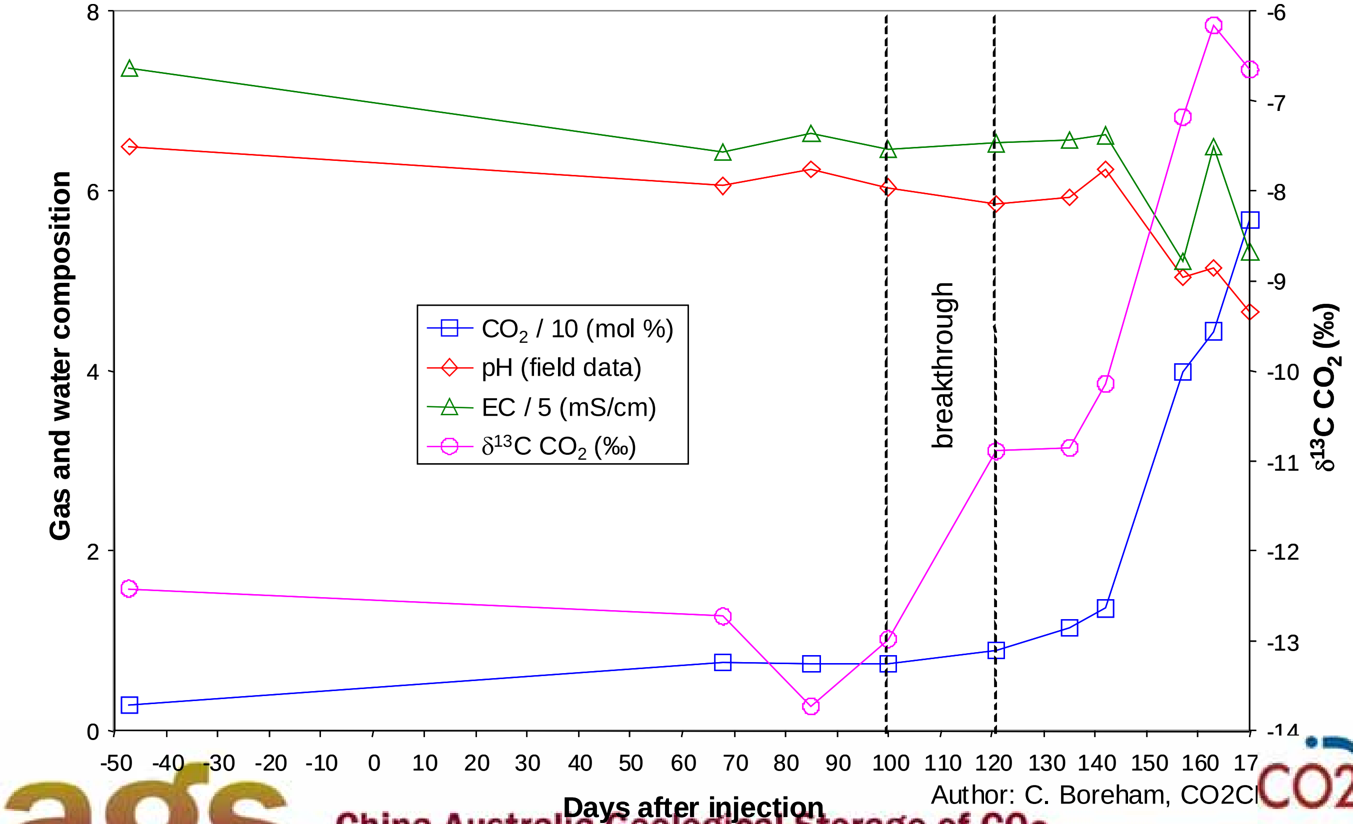
- Fluid sampling
- Use of tracers
- Temperature and pressure
- Developed by Lawrence Berkeley National Laboratory and CO2CRC

Image, CO2CRC

Containment monitoring: Groundwater

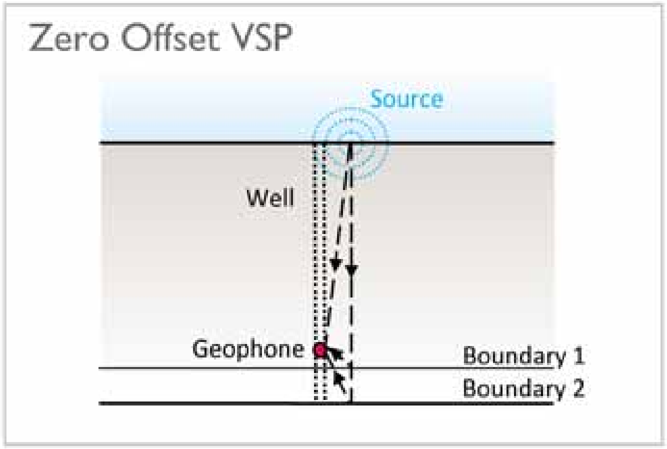
Downhole groundwater monitoring

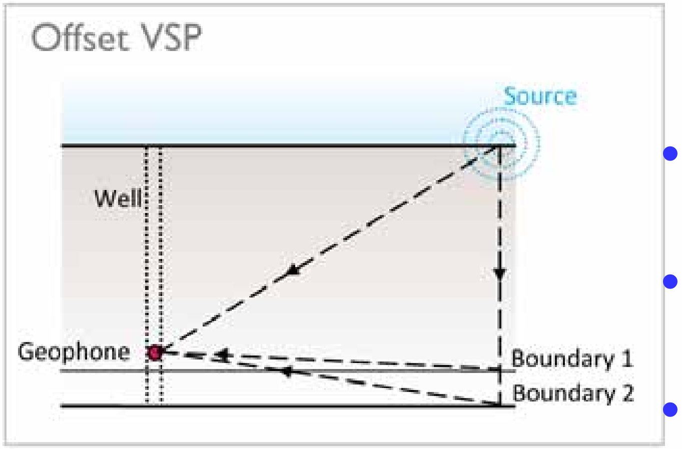
Detection of injected CO_2 arrival at the Naylor monitoring well at the Otway Project site.

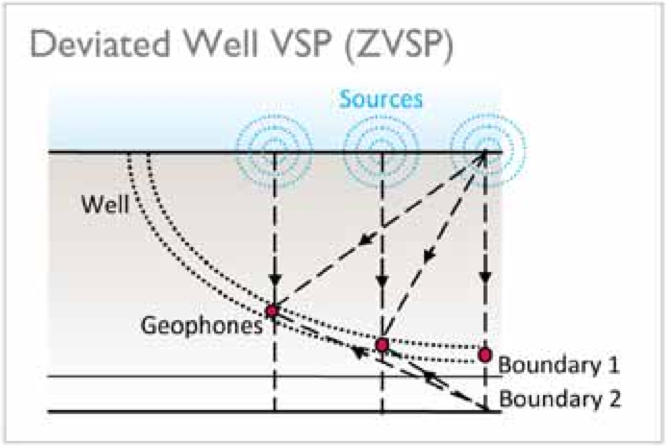


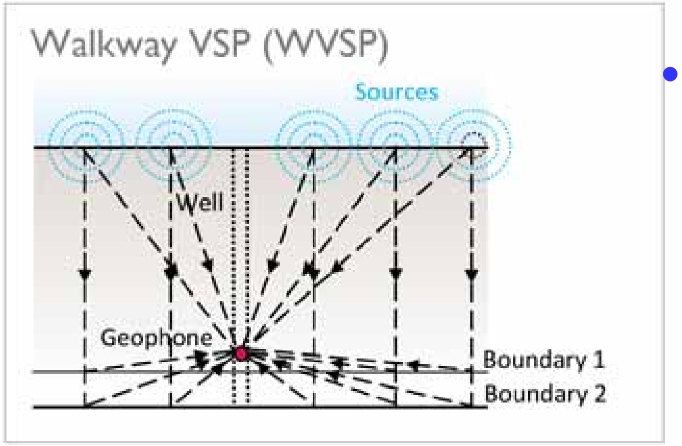
Author: C. Boreham, CO2CRC

Downhole seismic monitoring


Zero Offset VSP

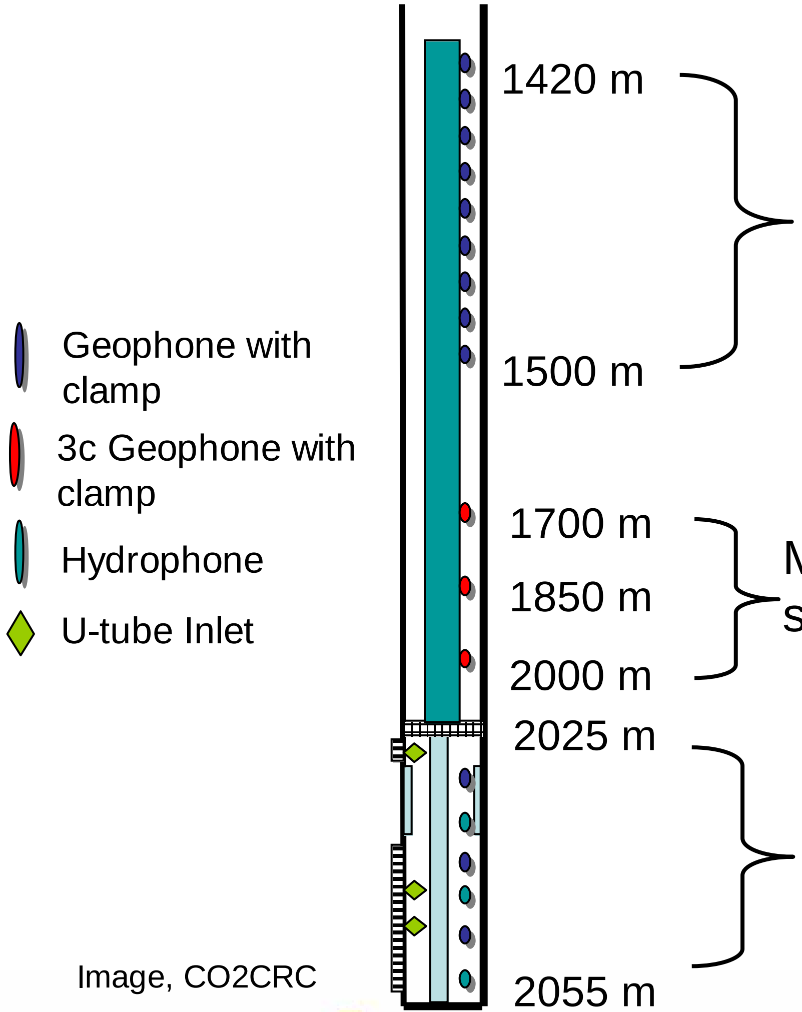

Offset VSP


Deviated Well VSP (ZVSP)


Walkway VSP (WVSP)

- Range of seismic techniques
- Vertical Seismic Profiling (VSP)
- High Resolution Travel time
- Microseismic surveys (measures creaks in the subsurface)

Downhole seismic monitoring



- 🟦 Geophone with clamp
- 🟥 3c Geophone with clamp
- 🟩 Hydrophone
- ◆ U-tube Inlet

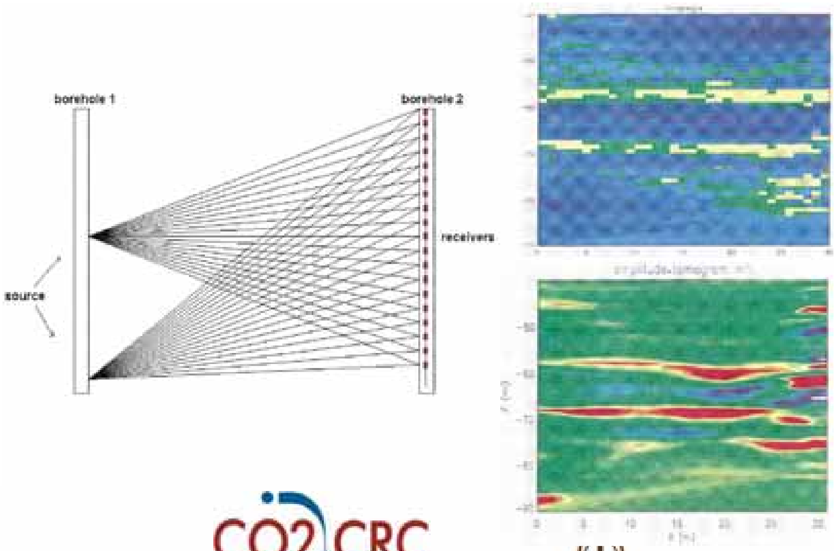
VSP seismic sensors

Microseismic sensors

Reservoir seismic monitoring sensors

The permanent array in the CO2CRC Otway project monitoring well

Image, CO2CRC



Downhole techniques: advantages (pro) and disadvantages (con)

- Pro: direct measurements, best accuracy
- Con: need several boreholes (expensive)
- Con: relatively small depth of investigation or limited spatial coverage
- Pro: can anchor models
- Pro: pressure monitoring is the main method used in conventional hydrocarbon production
- Con: mostly relatively untried techniques

General points

- Inferring sub-surface fluid behavior from indirect measurements can be ambiguous.
- Therefore it is better to use a variety of monitoring technologies to build confidence in the interpretation of the observations.
- Many years of experience in oil and gas development show that adequate understanding can be achieved over time.
- Direct measurements from monitoring wells if possible can aid in quantification.

Modified from CO2CRC

Assurance monitoring

- Check that there is no evidence of CO_2 affecting near-surface assets
- Ground water – dissolution, HCO_3, heavy metals…
- Soil – accumulation of CO_2 in root zone, plant death
- Atmosphere – exactly where we do not wish the CO_2 to go
- Remote sensing – imaging vegetation

Issues in assurance monitoring

- We cannot prove a negative. At what level is "no evidence" satisfactory?
- Where do we look? We have no expectation of leakage paths. They might be very indirect.
- The general method is to show that pre- and post-injection data are statistically identical.
- This may need to include some detailed modelling e.g. the effect of drought on groundwater, the effect of the annual cycle on ecosystem fluxes of CO_2

Conclusions

CO_2 storage can be monitored in a variety of ways

However:

- The footprint of a commercial scale storage site will be hundreds of km^2 - monitoring this in detail is impractical
- Monitoring will need to be hierarchical in space and time, organized around key risk events
- The simplest technique – in situ pressure monitoring – is well proven
- Monitoring cannot prove “no leakage” or weigh the stored CO_2 to 0.01% - but in combination with good models it can make “no leakage” very plausible.

CO2CRC Participants

Australian Government
Geoscience Australia

CSIRO

Curtin
University of Technology

MONASH University

THE UNIVERSITY OF ADELAIDE
AUSTRALIA

THE UNIVERSITY OF MELBOURNE

UNSW
THE UNIVERSITY OF NEW SOUTH WALES
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GNS SCIENCE

QER

Queensland Government

RioTinto

sasol
reaching new frontiers

SOLID ENERGY
Coals of New Zealand

STANWELL
CORPORATION LIMITED

Schlumberger

TOTAL

State Government Victoria
Department of Primary Industries

Government of Western Australia
Department of Mines and Petroleum

xstrata
coal

Supporting participants: Global CCS Institute, The University of Queensland, Process Group, Lawrence Berkeley National Laboratories

CRC AUSTRALIA

Established & supported under the Australian Government's Cooperative Research Centres Program

cags

China Australia Geological Storage of CO_2

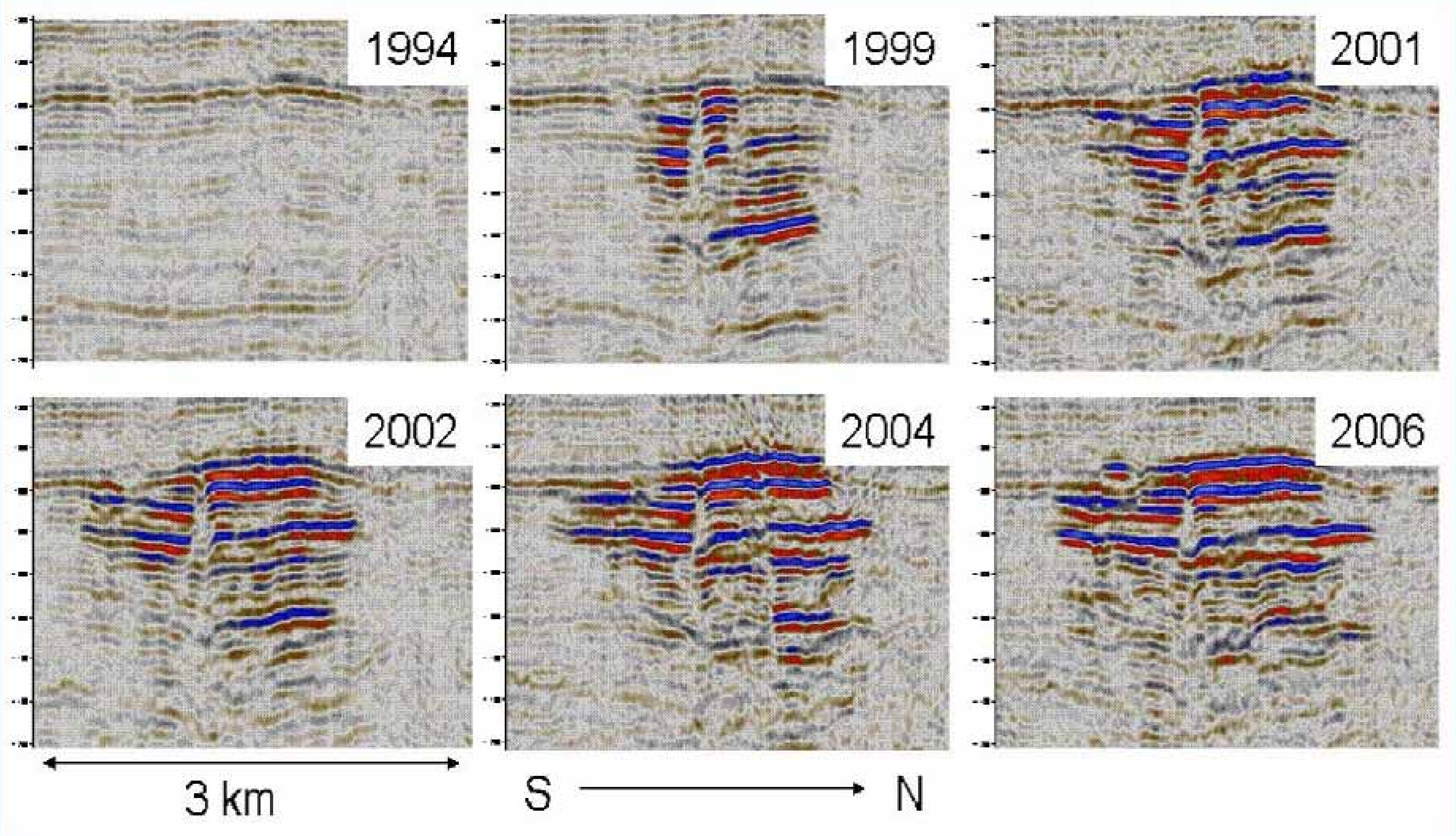
中澳二氧化碳地质封存

Questions?

Seismic monitoring

- The Sleipner Project – 13 years of experience

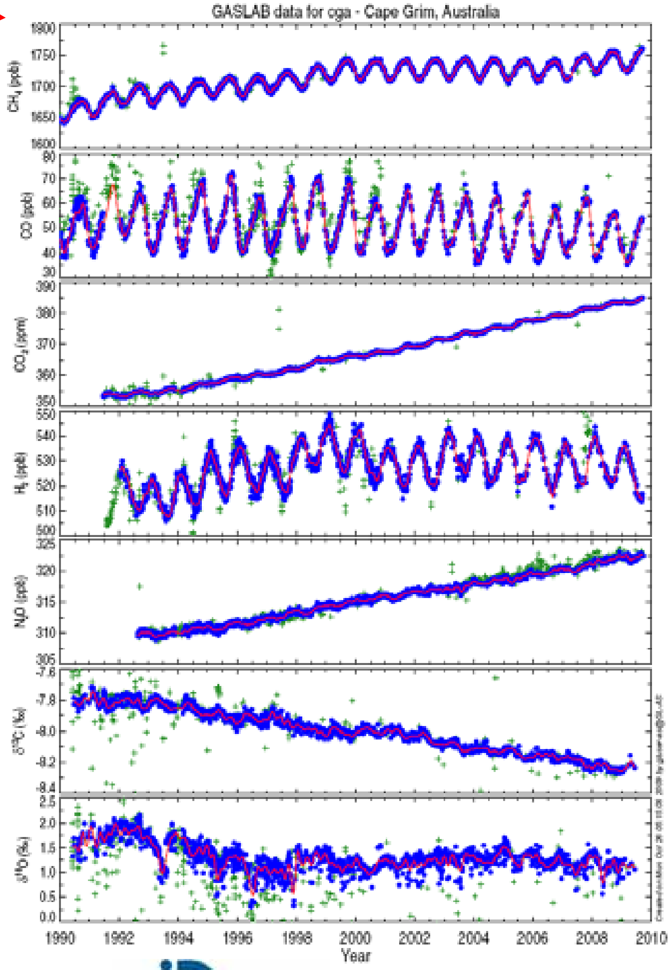
atest result: The Sleipner 4D seismics until 2006



Who cares about these measurements?

- The local community – probably the most important stakeholder group
- The financiers – the people who issue carbon credits, or administer whatever financial method is used to fund CCS
- The operators – who have a reputation to protect
- Anyone who cares about the climate

Cape Grim



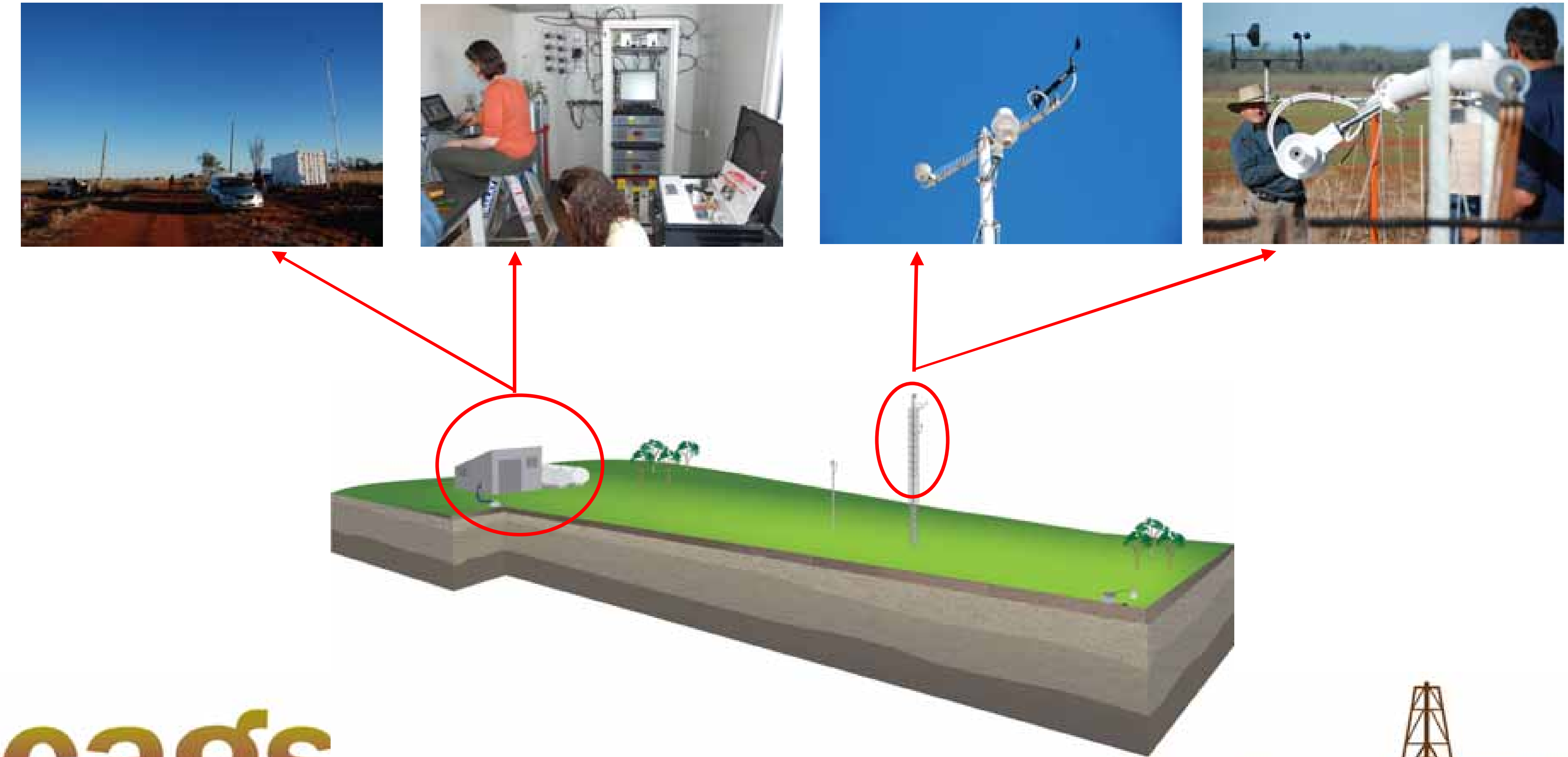
Seismic monitoring – CO2CRC Otway Project

- Seismic survey

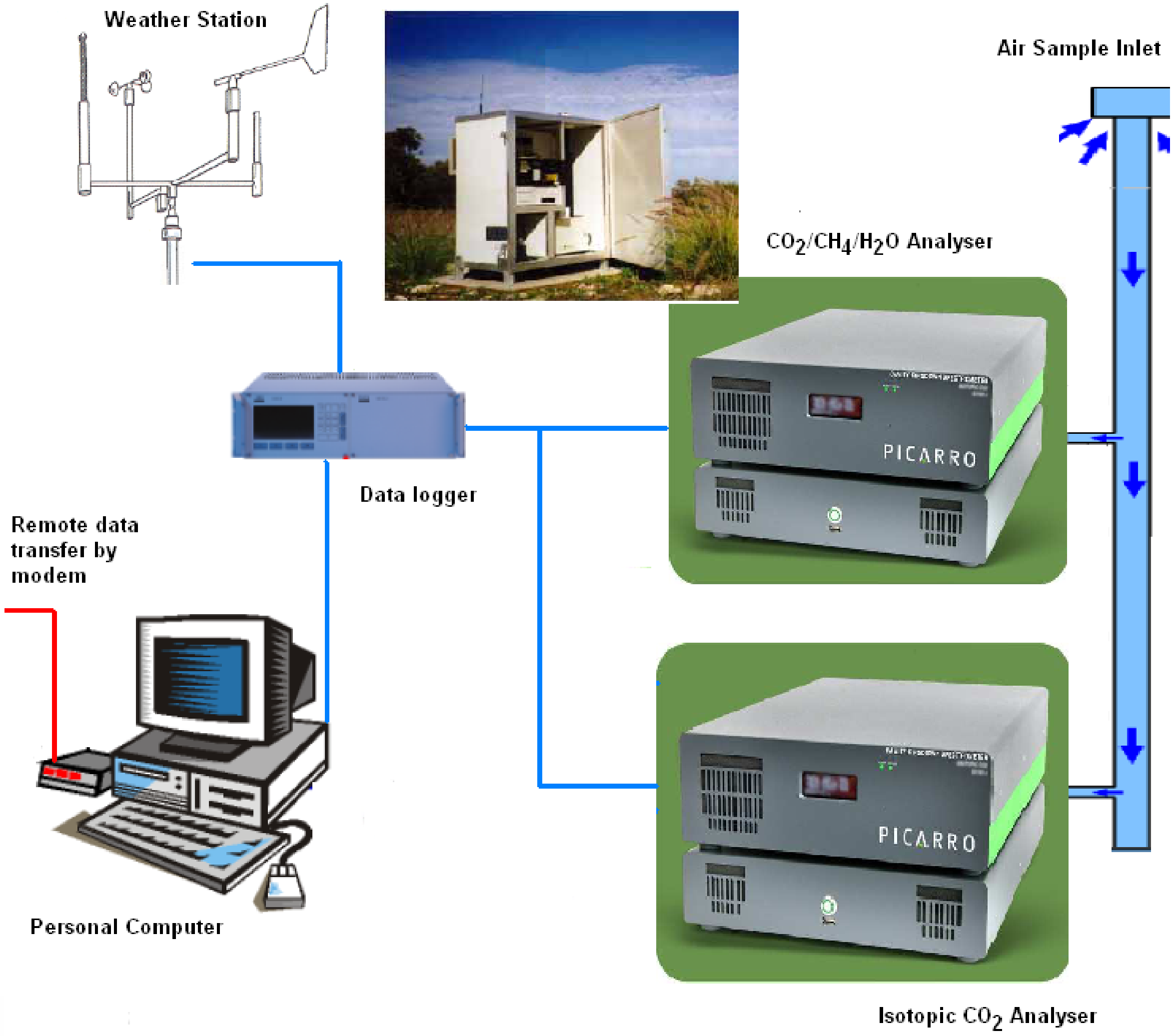
Image, CO2CRC

Baseline monitoring

Establishing an atmospheric baseline station in central Queensland



Atmospheric Monitoring Station



Containment monitoring at depth

Surface

- Conventional seismic surveys
- VSP (hybrid)
- Gravity surveys
- Some electromagnetic techniques

Remote

- Hyperspectral imaging
- INSAR

Downhole

- Saturation logging
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- Cross-well seismic
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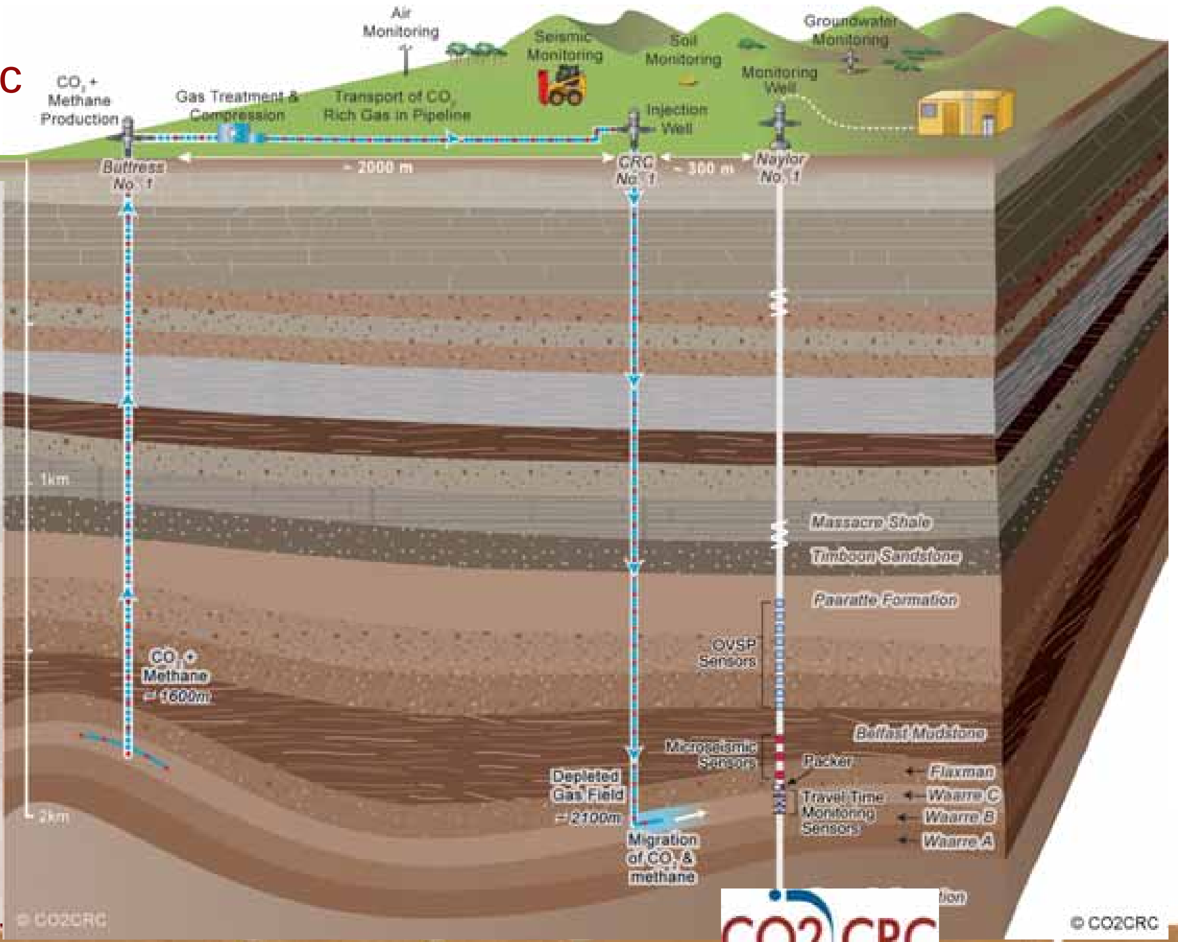


Atmospheric monitoring

- Monitoring using CO_2 concentration alone needs ideal conditions, so other species including CH_4,SF_6, CO and $^{13}CO_2$ are monitored to enhance sensitivity

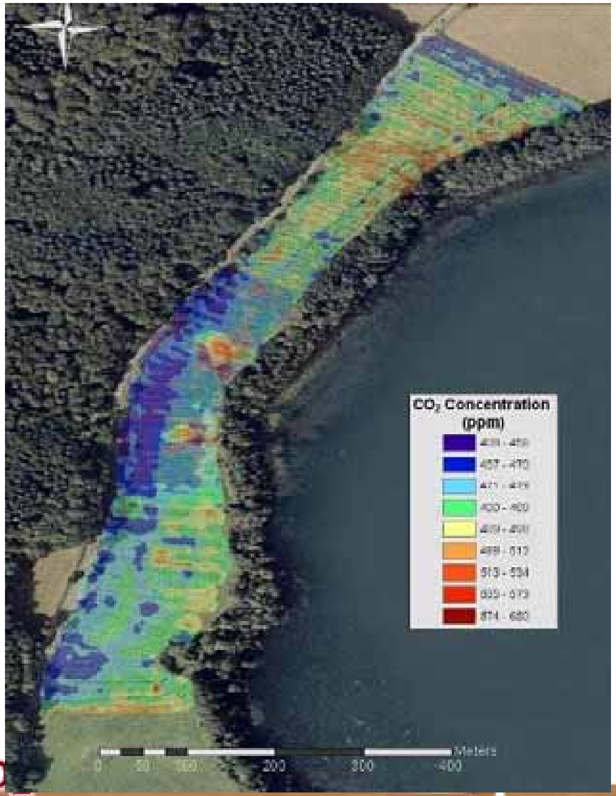


Image CSIRO, CO2CRC
D. Etheridge et al
CSIRO

CSIRO

CO2CRC

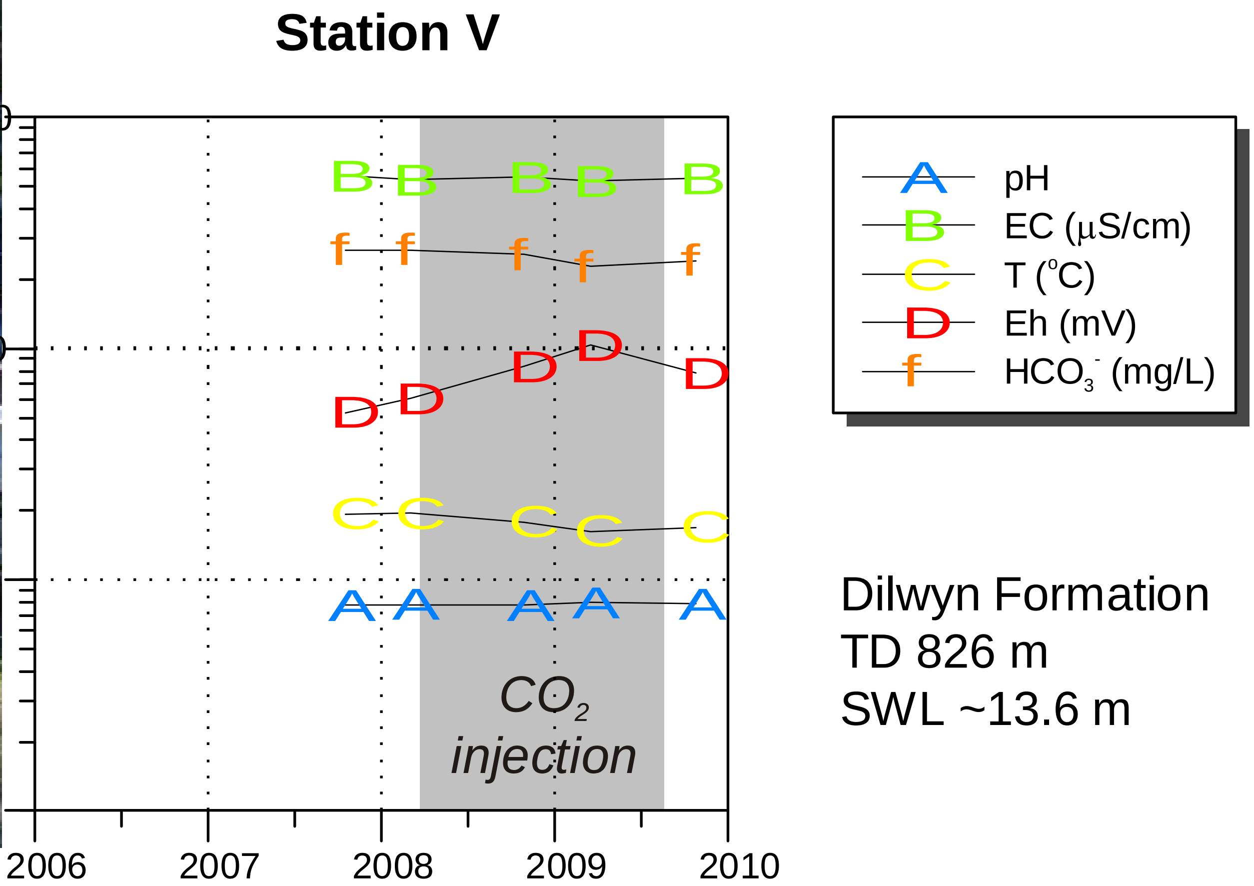
Soil Gas analysis

Soil gas measurement in the Phase 1 CO_2 injection area of the Weyburn oilfield. Note the *in-situ* soil gas probe to the right of the portable gas analyzer (red).

- Probes or accumulation chambers placed in or on the soil
- Grid pattern over expected footprint of leakage
- Samples analysed periodically often by portable gas analysers
- Does not provide total coverage
  - What sample density and frequency is appropriate?
  - How are adequate baselines established?

Slide Courtesy BGS

Water Bore sampling: Wannon Water: nr Otway Project



Dilwyn Formation
TD 826 m
SWL ~13.6 m