Australian Government

Geoscience Australia

Risk Evaluation and Monitoring

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Training School of CAGS
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Acknowledgements

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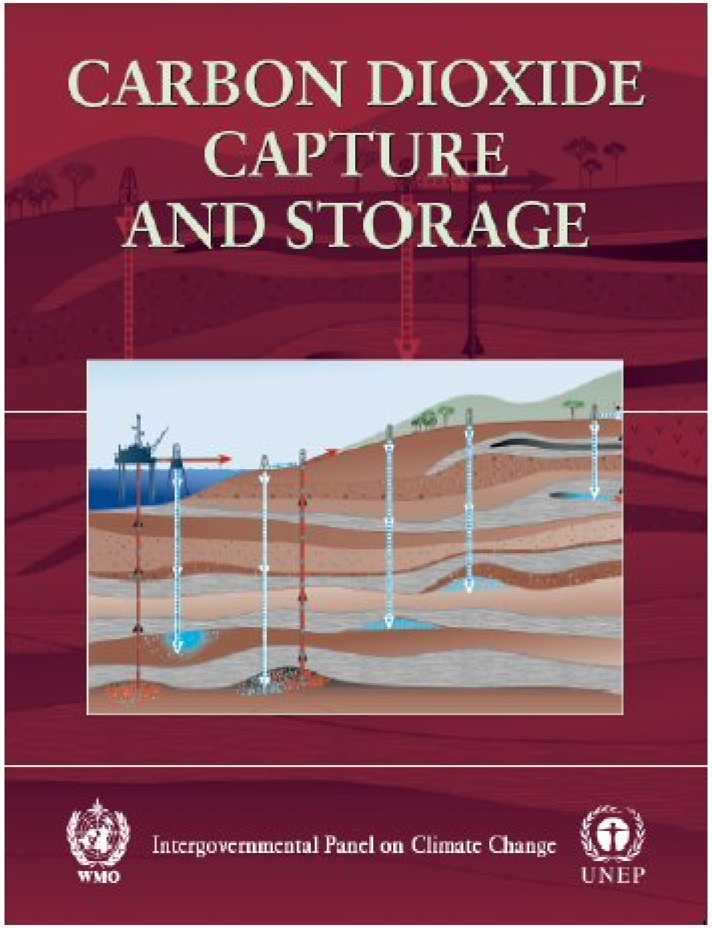
Introduction

- 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."



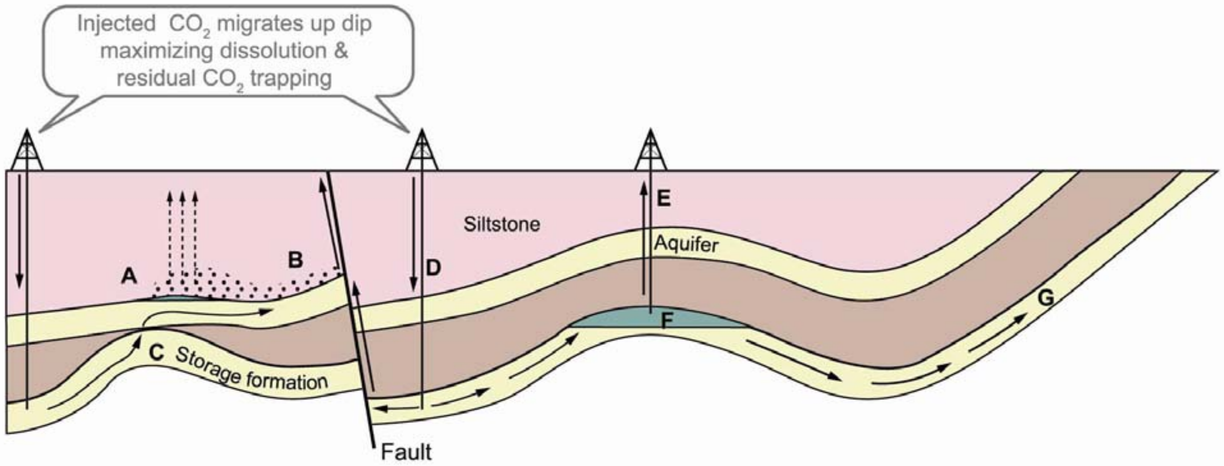
Concerns about Carbon Capture and Storage

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

Potential leakage pathways



Potential Escape Mechanisms

A. CO_2 gas pressure exceeds capillary pressure & passes through siltstone	**B.** Free CO_2 leaks from A into upper aquifer up fault	**C.** CO_2 escapes through 'gap' in cap rock into higher aquifer	**D.** Injected CO_2 migrates up dip, increases reservoir pressure & permeability of fault	**E.** CO_2 escapes via poorly plugged old abandoned well	**F.** Natural flow dissolves CO_2 at CO_2 / water interface & transports it out of closure	**G.** Dissolved CO_2 escapes to atmosphere or ocean

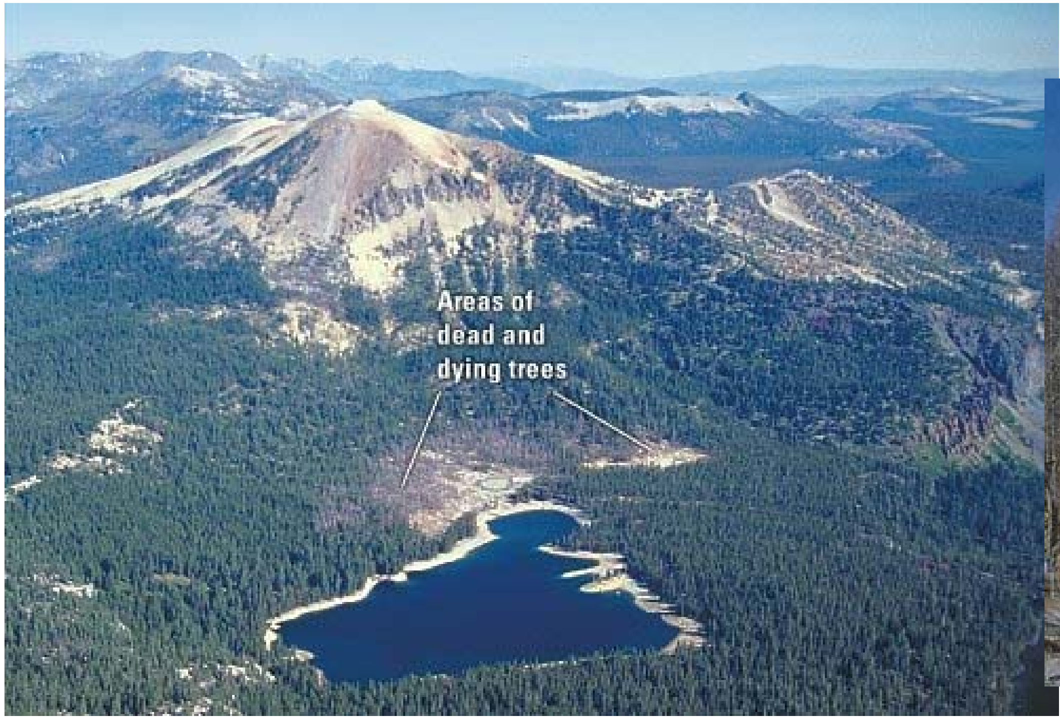
Remedial Measures

***A.** Extract & purify ground-water*	***B.** Extract & purify ground-water*	***C.** Remove CO_2 & reinject elsewhere*	***D.** Lower injection rates or pressures*	***E.** Re-plug well with cement*	***F.** Intercept & reinject CO_2*	***G.** Intercept & reinject CO_2*

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

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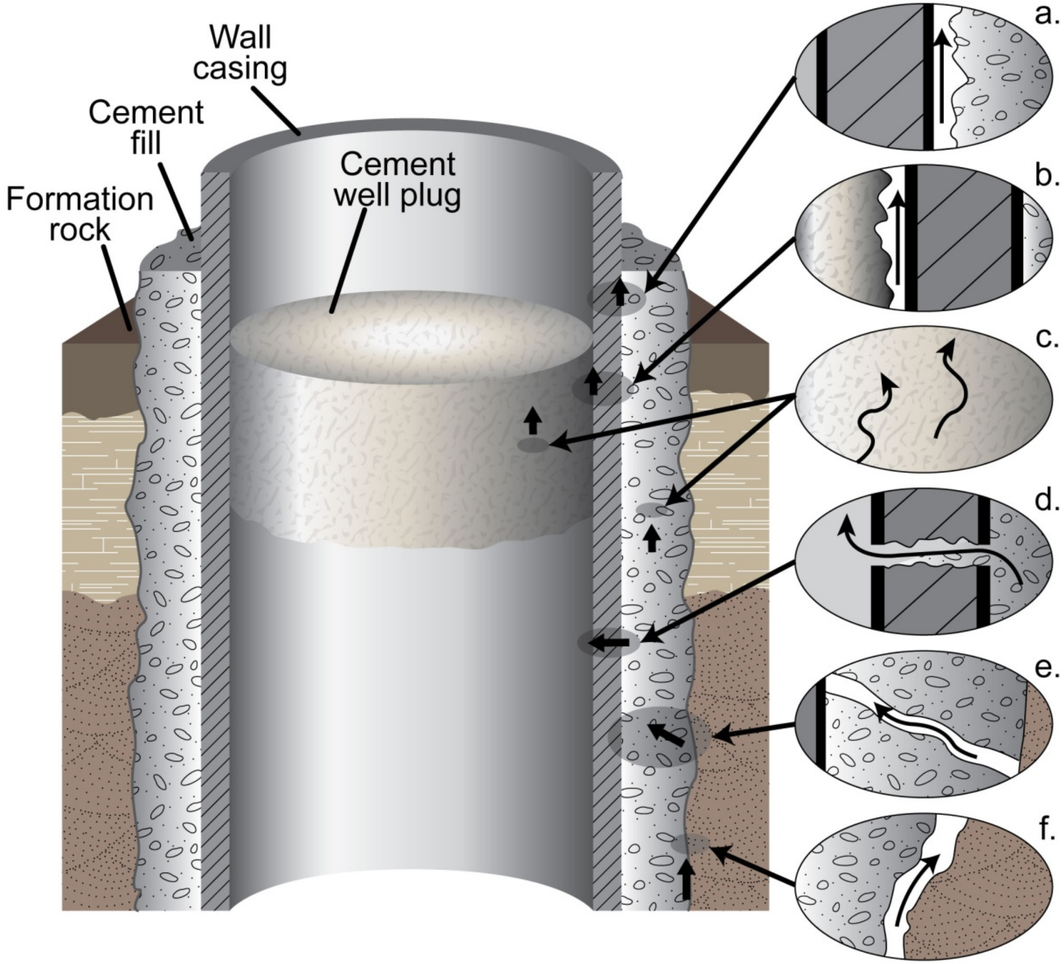
- Risk= Impact x probability

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.

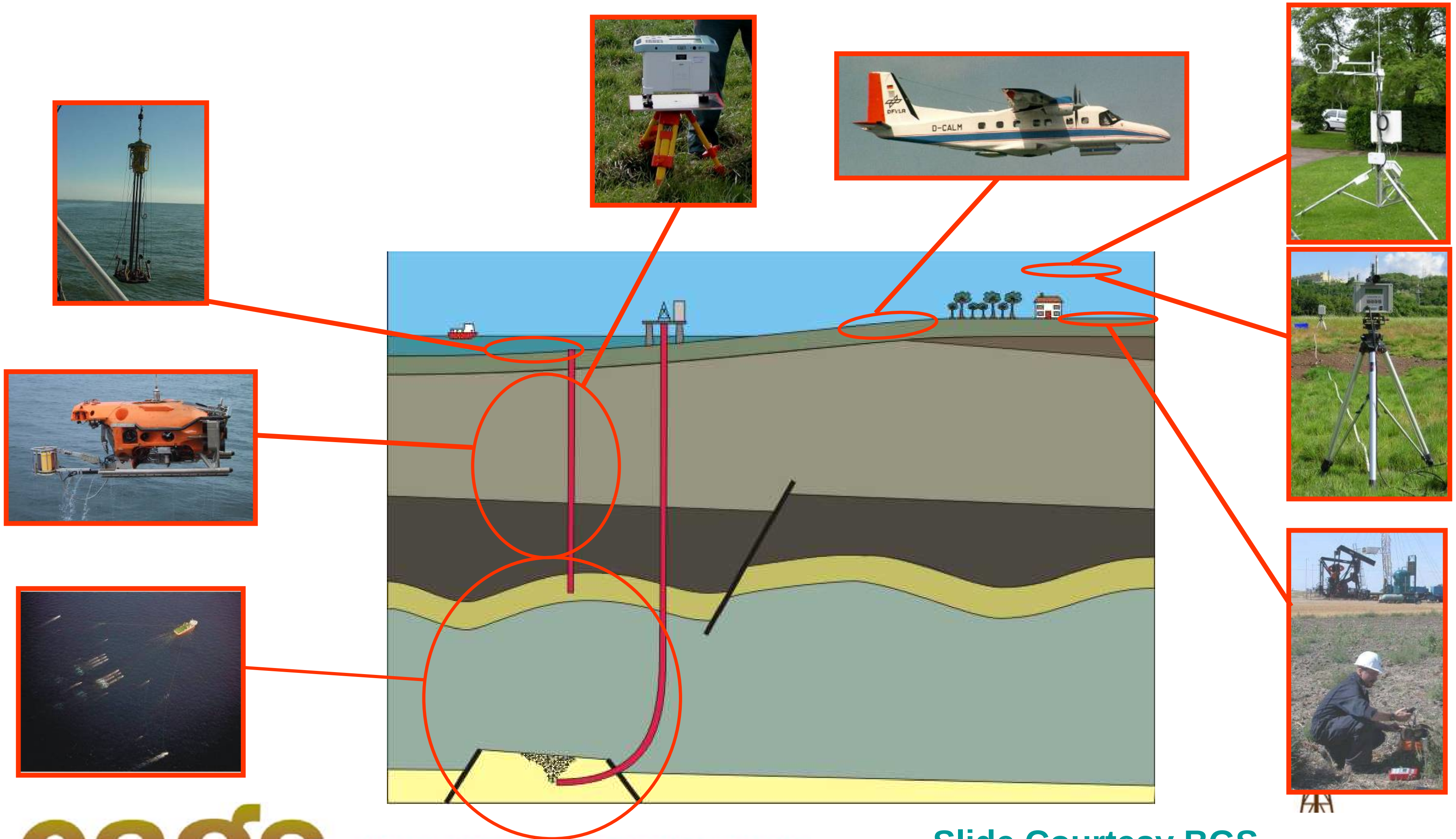
Risk Assessment

- There are a number of well established structured Risk Assessment approaches that may be used to evaluate a project and establish that it meets all safety and environmental thresholds (e.g. Risque Tesla, Swift)
- Different Projects around the world have used differing approaches
- Discussion of these approaches is not the subject of this presentation but any project will need such an evaluation early in the planning stages

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



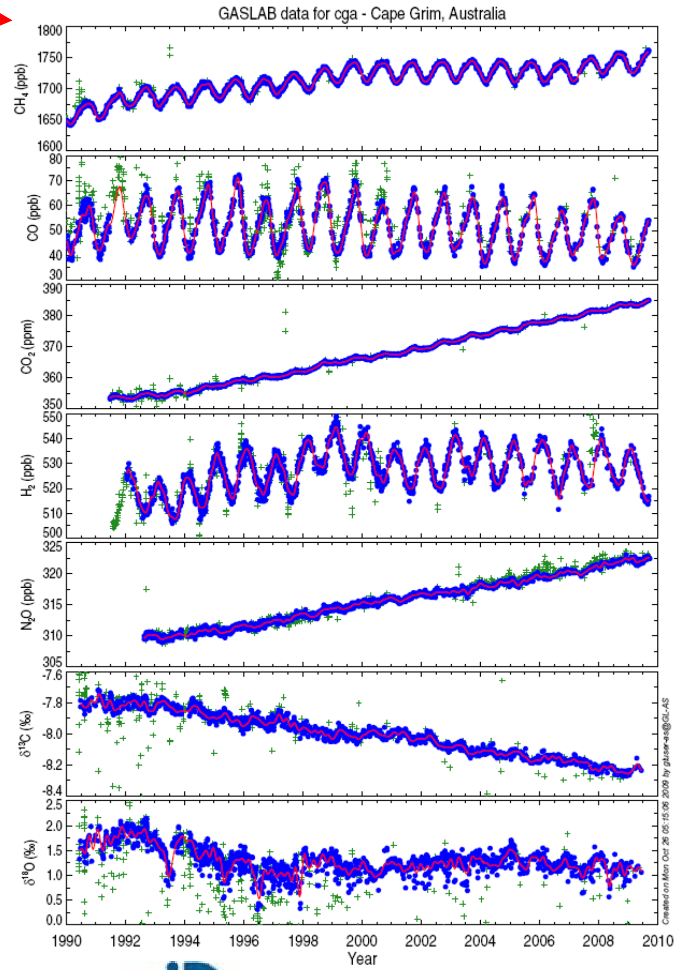
Slide Courtesy BGS

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

Who cares about these measurements?

Cape Grim

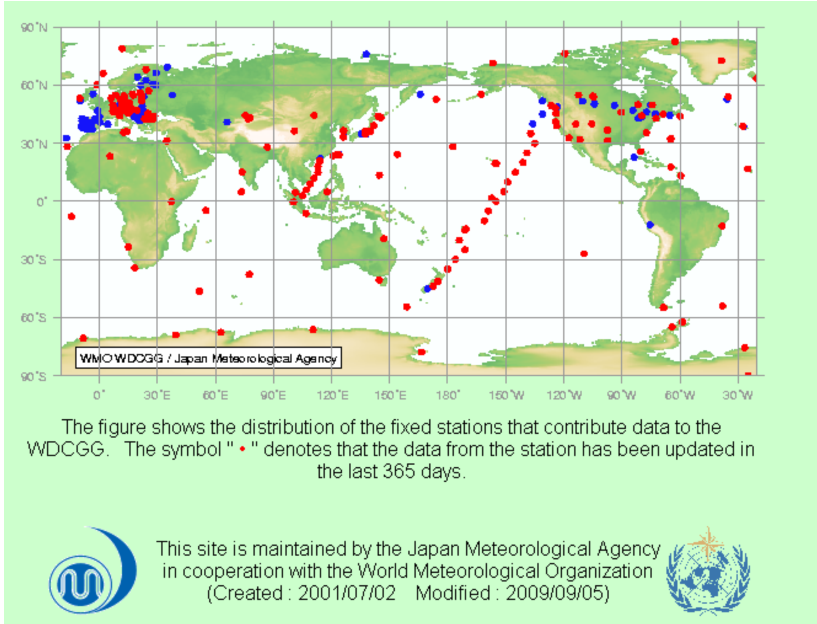


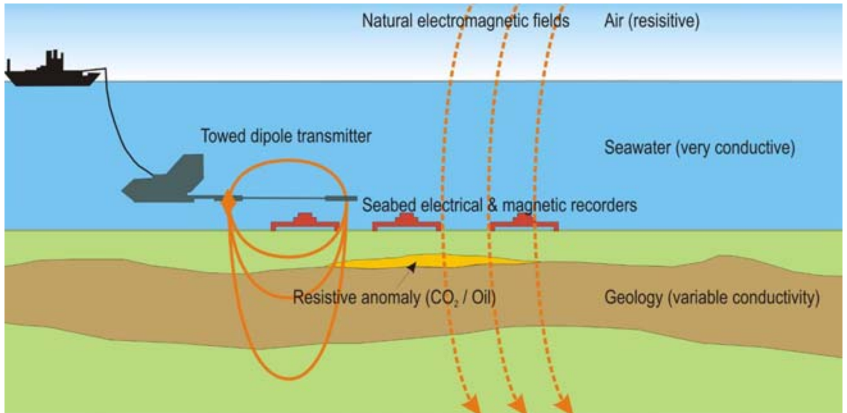
- The local community – probably the most important stakeholder group
- The financiers – the people who issue carbon credits, or administer whatever financial method is used to fund CCS
- The operators – who have a reputation to protect
- Anyone who cares about the climate

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





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

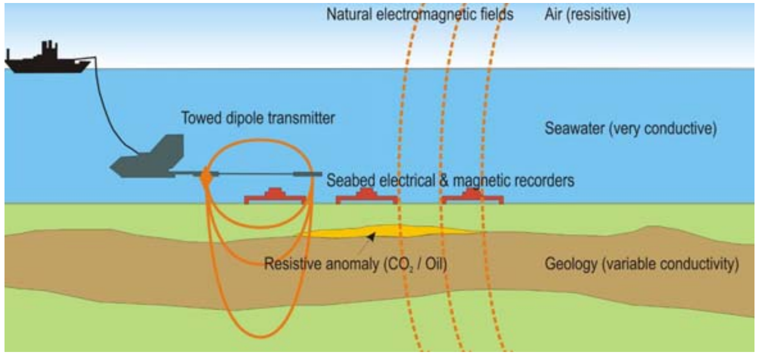
Saturation logging   Borehole gravity   Cross-well seismic
Cross-well electromagnetic   Pressure   Fluid sampling (tracers)

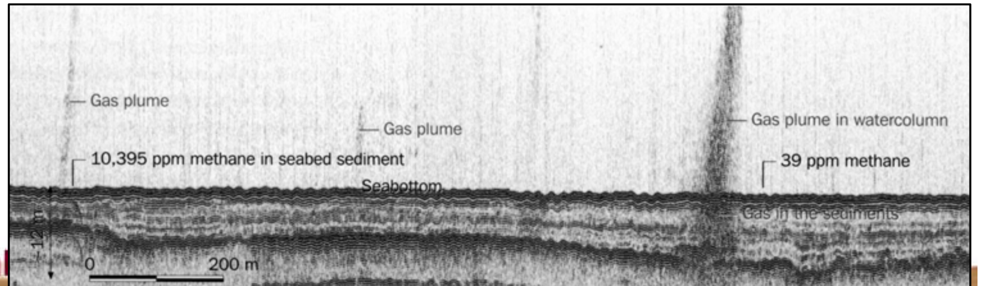
Thermal effects

Monitoring the plume within the formation

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

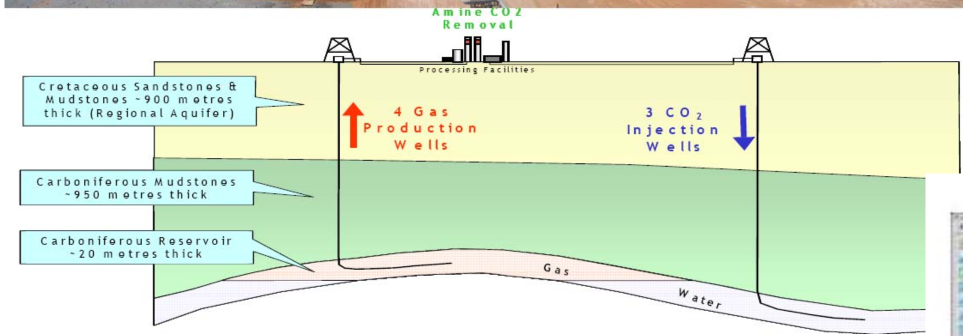
- Surface
  - Conventional seismic surveys
  - VSP (hybrid)
  - Gravity surveys
  - High-res acoustic
  - Some electromagnetic techniques





Remote Sensing

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



Surface deformation detected by synthetic aperture radar.

Injection of around 1 million tonnes CO_2 per annum since 2004

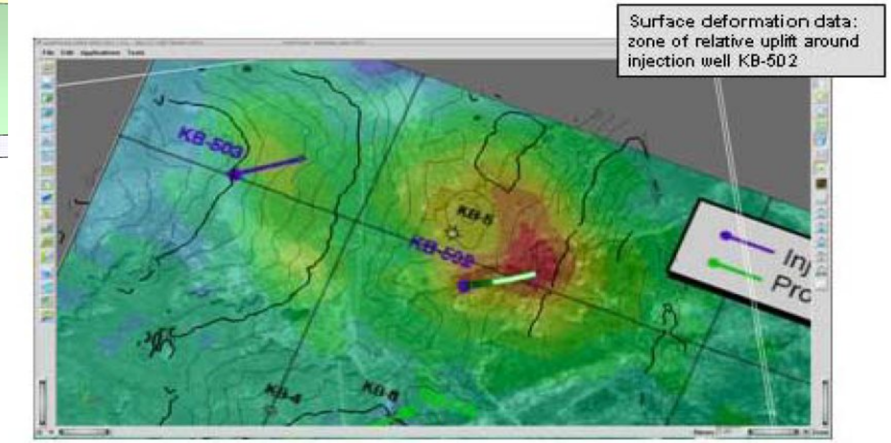
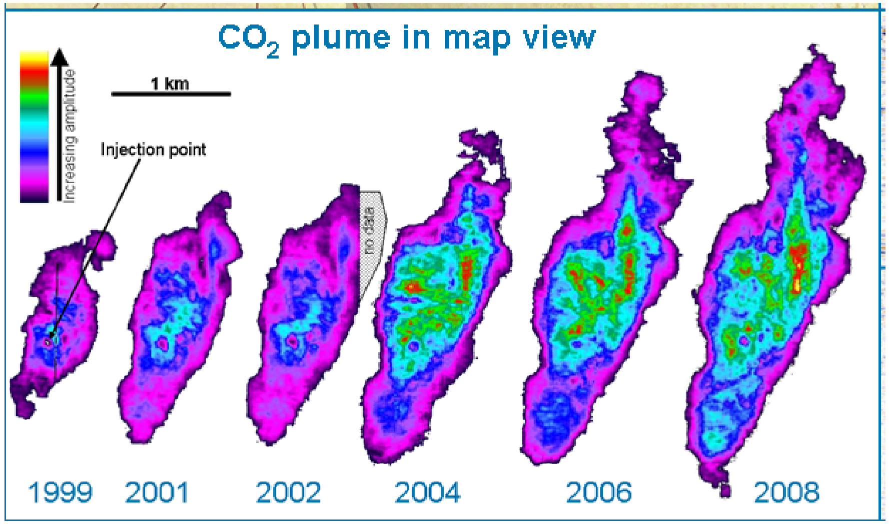
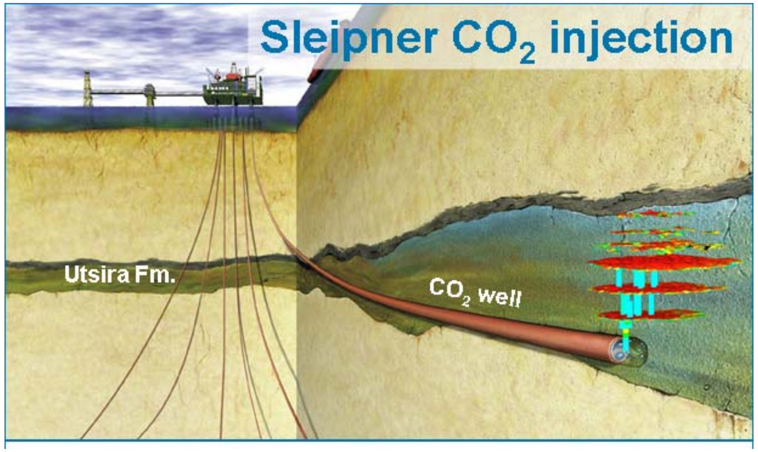


Figure 8: JAPEX/BGS Satellite Image August 2007

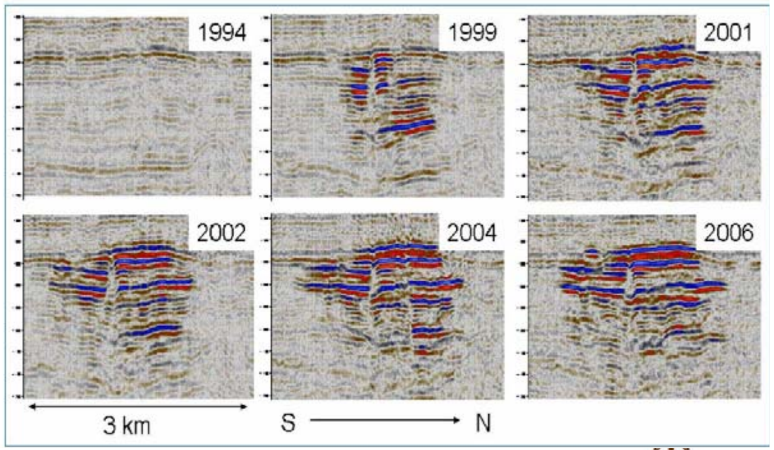
Seismic monitoring



The Sleipner Project 15 years of Experience

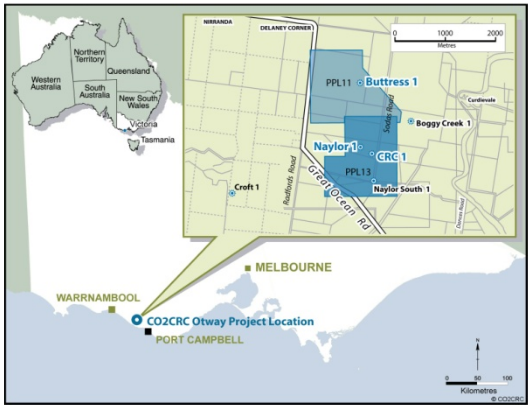


Latest result: The Sleipner 4D seismics until 2006



Onshore Seismic monitoring – CO2CRC Otway Project

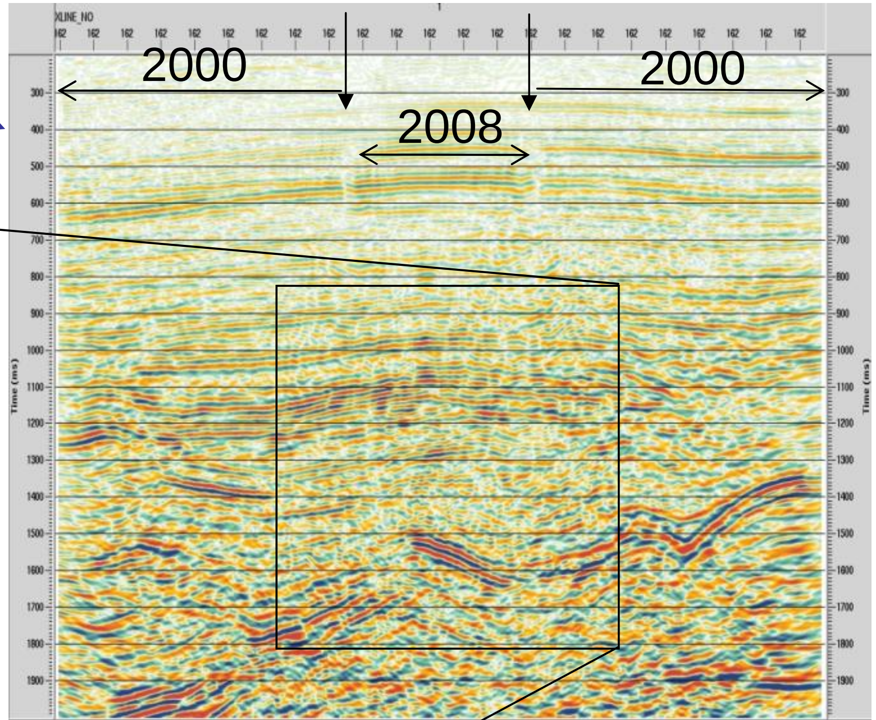
- Seismic survey

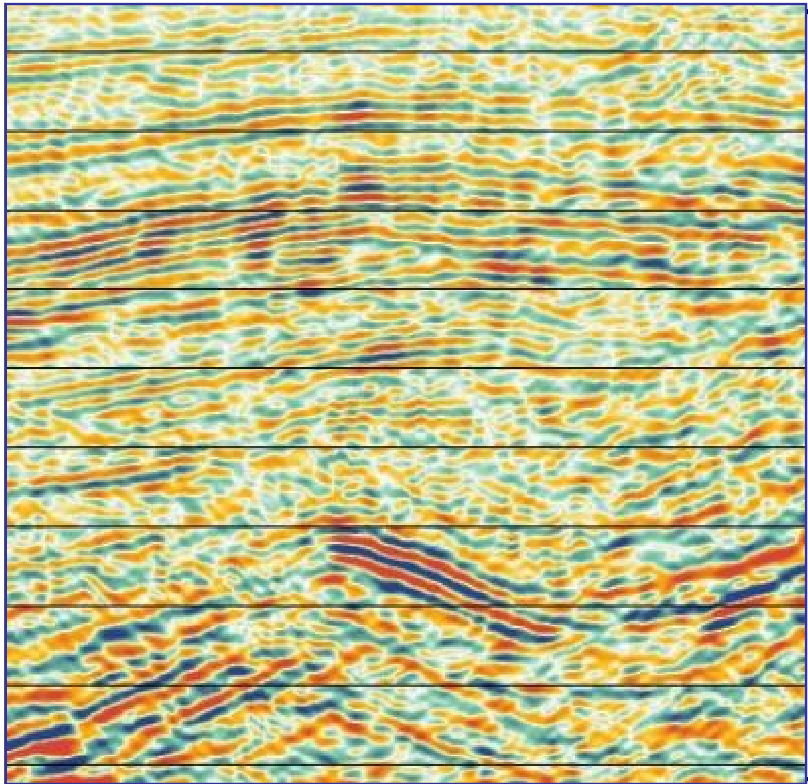


Image, CO2CRC

Time-lapse studies – CO2CRC Otway Project

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



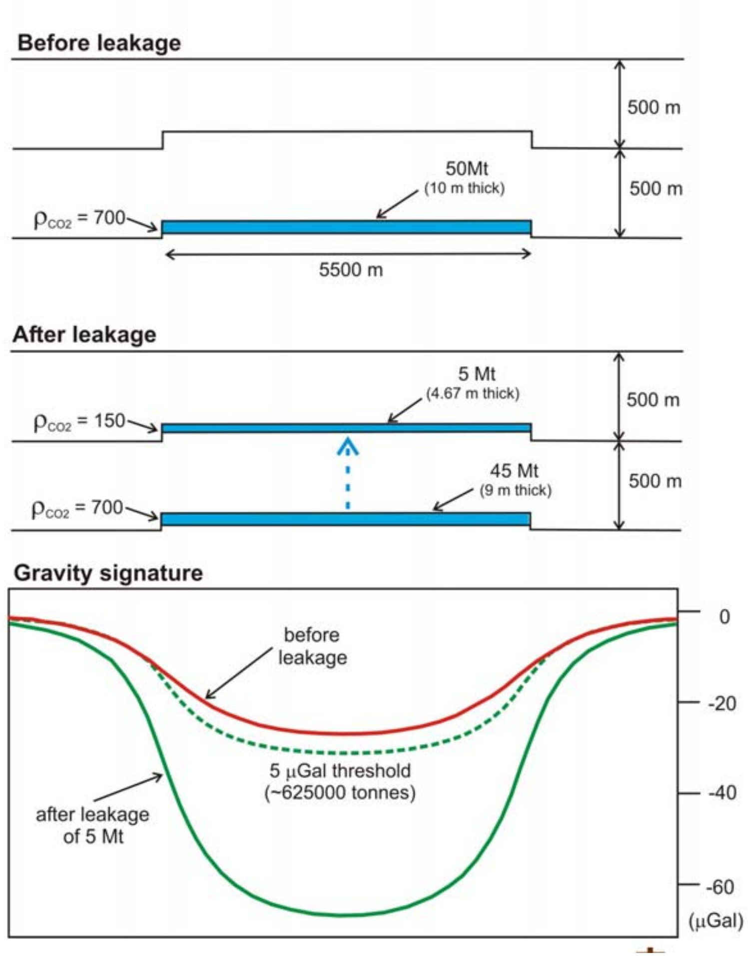


Pevzner & Shulakova, 08

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

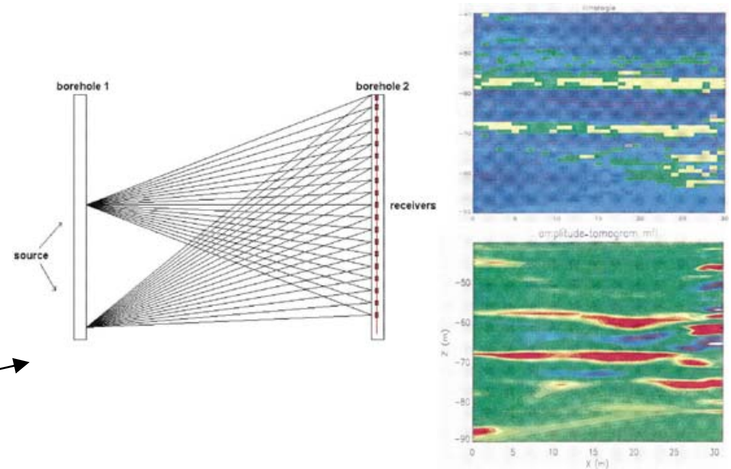
Gravity models to illustrate gravimetric signature caused by leakage of 5MT of CO_2 from a putative storage reservoir to shallower depth.

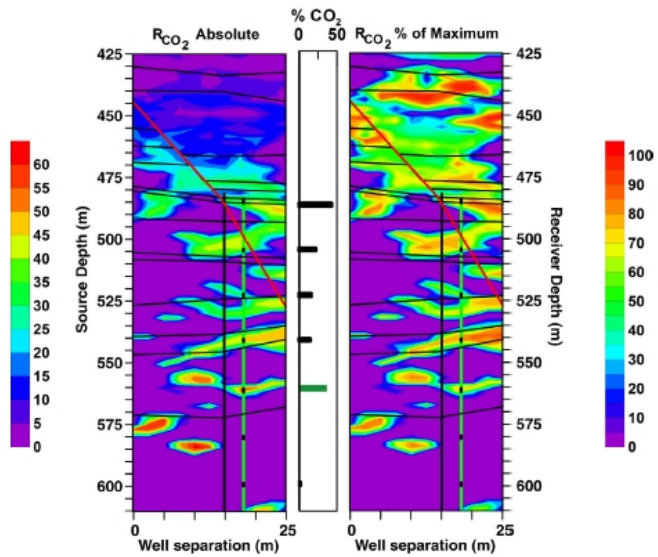
Surface techniques: advantages (pro) and disadvantages (con)

- 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

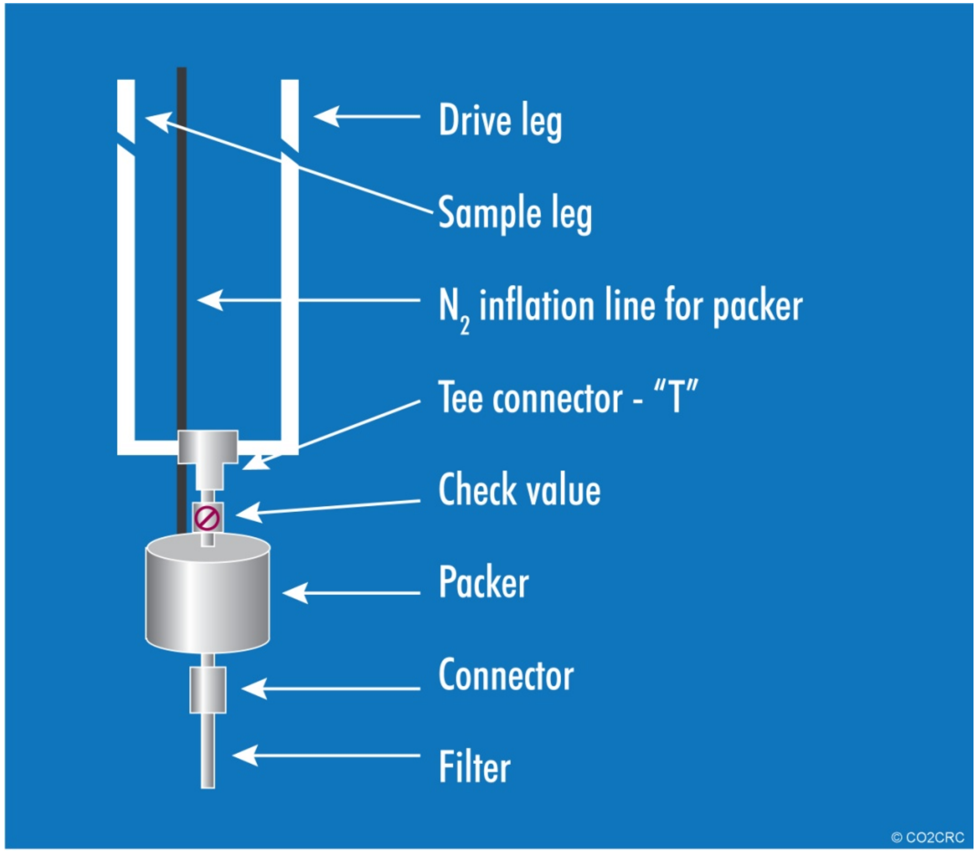
Containment monitoring at depth- measuring the CO_2 using downhole techniques

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

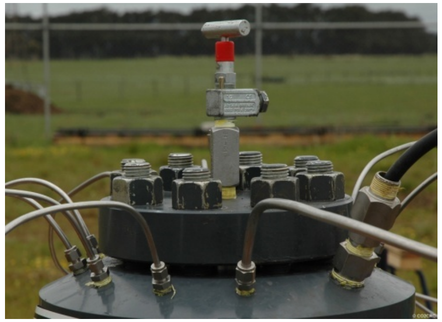




Containment monitoring at depth- measuring the CO_2 using downhole techniques

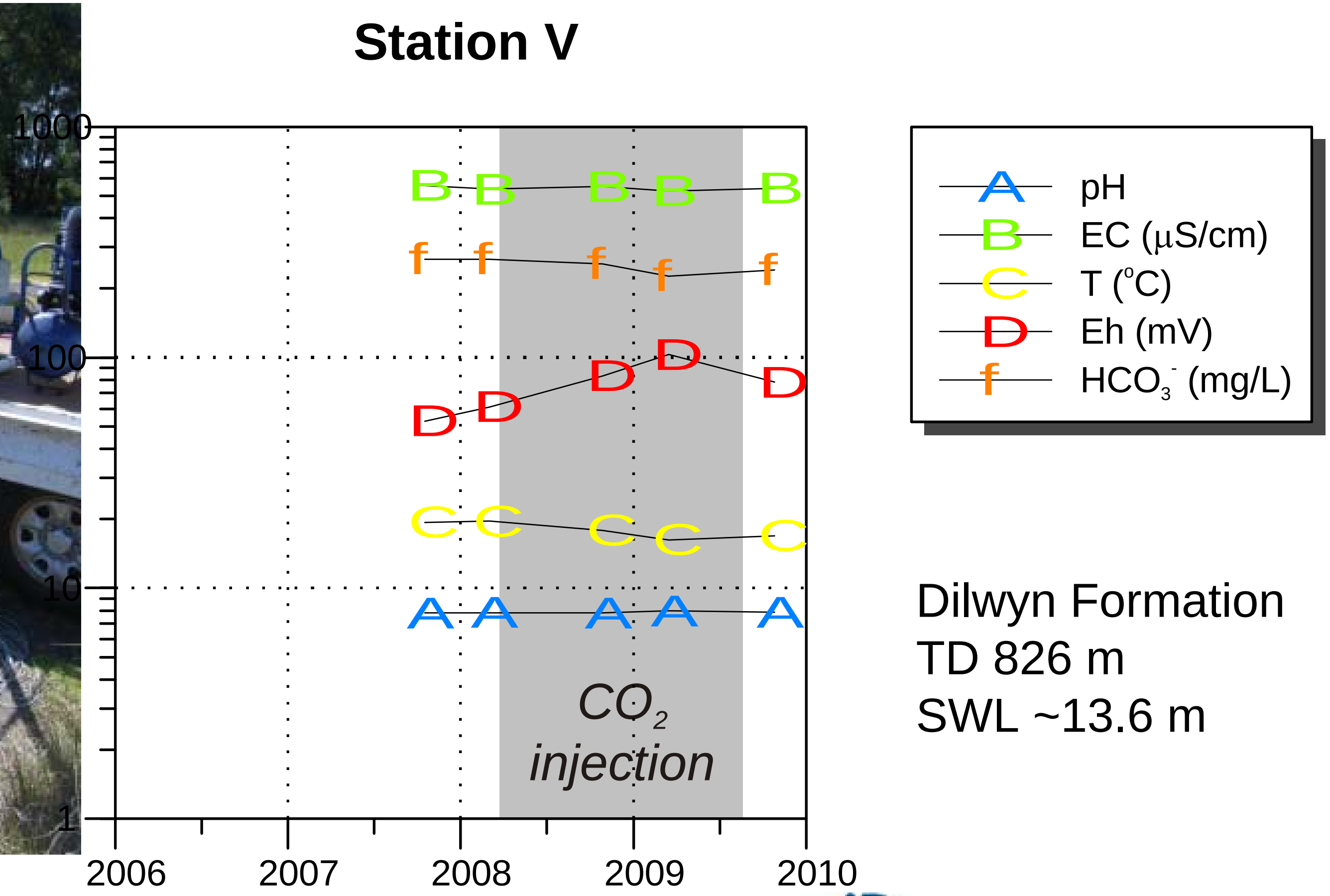


- Fluid sampling
- Use of tracers
- Temperature and pressure
- Developed by Lawrence Berkeley National Laboratory and CO2CRC



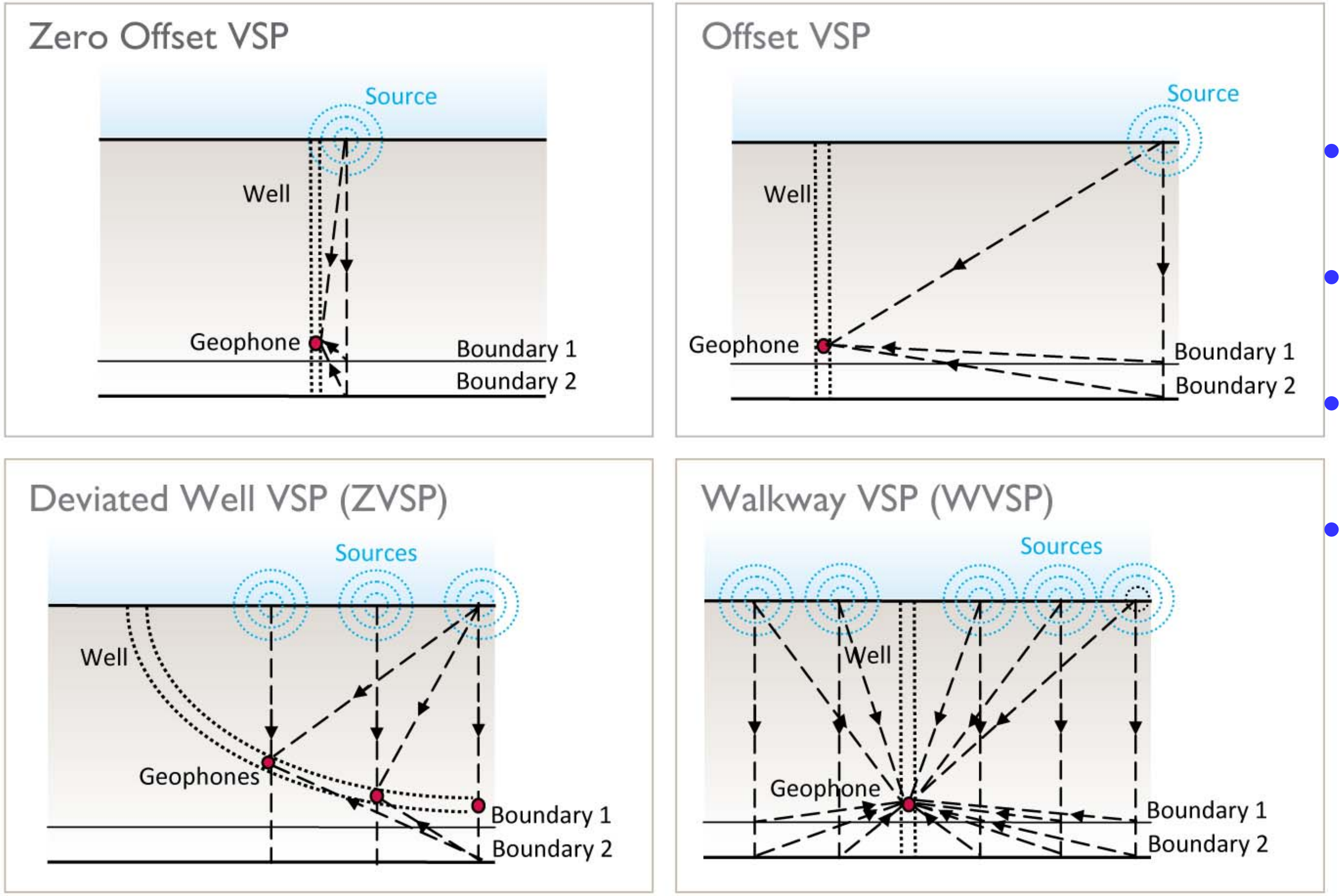
Image, CO2CRC

Water Bore sampling: Wannon Water: nr Otway Project



Dilwyn Formation
TD 826 m
SWL ~13.6 m

Downhole seismic monitoring



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

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 Sydney • Australia
The University of Western Australia — Achieve International Excellence
Anglo American
anlecr&d
BG Group
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Brown Coal Innovation Australia
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Shell
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

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Questions?