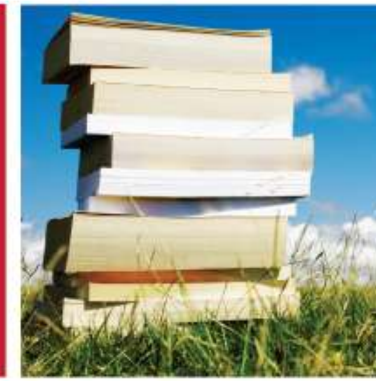
LEARNING BY DOING
THE CO2CRC OTWAY PROJECT



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Cooperative Research Centre
for Greenhouse Gas
Technologies (CO2CRC)


CO2CRC Otway Project Participants

RESEARCH PARTICIPANTS

Australian Government Geoscience Australia
Alberta Innovates Technology Futures
Berkeley Lab
CSIRO
Curtin University
GNS Science
The University of Adelaide Australia
The University of Melbourne
UNSW

INDUSTRY AND GOVERNMENT PARTICIPANTS/FUNDERS

Anglo American
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Brown Coal Innovation Australia
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한국지질자원연구원 Korea Institute of Geoscience and Mineral Resources
Chevron
NSW Industry & Investment
Research Science & Technology
INPEX
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Total
Solid Energy Coals of New Zealand
Stanwell Corporation Limited
State Government Victoria Department of Primary Industries
Government of Western Australia Department of Mines and Petroleum
xstrata coal
CRC

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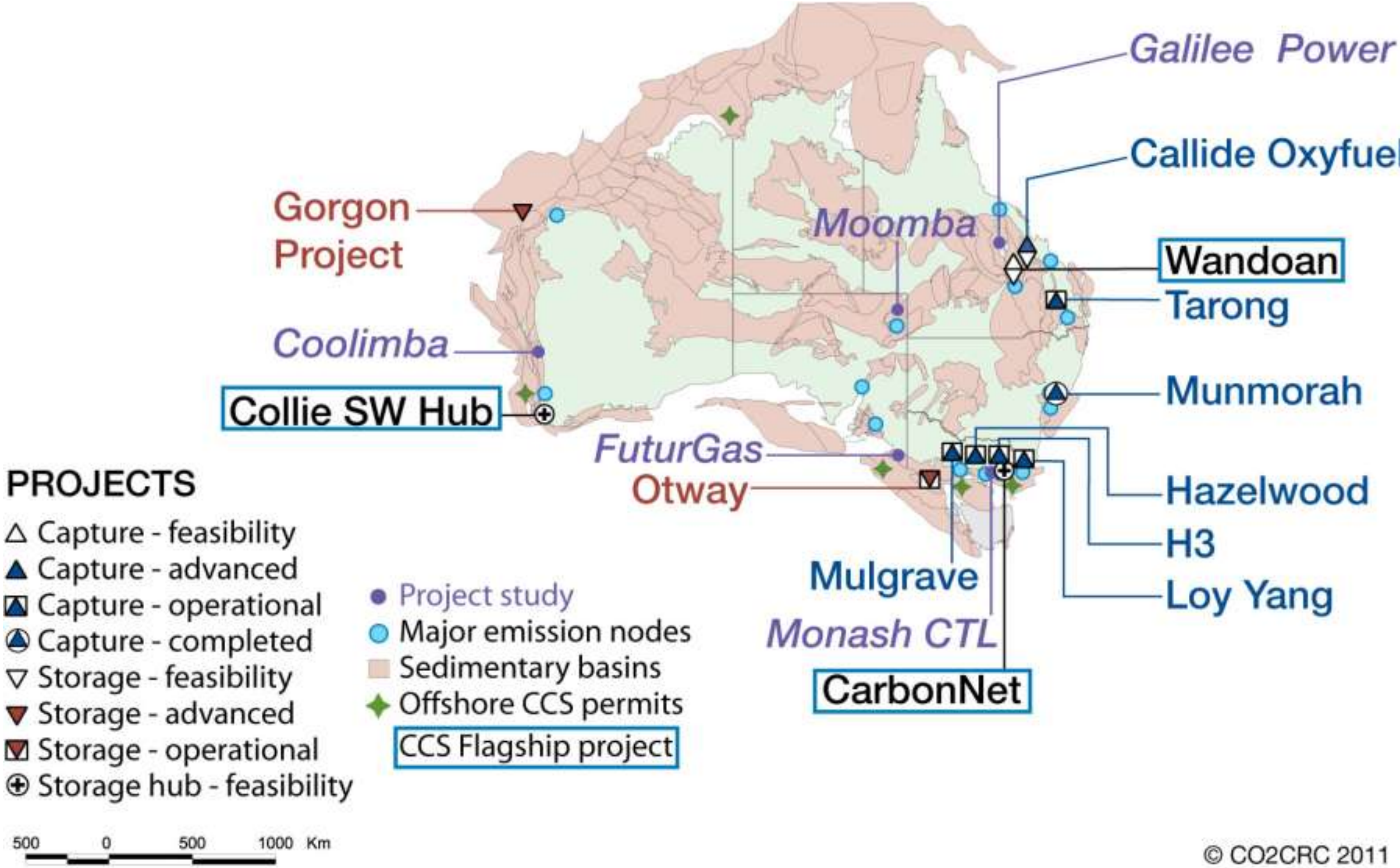
CCS Projects in Australia



CO2CRC Otway Project - Australia's first storage project

- **Injection commenced 2 April 2008 – 65,000 tonnes Buttress gas(79% CO_2, 19% CH_4) injected into depleted Gas Field**
- **Stage 1 cost A$40M -completed 2010**
- **Stage 2 cost A$20M plus - underway**
- **Monitoring and verification a key component**
- **Developments include regulation, risk, liability, technology**
- **Successful science, operations, communications, community**
- **Stage 2 examines fundamentals of CO_2 trapping and subsurface processes**

Community Engagement

- **Community Liaison Officer**
- **Community Reference Group meetings held quarterly**
- **Project updates in Community Newsletter**
- **Open Days held at site**
- **Visits for groups and media**
- **CO2CRC Website**

A very important activity for this project.

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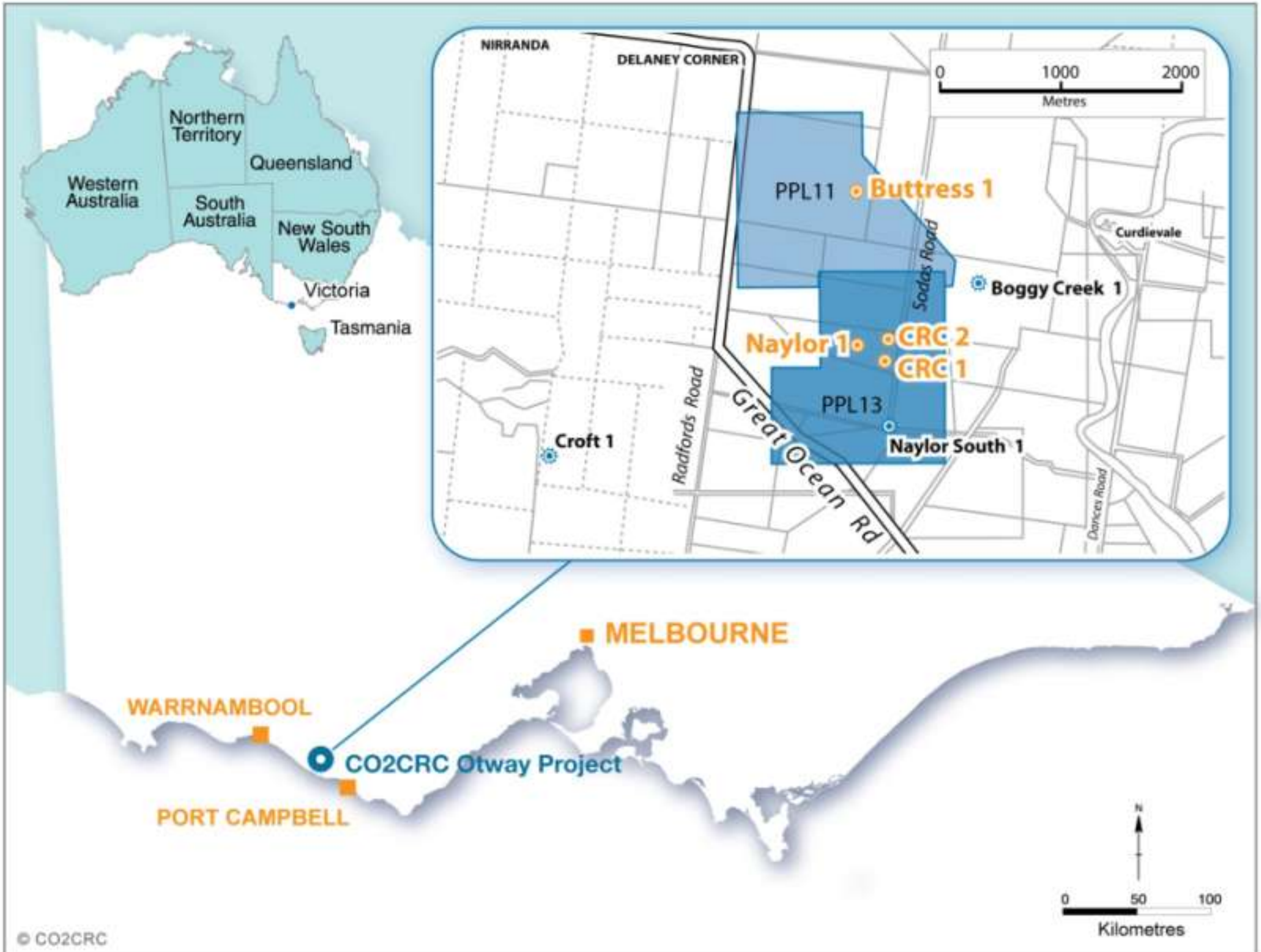
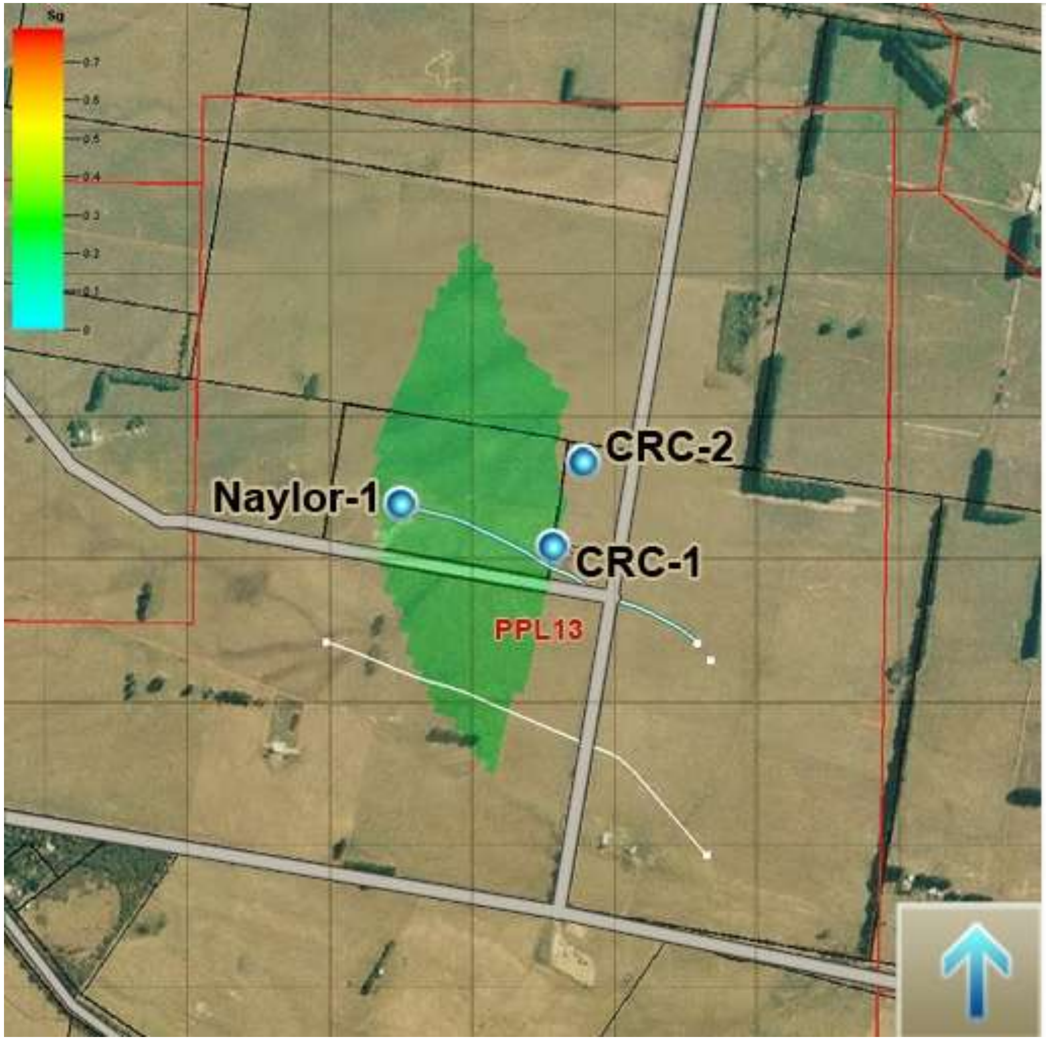
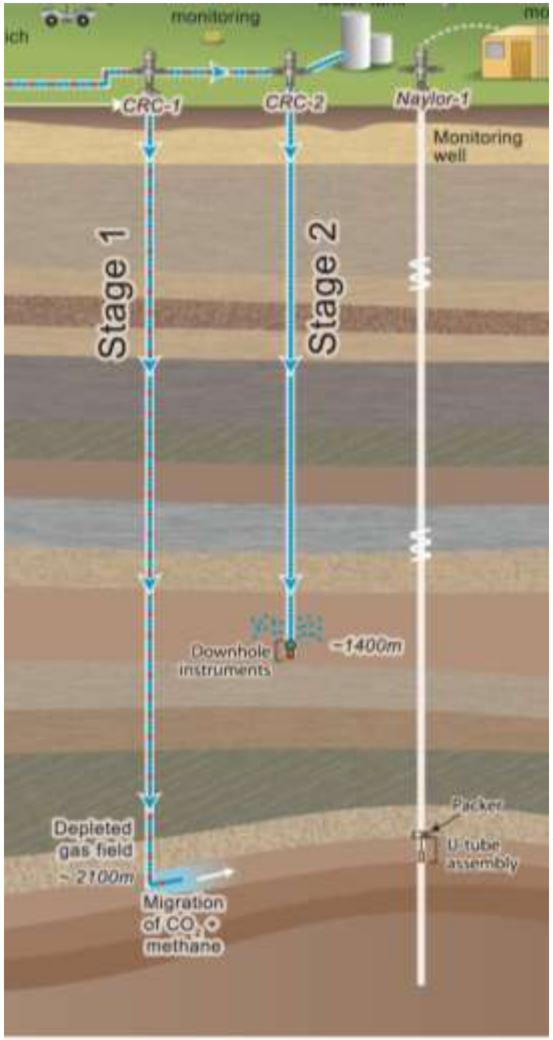
Location of CO2CRC Otway Project



CO2CRC Otway Project Aerial View

CO2CRC Otway Project

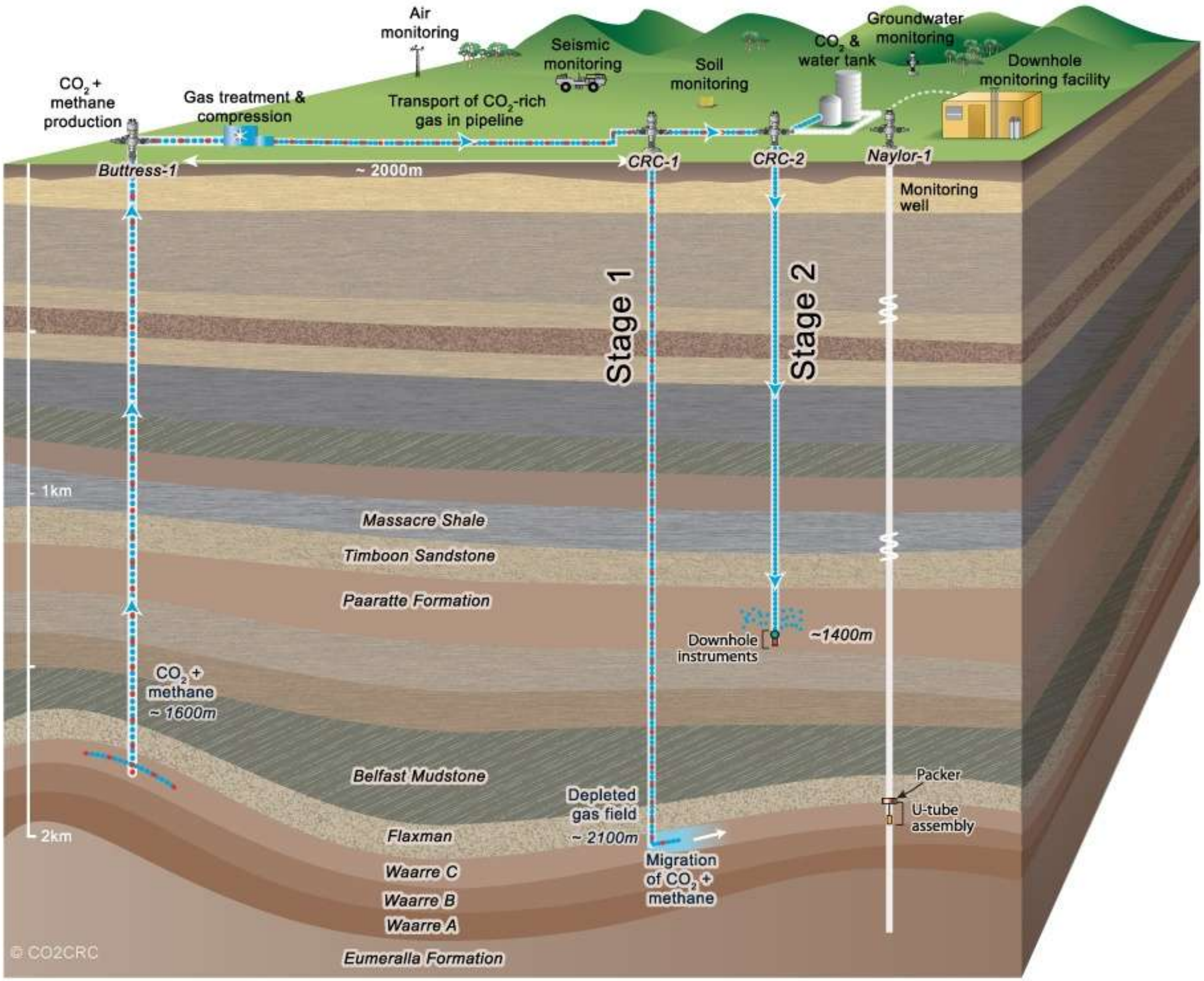




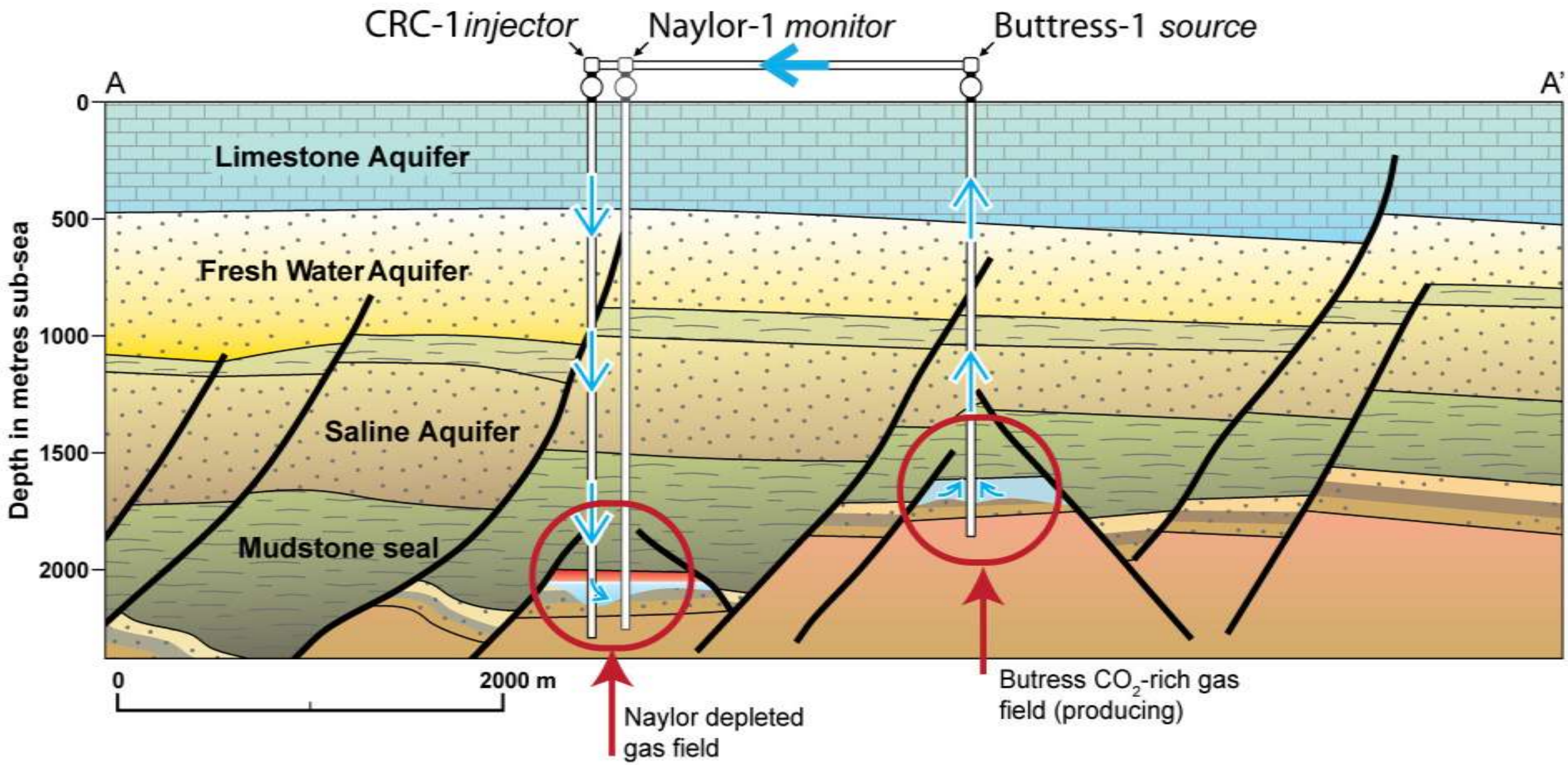
Paaratte Formation

Waarre C Formation

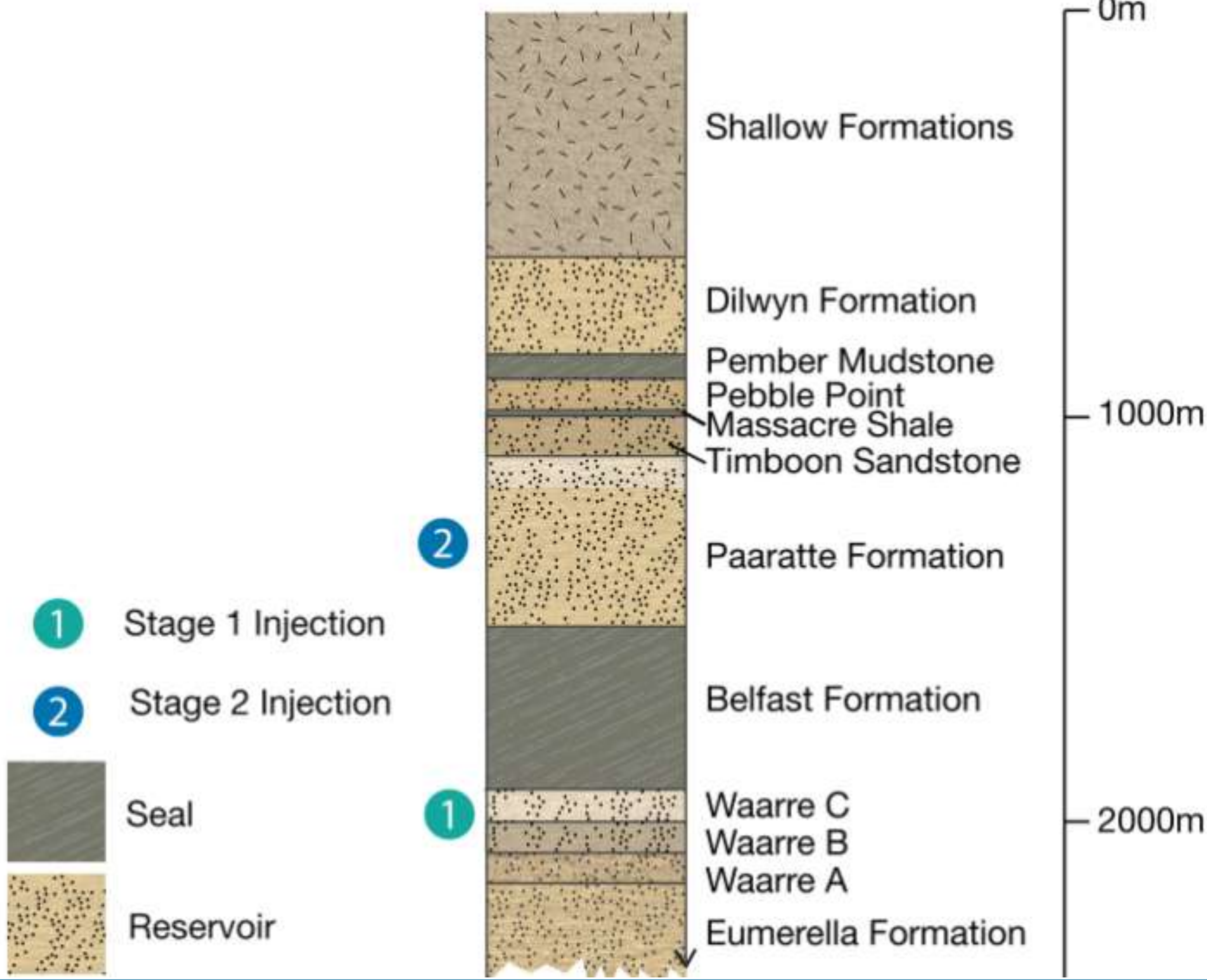
The CO2CRC Otway Project - Stages 1 & 2



Otway geological model



Schematic stratigraphic column of Otway Basin



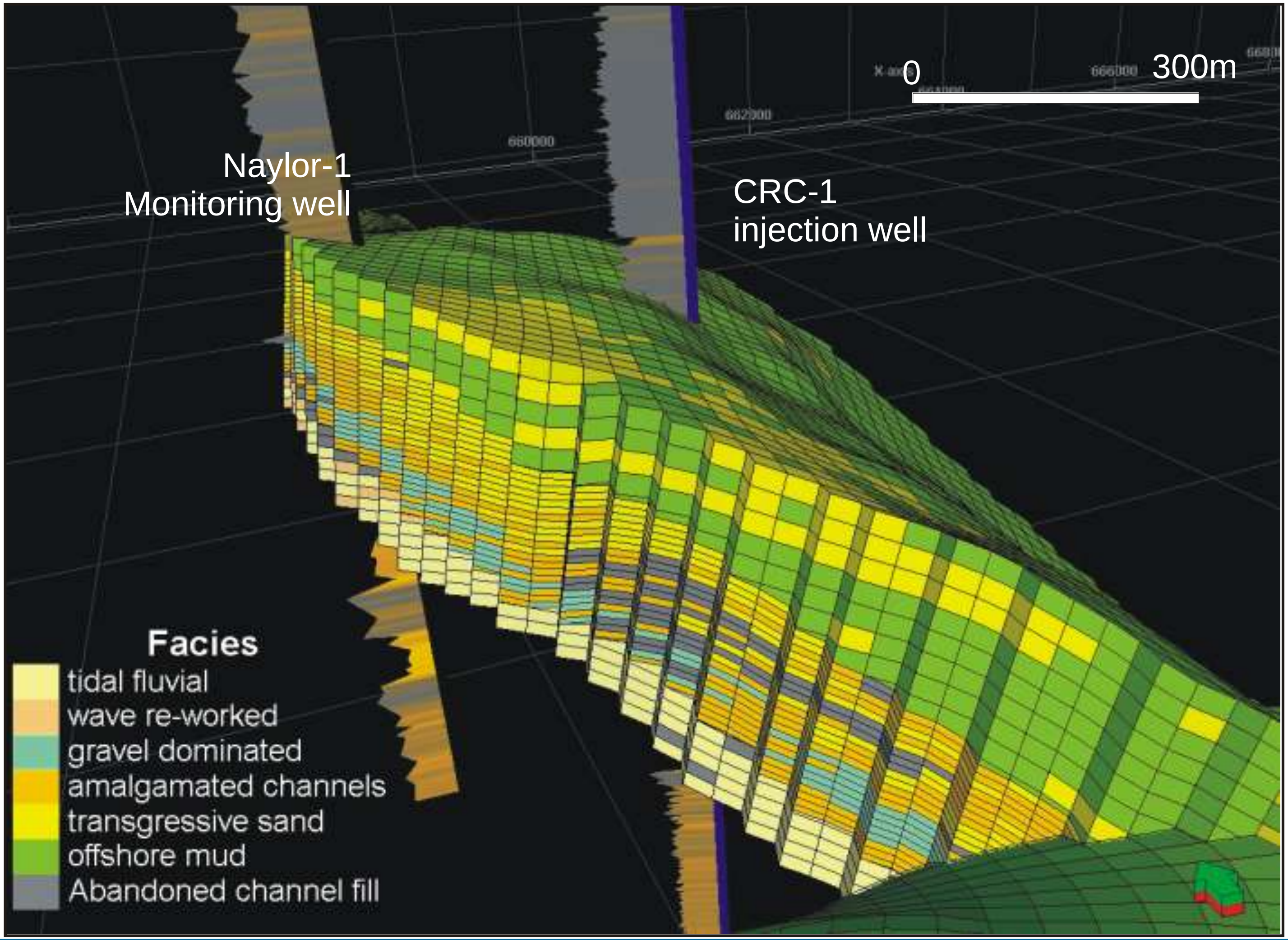
The CO2CRC Otway Project - Stage 1

Cooperative Research Centre for Greenhouse Gas Technologies (CO2CRC)

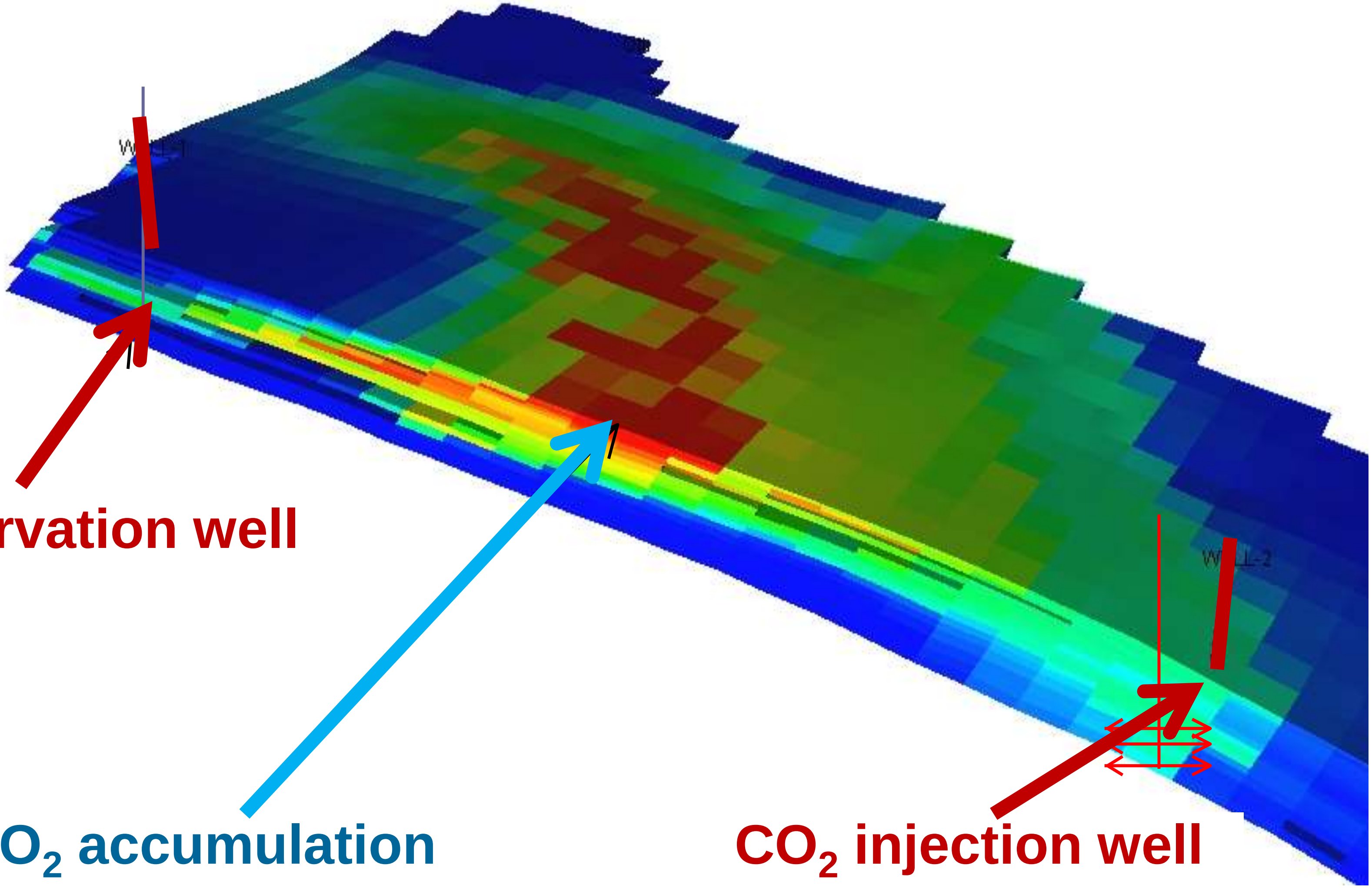
During injection

- **Monitor injection rate**
- **Monitor pressure and temperature downhole (in the reservoir)**
- **Fluid sampling**
- **Changes in temperature, pressure and composition of the injected fluid affect the density of CO_2**
- **Inject tracers as part of a monitoring program**

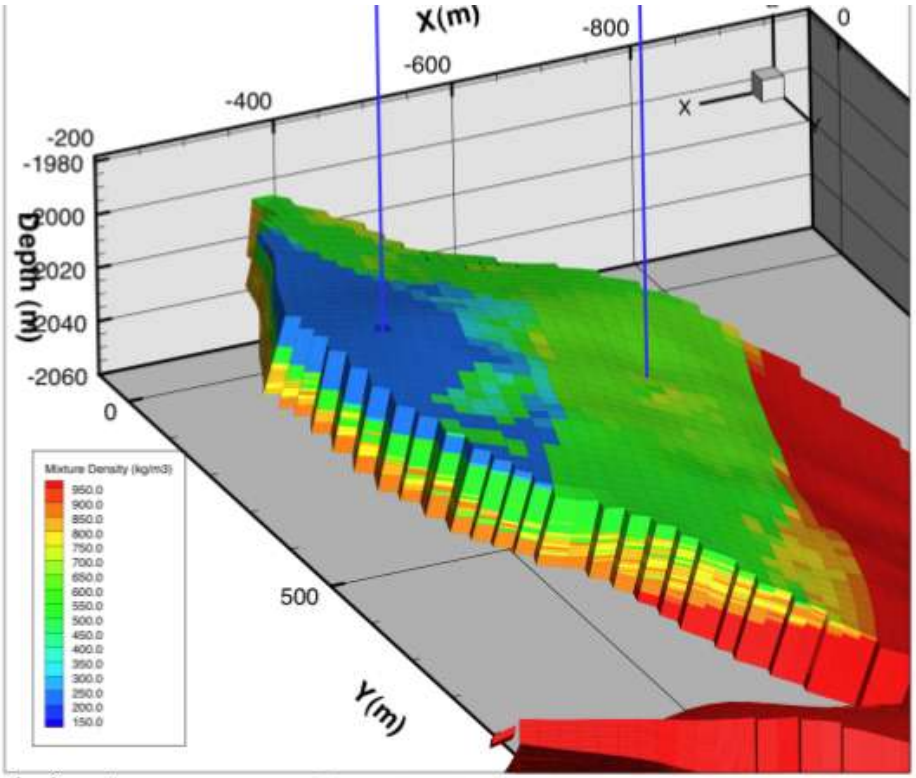
Geological Model at Reservoir Scale



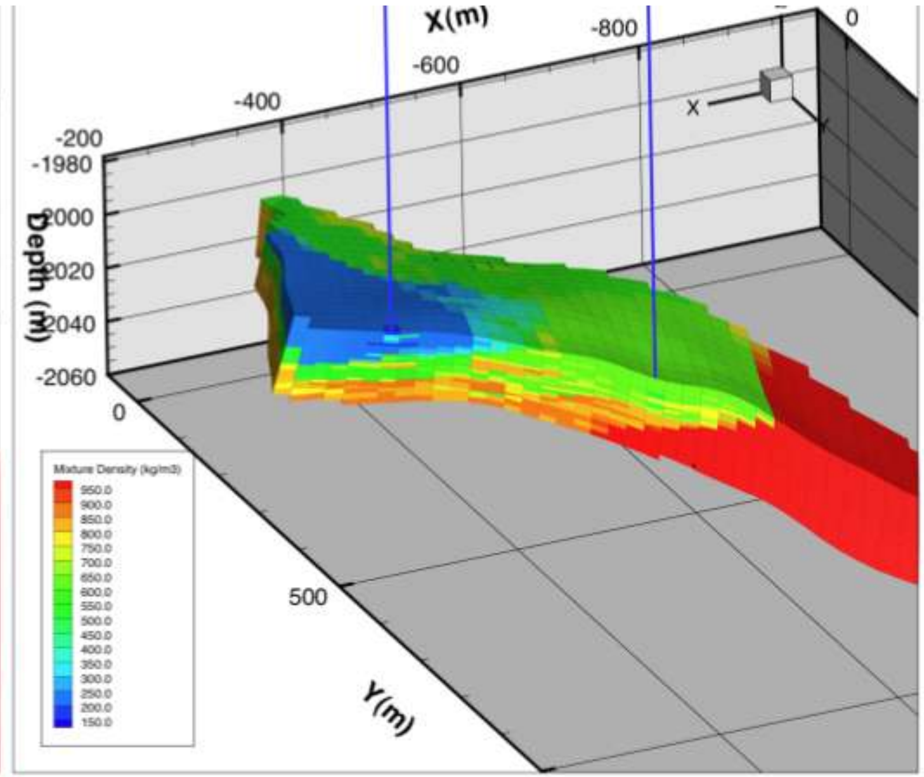
Modeling migration of carbon dioxide within the reservoir



CO2CRC Otway project: total fluid density



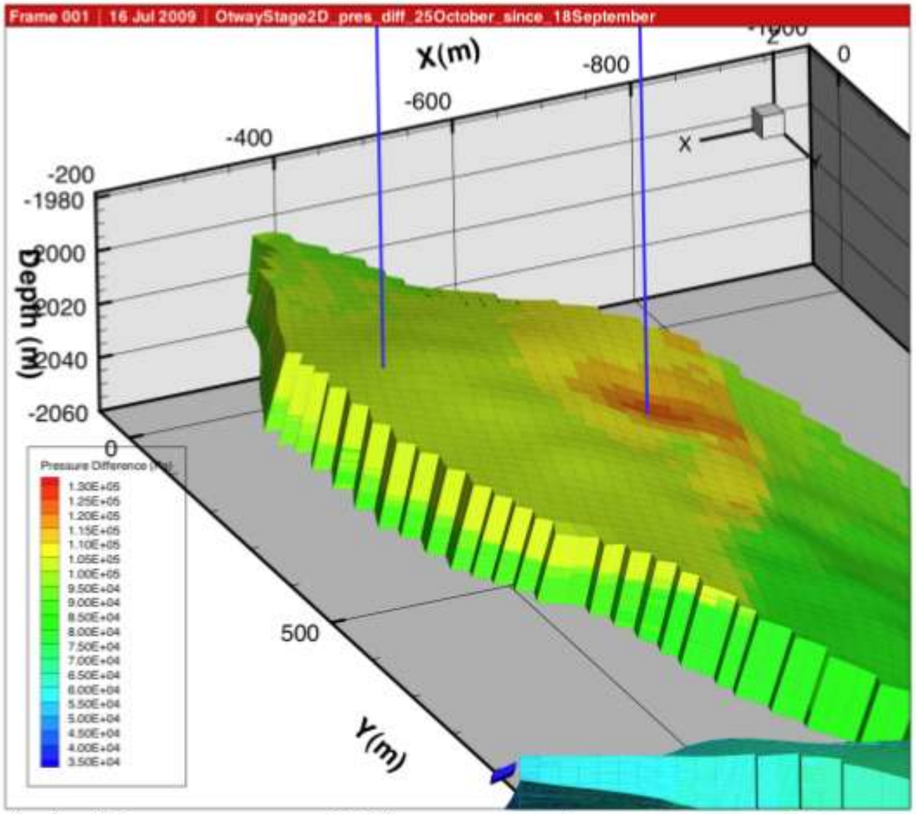
(a) Average fluid density: no cut-away.



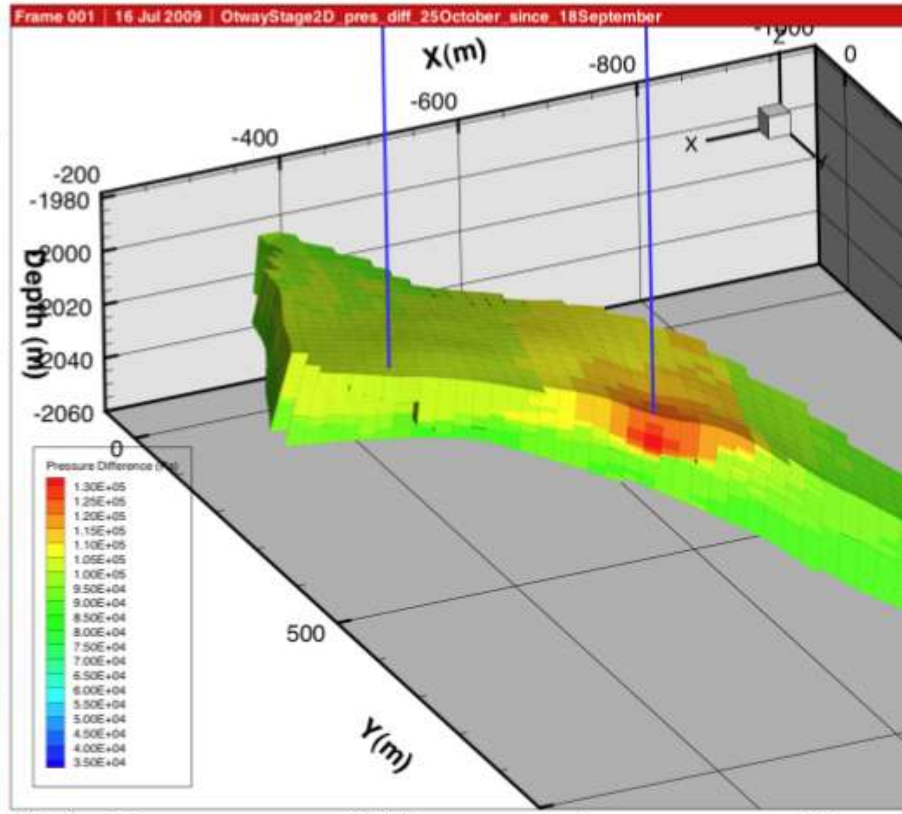
(b) Average fluid density: Cutaway.

(Paterson and Ennis-King, 2011)

CO2CRC Otway project: pressure difference



(a) Pressure difference between 18 Sept and 25 Oct: no cutaway.



(b) Pressure difference between 18 Sept and 25 Oct: cutaway.

(Paterson and Ennis-King, 2011)

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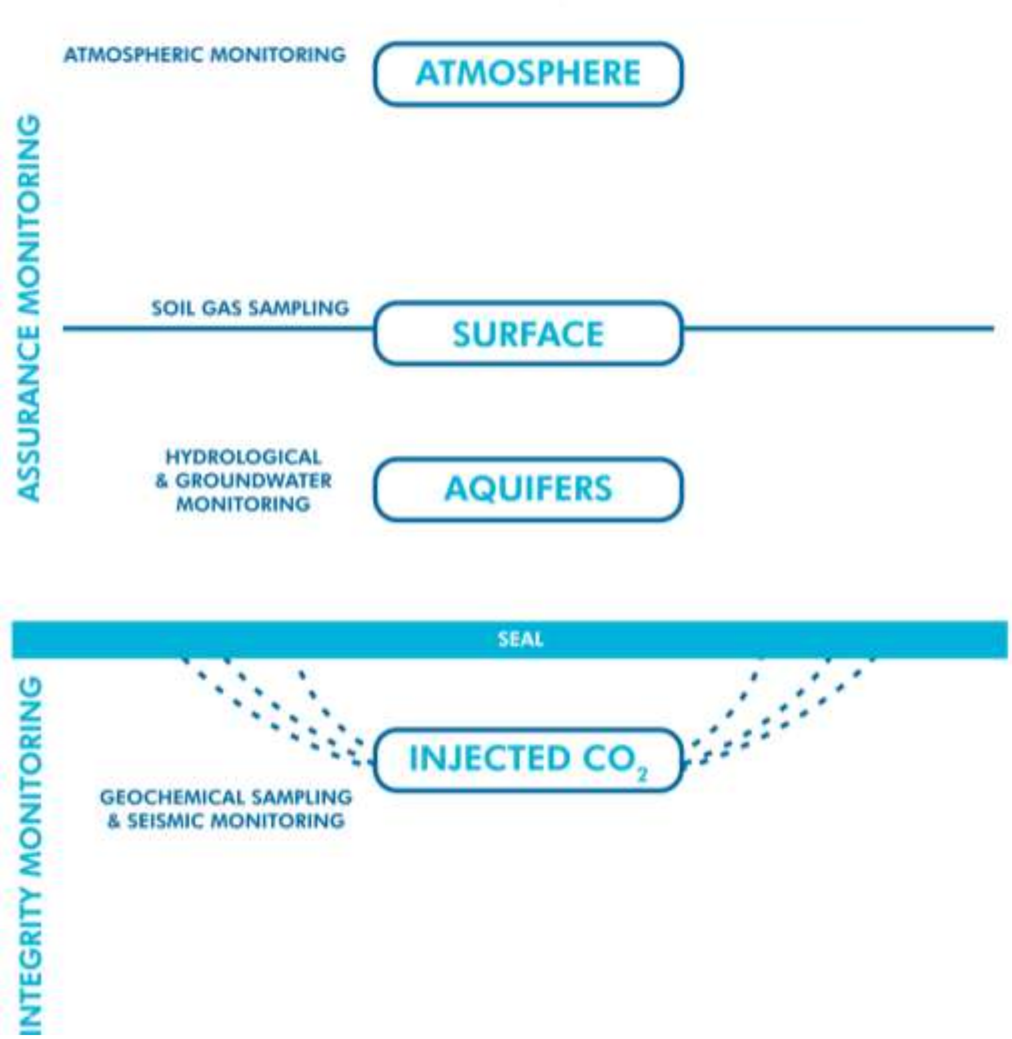
Monitoring the injected CO_2



Measuring the atmospheric concentration of CO_2

Measuring the concentration of CO_2 in the soil

Analysing the groundwater

Measuring the temperature and pressure, recording sound waves and detecting chemical changes

Monitoring to ensure security of storage

Downhole fluid sampling

Soil gas sampling

Groundwater sampling

Atmospheric sampling

Seismic surveys

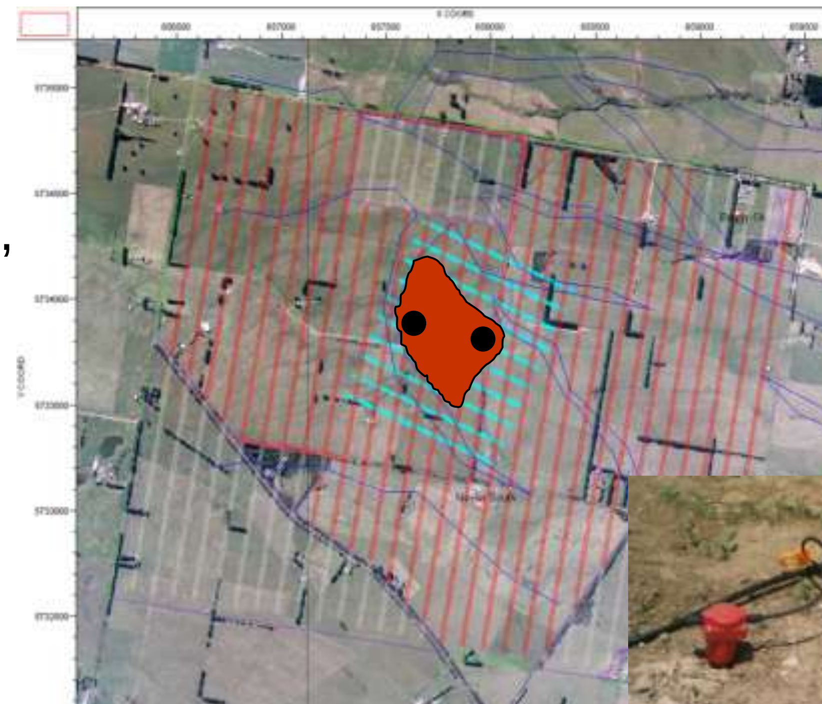
Small amounts of tracers added to see how CO2 moves through the rock.

3D surface seismic monitoring

Objective: to map the migration path of CO_2 plume from injector to producer



Methods: 4D or time-lapse surveys



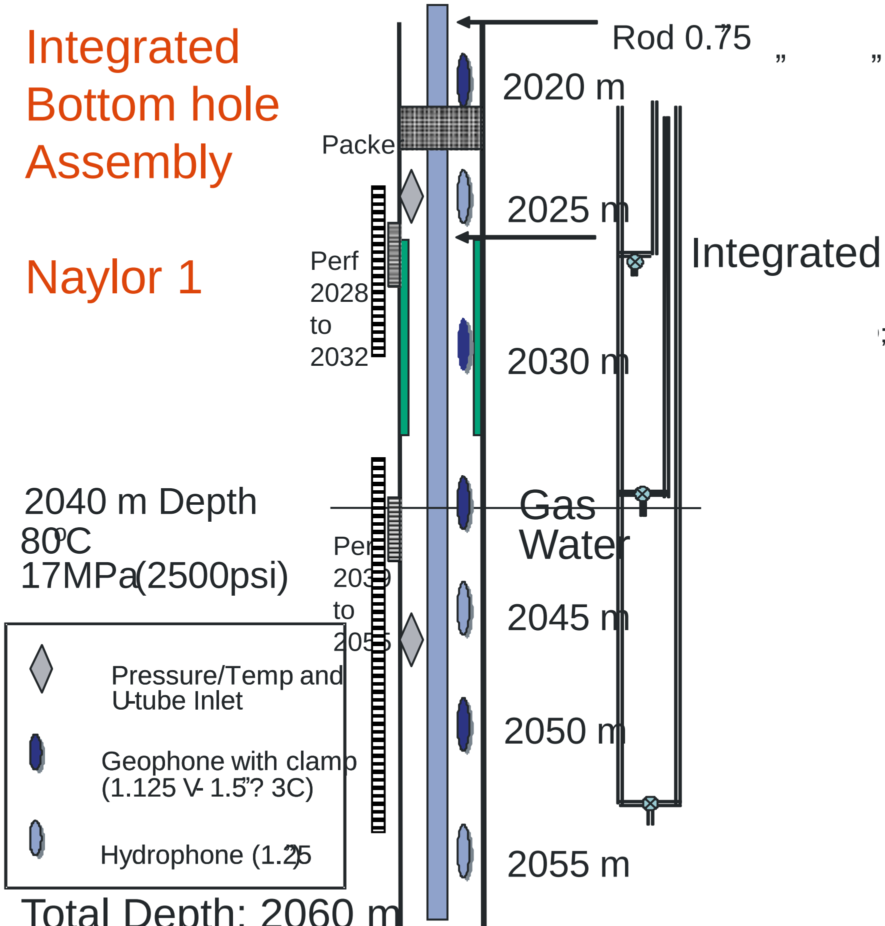
Repeatability of surveys before, during and after the CO_2 injection is very important for every aspect of acquisition (source and receivers positioning; source signal; hardware; time of year; processing)

Naylor-1 Site

Integrated
Bottom hole
Assembly

Naylor 1

2040 m Depth
80°C
17MPa(2500psi)



Total Depth: 2060 m

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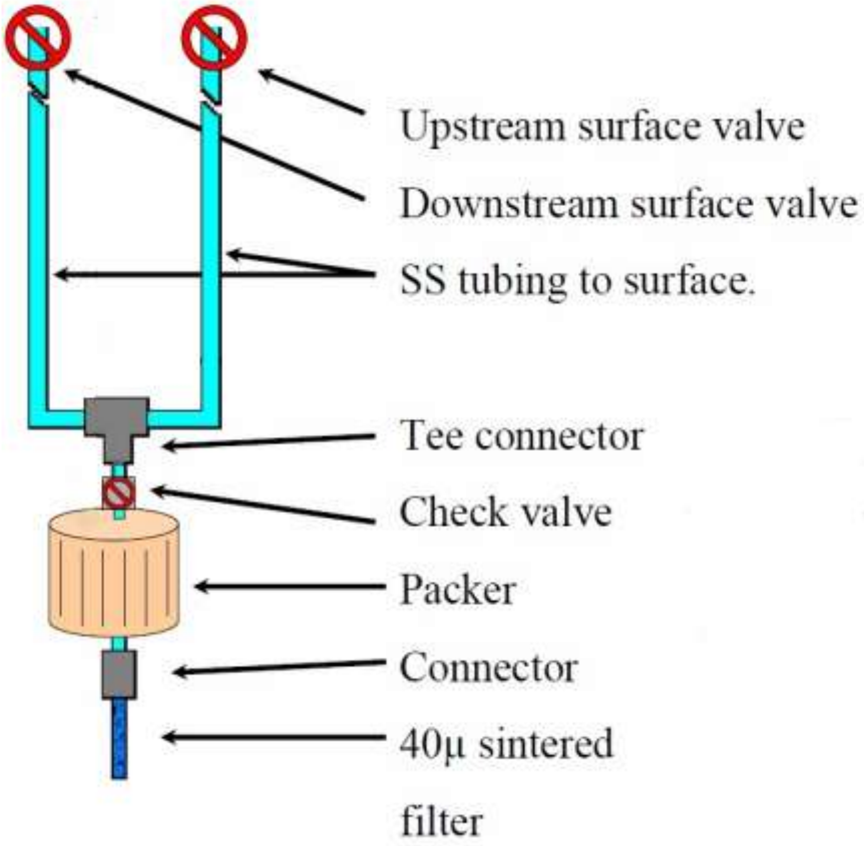
U-Tube system deployed at Otway (developed by LBNL)



Downhole fluid sampling from 2 kilometres confirms density stratification

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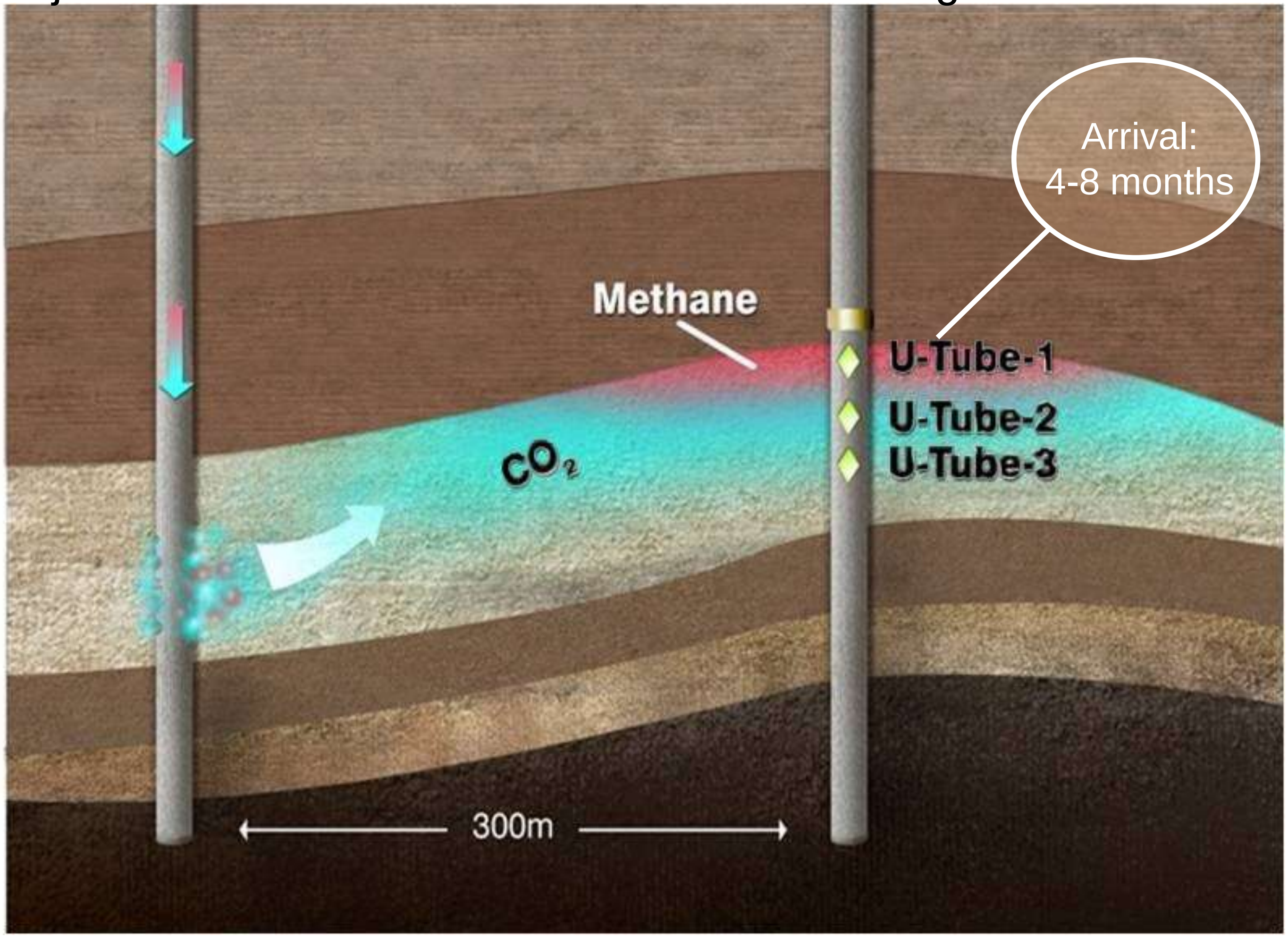
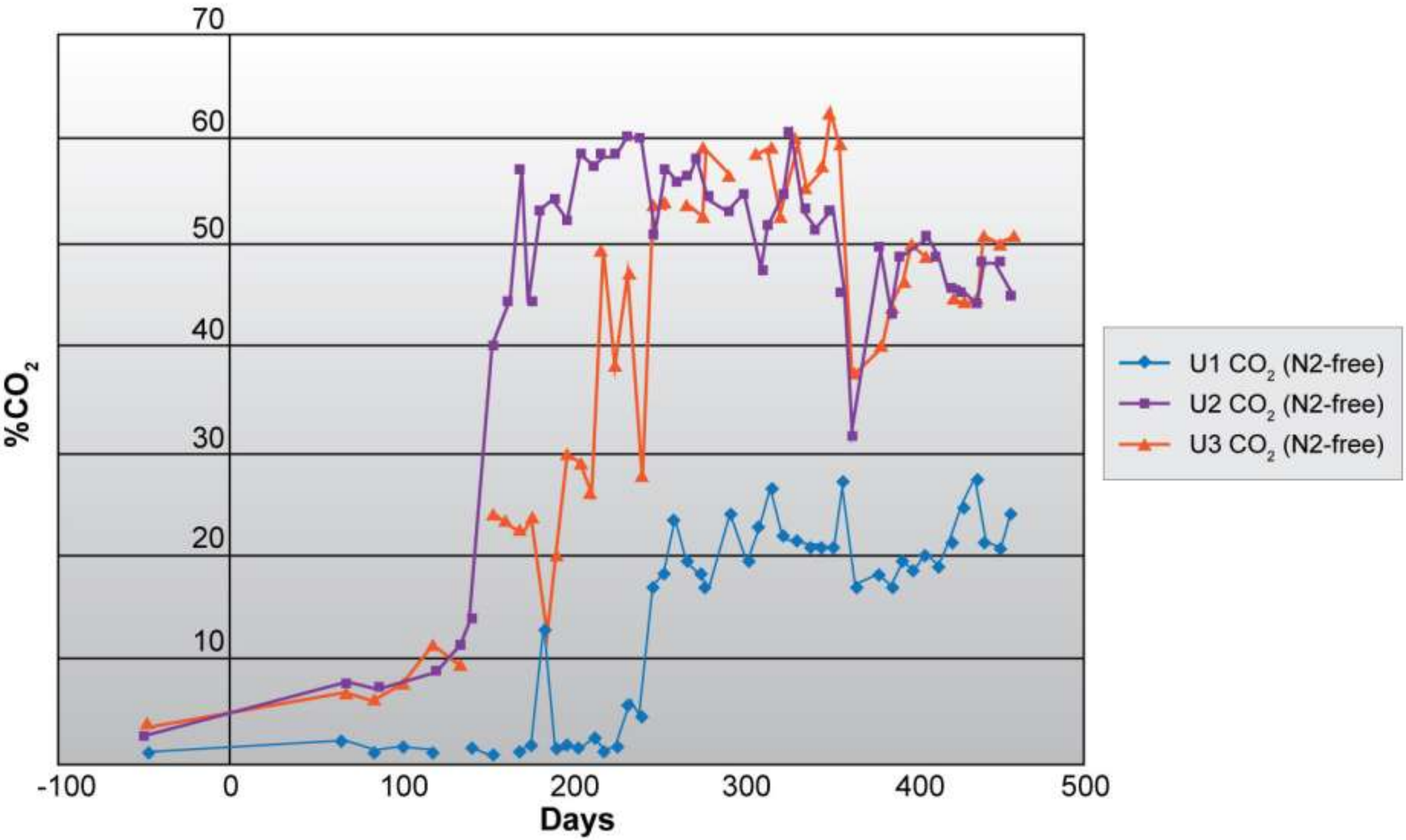
Injection phase – predictions matched results



Depth
~2000m

Naylor CO_2 sampling data confirms reservoir model



CO2CRC

Learnings from Otway 1

- Injecting CO_2 into depleted gas reservoirs is a viable, safe and permanent storage option
- CO_2 movement can be accurately predicted and monitored
- Well defined NG- CO_2 interface with little mixing
- Post-production, injected CO_2 replaces 60% of the space originally occupied by methane

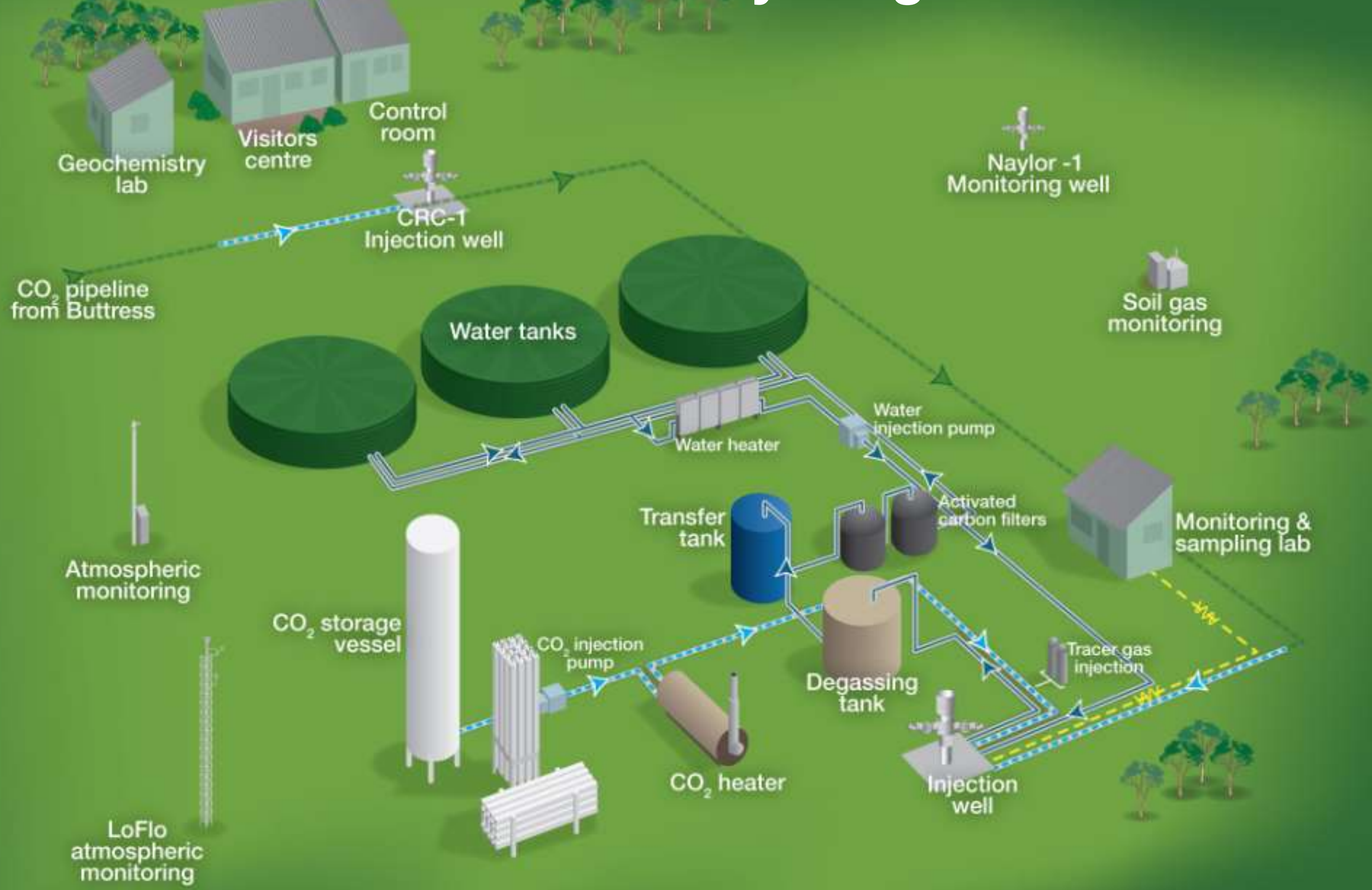
What CO2CRC Stage 1 achieved

- Demonstrated safe and effective storage of CO_2 in a depleted gas field with no leaks
- Confidence that would detect CO_2 migration into the overlying formation and a significant leak into the atmosphere or soil
- Reservoir models gave good predictions of “break through” of CO_2
- Able to sample ‘in situ’ formation waters from 2 km depth.
- Insights into the potential for CO_2 enhanced gas recovery
- Community supportive and interested
- Regulators are happy
- Set the scene for Stage 2

The CO2CRC Otway Project - Stage 2

Cooperative Research Centre
for Greenhouse Gas
Technologies (CO2CRC)

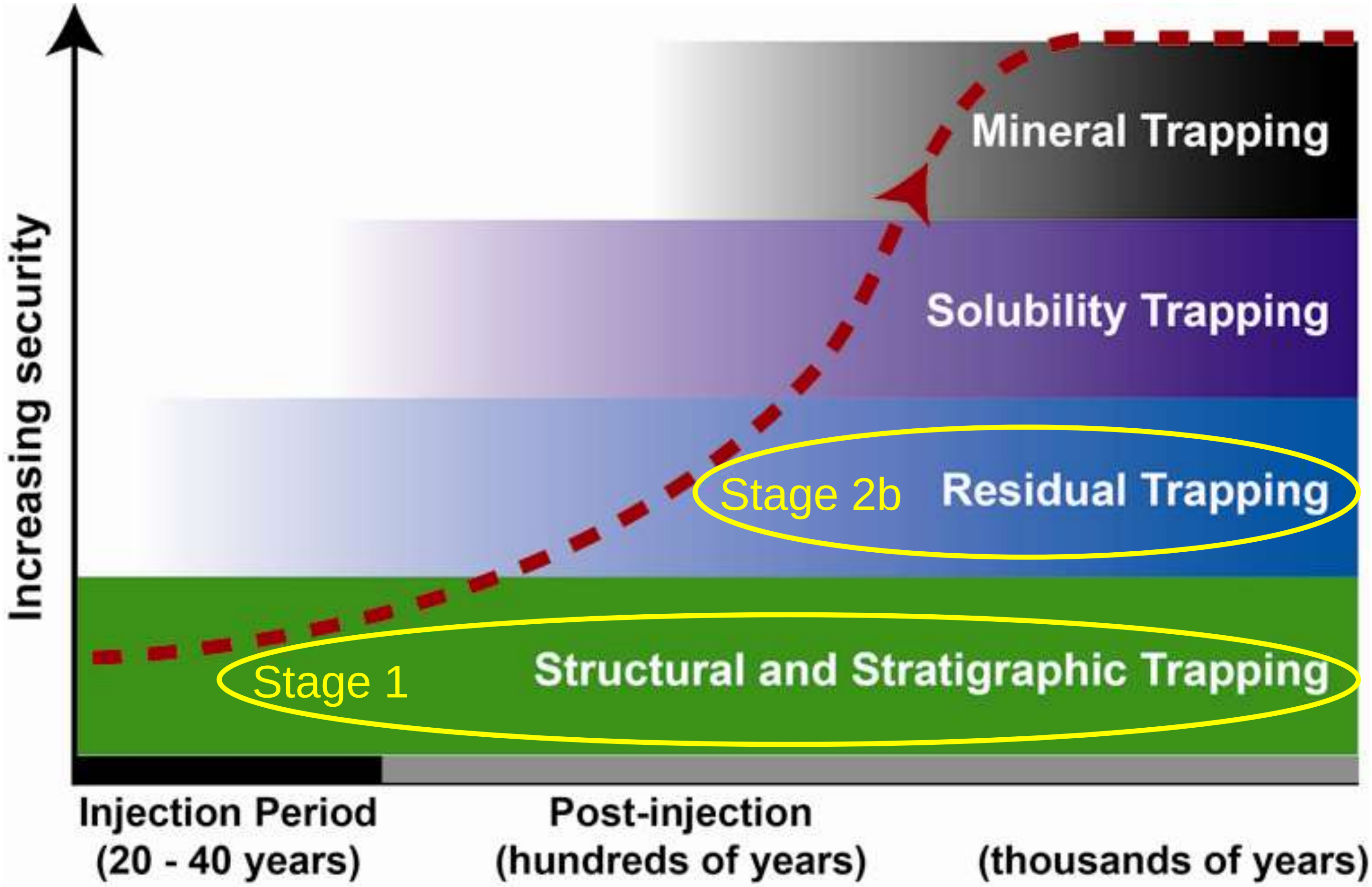
CO2CRC Otway Stage 2



Stage 2

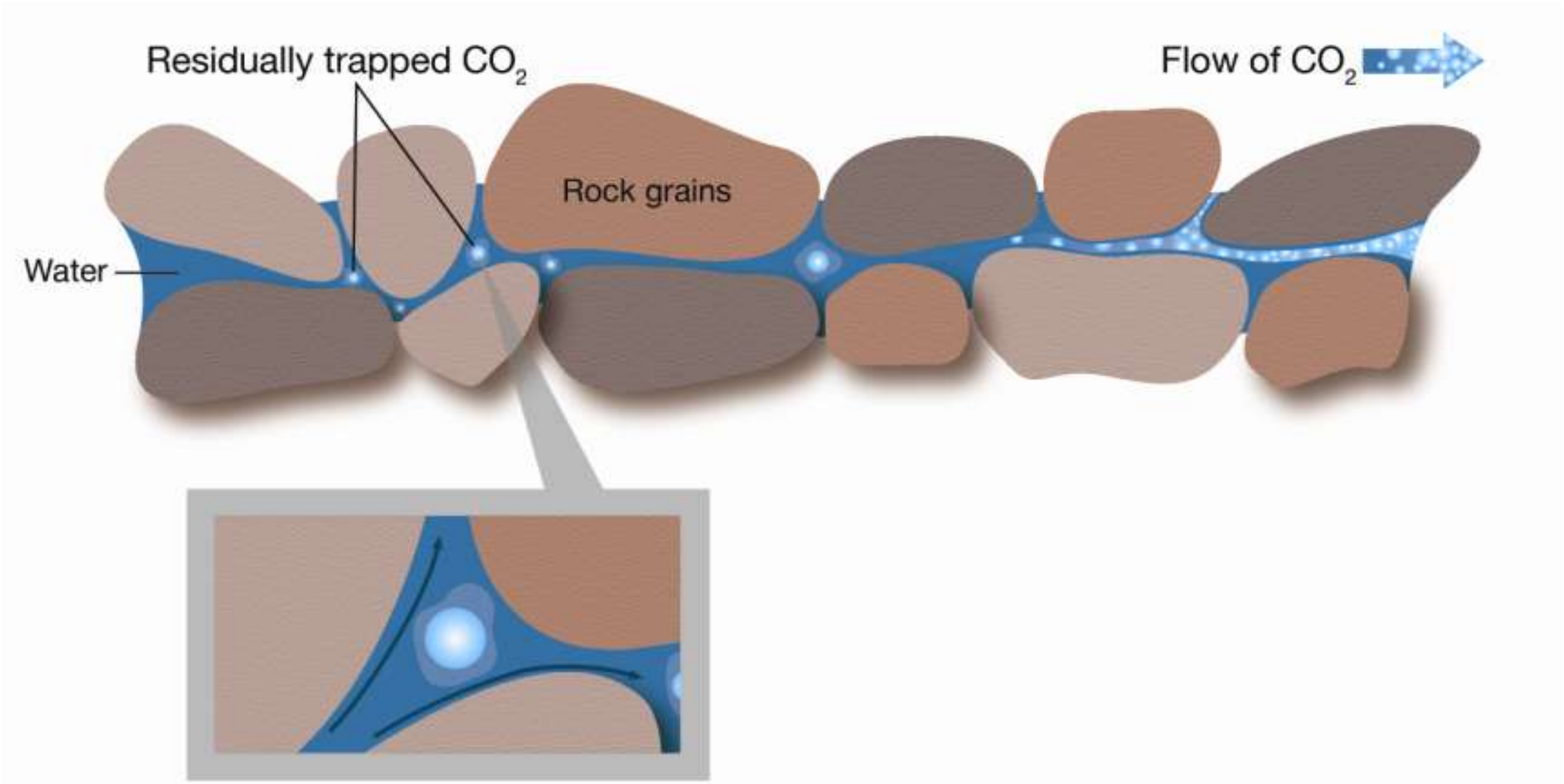
Project Stage	Scope	Objective
2A	Drill CRC-2	Appraise Paaratte formation for suitability as injection target. Detailed site characterisation with support from experimental data with laboratory determination of relative perm. and geophysical properties from cores.
2B	Residual Saturation tests	Investigating residual saturation processes using the Huff-n-Puff (inject/soak/back-produce) CO_2 injection testing method.
2C	Larger volume injection	Demonstrate that larger scale injection in an unconfined aquifer is safe and can be monitored reliably.

Trapping Mechanisms



Trapping in a saline formation

Residual trapping is where small amounts of CO_2 are disconnected from each other, trapped in the pore space.



Volumetric equation for capacity calculation

$$G_{CO_2} = A\, h_g\, \phi\, \rho\, E$$

G_{CO_2} = Volumetric storage capacity

A = Area (Basin, Region, Site) being assessed

h_g = Gross thickness of target saline formation defined by A

ϕ = Avg. porosity over thickness h_g in area A

ρ = Density of CO_2 at Pressure & Temperature of target saline formation

E = Storage "efficiency factor" (fraction of total pore volume filled by CO_2)

NETL DOE, 2006

Stage 2b – Residual Saturation Tests

- **Objective: Determine the residual CO2 saturation, Sgr**
- **Five (5) independent measurement approaches to determining residual trapping:**
  - Thermal test
  - Tracer test
  - History matching injection and production
  - Saturation logging using wireline Saturation Tool
  - Dissolution Test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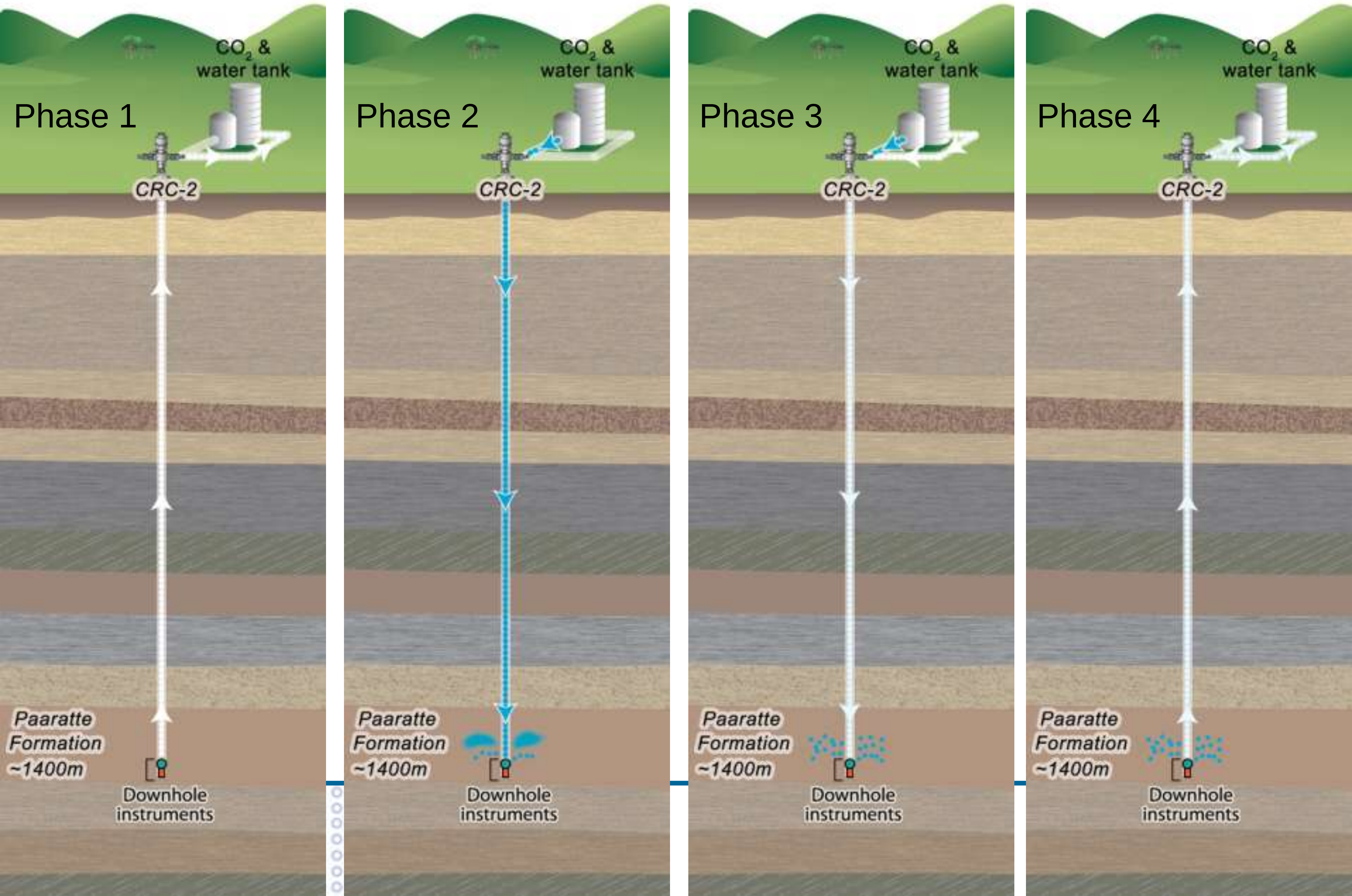
Four phases in the residual gas experiment



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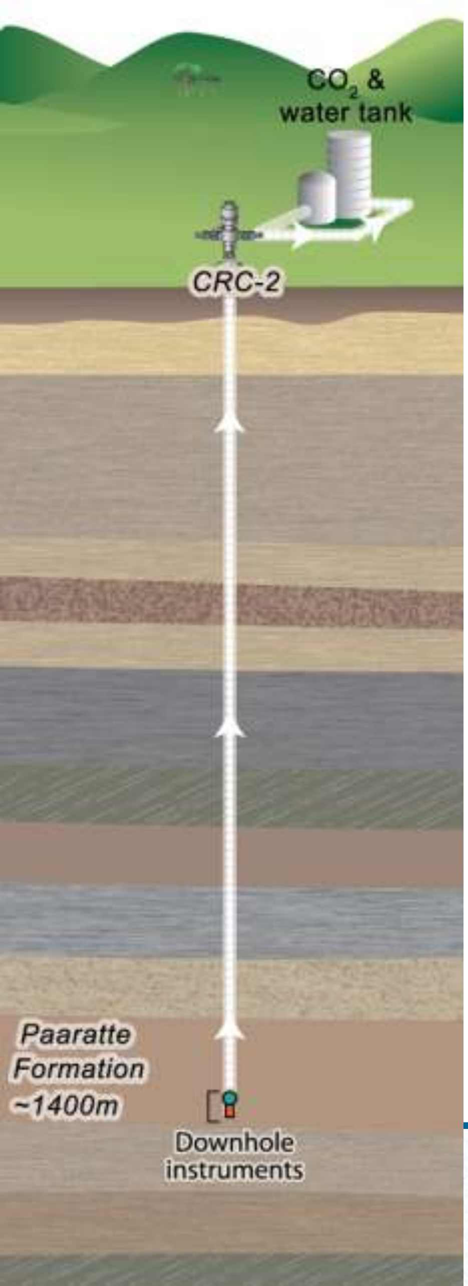
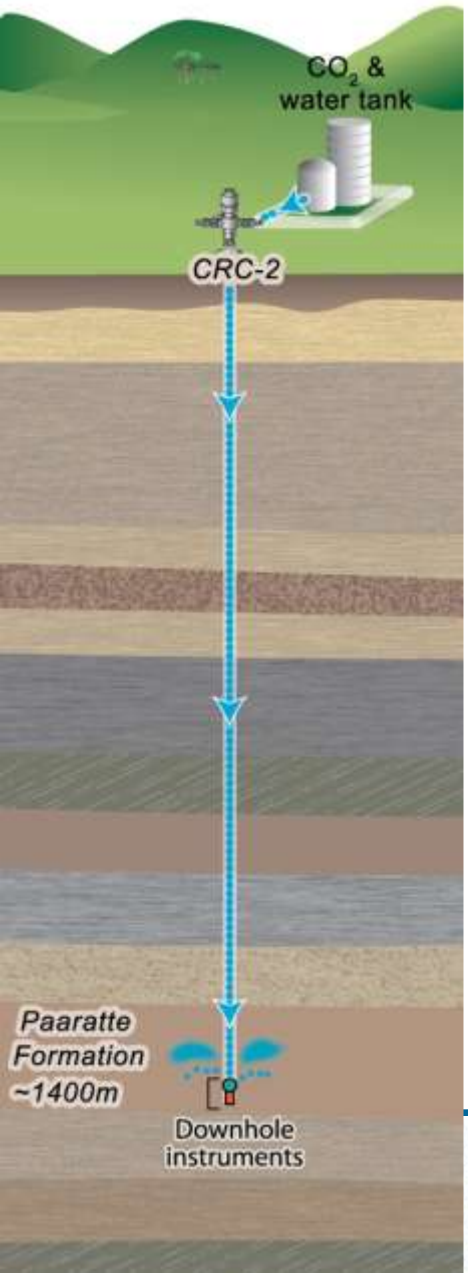


Phase 1

- **Water is extracted from the Paaratte Formation and stored in surface tanks**
- **Downhole instruments gather information on the formation**
- **Small quantities of tracer gases are injected in order to track how the CO_2 moves through the rock**

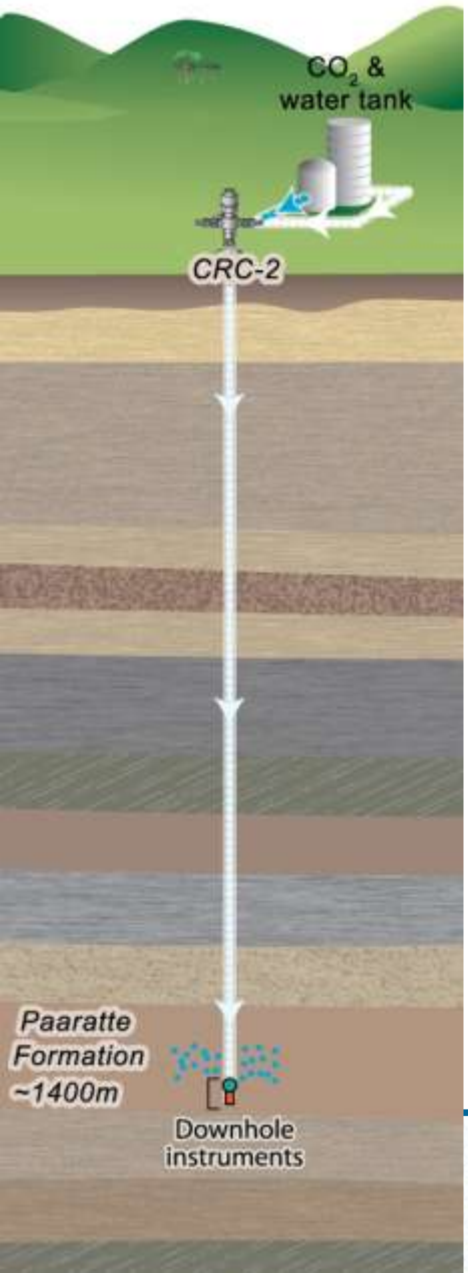
Four phases in the residual gas experiment



Phase 2

- **A relatively small amount of CO_2 (150 tonnes) is injected into the formation**
- **Some of this will dissolve, some will remain as free-phase CO_2 and some will be residually trapped**

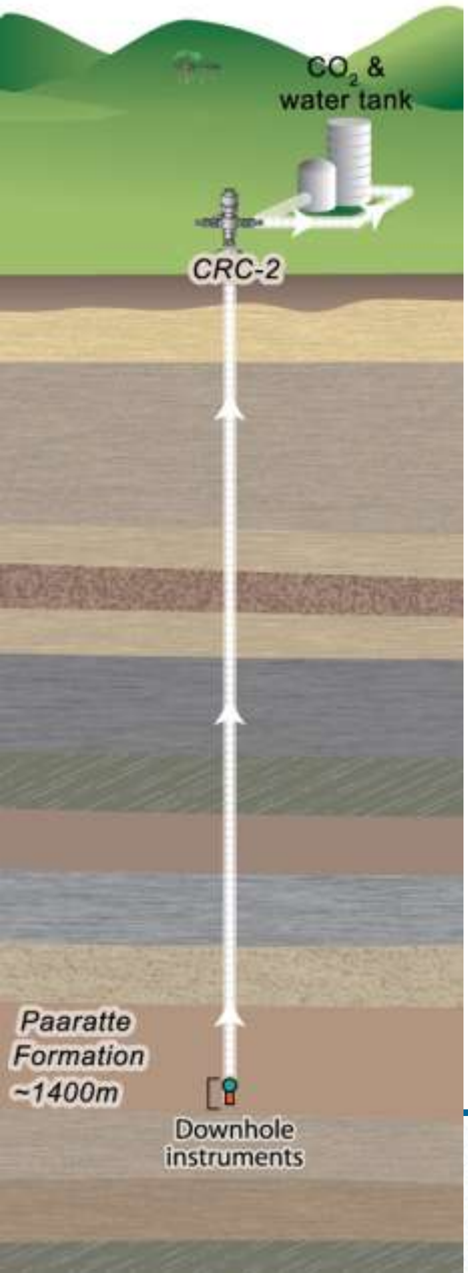
Four phases in the residual gas experiment



Phase 3

- **After a few days, the formation water is re-injected into the well**
- **On the way down, this water is mixed with CO_2, which dissolves in the water before it is injected into the formation**
- **This injection of formation water saturated with CO_2 will break up the CO_2 plume within the rock pores, increasing the amount of CO_2 that is residually trapped**

Four phases in the residual gas experiment



Phase 4

- **Water is extracted from the Paaratte Formation- this should remove any remaining mobile CO_2**
- **Downhole instruments gather information on the amount of CO_2 residually trapped.**
- **Other tests to determine the amount of CO_2 residually trapped include tracer concentrations and sampling of the formation fluid via the U-tubes**

Stage 2

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2C	Larger volume injection	Demonstrate that larger scale injection in an unconfined aquifer is safe and can be monitored reliably.

Tentative conclusions from Stage 2

- Subsurface behavior of the injected CO_2 can be very effectively modeled and monitored
- Huff and Puff provides new insights into CO_2 behavior
- Storage volumes can be verified
- Storage efficiency can be determined
- Can build public support for CCS as a mitigation mechanism

CO2CRC

What have we learned from CO2CRC Otway?

- Essential to take the regulator along with you, as the project is developed and implemented, particularly in the absence of clear regulations
- CCS R&D or pilot projects should not be regulated under the same regime as a commercial-scale project – potentially too onerous and too expensive
- Getting the right arrangements in place for handling liability is crucial to the development of the appropriate company structure – and vis versa
- Assume it will cost you more than the estimates suggest – we worked with a 20% contingency and used all of that
- You are unlikely to achieve the Sleipner “gold standard” of seismic imaging onshore and we have to be realistic about using onshore 3D seismic
- Onshore 3D seismic surveys are disruptive to landowners and we will need effective fixed seismic arrays for onshore monitoring
- Tracers are very valuable in a research environment but are not appropriate for ongoing use in large scale CCS projects because of the problems of contamination
- Effective relations can be built up with the local community, but start very early, be completely open – and still expect at least one difficult person!

The success of the CO2CRC Otway Project has been dependant on the work of many talented people and the support of a large number of organizations.

My thanks to all of them!