Case Study:

The Gorgon CO_2 Injection Project

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Gorgon CO_2 Injection Project

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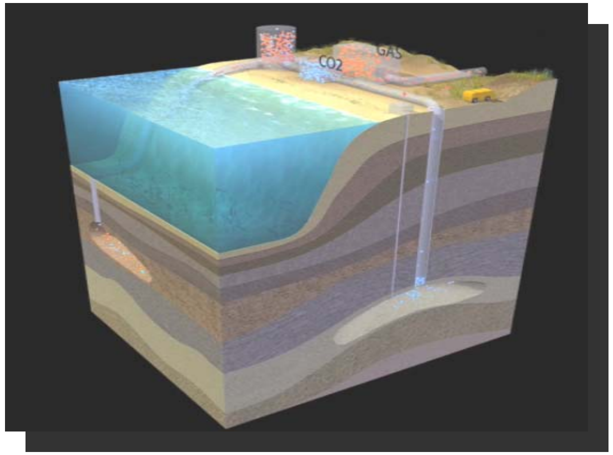
Chubu Electric, Osaka Gas and Tokyo Gas

Key Messages

- The Gorgon Project Joint Venture Partners have agreed to construct the world's largest subsurface CO_2 disposal facility on Barrow Island, off Australia's northwest coast
- Subsurface disposal of CO_2 requires many of the same technologies and skills as other major petroleum developments:
  - Data acquisition and subsurface evaluation using multidisciplinary subsurface teams
  - Coordinated approach to field development planning and uncertainty management
  - Integrated reservoir surveillance planning to monitor subsurface CO_2 behaviour following injection
- The CO_2 Injection Project was therefore treated with the same attitude and approach as for the gas field development plans
- The technical feasibility of CO_2 disposal beneath Barrow Island has undergone several phases of Joint Venture and State Government sponsored peer review



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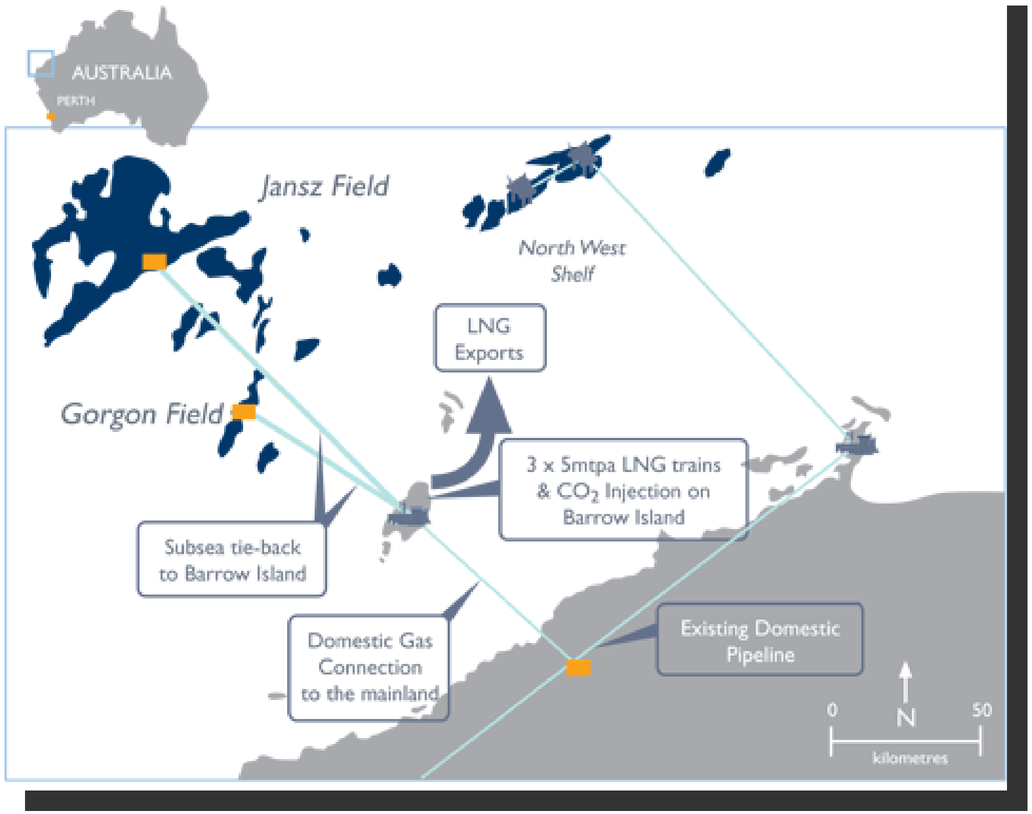
Gorgon Project Development Concept

- Gas produced from subsea wells in Gorgon & Jansz fields (>2 Bcf/day gross)
- LNG (15 MTPA) + Domestic Gas (300 TJ/d) processed & exported from Barrow Island
- Gorgon gas ~14% CO_2
- Jansz gas <1% CO_2
- CO_2 separated and injected into Dupuy formation below Barrow Island (1.6-2.4 Tcf total CO_2)
- Project now under construction
- First gas production 2014
- Additional discovered fields under evaluation for future tieback



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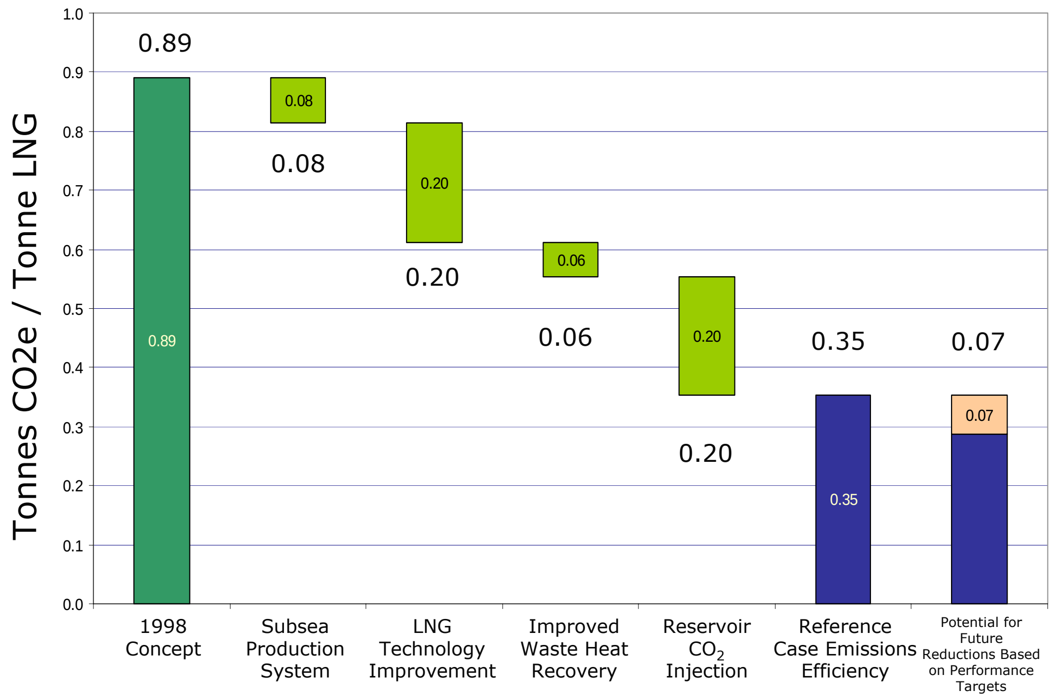
Reservoir CO_2 Injection Project

- The first major project in Australia to significantly reduce project emissions by the underground injection of carbon dioxide
- Project emissions expected to be reduced by approximately 40% (~3.4-4 MTPA CO_2equivalent)
- About A$2 billion will be invested in the design and construction of the CO_2 project
- Costs per tonne remain less expensive than alternate abatement options
- Number of world firsts
  - First geosequestration legislation
  - First CO_2 injection project to undergo detailed environmental impact assessment (including public review and comment)
  - Largest subsurface CO_2 disposal project in the world



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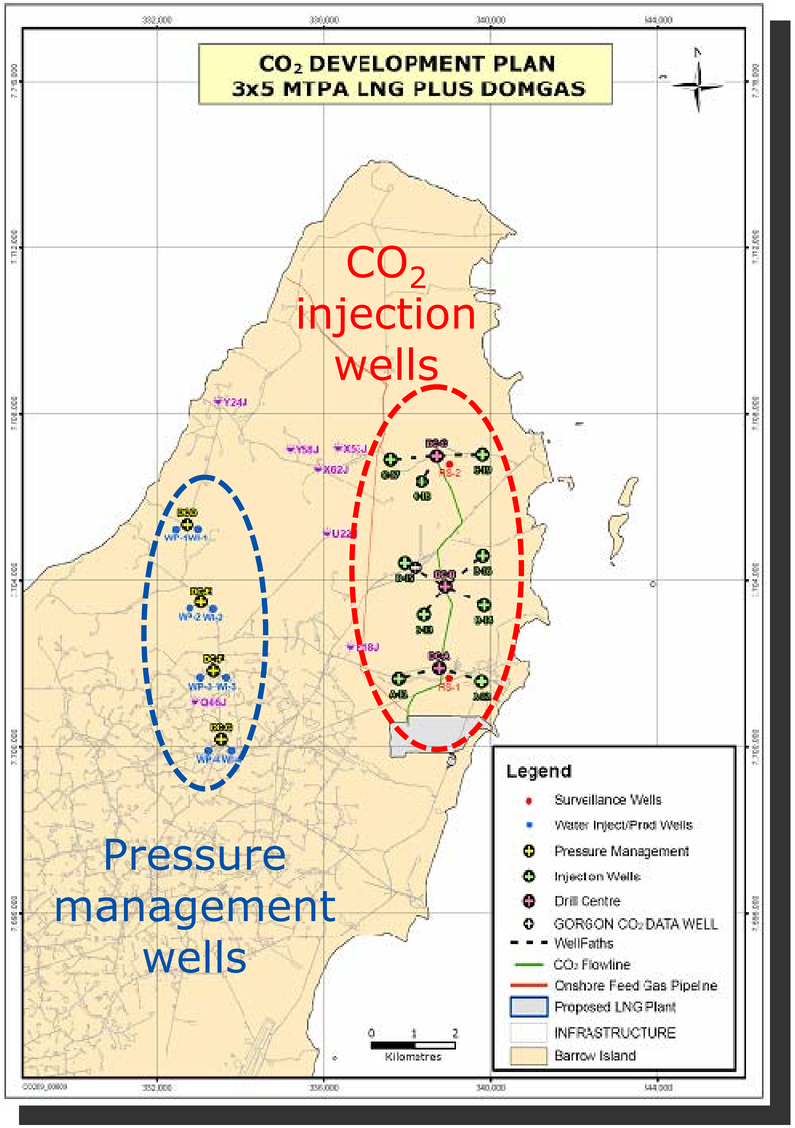
Site screening and selection

- Four criteria considered:
  - <u>Containment risk</u> – e.g. security of top seal, distance to faults, number / condition of existing well penetrations
  - <u>Storage capacity</u> – e.g. gross rock volume, regional structure capacity, reservoir architecture, connected aquifer extent
  - <u>Injectivity</u> - e.g. permeability, thickness and extent of target reservoir sands
  - <u>Risk to other assets</u> – e.g. risk of fluid / pressure interference with other operating, discovered or undiscovered hydrocarbon fields
- 19 sites / concepts initially assessed in screening study:
  - Saline aquifers
  - Existing hydrocarbon fields
  - Enhanced Oil Recovery opportunities
- Five sites further assessed with screening-level simulation studies
- Barrow Island Dupuy Formation only site that adequately satisfied all criteria

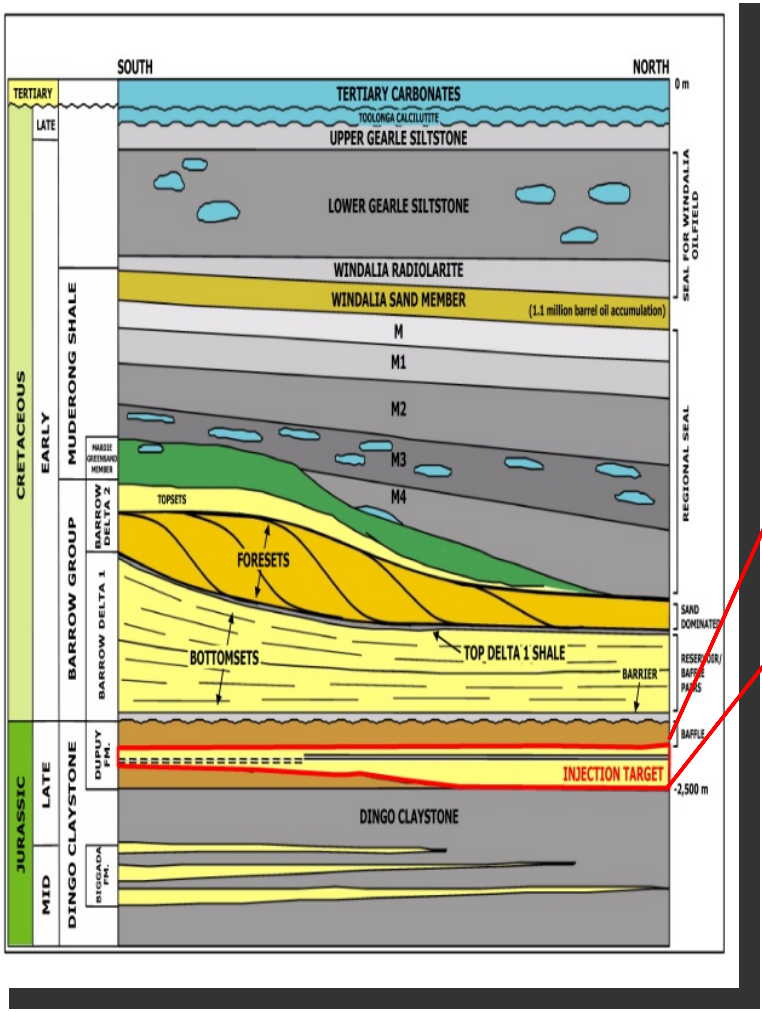
CO_2 Reference Case Development Plan

- Project sited on north-east of island
- Nine CO_2 injection wells (with space for nine more) from three drill centres
- Four water production wells + water injection wells
- Peak stream day CO_2 rate: 220 MMscf/d
- CO_2 volume: 1.6 – 2.4 Tcf (~ 80-130 million tonnes)
- Reservoir Surveillance:
  - Surveillance wells - two initially plus two in later field life
  - Repeat 4D seismic (if successful) + Vertical Seismic Profiles
  - Soil Gas surveys
- Abandonment of existing Dupuy wells in plume area; program for ensuring existing well penetrations in the plume area do not provide leakage pathways
- Commitment to make data from the ongoing monitoring available to the public



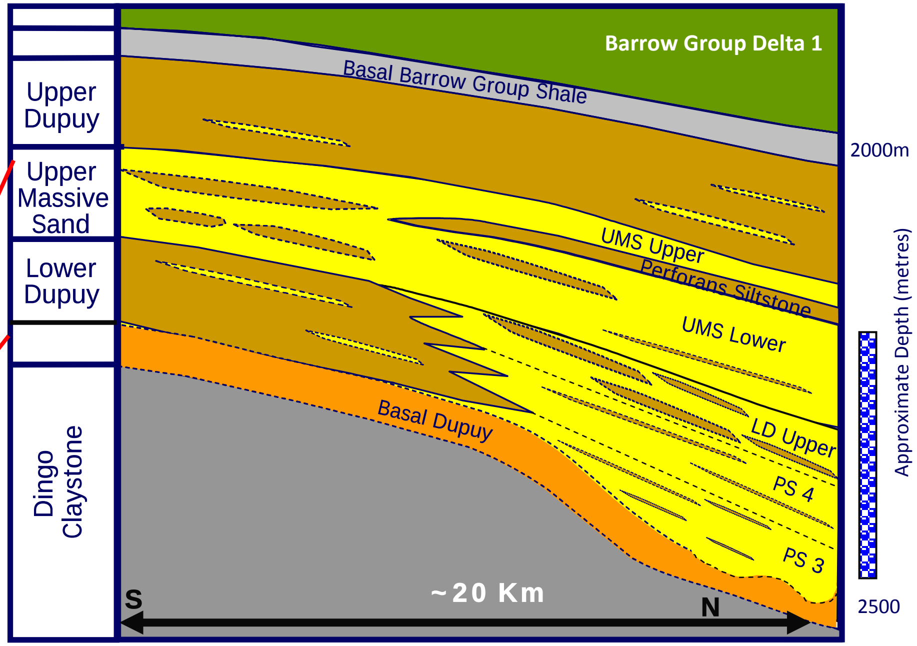
CO_2 Injection Interval – Barrow Island

Barrow Island Stratigraphy



- Site selection was vital – Dupuy has adequate permeability for injectivity but low enough for good residual gas trapping
- Adequate existing subsurface data
- Several seals between injection zone and surface

Dupuy Formation



Proposed injection interval

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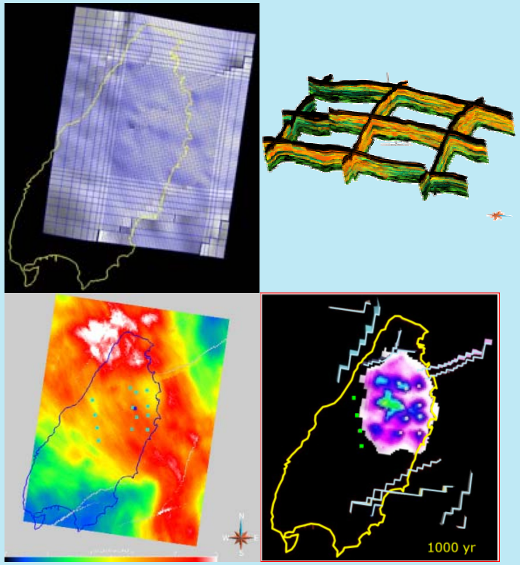
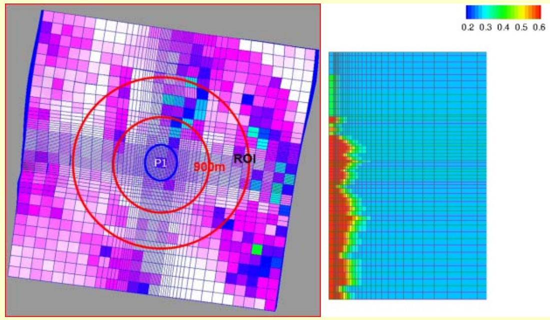
Reservoir Simulation – Testing Development Plan

- CO_2 plume migration influenced by pressure management wells, reservoir quality & distribution, buoyancy, rate of dissolution
- Effects incorporated into reservoir simulation models
- Wide range of subsurface uncertainties investigated using:
  - Full field models (testing overall development plan)
  - Sector models (investigating specific effects, e.g. near-wellbore)
- Development plan tested against two main criteria:
  - **INJECTIVITY** – i.e. scheme must handle <u>rate</u> of produced CO_2 from Gorgon
  - **CONTAINMENT** – i.e. scheme must retain total <u>volume</u> of CO_2 in the subsurface

Full field modeling



Sector modeling



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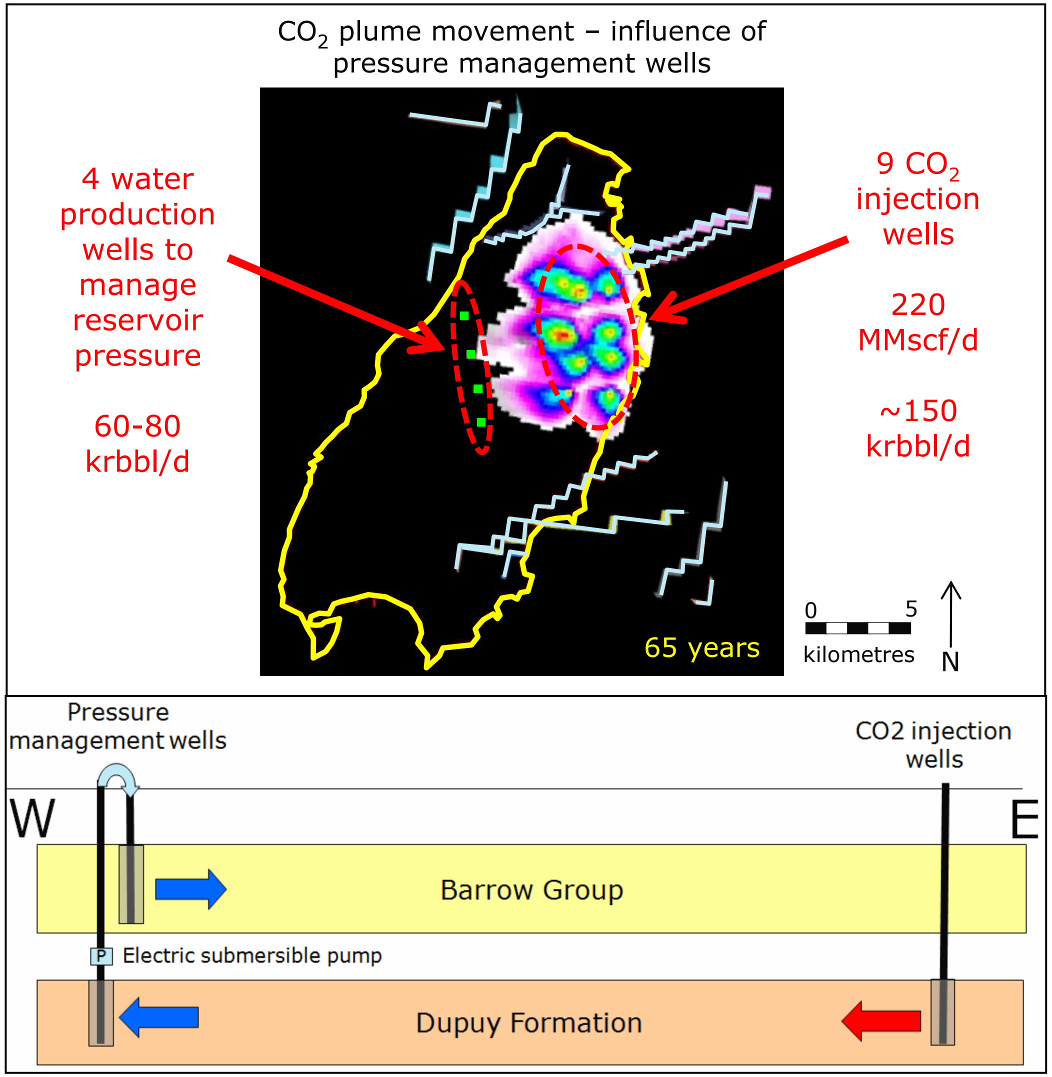
Pressure Management Concept

- Pressure management required to reduce impact of rising pressure on CO_2 injection performance:
  - Maintain injection rates
  - Avoid reaching bottom hole pressure limit
- 100% offtake balance not necessary – expect large connected aquifer to "absorb" much of the pressure increase
- Produced water injected into overlying Barrow Group (depleted)



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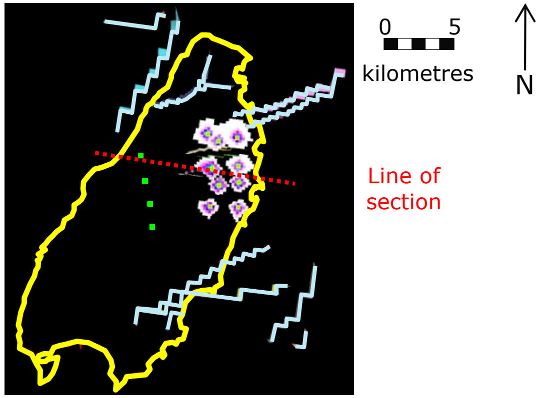
Growth of CO_2 plume over time

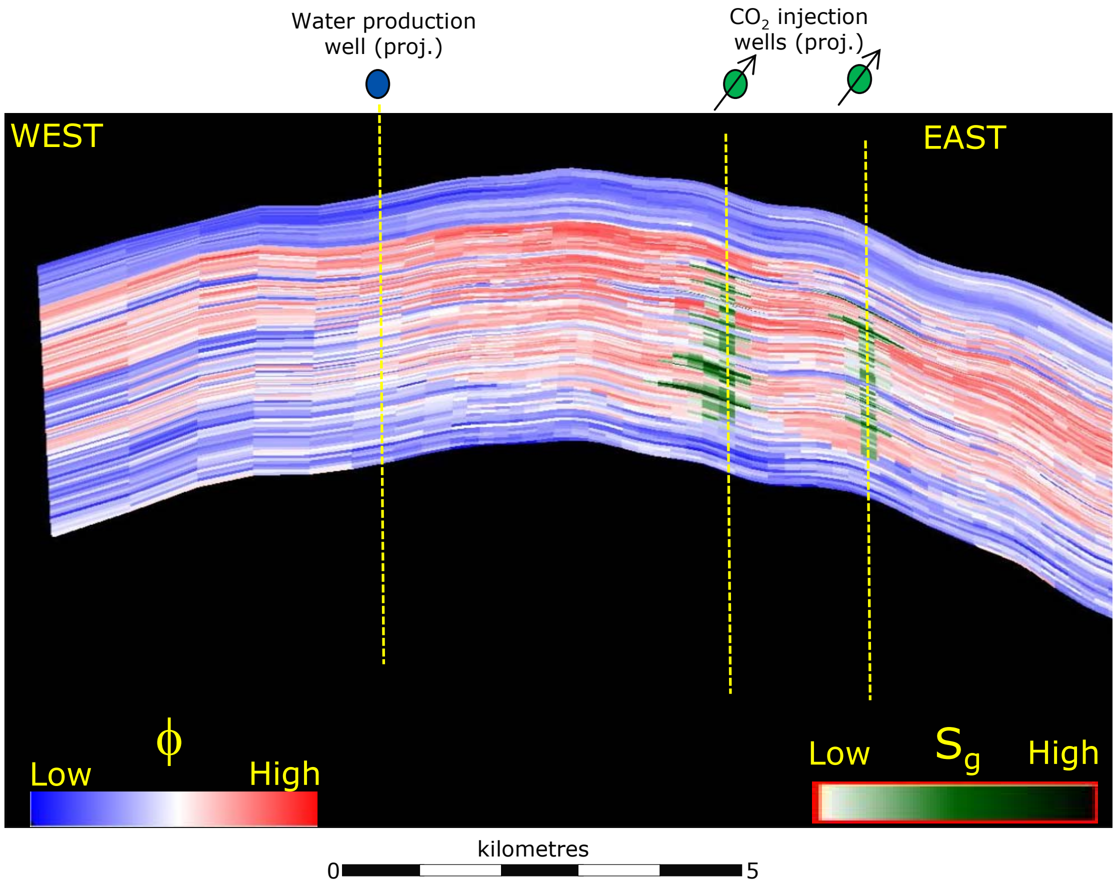
YEAR
0005

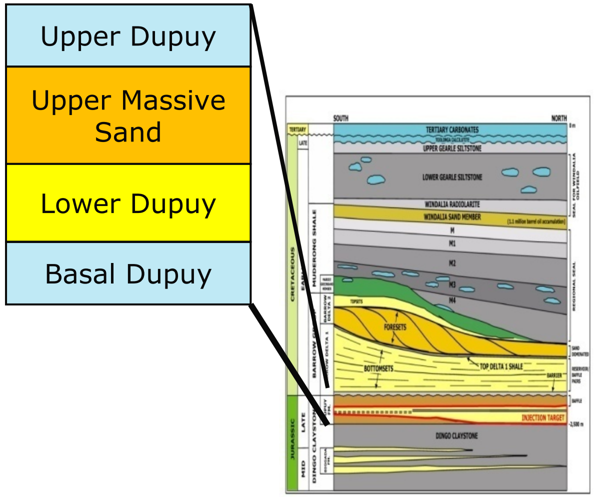
- Plume movement influenced by water offtake, reservoir depositional trends and structure
- Growth in plume area is rapid during injection, but limited following site closure
- CO_2 concentrated in centre, very diffuse at edges



Net CO_2 Thickness: $\Sigma\ S_g.\Phi.h$

0 7 14m





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Growth of CO_2 plume over time

YEAR
0010

- Plume movement influenced by water offtake, reservoir depositional trends and structure
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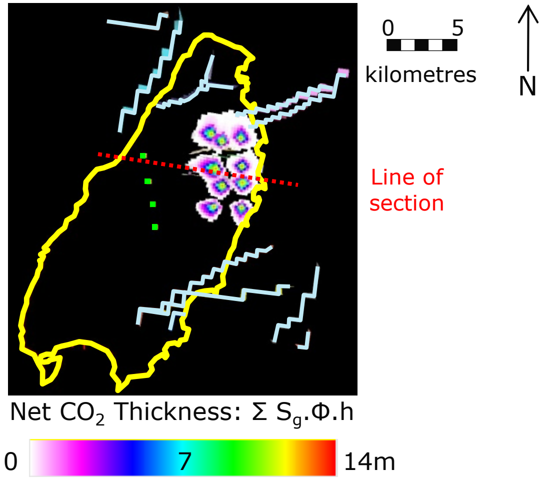

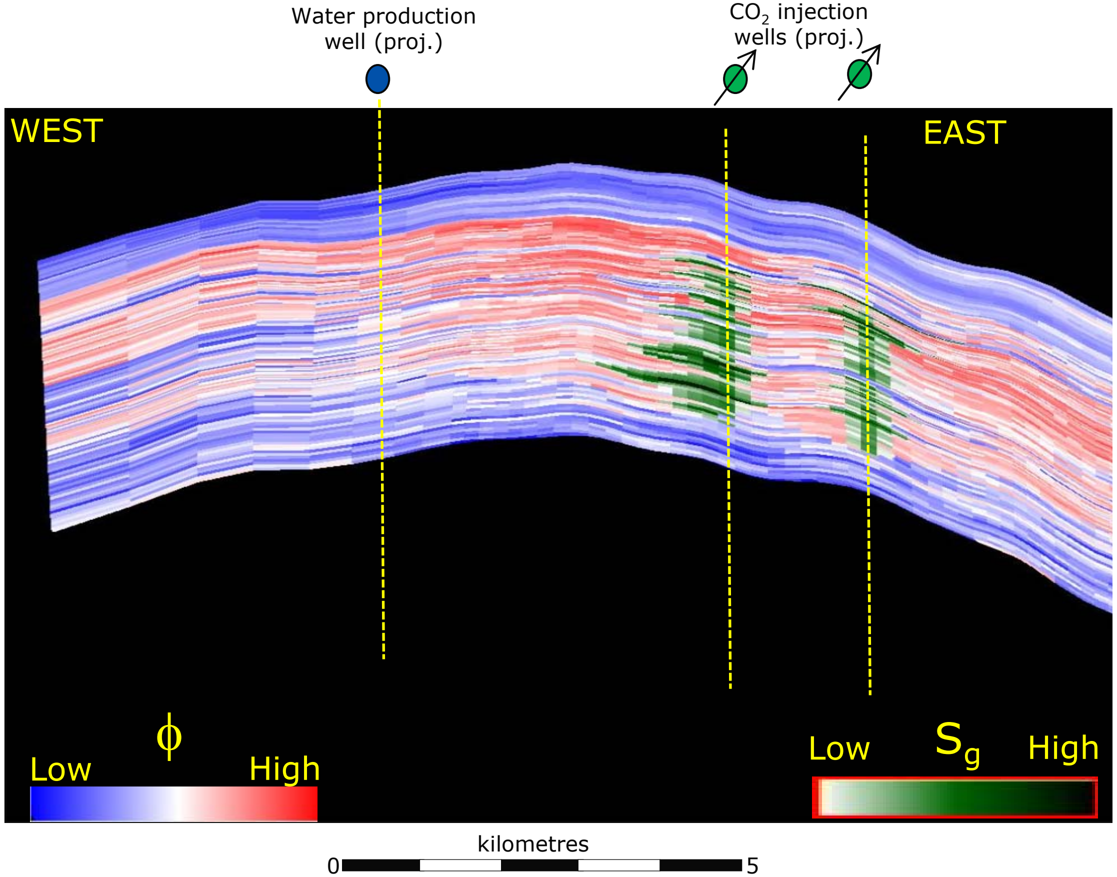

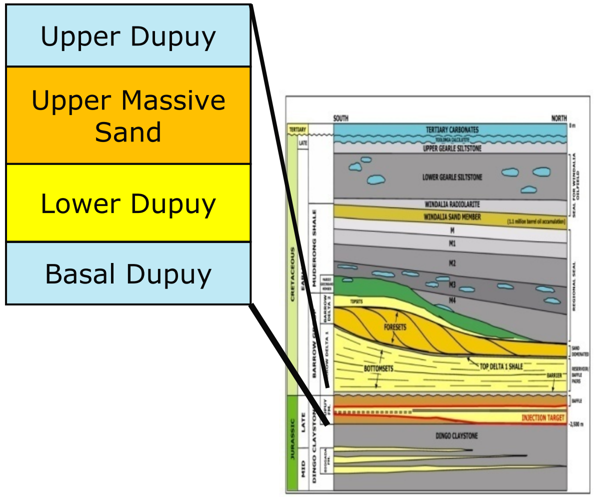

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Growth of CO_2 plume over time

YEAR
0020

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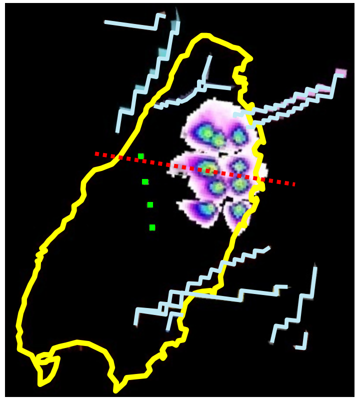
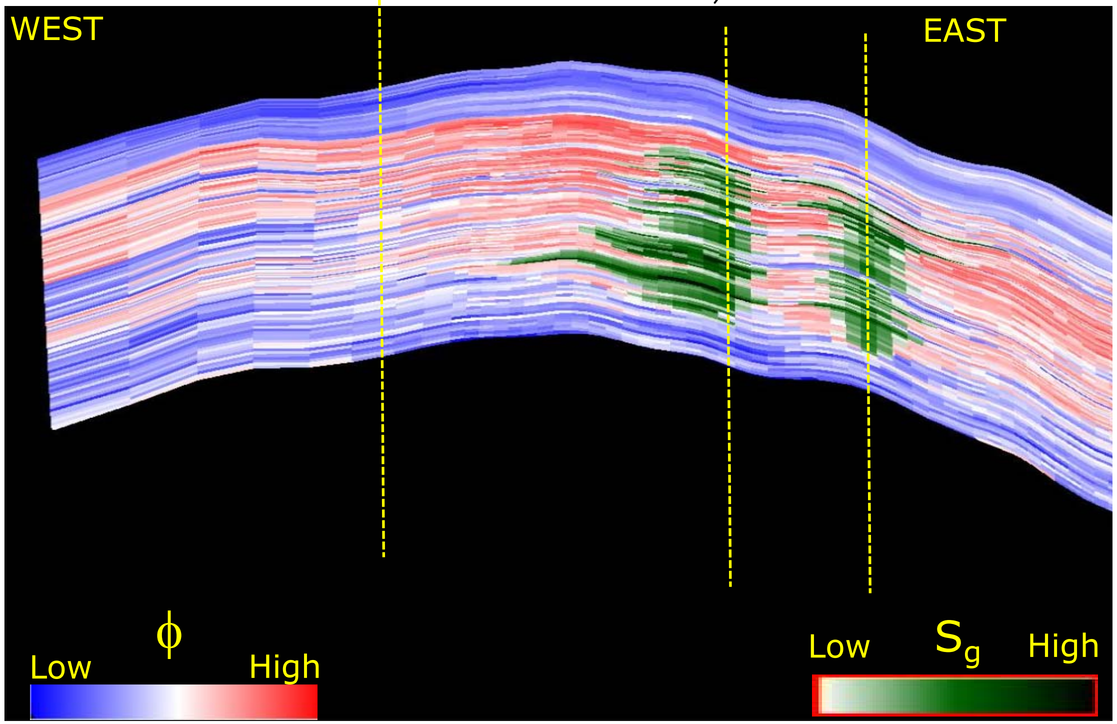


Net CO_2 Thickness: $\Sigma\ S_g.\Phi.h$

0 7 14m

Water production well (proj.)

CO_2 injection wells (proj.)



kilometres

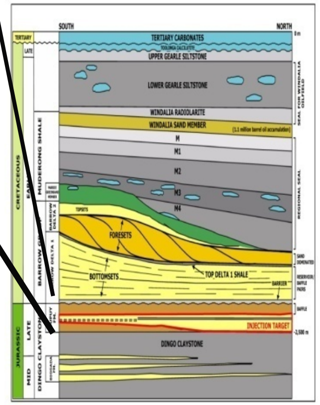
0 5

Upper Dupuy

Upper Massive Sand

Lower Dupuy

Basal Dupuy



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Growth of CO_2 plume over time

YEAR 0040

- Plume movement influenced by water offtake, reservoir depositional trends and structure
- Growth in plume area is rapid during injection, but limited following site closure
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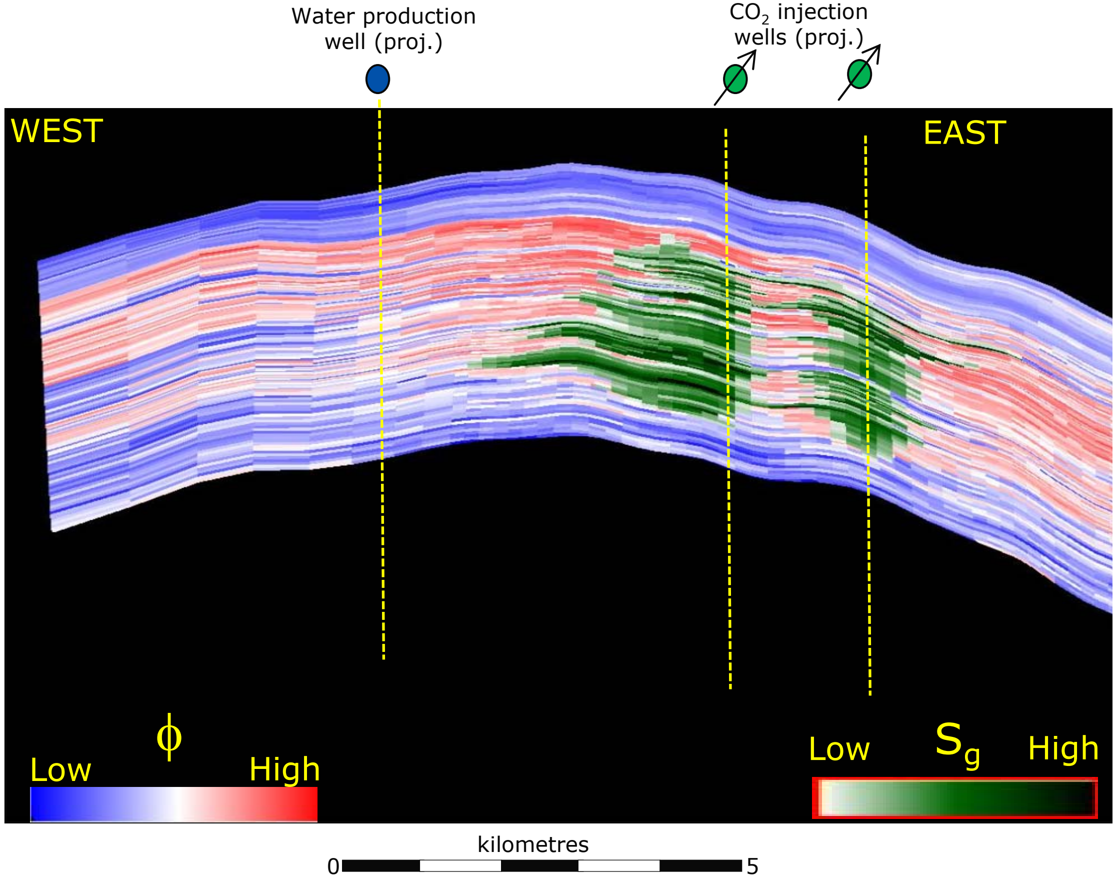
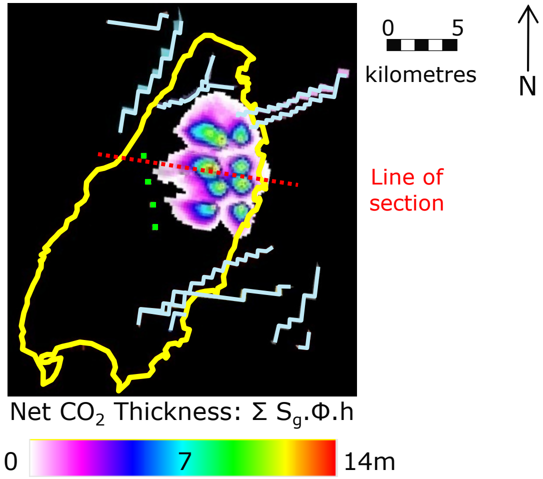
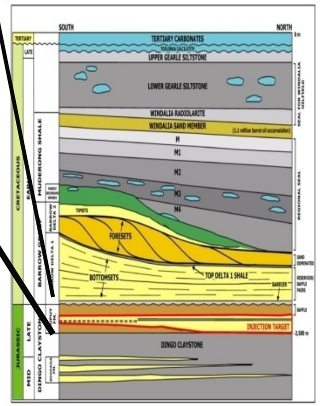




Upper Dupuy
Upper Massive Sand
Lower Dupuy
Basal Dupuy



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Growth of CO_2 plume over time

YEAR
0065

- Plume movement influenced by water offtake, reservoir depositional trends and structure
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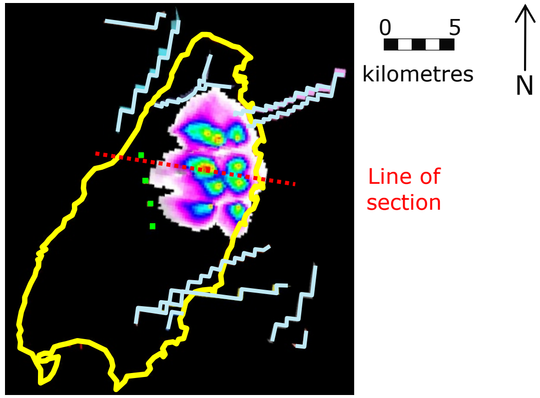
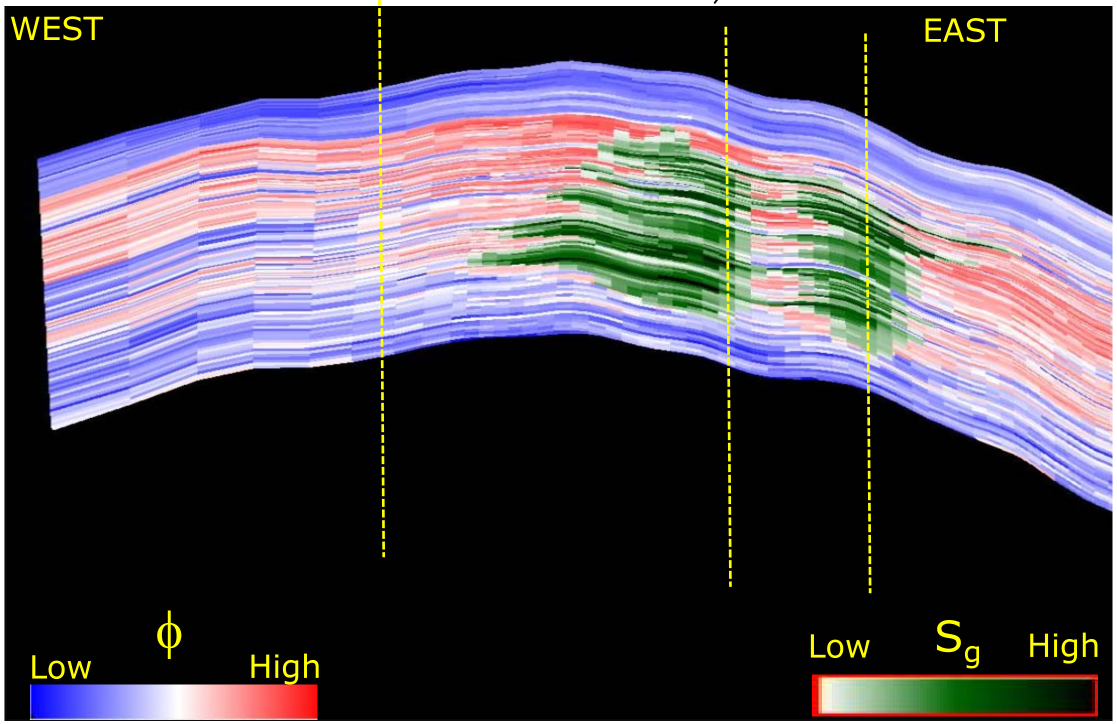


Net CO_2 Thickness: $\Sigma S_g.\Phi.h$

0 7 14m

Water production well (proj.)

CO_2 injection wells (proj.)



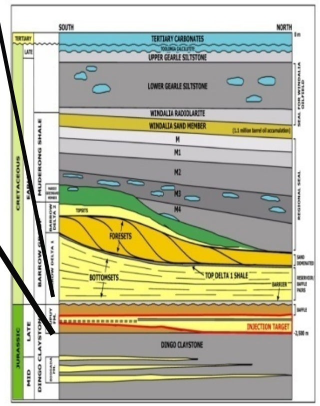
kilometres
0 5

Upper Dupuy

Upper Massive Sand

Lower Dupuy

Basal Dupuy



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Growth of CO_2 plume over time

YEAR
0100

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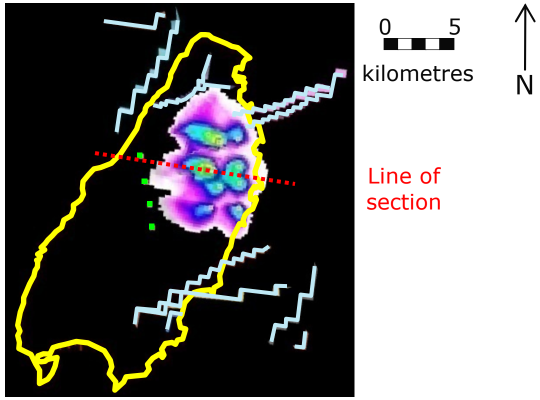

Net CO_2 Thickness: $\Sigma\ S_g.\Phi.h$

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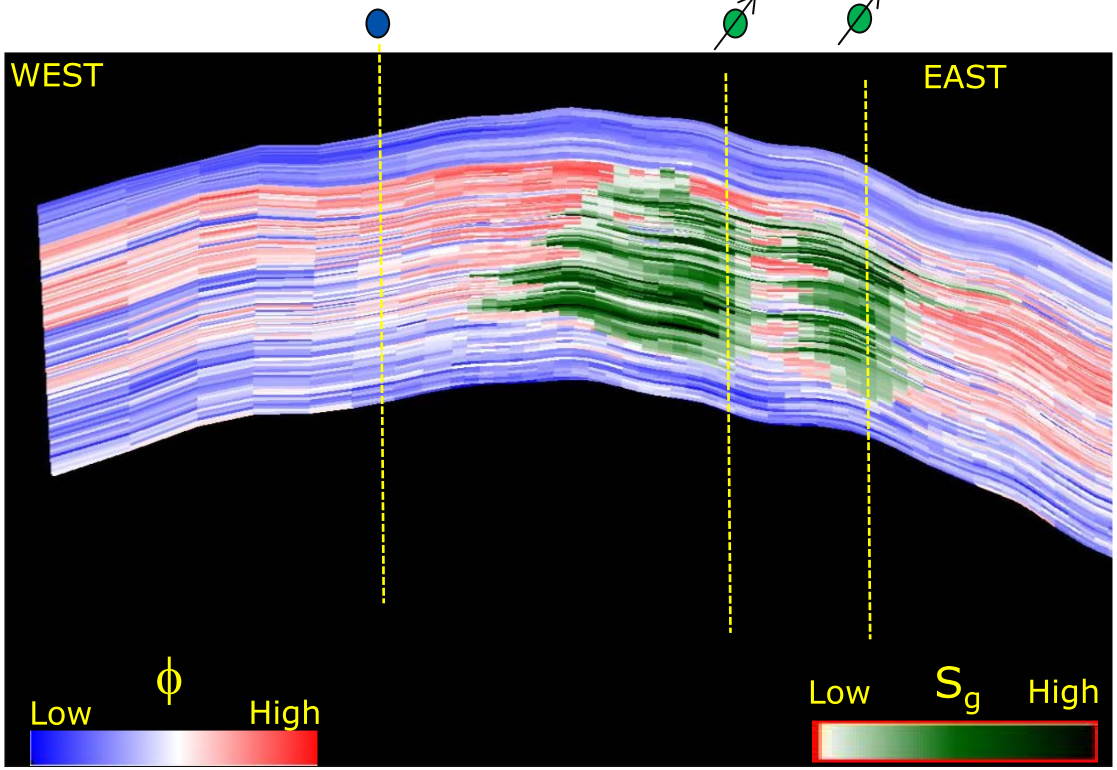
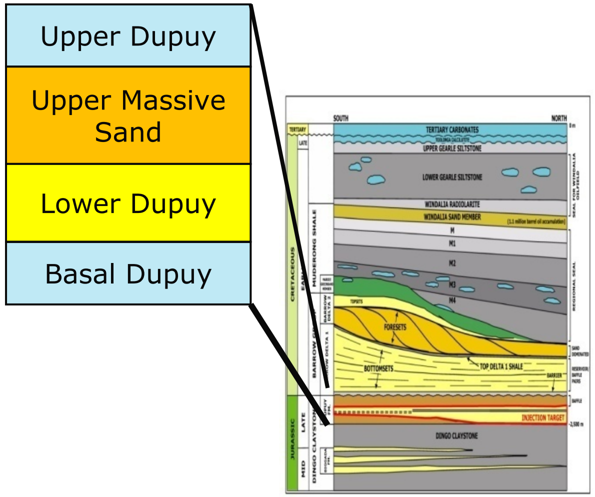
Water production well (proj.)

CO_2 injection wells (proj.)



kilometres
0 5



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Growth of CO_2 plume over time

YEAR 0500

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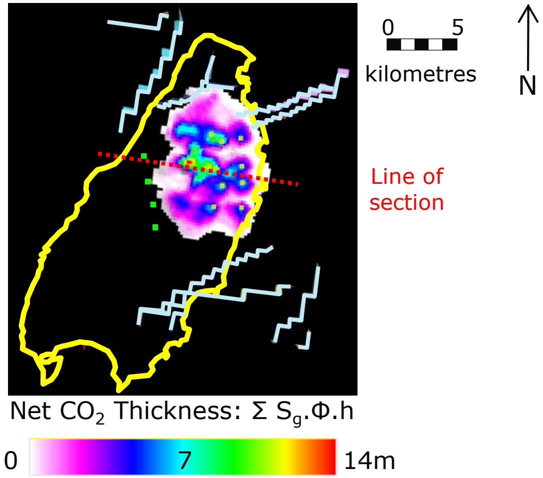

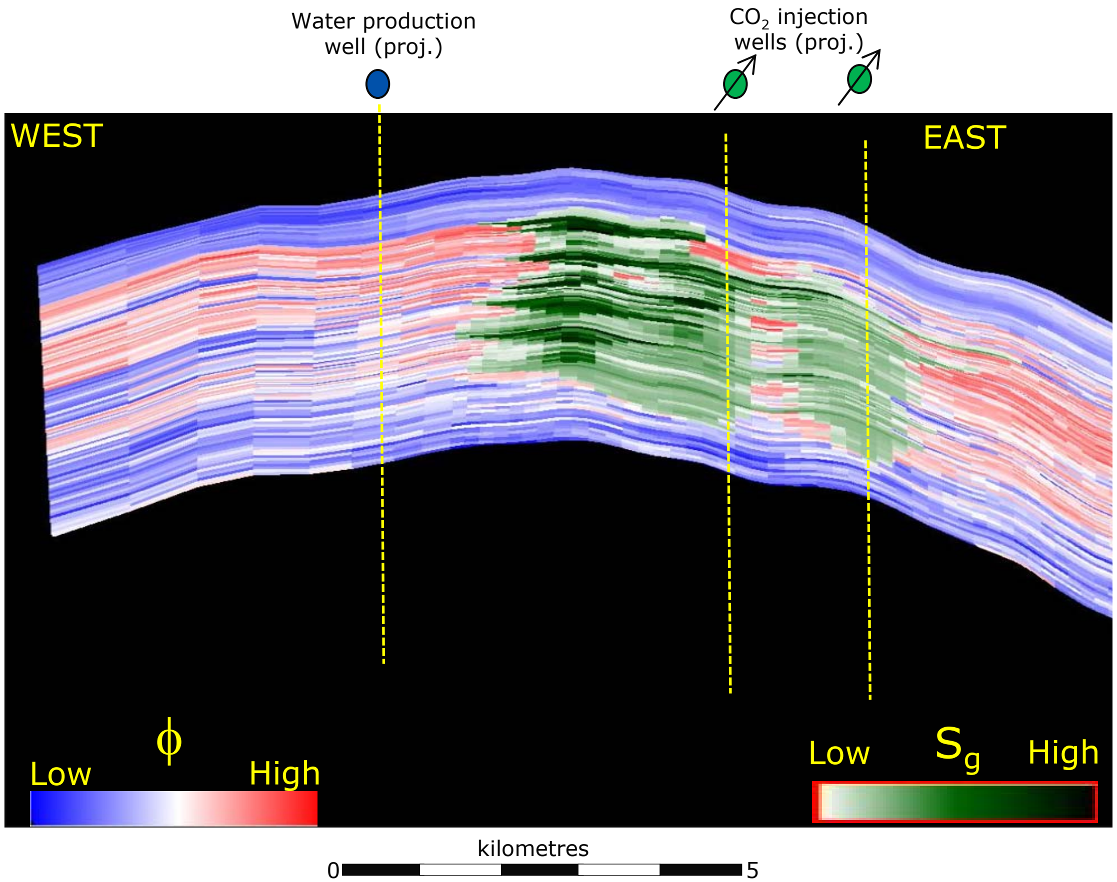

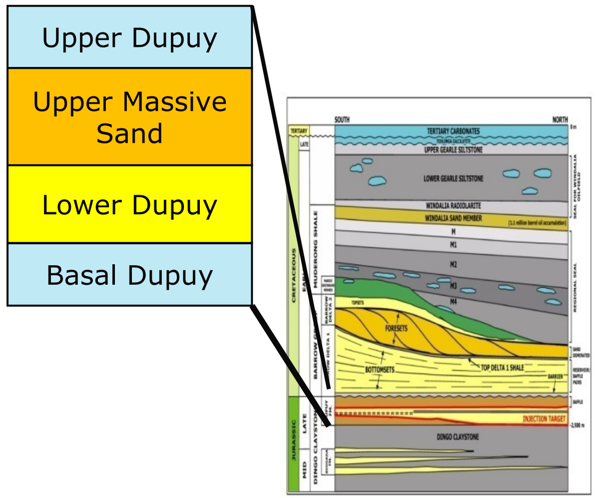

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Growth of CO_2 plume over time

YEAR 1000

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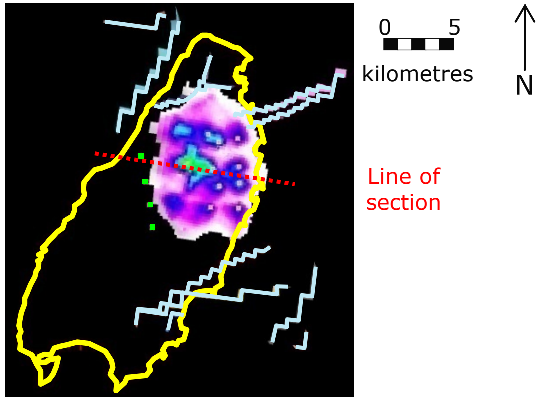
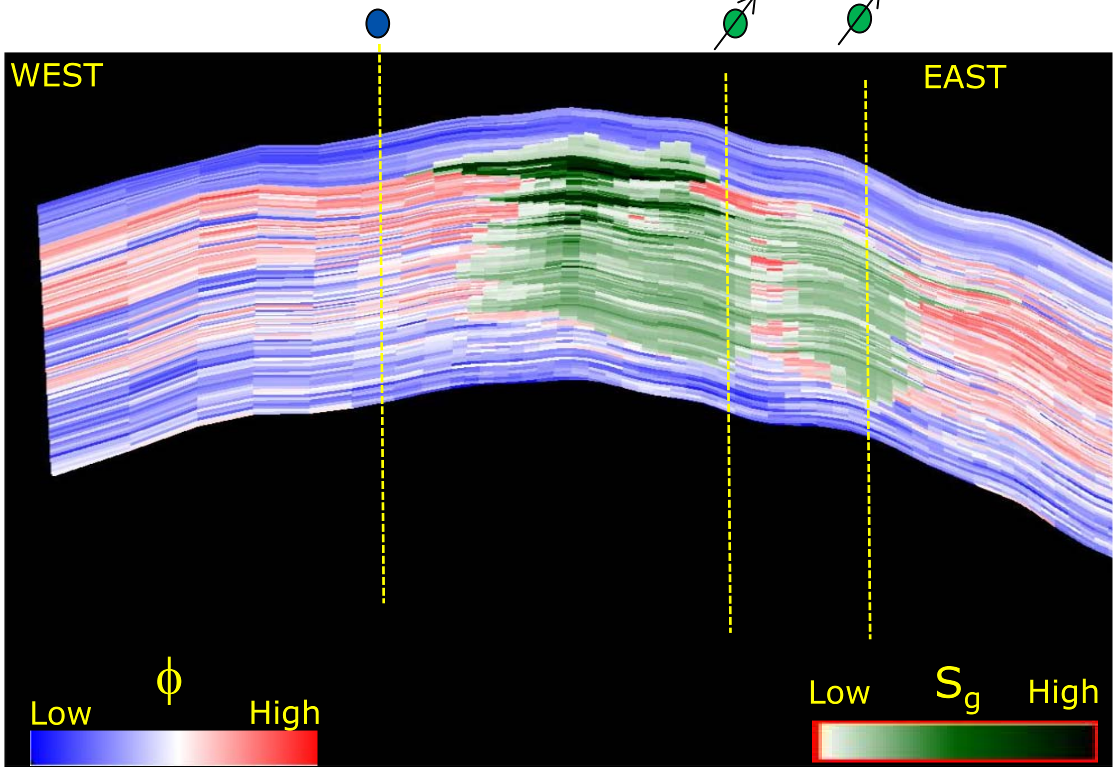


Net CO_2 Thickness: $\Sigma\ S_g.\Phi.h$

0 7 14m

Water production well (proj.)

CO_2 injection wells (proj.)



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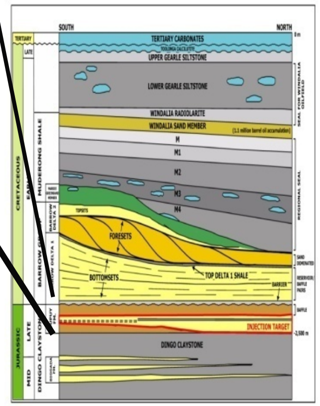

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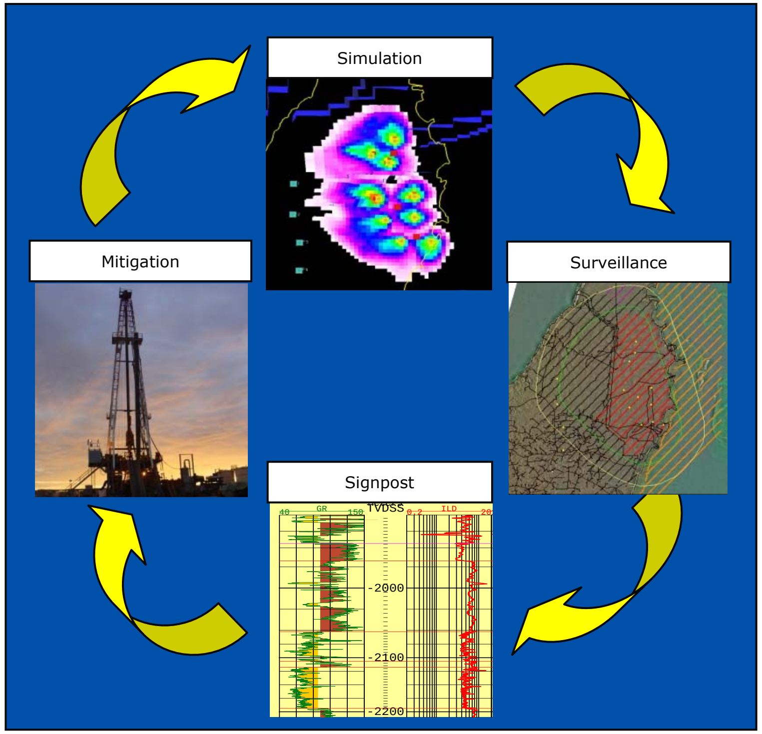
Managing Risk – Reservoir Surveillance Objectives

- Reservoir surveillance options have been selected to assist responsible reservoir management
- Reservoir surveillance focused on early identification of uncertainty “signposts” (as per Uncertainty Management Plan)
- When signposts are identified, then mitigation plans can be implemented to ensure the injected carbon dioxide continues to be properly managed
- Integration of reservoir surveillance and reservoir simulation data will assist the demonstration of site integrity



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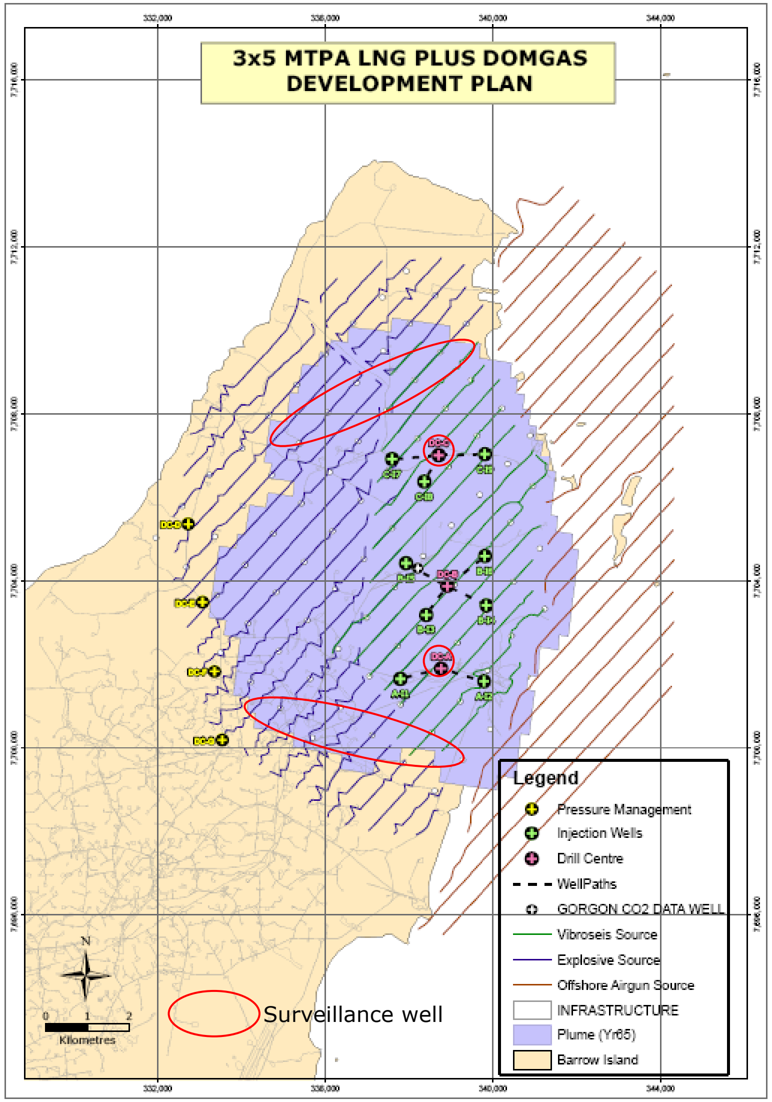
Integrated Monitoring Plan

- CO_2 Injection & Pressure Management Wells
  - Wellhead pressure and flow rate
  - Continuous down-hole pressure
  - PLT & casing/cement integrity logs
- Surveillance Wells – Vertical distribution and volumetric calculation
  - Continuous downhole pressure (Barrow Gp)
  - Saturation & casing/cement integrity logs
  - Vertical Seismic Profiling (VSP)
- 4D Surface Seismic – Lateral extent and broad vertical distribution
  - 3D baseline survey
  - Repeat 2D and 3D surveys determined by viability of seismic for monitoring plume position
- Soil Gas - Verification
  - Soil gas flux sampling over the 3D seismic source grid and at potential near-surface seepage points
- Surface – Safety & environment
  - Pressure sensors and CO_2 detection equipment within compression and pipeline facilities



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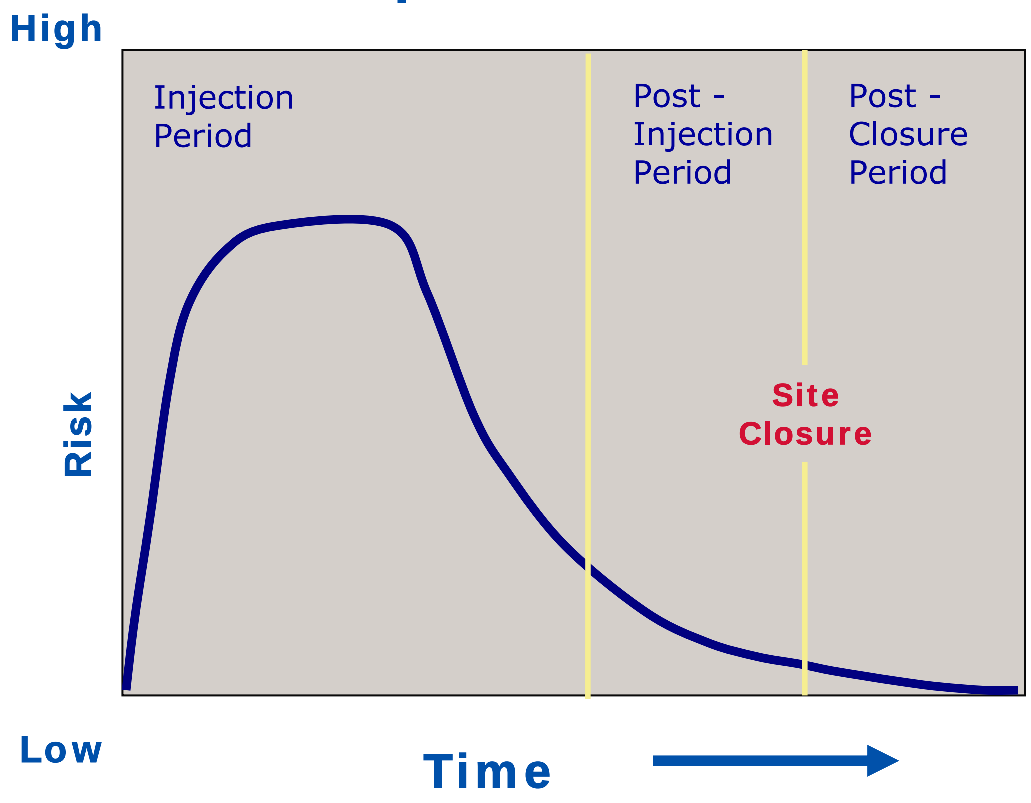
Reservoir Monitoring, Risk Mitigation & Site Closure

- Monitoring aimed at identifying signposts so that effective mitigation actions can be implemented
- Site closure is the point where operational responsibility ends and is marked by satisfaction of site closure criteria
  - Criteria to be determined by legislation
  - Future land use objectives can be met
  - Residual risk of leakage and resulting liability is acceptably low
  - Any ongoing costs are low or otherwise appropriately managed
  - Liability transferred to State and Commonwealth Governments

Conceptual Risk Profile



Concluding Messages

- The Gorgon CO_2 Injection Project is first of its kind in many technical and regulatory aspects
- The same attitude and approach to subsurface studies and development was adopted for the CO_2 project as for the hydrocarbon fields
- Much effort was invested into project assurance for internal and external stakeholders
- Pressure management wells are fundamental to the development plan
- Reservoir surveillance is important to maintain performance and to capture lessons learned

Acknowledgements

The authors wish to thank Chevron and the Gorgon Joint Venture Participants:

- ExxonMobil
- Shell
- Chubu Electric
- Osaka Gas
- Tokyo Gas