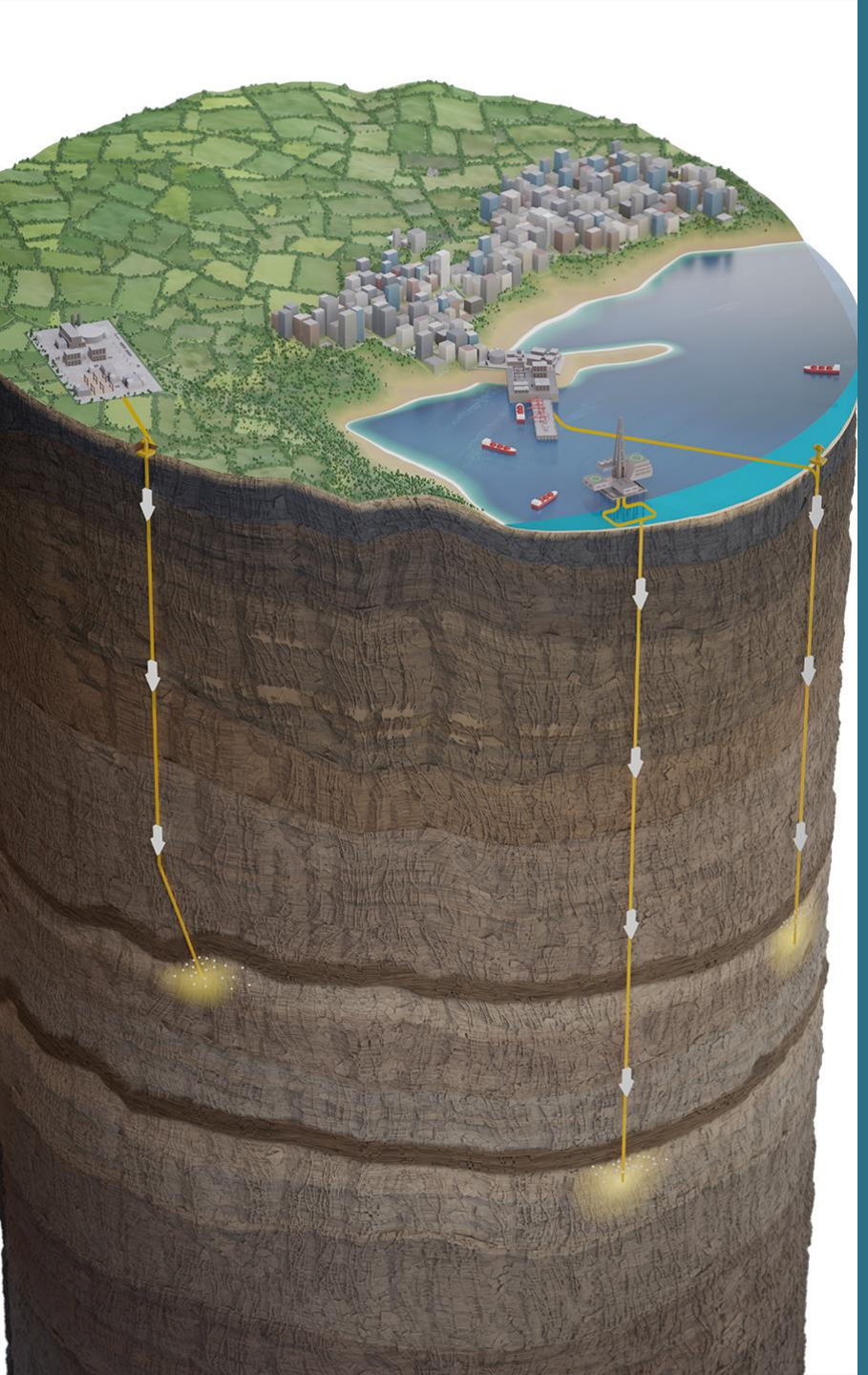

Australian Government
Geoscience Australia

Exploring for the Future

CSIRO

The potential for CO_2 storage in residual oil zones in onshore Australian basins

Australian Energy Producers Conference, 20-23 May 2024

Aleks Kalinowski[1], Eric Tenthorey[1], M. Ben Clennell[2], Mojtaba Seyyedi[3], Richard Kempton[2], Samuel Jackson[2], Claire Patterson[1], Siyumini Perera[2]

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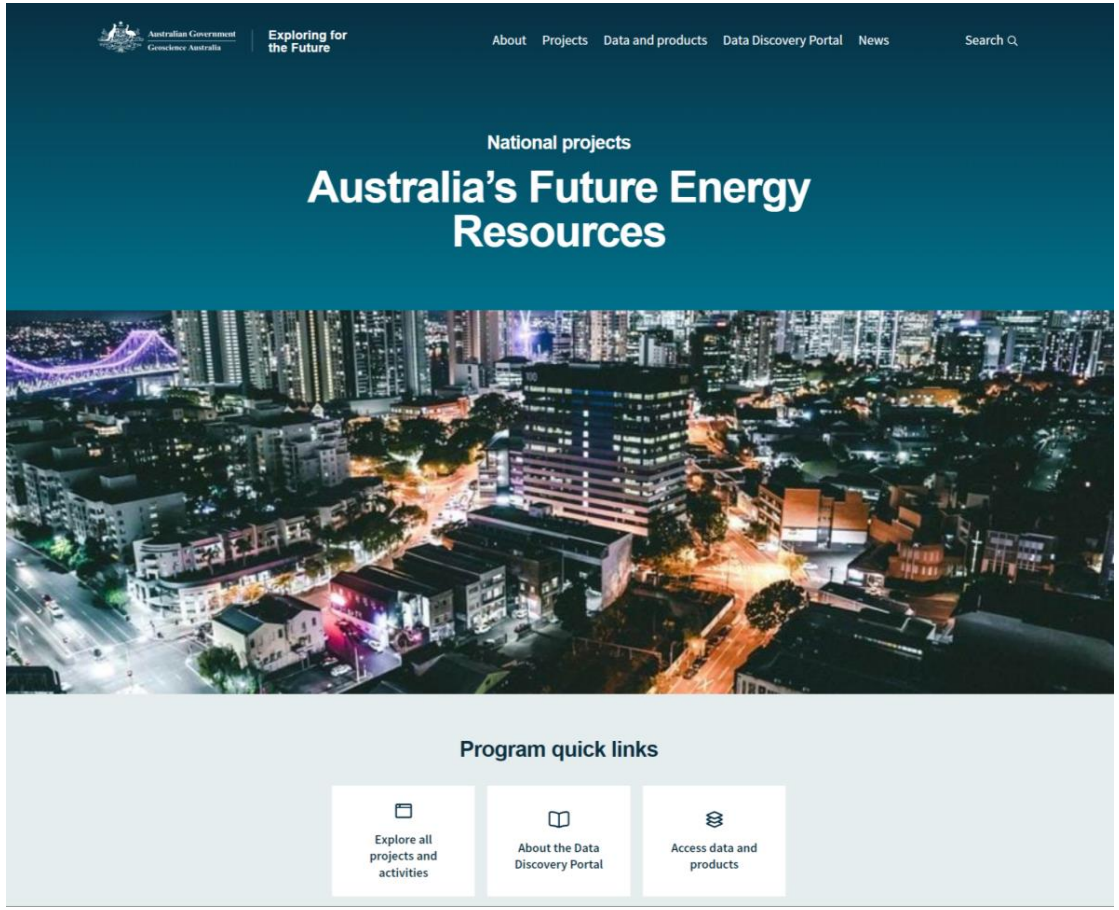
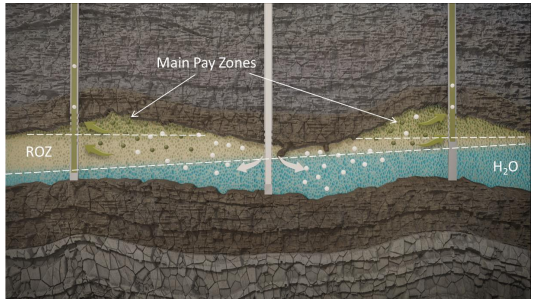
[3] Global CCS Institute

Acknowledgements: Paul Strong, Martin Kennedy, Tess Dance, Bridgeport Energy Limited

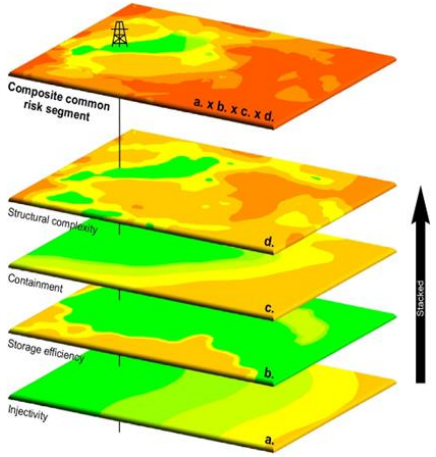
Introduction: Exploring for the Future Program (2016-2024)



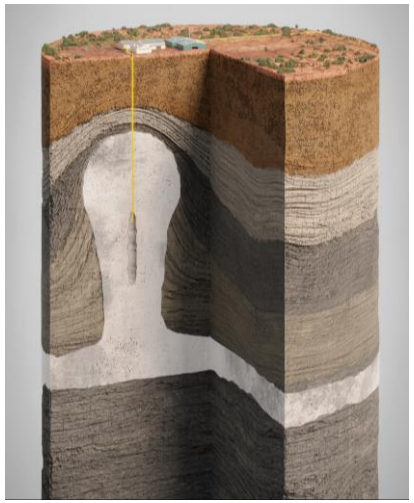
AFER (2020-2024)
eftf.ga.gov.au/australias-future-energy-resources



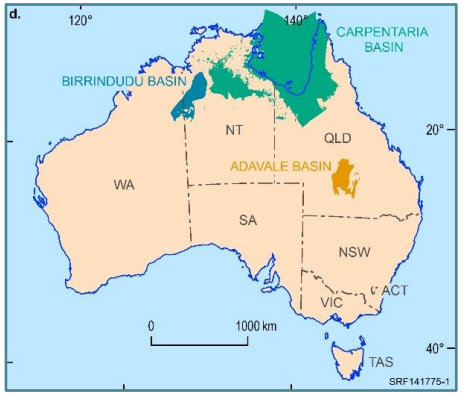
CO_2-EOR-Storage in residual oil zones



HC and CO_2 storage resources assessments

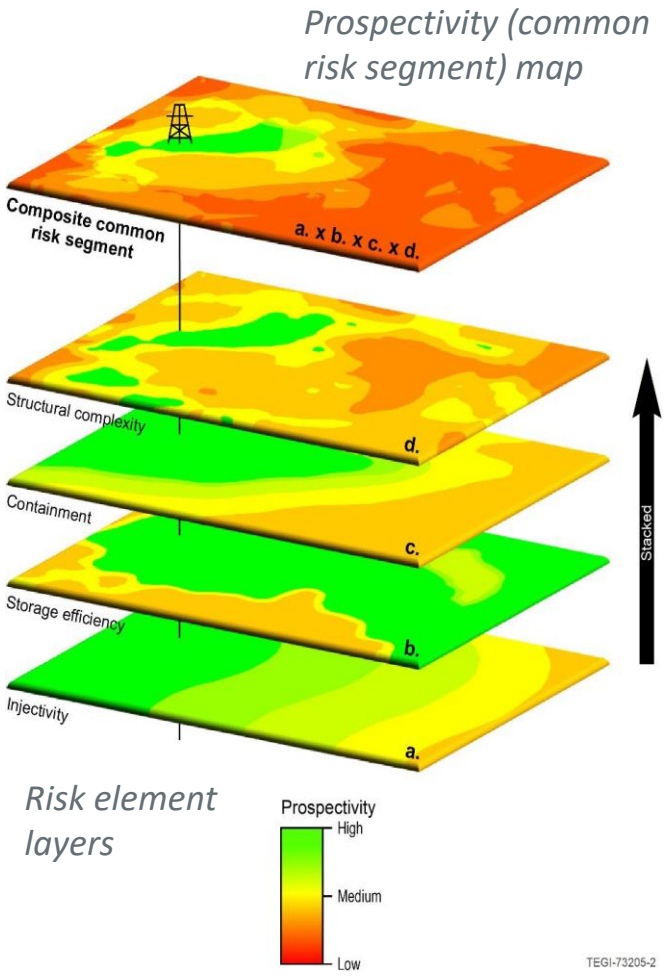


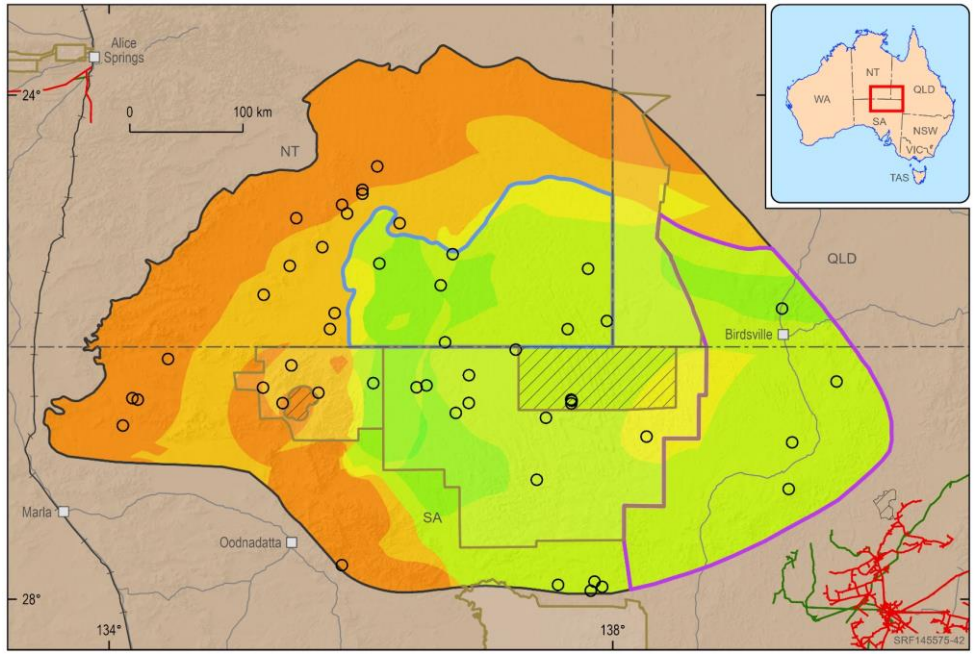
Hydrogen studies



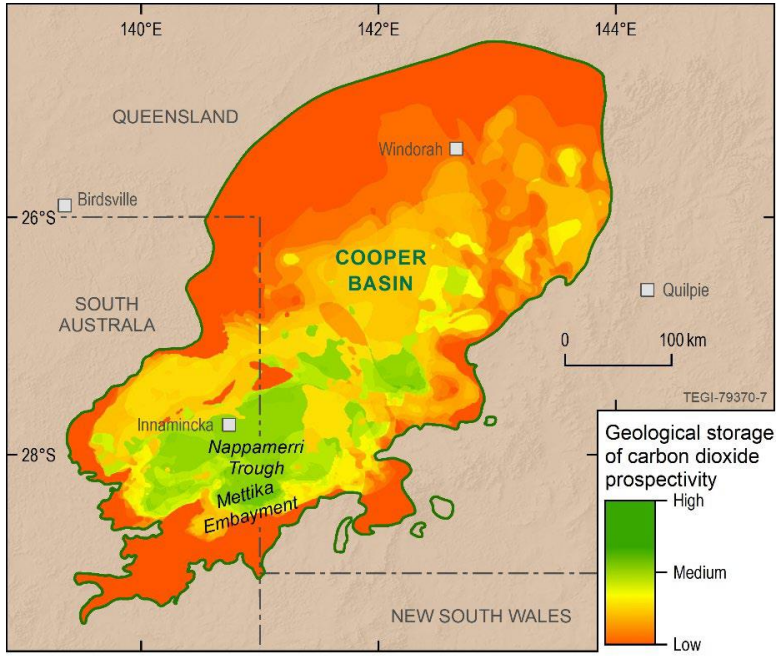
Basin inventories

Introduction: CO_2 storage resource assessments





CO_2 storage prospectivity map for the Pedirka - western Eromanga region
(*Bernecker et al., this conference*)



CO_2 storage prospectivity map for the Toolachee Play interval, Cooper Basin
(*TEGI, 2023*)

Australia's Future Energy Resources (EFTF) Energy Resources Assessments

eftf.ga.gov.au/energy-resources-assessment

Trusted Environmental and Geological Information

ga.gov.au/about/projects/resources/trusted-environmental-geological-information-program

Introduction: Residual oil zones – what are we looking for?

The APPEA Journal 2021, **61**, 118–131
https://doi.org/10.1071/AJ20076
Peer reviewed paper

CO2-EOR+ in Australia: achieving low-emissions oil and unlocking residual oil resources

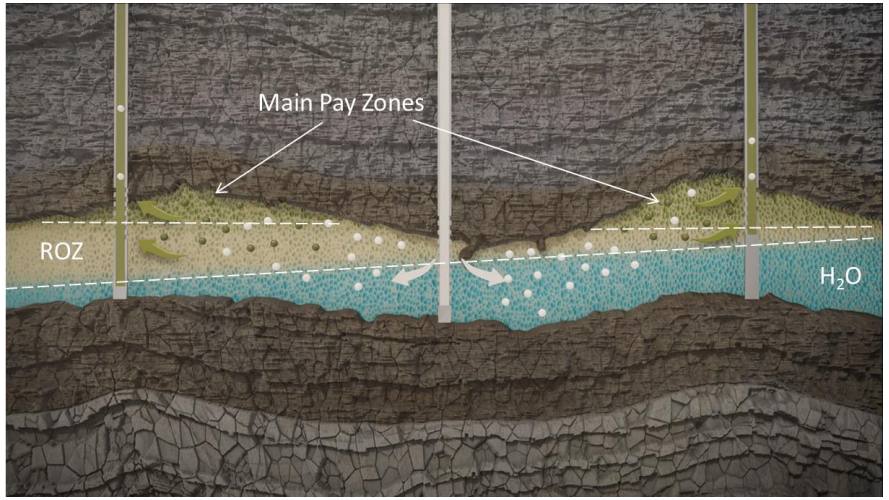
Eric Tenthorey[A,C], *Ian Taggart*[B], *Aleksandra Kalinowski*[A] *and Jason McKenna*[B]

[A]Geoscience Australia, GPO Box 378, Canberra, ACT 2601, Australia.
[B]GeoGem Consultants, Unit 20, 5 Spyglass Grove, Connolly, WA 6027, Australia.
[C]Corresponding author. Email: Eric.Tenthorey@ga.gov.au

Description	Net utilisation tCO_2/bbl oil	Net negative?
"Average" CO_2 EOR	0.3 - 0.5	No
"Good" CO_2 EOR (minimum CO_2)	0.15 - 0.2	No
Conventional EOR+	0.3	No
Advanced EOR+	0.6	Possible
Maximum storage EOR+	0.9	Yes

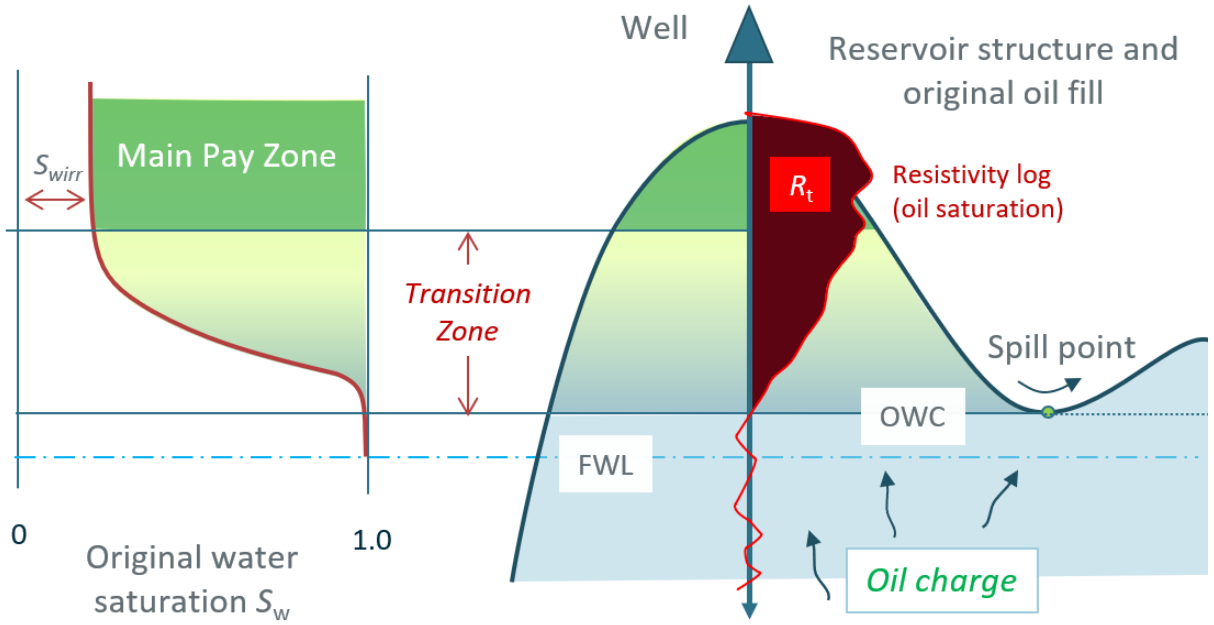
- For 20 mmbbl oil : 6 – 18 $MtCO_2$ stored (0.3 – 0.9 tCO_2/bbl)
- Carbon neutral > ~0.5 tCO_2/bbl

- Geological **Residual oil zones (ROZs)** are naturally water-flooded reservoirs below the oil-water contact (brownfield) or without a main pay zone (greenfield) that contain some immobile oil.
- Potentially large CO_2 storage resource – add to storage resources of depleted fields, benefitting from existing infrastructure, experience, and knowledge?
- S_o ~10-30% - potential additional oil production through CO_2-EOR similar to tertiary production in depleted fields - commercial production in North America, e.g. Seminole, Tall Cotton



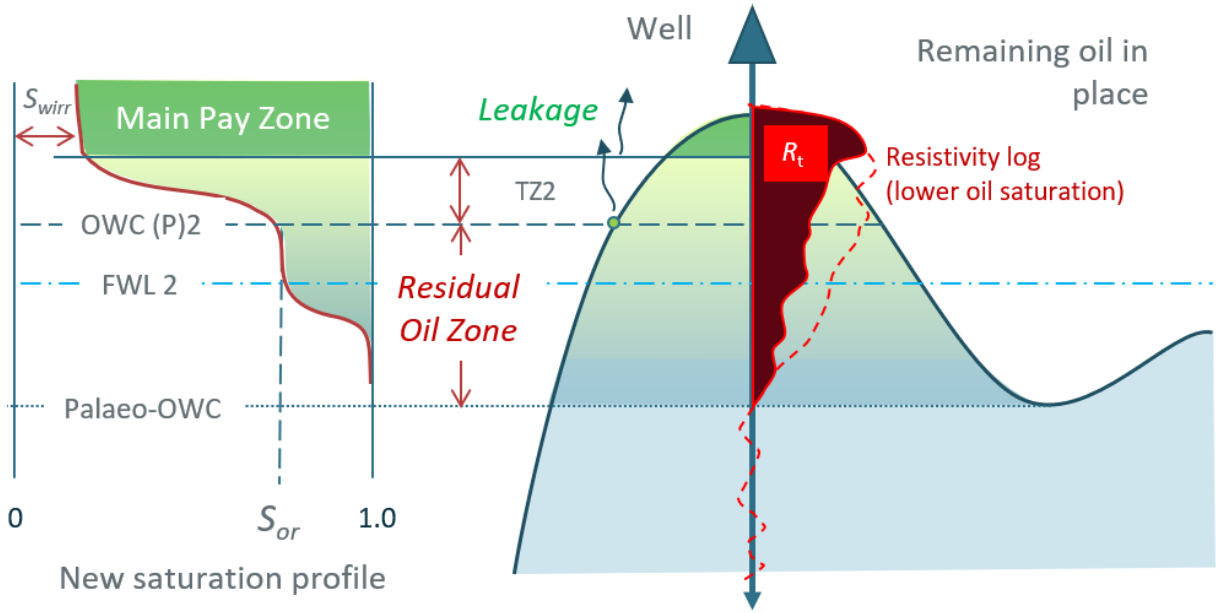
Introduction: Residual oil zones – what are we looking for?

Primary drainage: filling a reservoir (conventional field)



- Oil migrates up into a trap (impermeable seal above)
- Reservoir fills down from top
- Capillary pressure increases with height of trapped oil column, oil invades smaller pores and water is expelled to irreducible level (10-20%)
- Thin transition zone
- Oil column and TZ detected through resistivity (higher = more oil)

Imbibition: formation of ROZ



- Oil leaks during tilting or seal breach and is replaced by water, disconnected blobs of oil remain
- Residual oil saturation typically ~10-30%
- ROZ left beneath MPZ may be 10's m thick, or can look like a transition zone
- Resistivity changes, ROZ lower than MPZ & TZ
- Resistivity is key to identification & quantification of oi in place

Introduction: This study

Key questions addressed through the ROZ study:

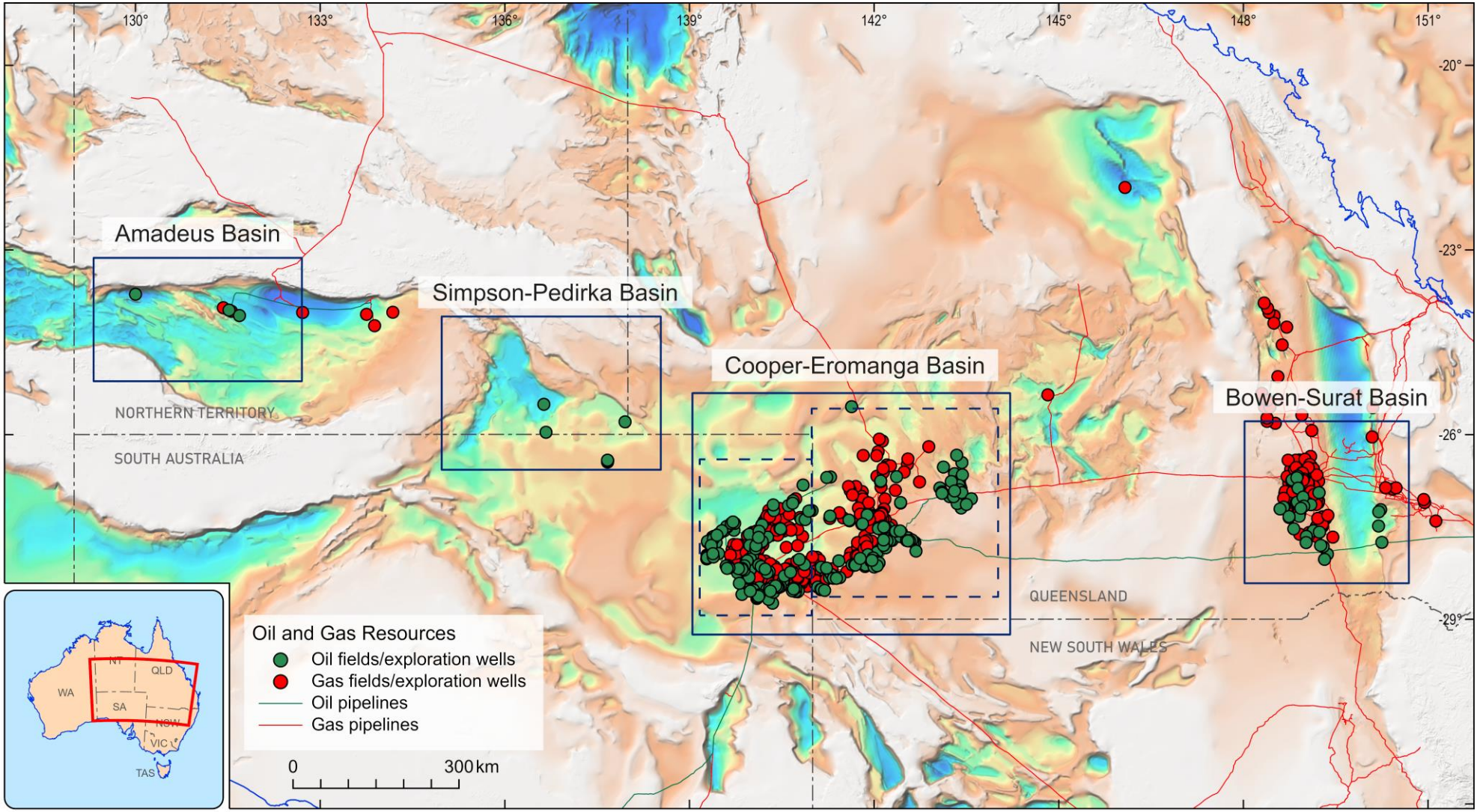
Q1: Can we identify geological residual oil zones in Australian basins?

- Petrophysical appraisal to identify, qualify, characterise ROZs.

Q2: How much CO_2 could be stored and how much oil could be produced?

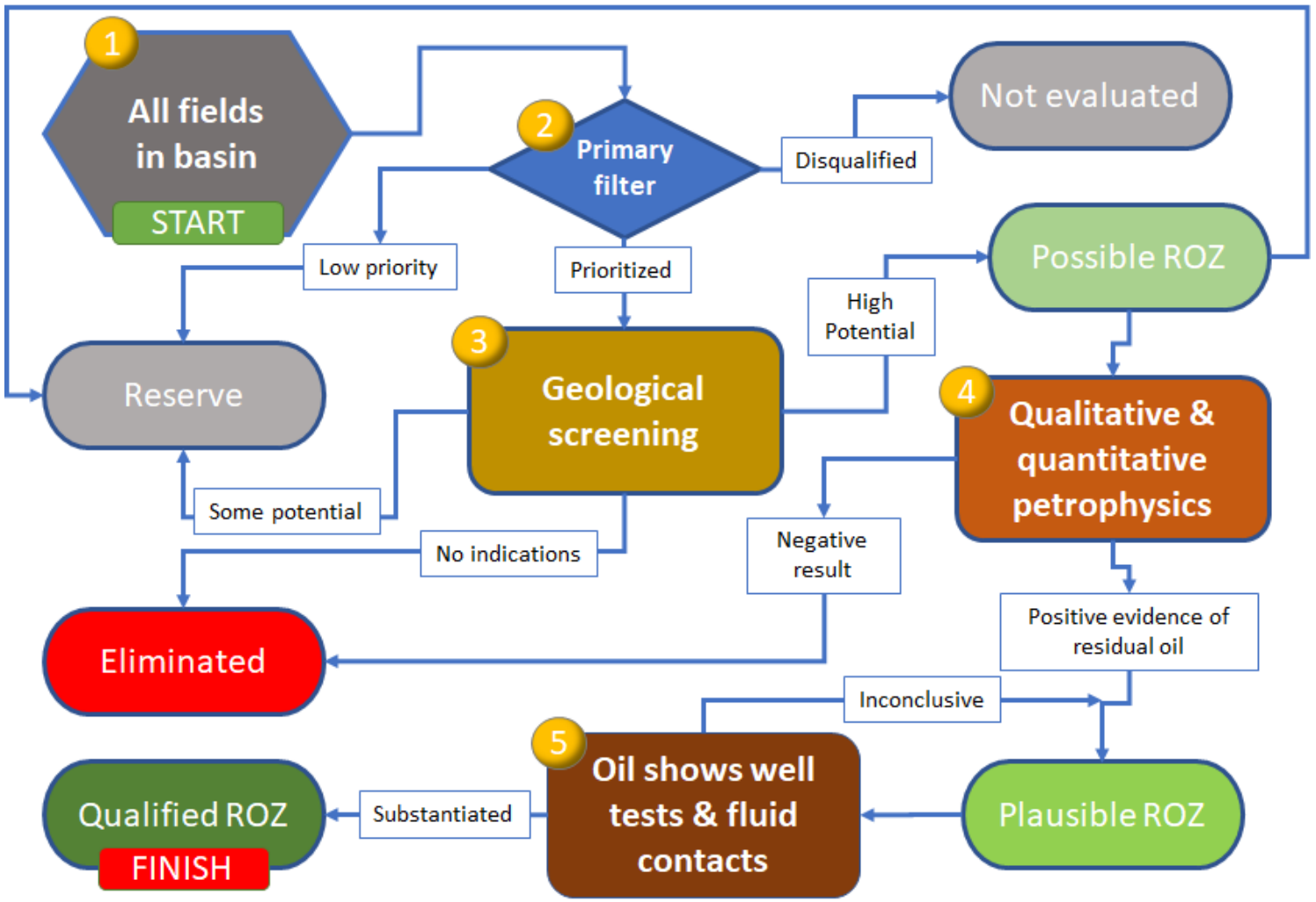
- Reservoir modelling of CO_2-EOR-storage to estimate CO_2 storage efficiency and to predict the behaviour of injected CO_2 and residual oil.

Petrophysical appraisal: **Study area**

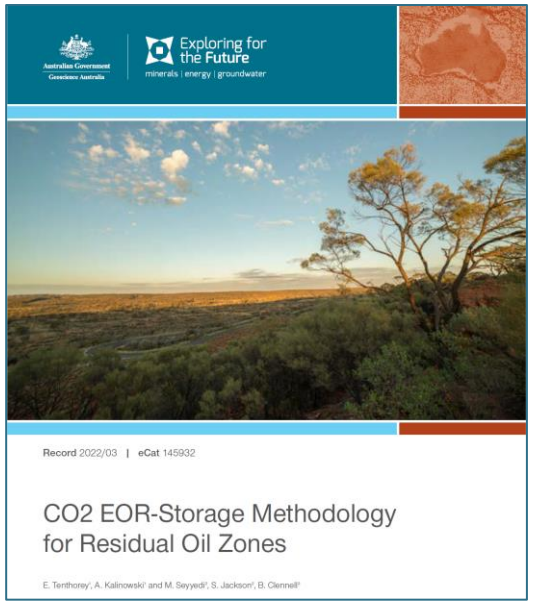


Fields and Pipelines from GPInfo. Background OzSeeBase from Geognostics. The EDIN Fields & Wells Database (IHS-S&P) was also used

Petrophysical appraisal: **Workflow**



New integrated workflow for ROZs



eftf.ga.gov.au/carbon-co2-storage-residual-oil-zones

Petrophysical appraisal: **Workflow**

Steps 1-3: Preliminary and geological screening

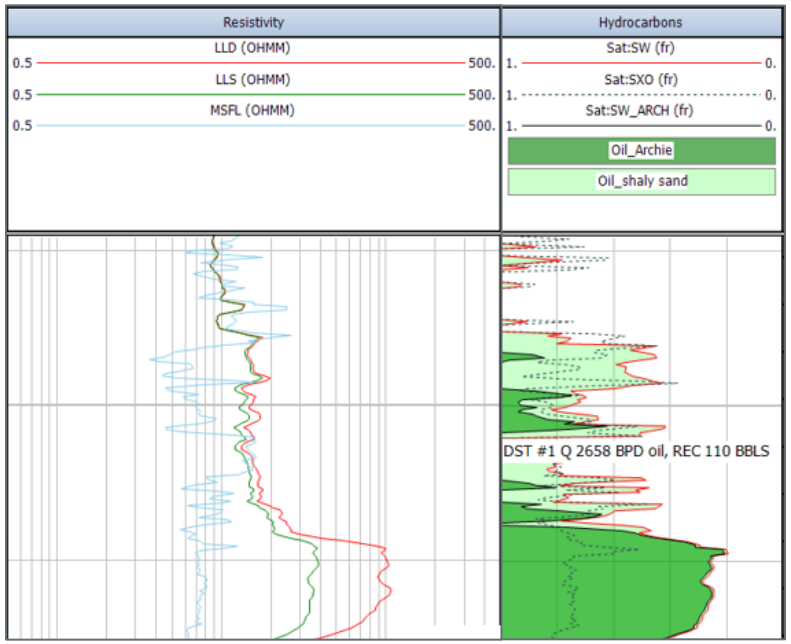
- Data compilation, filtering out unsuitable options (depth-MMP, reservoir quality, gas only)
- Geological screening - petroleum systems, pay zones, production history (WCRs, logs, literature)

Step 4: Petrophysical analysis

- Qualitative & quantitative
  - Archie analysis (dark green) - using electrical resistivity to determine S_w and S_o (S_o=1-S_w)
  - Shaly sand model (light green) – modified Archie's equations to account for conductive minerals
- Oil = high resistivity (not conductive)
- Saline water = low resistivity (conductive)

Resistivity ← *More conductive* / *More resistive* →

Hydrocarbons ← *More water* / *More oil* →

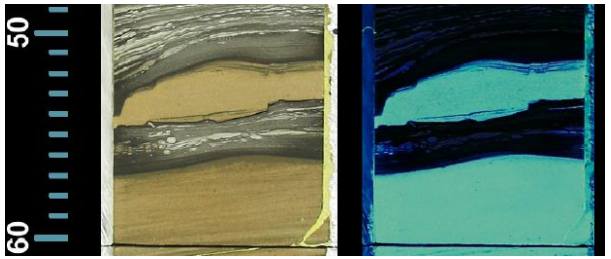


Step 5: Direct evidence

Match petrophysical interpretation with evidence from shows and fm tests

Increasing evidence of oil

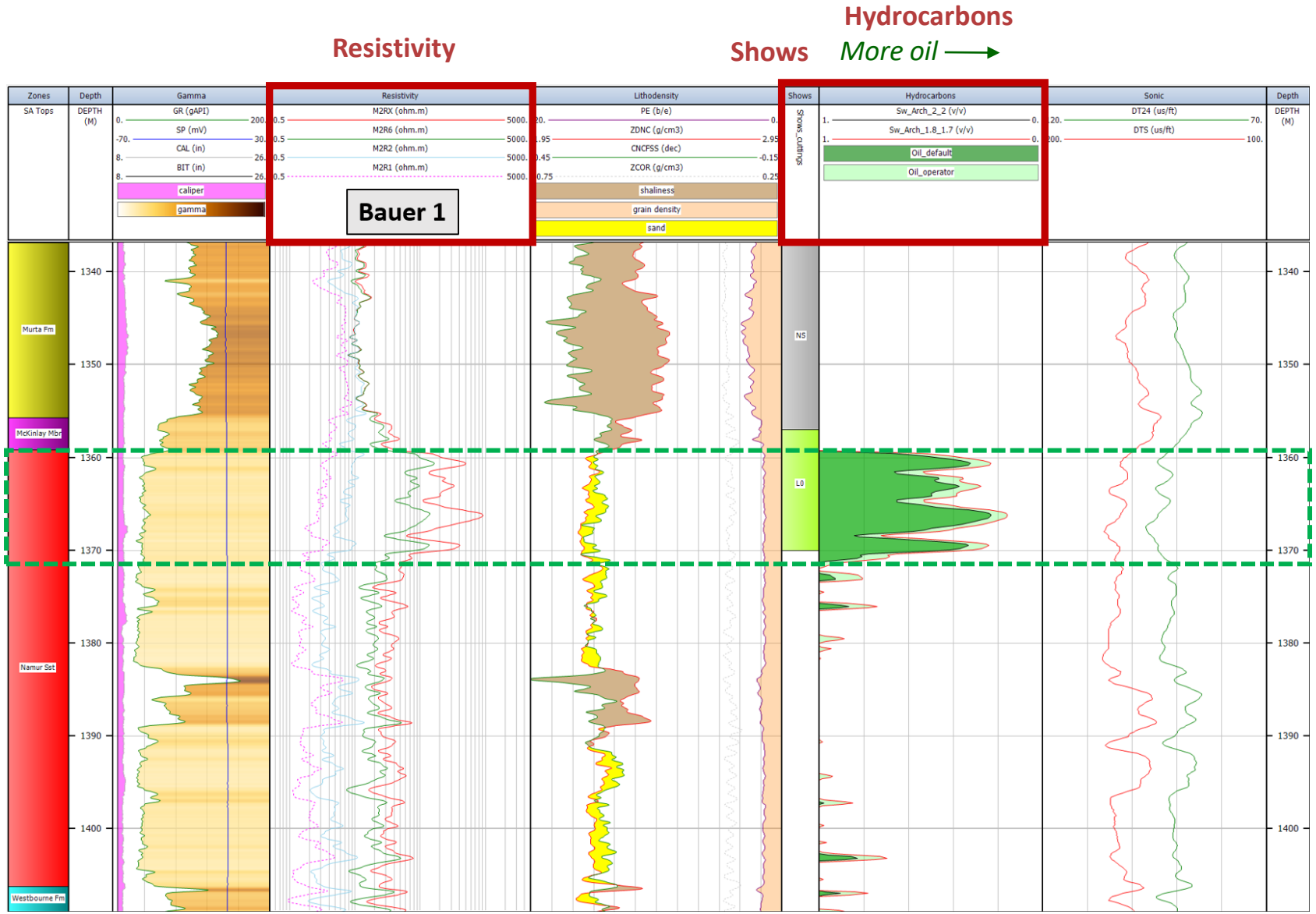
TYPE	NAME	CODE
EVIDENCE FROM CORE & CUTTINGS:		
OIL TRACE	Residual oil	L0
OIL TRACE	Oil staining	L0
OIL TRACE	Minor fluorescence	L0
OIL TRACE	Minor cut	L0
OIL INDICATION	Major cut	L1
OIL SHOW	Bleeding oil	L2
EVIDENCE FROM FM FLOW: DST		
OIL SHOW	Unmeasured oil	L2
OIL RECOVERY	Discrete oil	L3
OIL DISCOVERY	Oil Flow	L5



(Bauer 5 WCR)

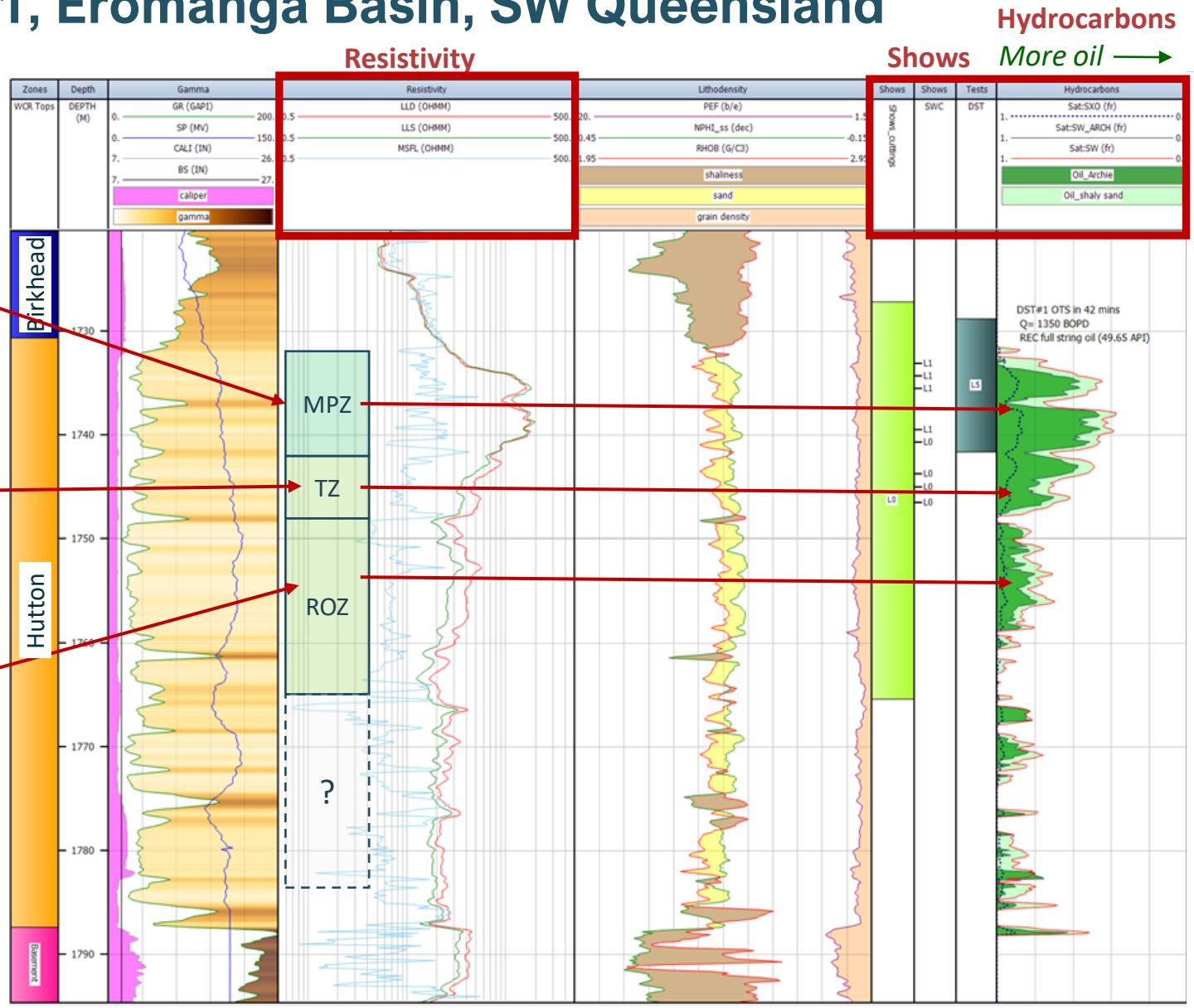
Petrophysical appraisal: Example of an oil column with no ROZ indicators

- **Bauer 1**, on western flank of the Eromanga Basin, drilled to test for oil in the Namur Ss
- Discovery of major oil field > 50 mmbbl, > 30 mmbbl produced
- Oil occurrence limited to top 12 m of Namur Ss
- Oil saturation calculated as 40-80% in main oil column (Archie analysis)
- Oil shows from McKinlay Member to base of oil column
- Thin transition zone; sharp base to OC; **no indication of ROZ**

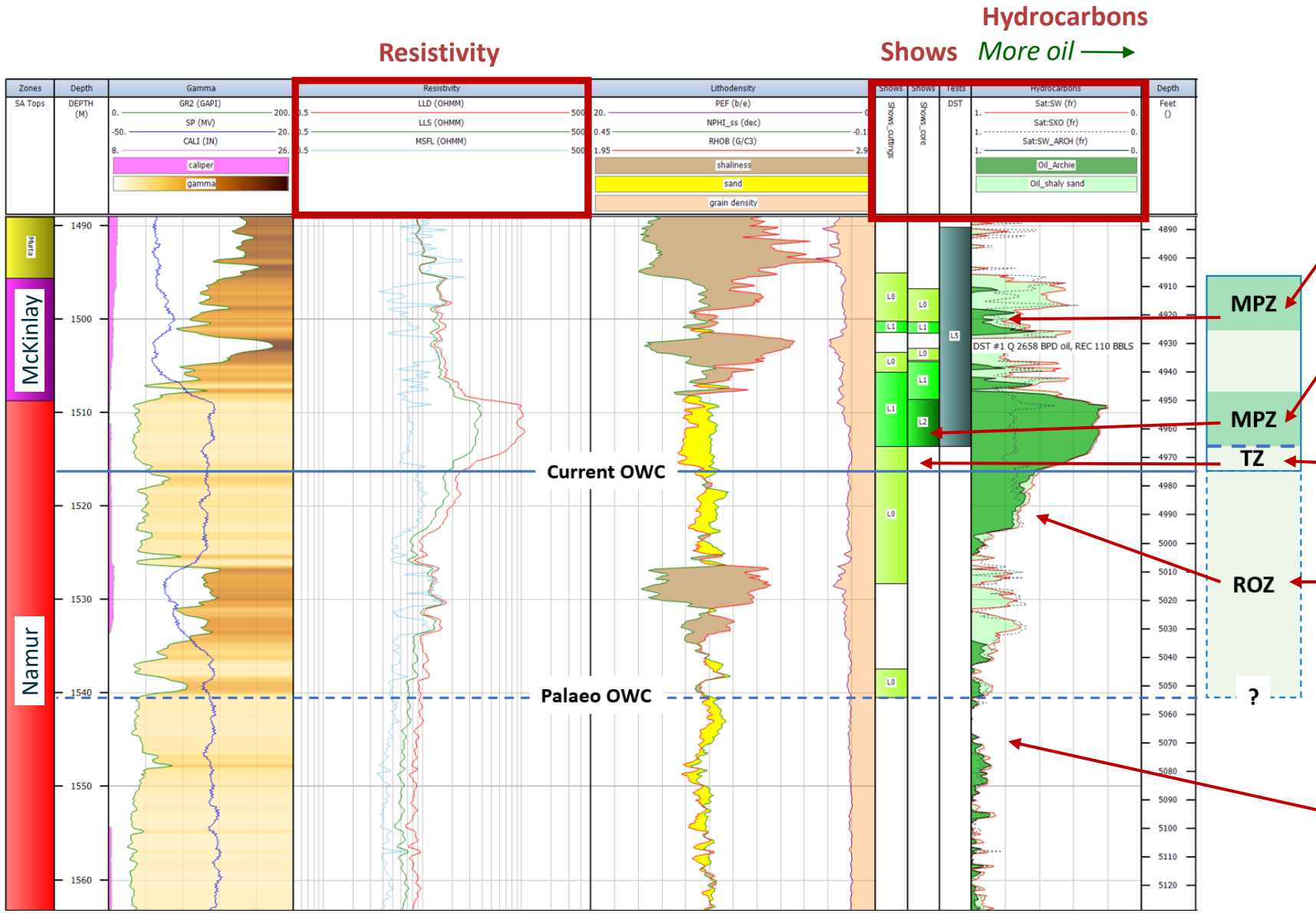


Petrophysical appraisal: Bolan 1, Eromanga Basin, SW Queensland

- Classic example of ROZ in Hutton Ss, SE flank of Eromanga Basin
- Main pay zone 1730-1742 m
  - Tested and flowed dry oil
  - S_{oil} up to 60% (shaly sand model)
  - Strong shows in sidewall cores
  - Oil traces in cuttings
- Transition zone 1742-1748 m
  - S_{oil} 20-50%
  - Oil traces in sidewall cores
  - Oil traces in cuttings
- Residual oil zone 1748- ~1765 m
  - S_{oil} 10-20%
  - Patchy oil below 1760 m
  - Oil traces in cuttings to 1765 m



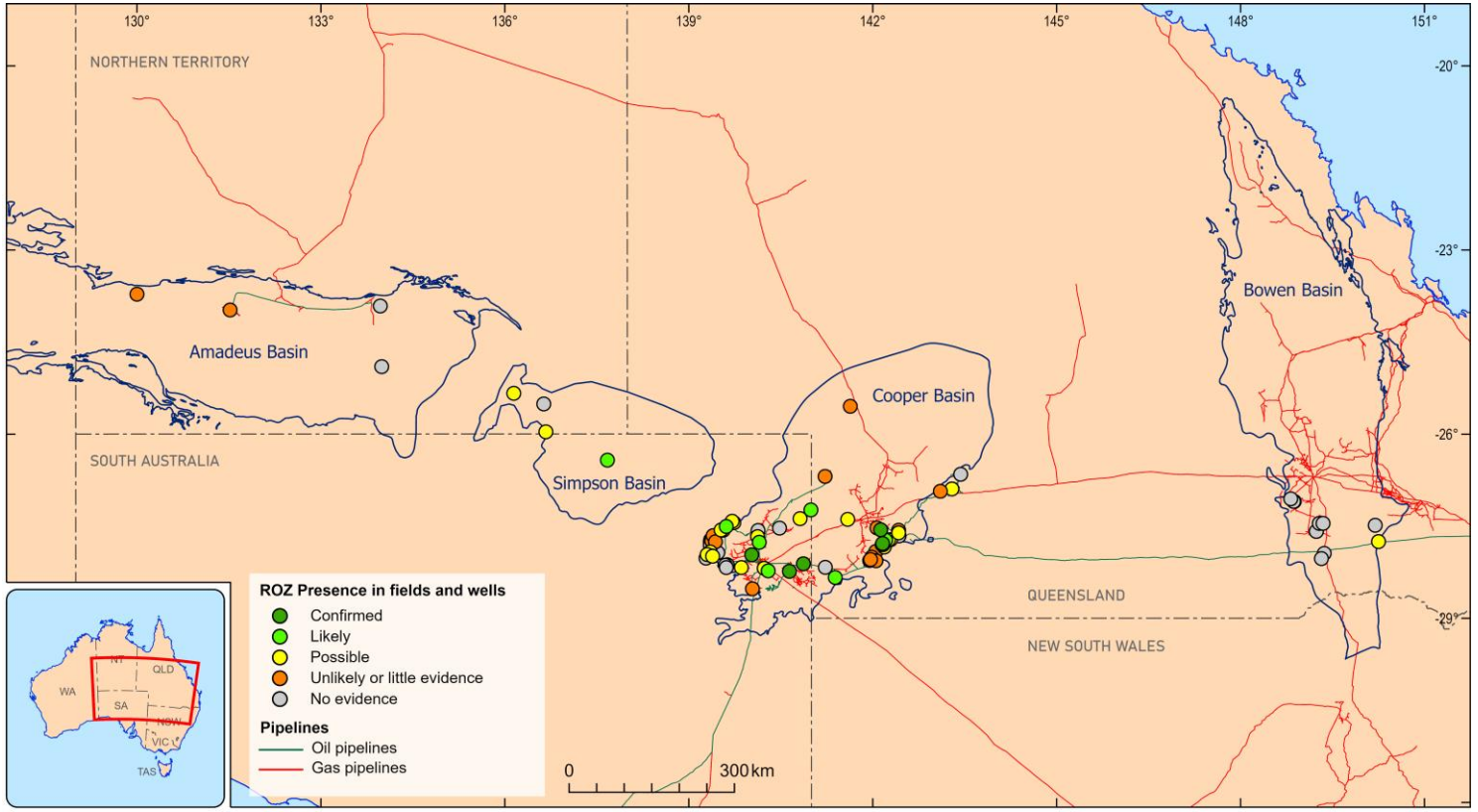
Petrophysical appraisal: Dullingari 29, Eromanga Basin, SA



- Pay in top Namur Sandstone passes up into McKinlay Member shaly sand
- Main oil column base marked by strong shows in core
- Shows in cuttings become weaker in transition zone
- **Confirmed ROZ** that can be seen in multiple wells below transition zone, S_{or} **15-30%** from Archie and shaly sand analysis; qualified by consistent oil shows in cuttings
- Weak oil indications may be sporadic, not part of a ROZ

Petrophysical appraisal: **Summary**

- Right: Summary for fields examined from South Australia (Cooper-Eromanga Basin)
- Below: Likelihood of ROZ presence in fields and wells



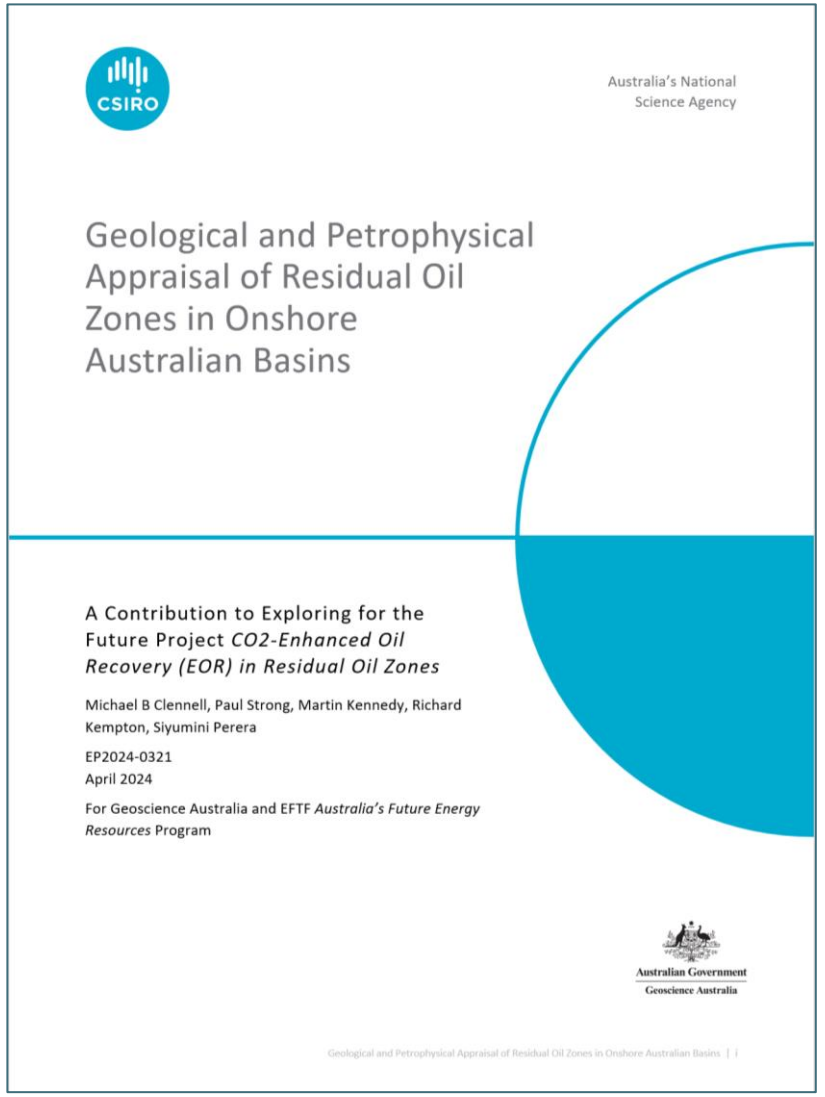
RESULT	FIELD NAME	OIL IN PLACE MMBBL	CUMUL PROD MMBBL	NUMB WELLS	FIELD SQKM	COMMENTS
Confirmed	Dullingari	47	11.074	93	44	ROZ in Namur multiple wells
	Strzelecki	40	18.145	34	26	Oil below MOC in Namur and Hutton.
	Gidgealpa	27.1	12.377	66	30.35	Oil below MOC in Hutton, low S_{or}
Likely	Big Lake*	3.7	1.846	160	80	Residual oil in BL55, Adams 2002
	Merrimelia*	28	12.613	66	30	Residual oil indications in Hutton
	Acrasia*	3.7	1.099	8	1.1	Hutton-Birkhead potential
	Martlet	2.36	0.844	5	0.7	Oil below producing horizon in Namur
Possible	Moomba*	38.3	8.442	276	200	Residual oil in M99, production related?
	Tirrawarra	111	29.051	98	50.6	Higher saturation at top of column vs base in Tirrawarra sst; may be mobile
	Callawonga	24	7.92	22	2.86	Shows but only traces of oil below MOC
	Elliston	0.283	0.134	2	0.13	Just a transition zone
	Flax/Juniper	55.7?	0.181	11	12.25	Possible ROZ but oil below MOC mobile?
	Silver Sands	1.2	0.049	1	0.92	Oil below OWC in Namur, TZ in Hutton
	Parsons*	12.5	4.411	9	1.03	Need to look at more wells
	Charo	8	2.984	19	7	Shows in Birkhead
	Snatcher	7	1.586	16	4.68	Shows in Birkhead
	Spencer	12	3.794	11	3	Hutton-Birkhead potential
	Christies	4.2	2.206	7	0.21	Possible oil below pay in Namur
	Spitfire	6	1.781	8	2.47	Oil below pay in Birkhead
Unlikely	Dirkala	3	0.820	6	2.5	No evidence
	Growler	15.5	6.785	19	11.47	Large field, need to see more wells
	Pennington	7	1.337	7	1.06	Only some shows below MOC
	Basham	3.5		1	1	Weak shows only
	Kalladeina	4.6	0.568	15	1.9	Weak shows only
No Evidence	Butlers	10	3.504	13	1.98	Nothing to see in B1 or B10
	Bauer*	53	31	80	15.59	Sharp contacts, no residual zone
	Arno	1.1	0.024	4	1.13	Screened with Bauer
	Sellicks	3.5	0.421	3	0.41	Possible missed oil in Birkhead
	Sturt	8.11	2.887	13	4.54	Poolowanna reservoir
	Malgoona	4	0.324	4	2	Merrimelia reservoir
	Tantanna*	36	8.026	13	1.5	Poolowanna reservoir
	Hanson	7	2.088	14	0.68	Possible missed oil in Birkhead
	Bookabourdie	0.8	0.149	12	10.05	High EOR potential but no ROZ
	Moorari-Woolkina	15.5	4.039	22	7.2	High EOR potential in Tirrawarra but full reservoir thickness produces oil and gas

Petrophysical appraisal: **Summary**

- Developed and used a new integrated workflow to screen for, identify and qualify ROZs in oil fields
- Identified ROZs below the main oil column in several fields and isolated single oil discovery wells
  - Most are from Jurassic reservoirs in the Eromanga Basin
  - Most are < few 10's metres thick, with average S_{or} < 10%
  - Hutton Ss and Namur Ss appear to be good targets for CO_2 injection
- Not comparable to the large (Bbbl) ROZs that are being produced via CO_2-EOR in North America

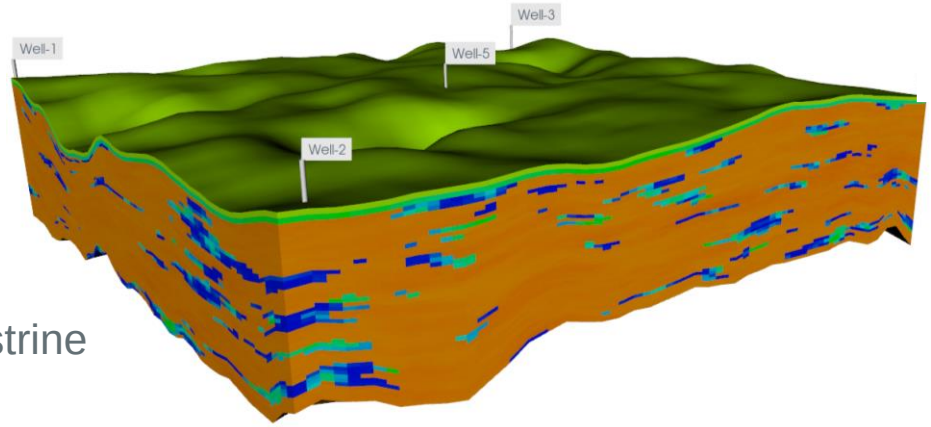
Final report, interpreted dataset, and previous publications will be available by 30 June 2024 at

eftf.ga.gov.au/carbon-co2-storage-residual-oil-zones

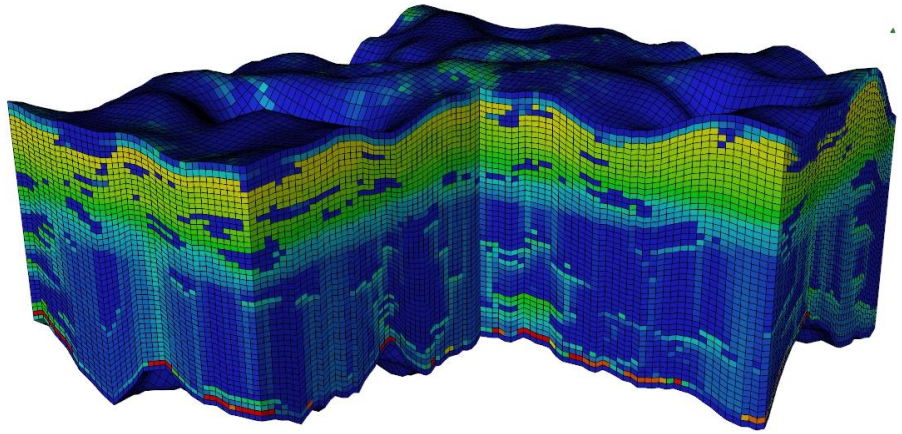


Modelling: **Workflow**

- Aims: estimate the CO_2 storage efficiency of ‘typical’ Australian ROZs
- Static model built using Petrel™
  - Conceptual model using simplified geology based on the Jurassic Hutton Ss (braided-fluvial reservoir) and Birkhead Fm (fluvial-lacustrine seal)
  - Binary distribution of rock types with high net to gross: 87% sandstone reservoir facies and 13% impermeable mudstone facies
  - Distribution of petrophysical properties within the sandstones generated based on a statistical distribution of ϕ and k taken from WCRs.
- Dynamic modelling completed using CMG GEM compositional modelling framework
  - 5 spot well pattern
  - CO_2 injection at 0.1, 0.4, 1 Mtpa for 20 years, 2 well perforation scenarios
  - Results broadly applicable to other basins
  - Model is freely available for other users to run different scenarios

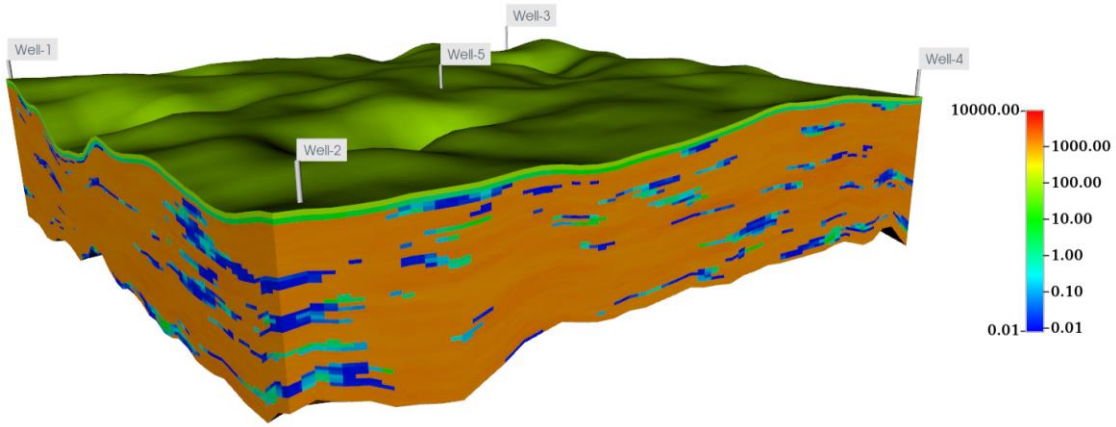


- 300,800 cells, dimensions 2 km × 2 km × 103 m, depth 1741-1845 m
- Grid cells 25 m × 25 m × 2.2 m (x-y-z)
- Porosity 2-25 %, kh 0.01 – 4,000 mD, kv = 10% kh

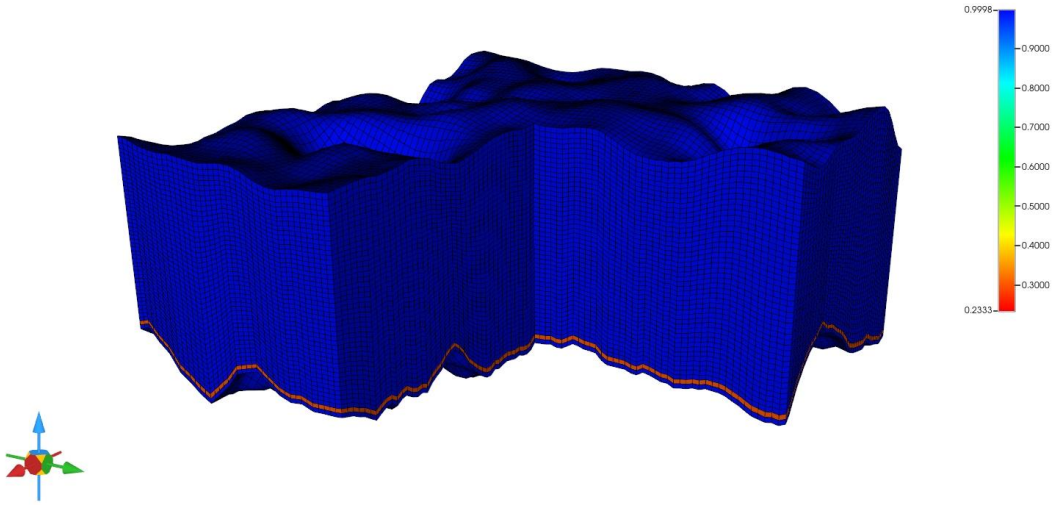


Modelling: Initialising the ROZ

1. Static model vertical permeability distribution (mD)



2. Pre-migration model – 100% water saturated



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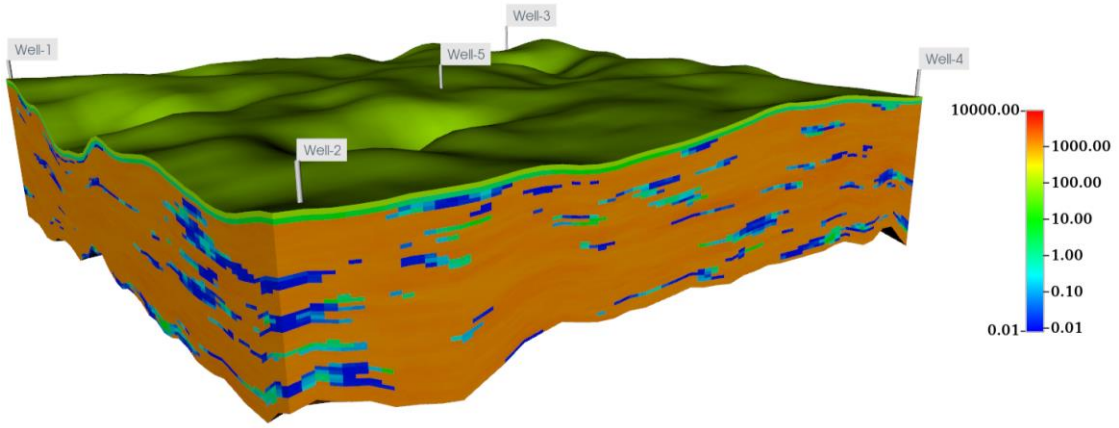

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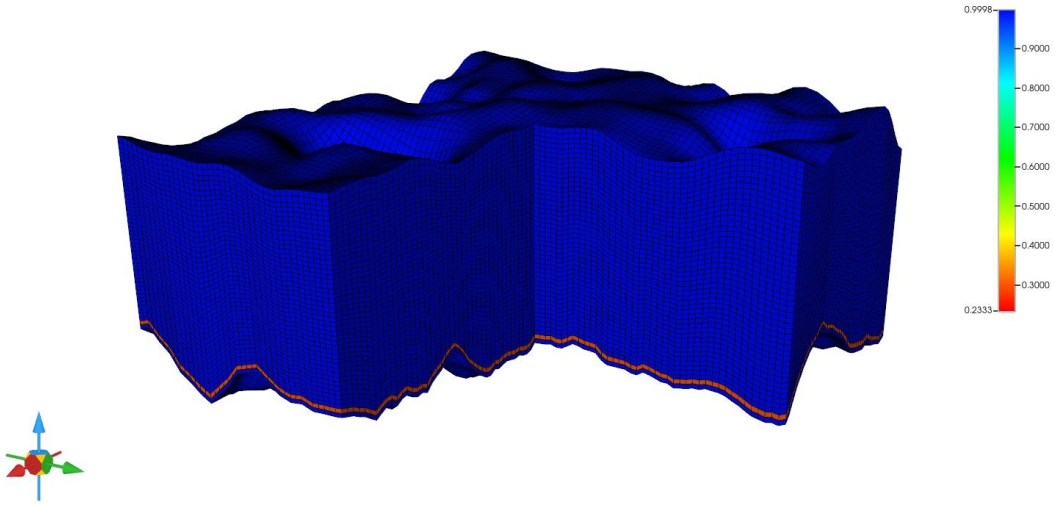
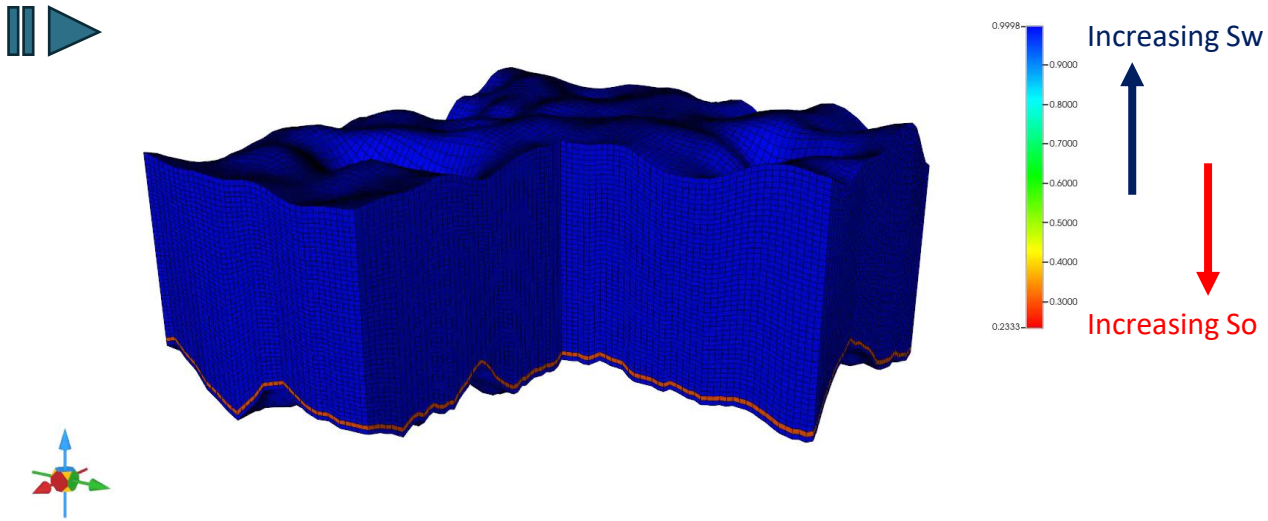


3. Water saturation after primary oil migration (477 yrs)



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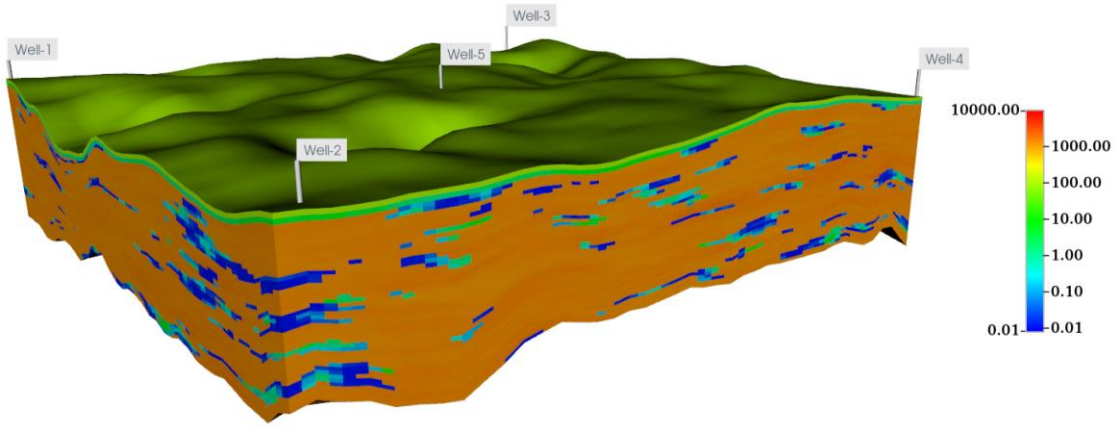

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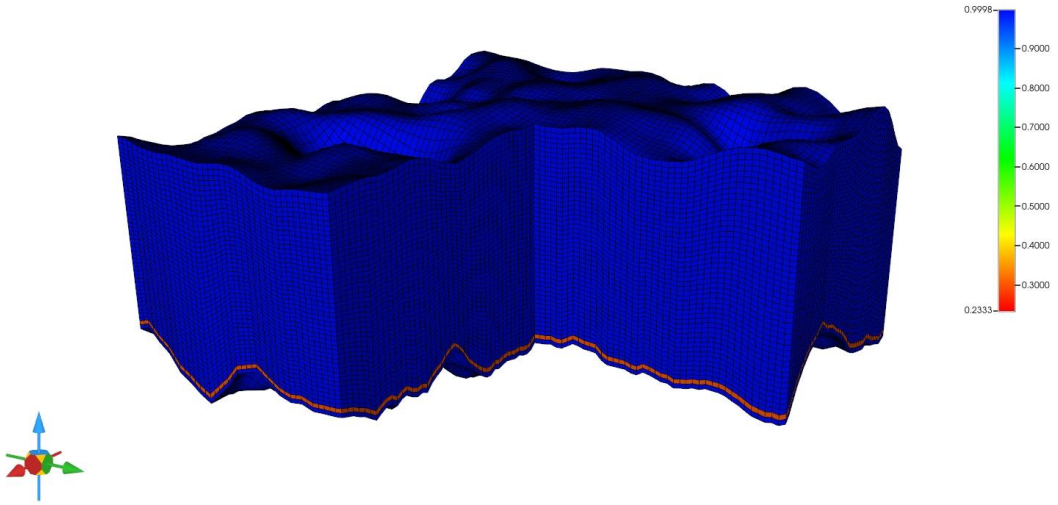

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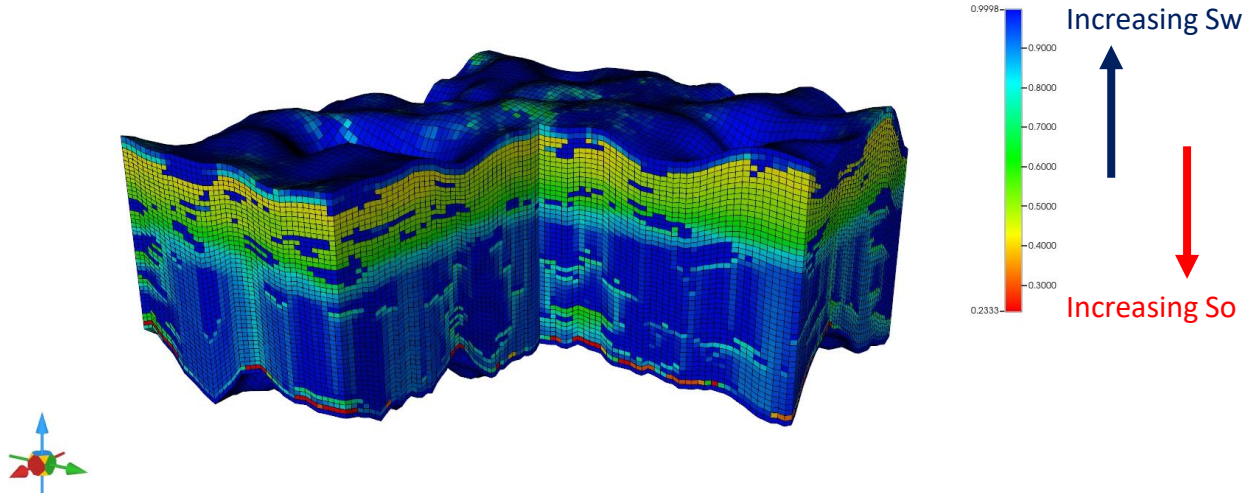
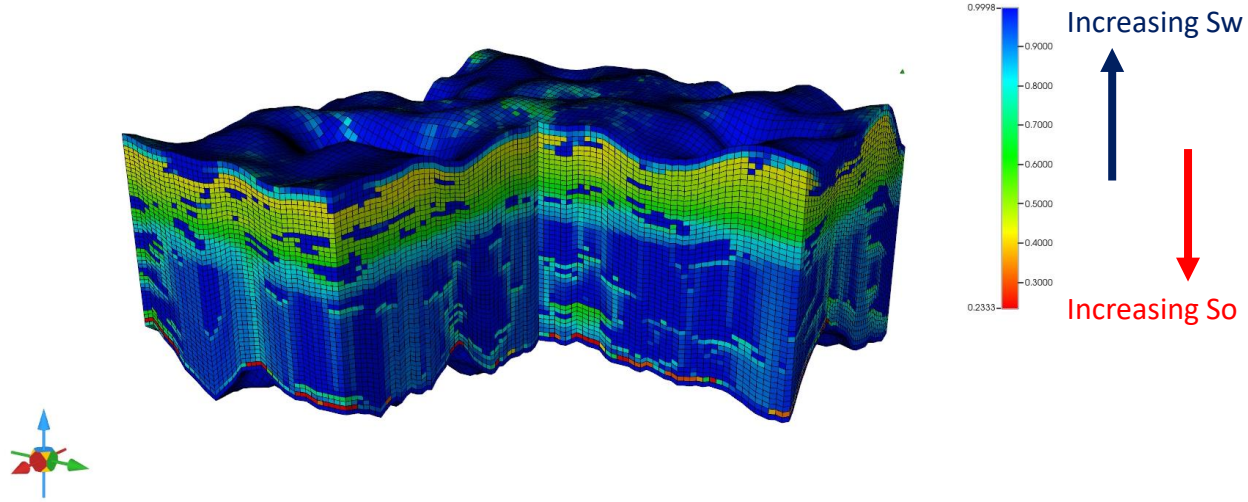
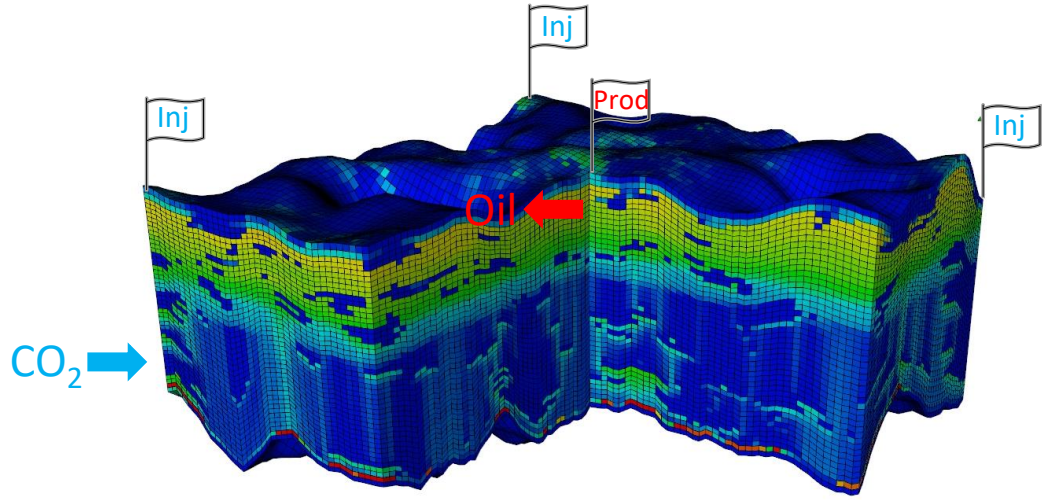


4. Water saturation at end of aquifer encroachment (30 yrs)



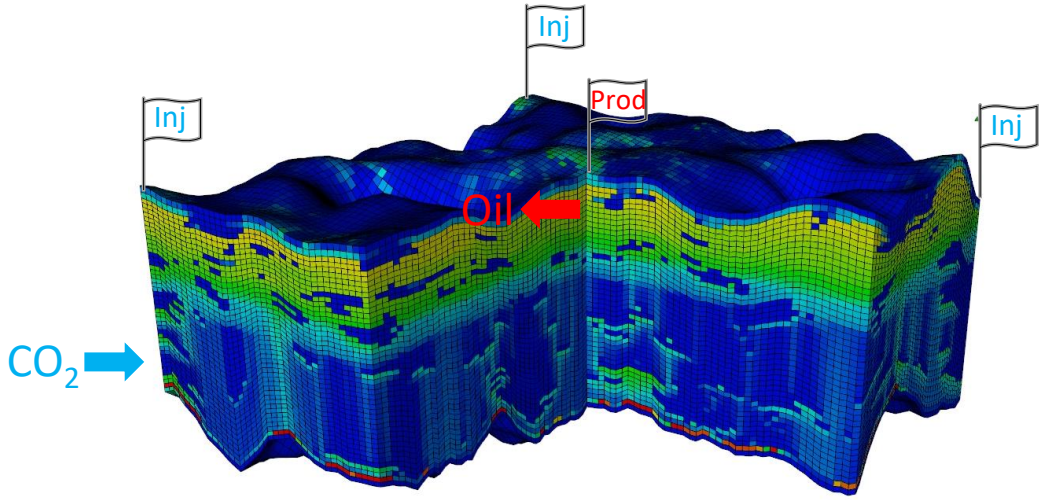
Modelling: CO_2 injection results - scenario 1

- CO_2 injection at the bottom of the reservoir
- Oil production from the top of the reservoir
- 20-year injection period, 1 Mtpa

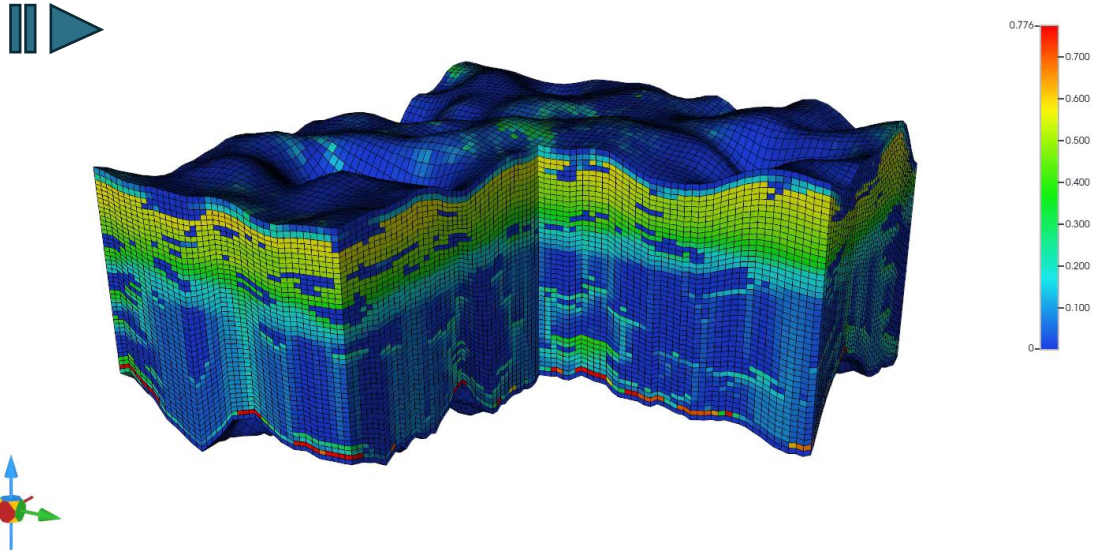


Modelling: CO_2 injection results - scenario 1

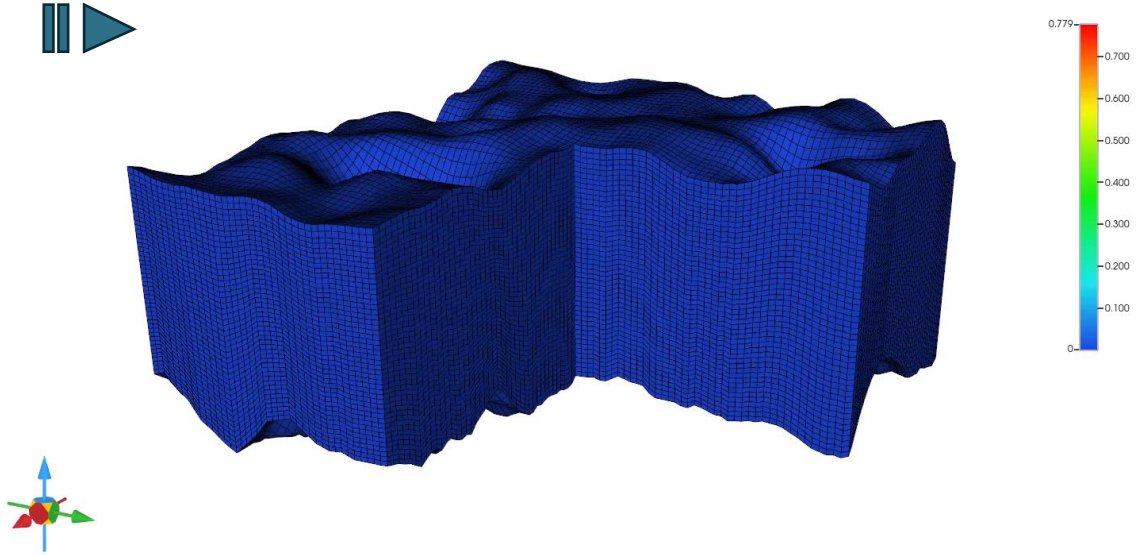
- CO_2 injection at the bottom of the reservoir
- Oil production from the top of the reservoir
- 20-year injection period, 1 Mtpa



Oil saturation

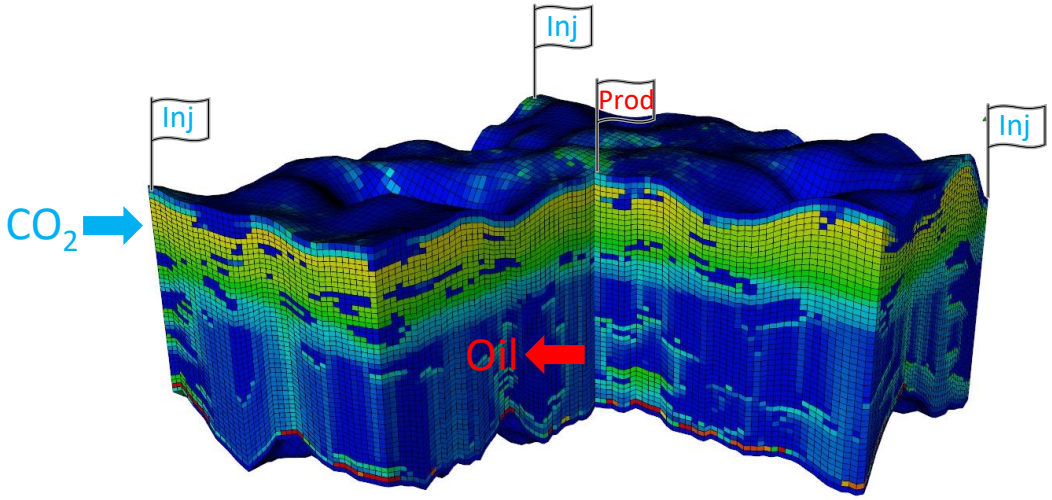


CO_2 saturation



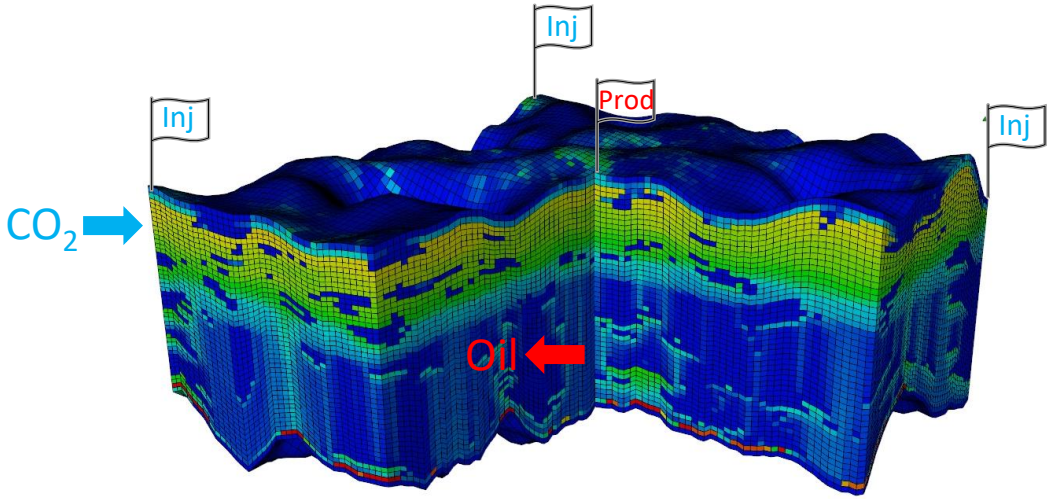
Modelling: CO_2 injection results - scenario 2

- CO_2 injection at the top of the reservoir
- Oil production from the bottom of the reservoir
- 20-year injection period, 1 Mtpa

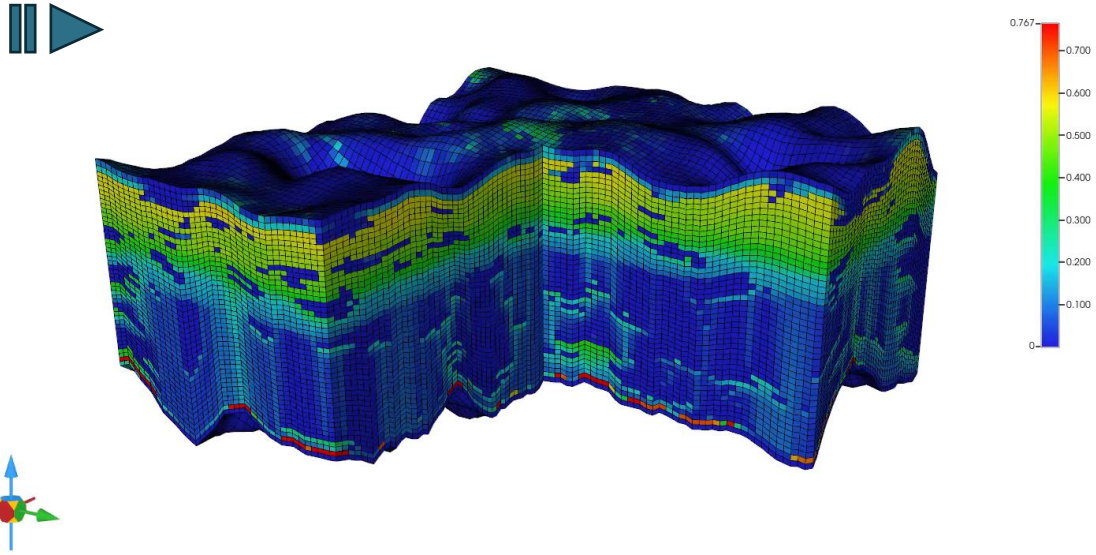


Modelling: CO_2 injection results - scenario 2

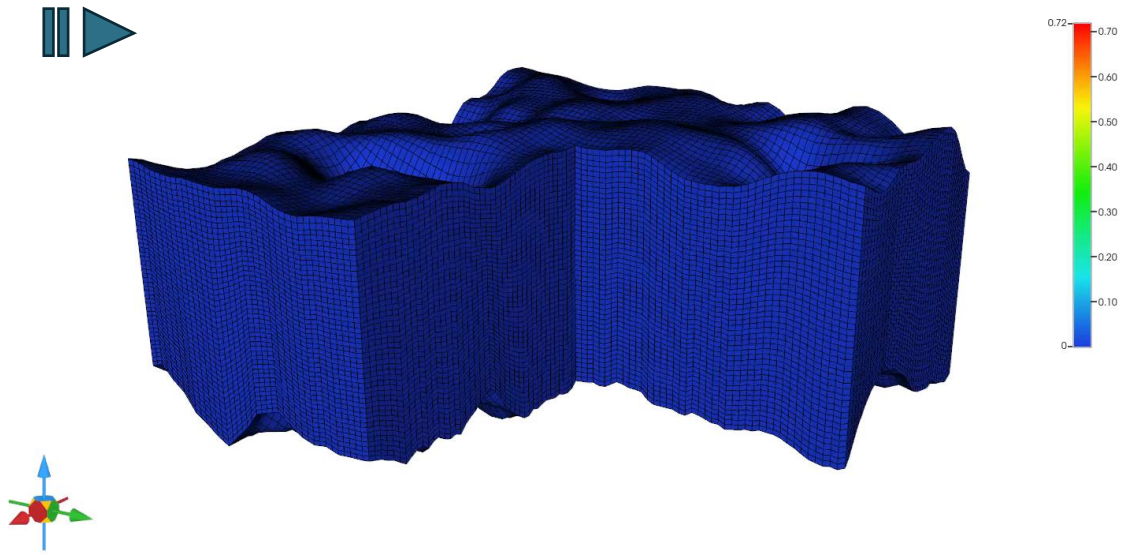
- CO_2 injection at the top of the reservoir
- Oil production from the bottom of the reservoir
- 20-year injection period, 1 Mtpa



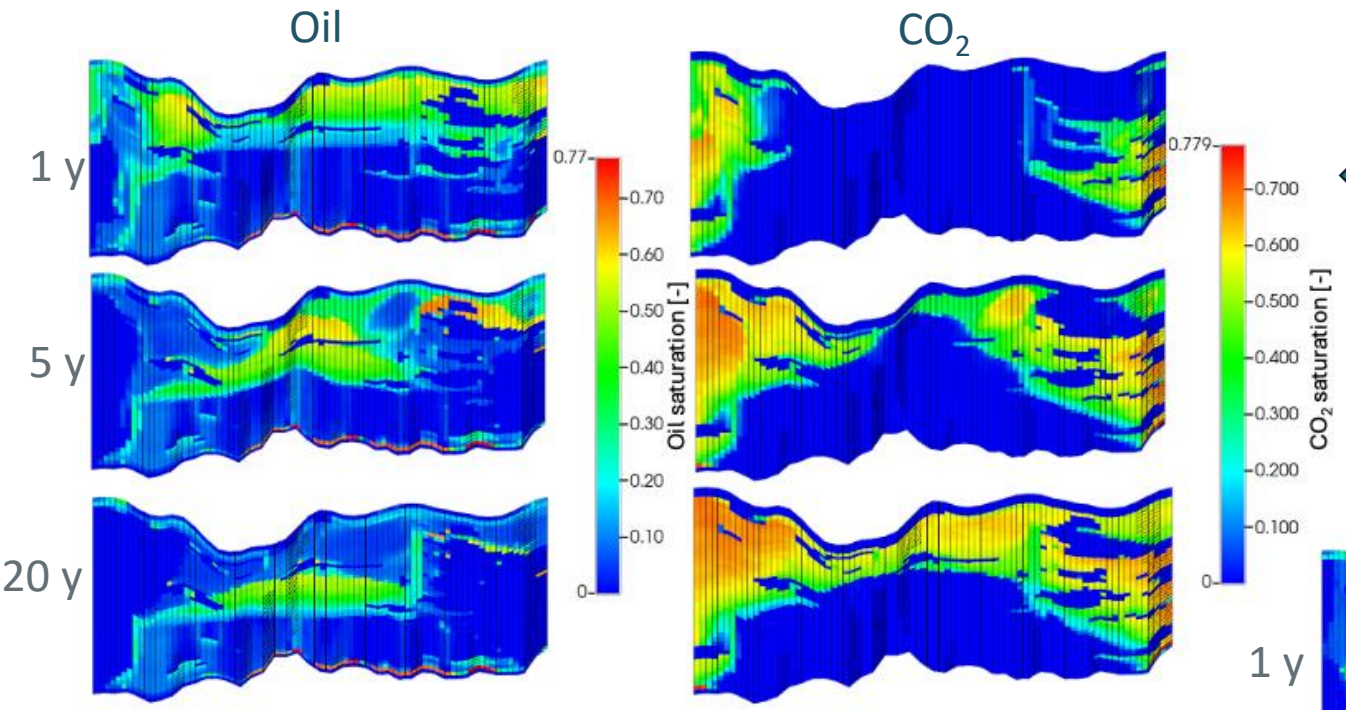
Oil saturation



CO_2 saturation



Modelling: CO_2 and oil saturation after 1, 5, 20 years of injection at 1 Mtpa



Scenario 1

CO_2 injection at the bottom of the reservoir

Oil production from the top of the reservoir

- 9.56 $MtCO_2$ stored
- 16.84% storage efficiency
- 7.12% OOIP produced

Scenario 2

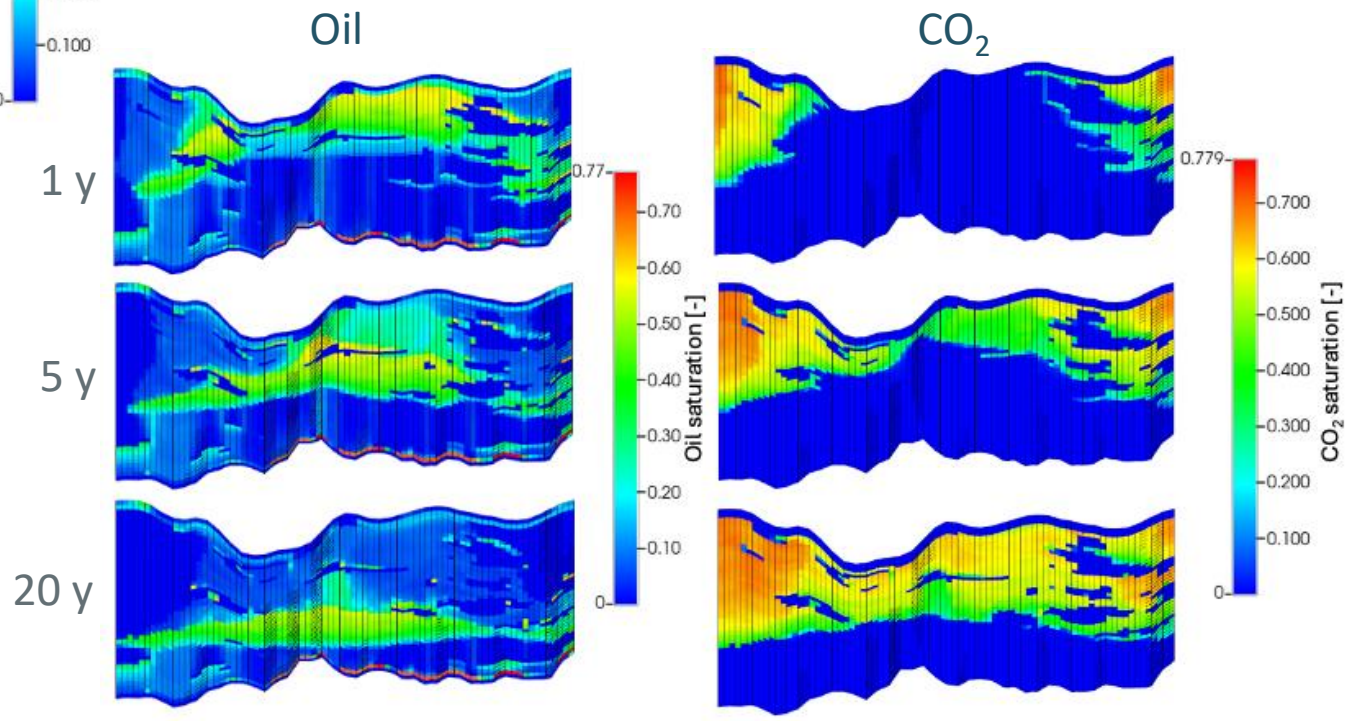
CO_2 injection at the top of the reservoir

Oil production from the bottom of the reservoir

13.35 $MtCO_2$ stored

18.46% storage efficiency & 30 PV% sweep efficiency

7.64 % OOIP produced

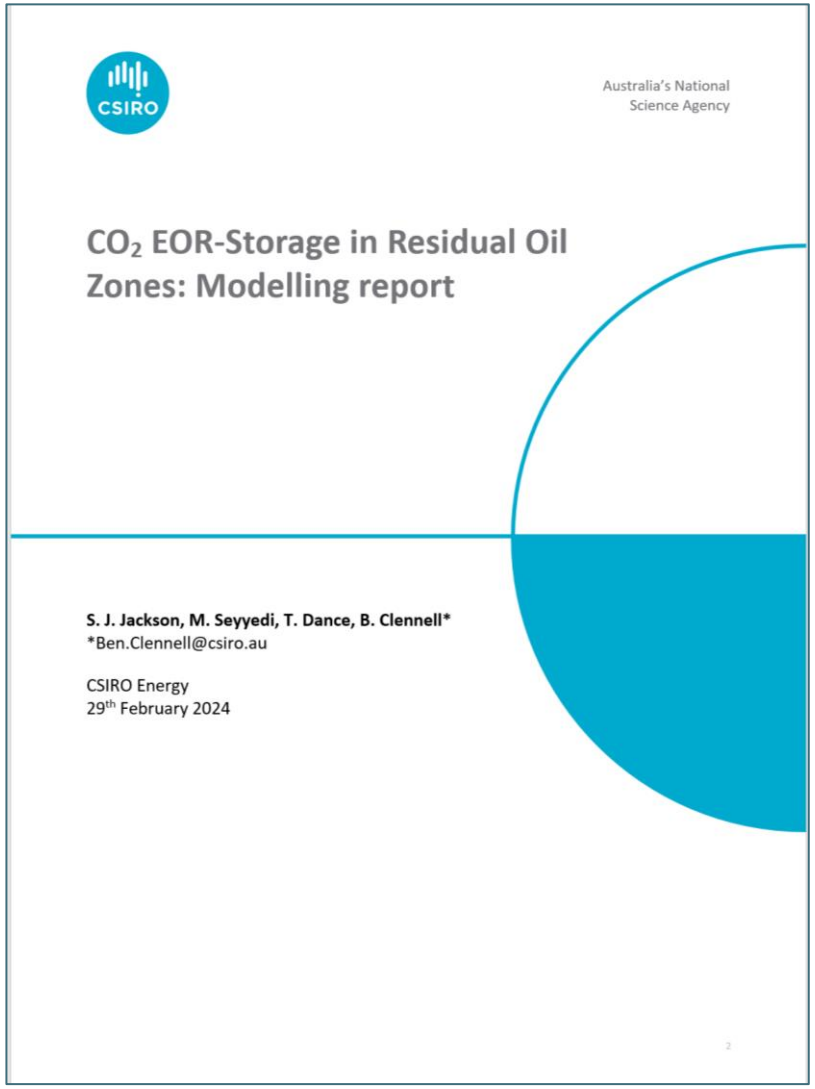


Modelling: **Summary**

- Modelled CO_2-EOR-storage in a ‘typical’ Australian ROZ based a Cooper-Eromanga reservoir.
- Developed a novel initialisation protocol for the ROZ.
- Modelling has shown that CO_2 injection under fully miscible conditions can efficiently mobilise and recover large amounts of oil from moderately heterogeneous reservoirs.
- CO_2-oil interactions increase the density and viscosity of CO_2, enhancing CO_2 sweep efficiency and lateral flow, & improving storage efficiency.
- Maximum CO_2 storage achieved with a gravity stable flood from top of reservoir.
- The extent of these effects depends on the quantity and spatial distribution of residual oil in place, the miscibility of CO_2 at reservoir conditions, well locations and configurations.
- Total production small compared to CO_2 injected. Utilising the high storage capacity without oil production may be a more beneficial use of these assets.

Final report, modelling datasets, and previous publications will be available by 30 June 2024 at

eftf.ga.gov.au/carbon-co2-storage-residual-oil-zones



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Thank you

Exploring for the Future Showcase

13-16 August, 2024

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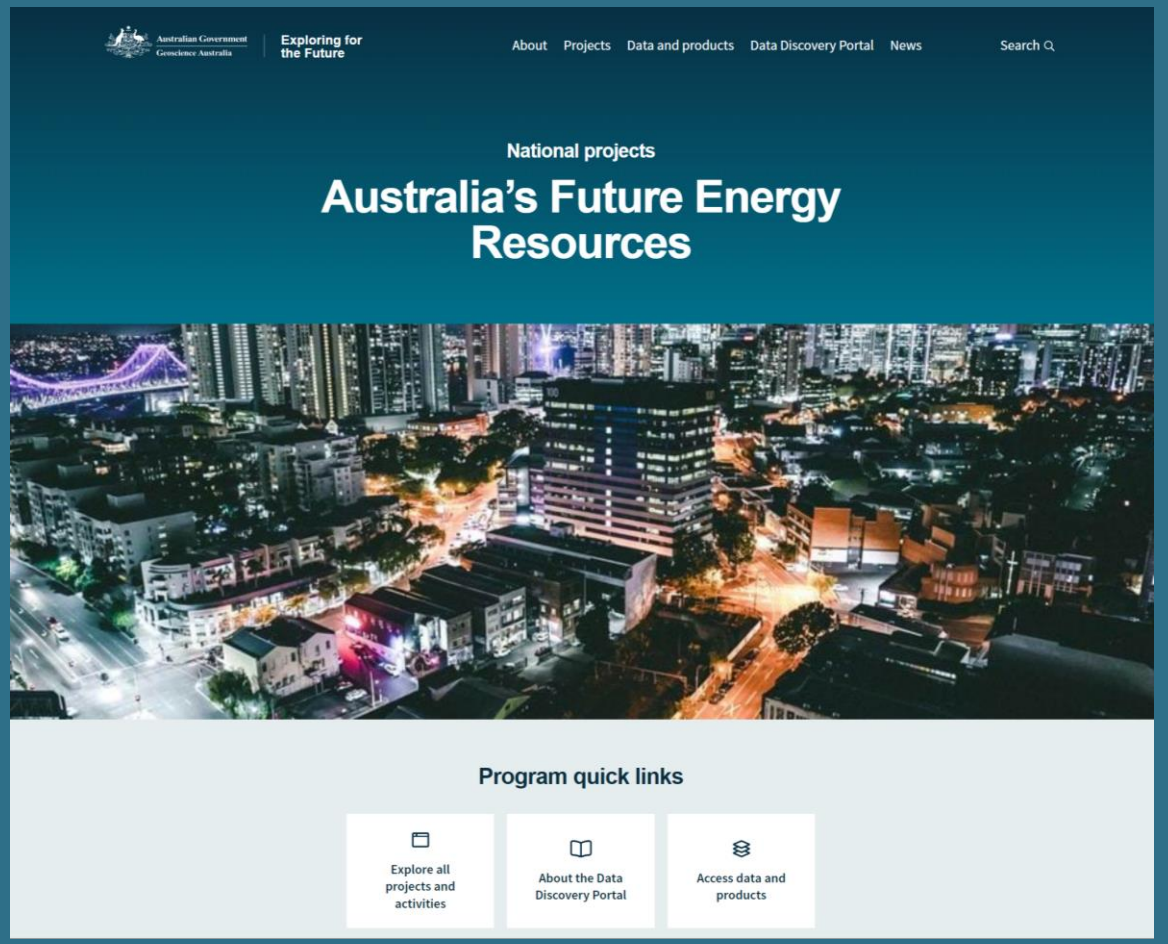

Further information

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