Enhanced Oil Recovery: Status and Potential in Australia

Dominic Pepicelli

South Australian Department for Energy and Mining

IEA EOR TCP – Copenhagen, Denmark

6th September 2018

Government of South Australia

Department for Energy and Mining

Disclaimer

The information contained in this presentation has been compiled by the Department for Energy and Mining (DEM) and originates from a variety of sources. Although all reasonable care has been taken in the preparation and compilation of the information, it has been provided in good faith for general information only and does not purport to be professional advice. No warranty, express or implied, is given as to the completeness, correctness, accuracy, reliability or currency of the materials.

DEM and the Crown in the right of the State of South Australia does not accept responsibility for and will not be held liable to any recipient of the information for any loss or damage however caused (including negligence) which may be directly or indirectly suffered as a consequence of use of these materials. DEM reserves the right to update, amend or supplement the information from time to time at its discretion.

SOUTH AUSTRALIA

Government of South Australia

Department for Energy and Mining

Contents

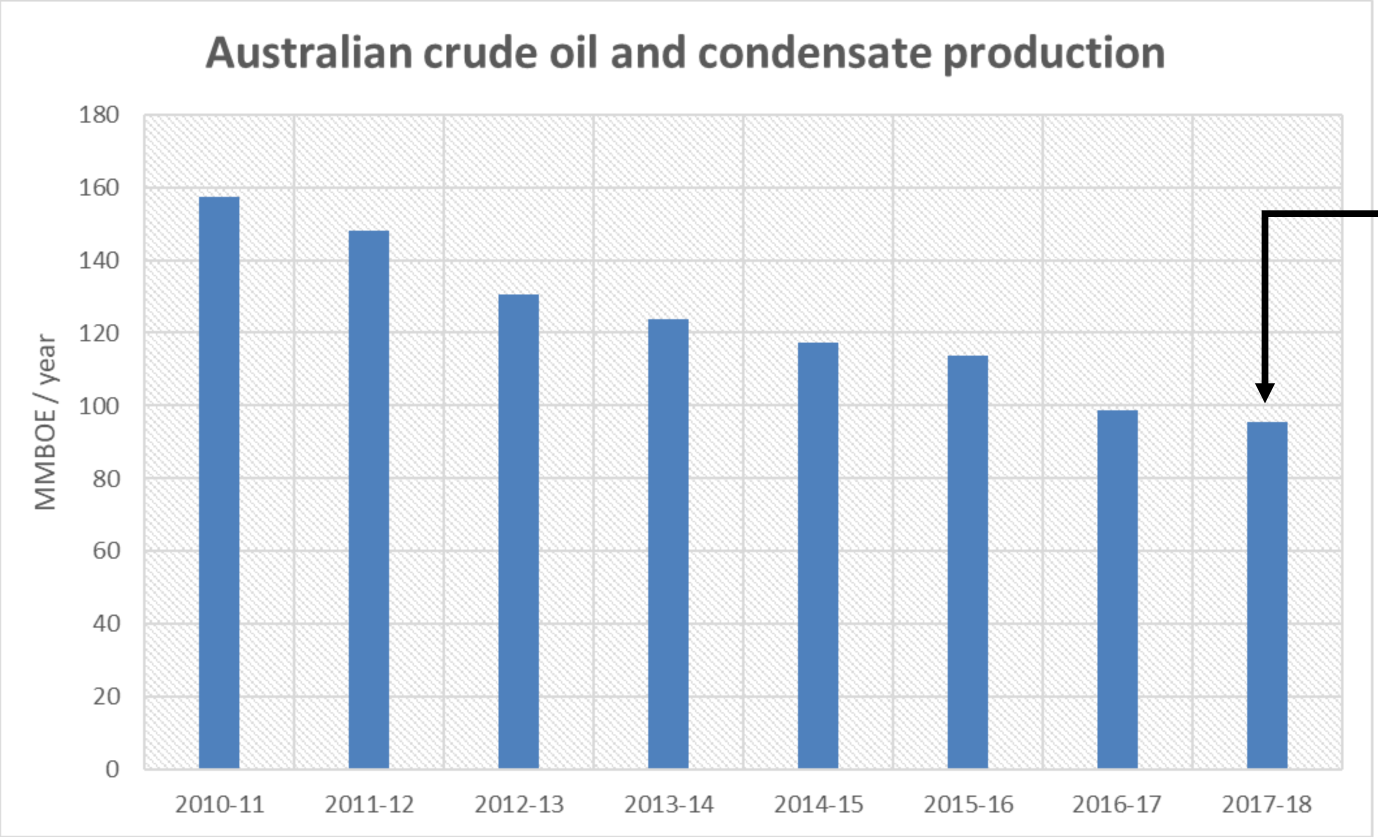
South Australia

Government of South Australia

Department for Energy and Mining

1. Status of EOR in Australia

Government of South Australia
Department for Energy and Mining



Australian Petroleum Statistics, June 2018

In October 2017 Australia's liquid fuel supply levels dropped to an equivalent 48 days of net imports – below the 90 day supply required by the International Energy Agency (IEA) Agreement on an International Energy Program (IEP), of which Australia is a signatory.

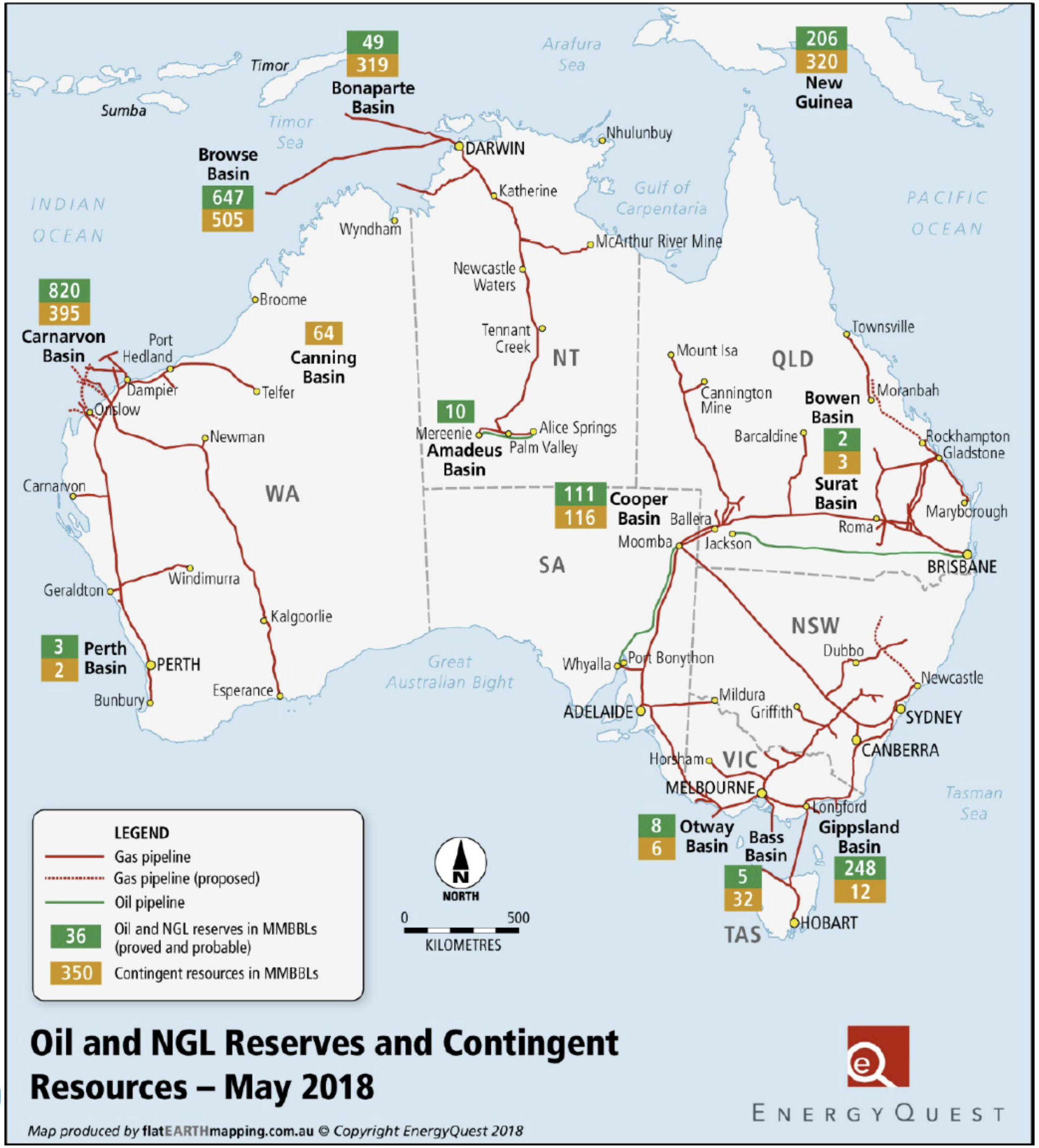
Australian Oil in Place

- Australian OIP = 12 billion barrels OIP (including offshore Browse Basin)
- Includes only oil in conventional reservoirs, not source rocks.

Basin	Location	Oil in Place million bbl
Gippsland	Offshore	5748
Carnarvon	Offshore	2852
Bonaparte	Offshore	627
Cooper	Onshore	759
Eromanga	Onshore	295
Surat	Onshore	96
Perth	Onshore	56
Offshore		9126
Onshore		1206
Total		10,433

Steve le Poidevin and Denis Wright, Geoscience Australia, 2005

- Australian 2P oil reserves = 1.9 billion barrels.



- In excess of 10 billion barrels remaining underground.

Polymer injection

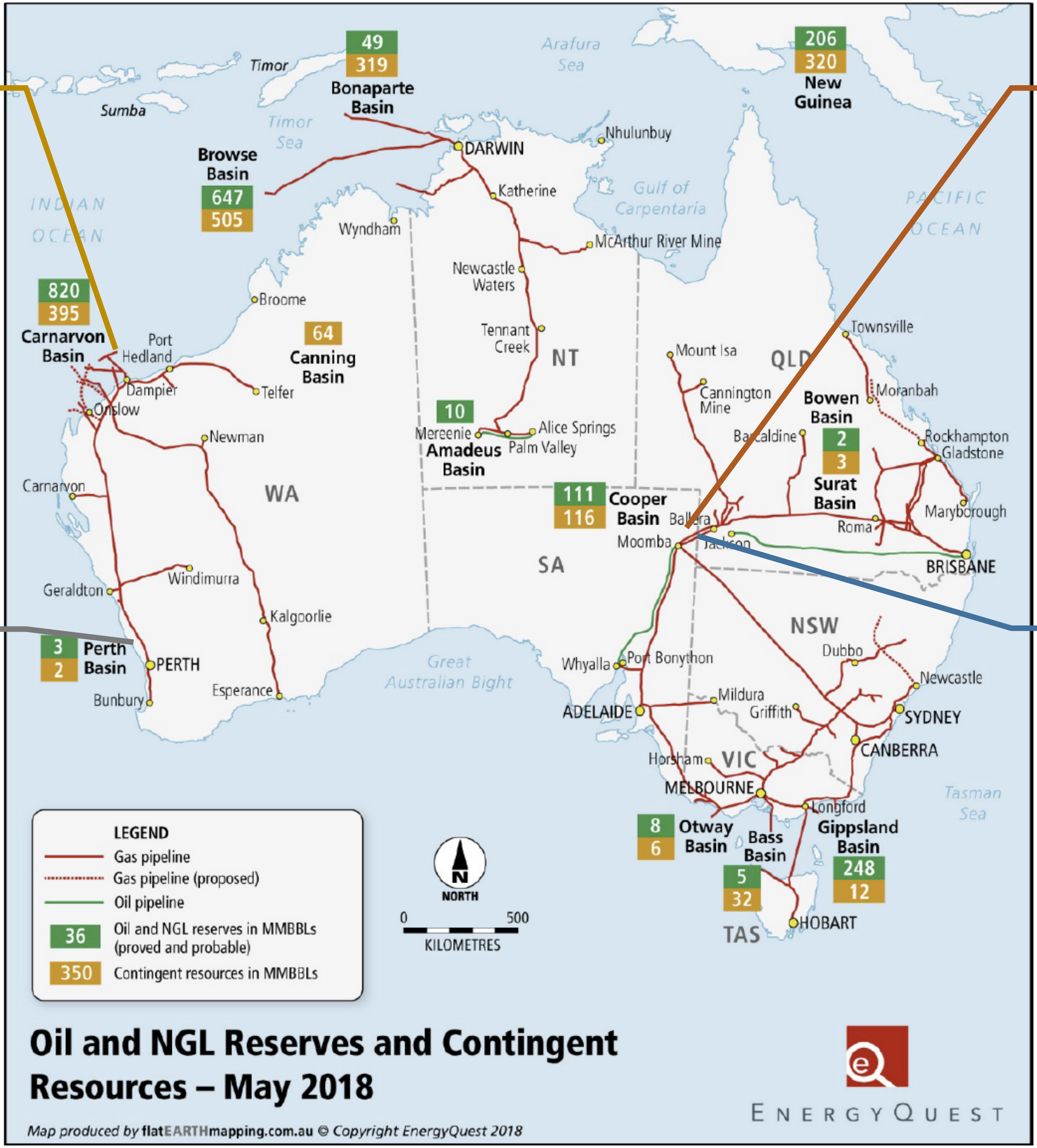
(field trial stage)

- Chevron

CO_2 foam injection
+
Surfactant injection

(research stage)

- Curtin University



CO_2 injection, including ROZ

(field trial stage)

- University of Adelaide
- University of New South Wales

Low-salinity water injection

(field trial stage)

- University of Adelaide

- Australian 2P gas reserves = 115,000 PJ or 20 billion barrels (oil equivalent).

- Includes gas in both conventional and unconventional reservoirs.

Natural Gas Reserves and Contingent Resources – May 2018

Map produced by flatEARTHmapping.com.au © Copyright EnergyQuest 2018

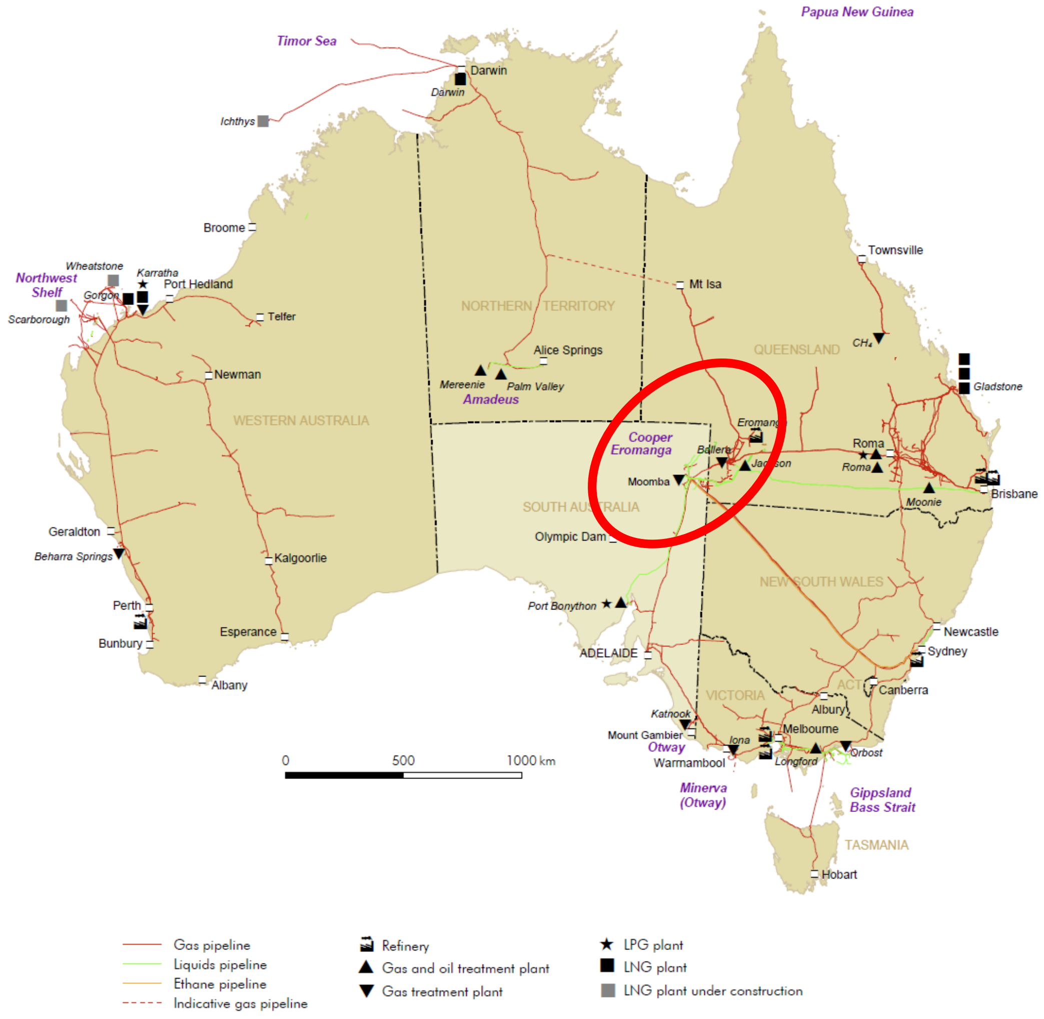
Microbial Enhancement of CSM

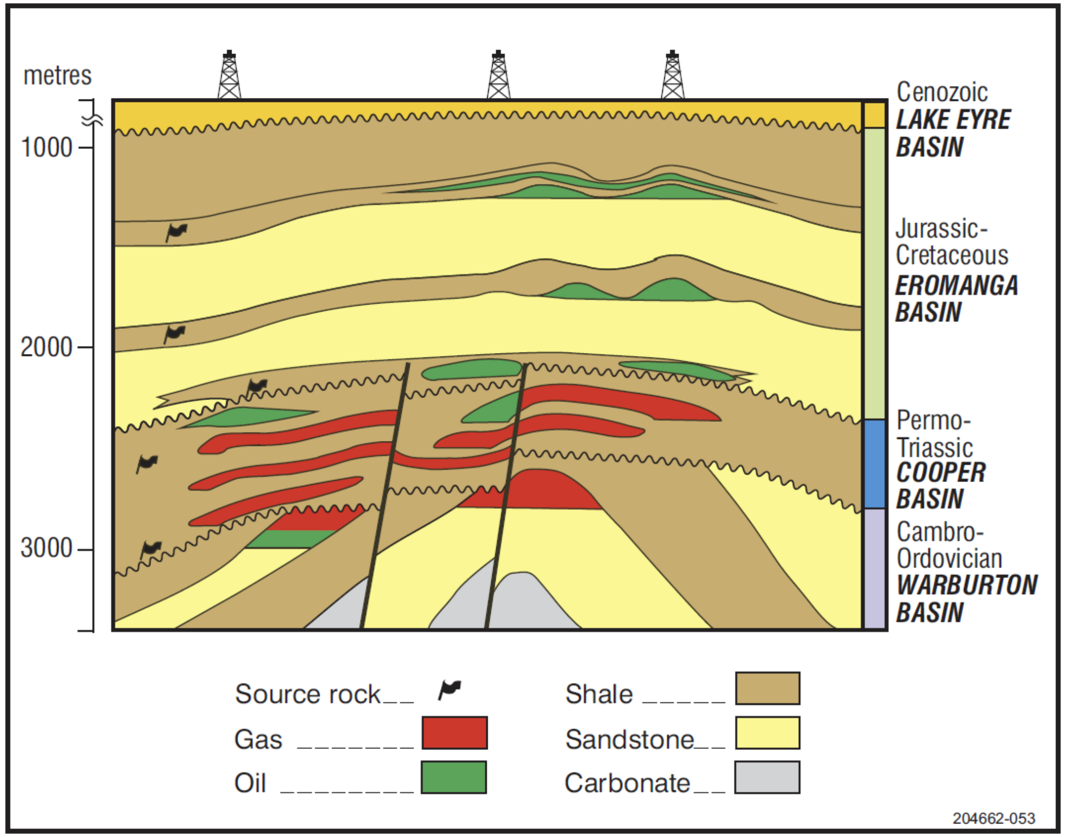
(field trial stage)

- CSIRO

2. Cooper and Eromanga Basin Potential

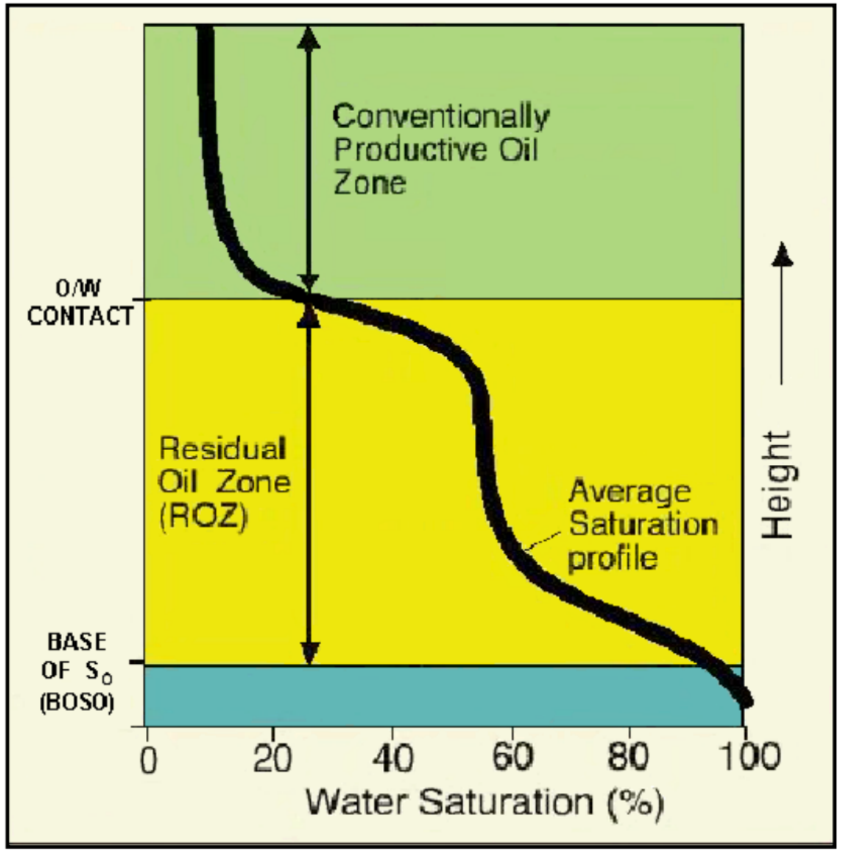
Government of South Australia
Department for Energy and Mining



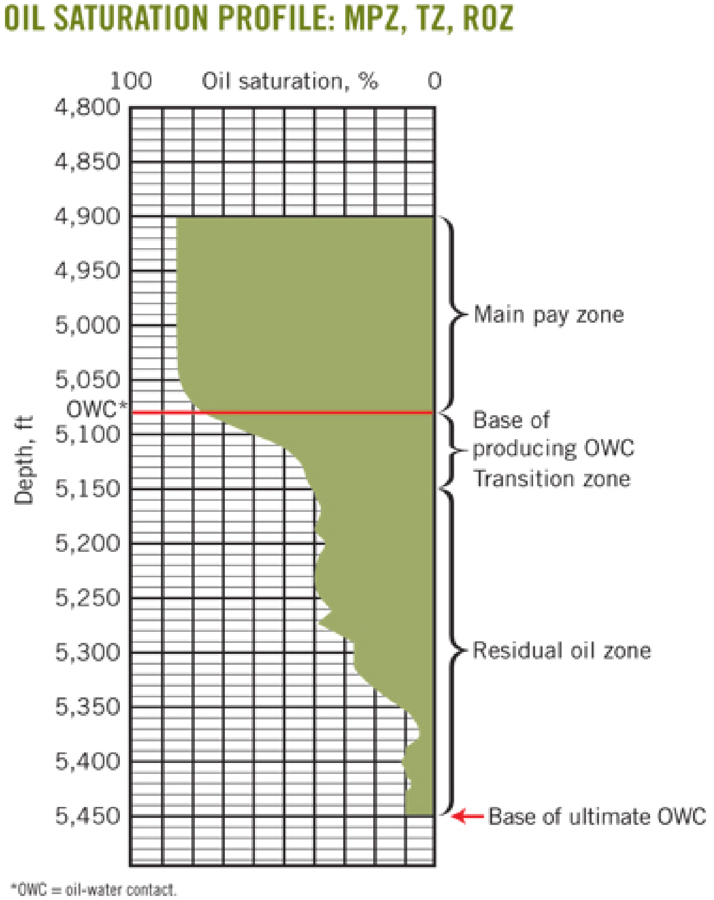


Conventional traps in the Cooper and Eromanga petroleum basins, DEM-ERD

2.1. CO_2 EOR in Residual Oil Zones (ROZ)

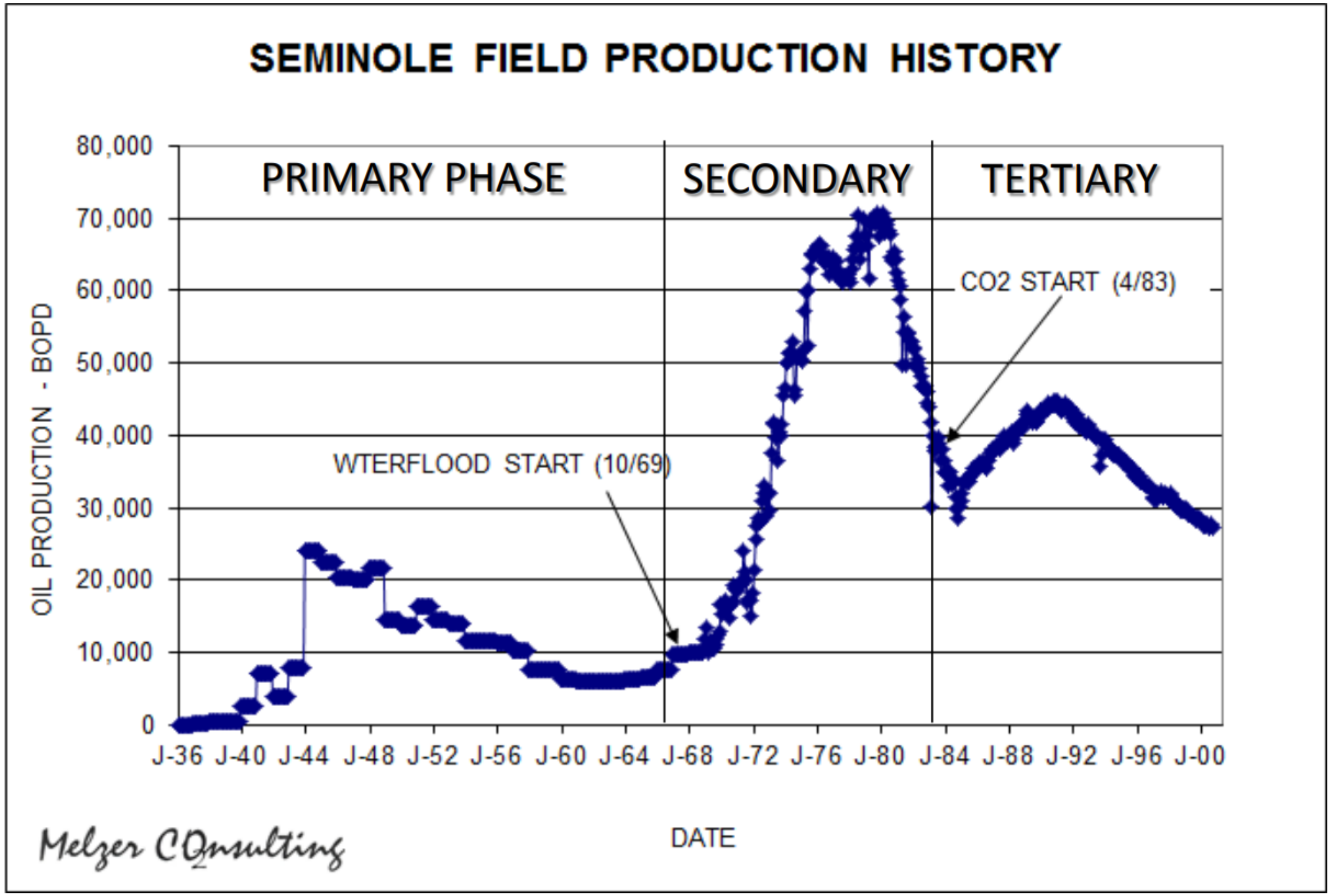


Seminole Field – Trentham et al., 2010



Wasson Field – Koperna and Kuuskraa, 2006

Production example from US Permian Basin



Melzer et al., 2013

ROZ types

- Regional or local basin tilt (Type 1):

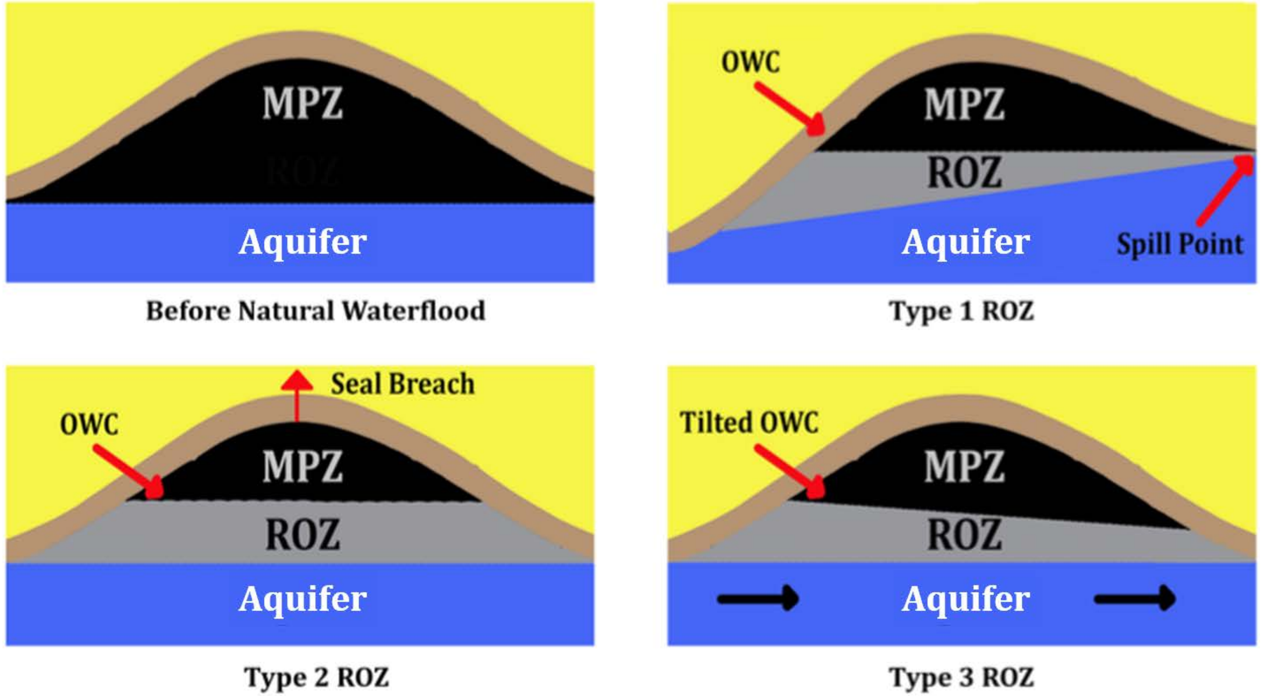
Regional basin tilt causes displacement of oil to a spill point via a natural water drive. The resulting ROZ is wedge shaped, and can contain large volumes of oil if tilt is significant or if the initial reservoir is extensive.

- Breached and reformed seals (Type 2):

In this case loss of oil is due to a seal breach, which may occur due to a build-up of fluid pressure or fault reactivation.

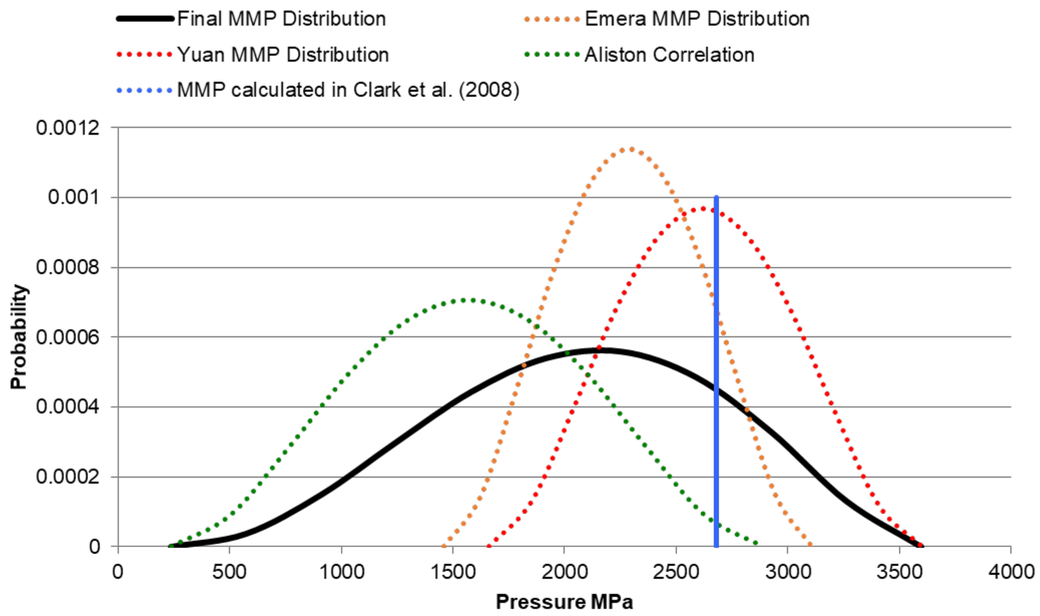
- Altered hydrodynamic flow fields (Type 3):

Most common form of ROZ in Texas' Permian basin. This arises due nearby or distant uplift, generating hydrodynamic forces that allow water to sweep the formation laterally, which creates tilted oil-water contact. The water migration fairways been mapped in the Permian basin to help identify residual oil zones. (Melzer *et al.*, 2006).

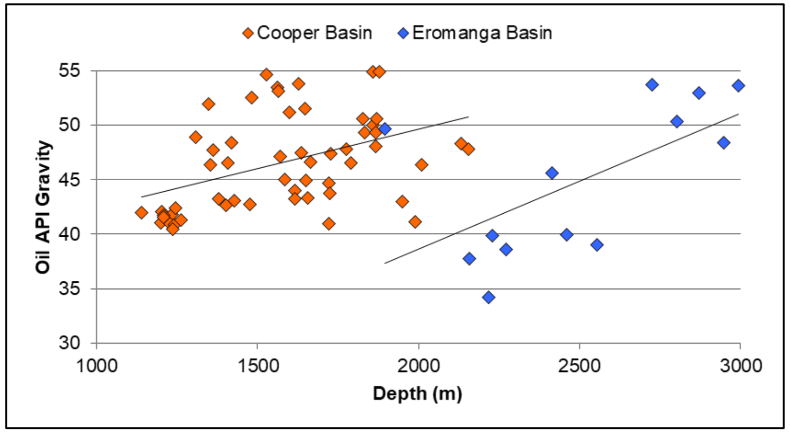


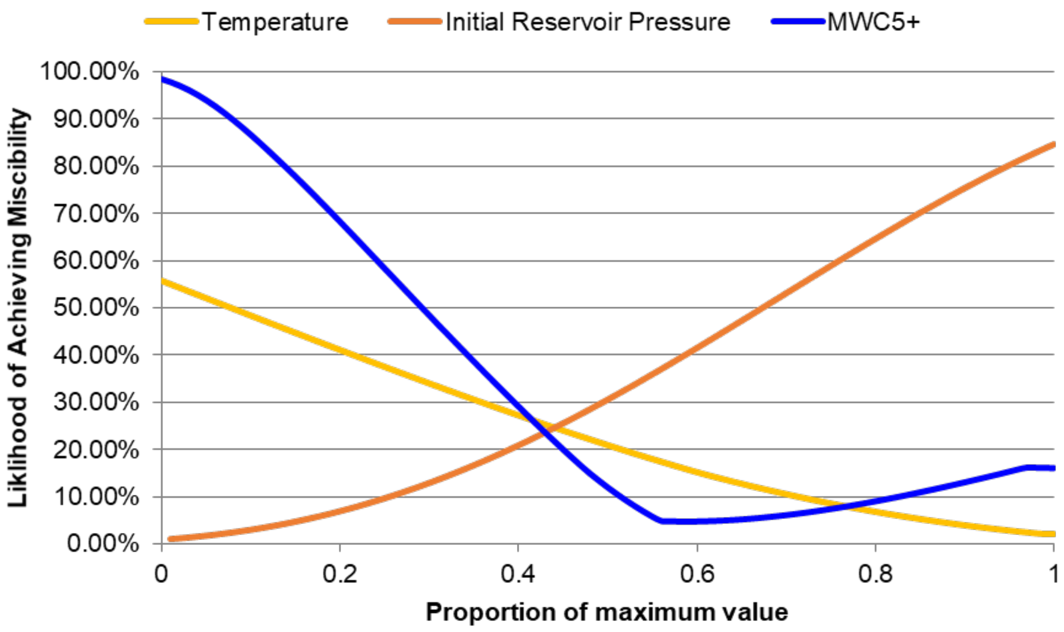
Processes of ROZ formation (natural waterflood) (adapted from Melzer *et al.*, 2006).

Screening for CO_2 miscibility



MMP distributions of the Tirrawarra field, accompanied by the slim tube MMP measured by slim tube tests (Clark *et al.*, 2008).





Screening study results extract

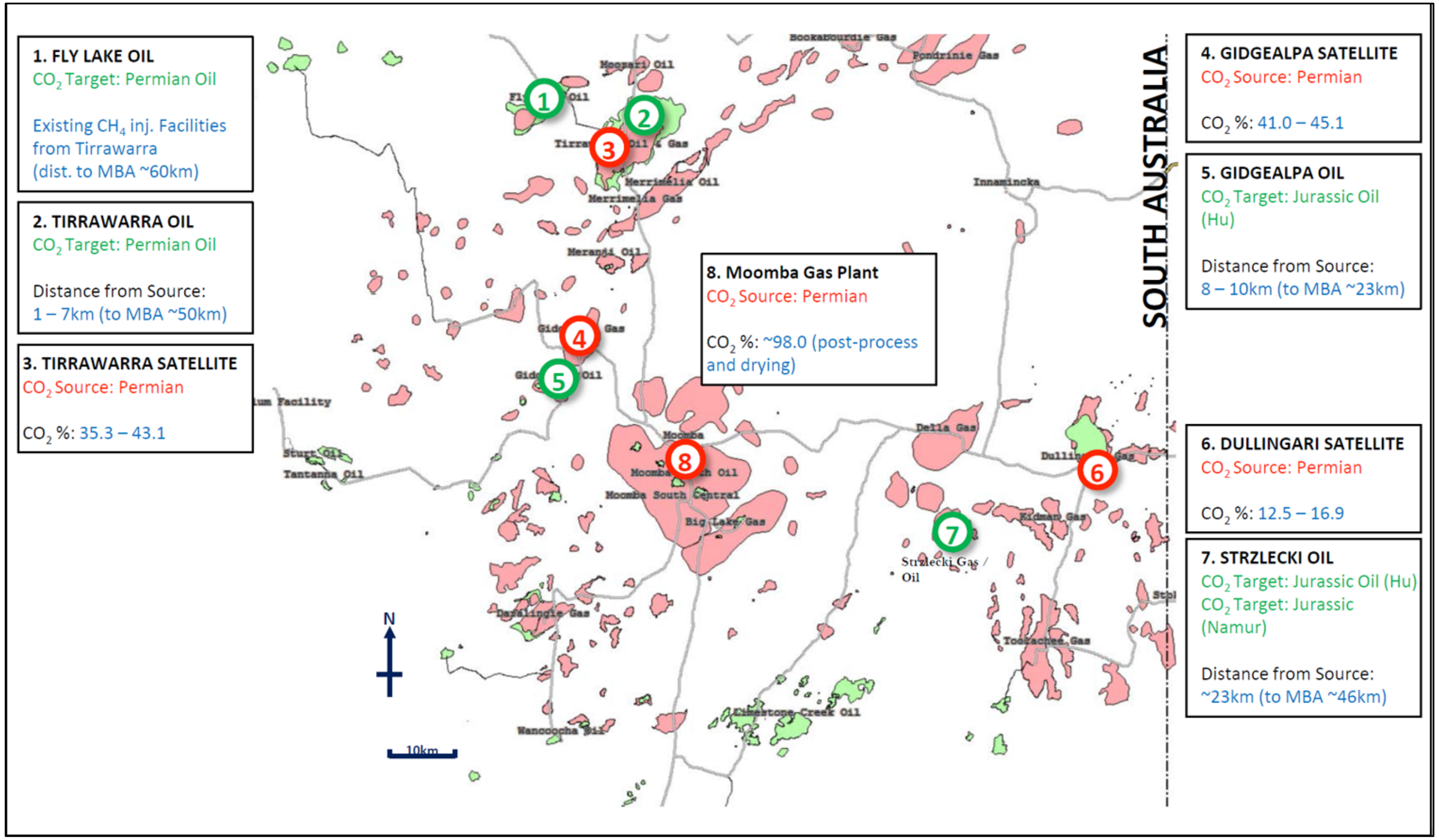
Very Low Potential	Low potential	Potential	High Potential	Very High Potential

1	2	3	4	5	6	7
Field	**Formation**	**Depth** (m)	**Temperature** (°C)	**API gravity**	**MW$_{C5+}$** (g/mol)	**Initial Reservoir Pressure** (MPa)

8	9	10	11	12
MMP (MPa) (Alston *et al.*, 1985) – $X_{Vol}/X_{Int} = 1$	**MMP** (MPa) (Yuan *et al.*, 2005) – $X_{Vol}/X_{Int} = 1$	**MMP** (MPa) (Emera, 2006) – $X_{Vol}/X_{Int} = 1$	**Most likely MMP** (MPa) - $X_{Vol}/X_{Int} = 1$	**Likelihood of achieving miscibility** - $X_{Vol}/X_{Int} = 1$
MMP (MPa) (Alston *et al.*, 1985) – Typical gas	**MMP** (MPa) (Yuan *et al.*, 2005) – Typical gas	**MMP** (MPa) (Emera, 2006) – Typical gas	**Most Likely MMP** (MPa) – Typical gas	**Likelihood of achieving miscibility** – Typical gas

1	2	3	4	5	6	7	8	9	10	11	12
Arrakis	Birkhead	1867	95	48	164	19.0	18.7	14.7	16.7	16.7	70.69%
							18.6	13.5	15.5	15.9	74.91%
Big Lake	Birkhead	1950	130	43	179	19.5	23.2	21.7	24.5	23.1	23.72%
							23.1	18.9	21.9	21.3	40.34%
Big Lake	Hutton	2008	136	46	191	19.8	24.6	26.4	28.5	26.5	5.08%
							24.4	21.9	24.5	23.6	22.81%
Big Lake	Namur	1728	119	47	159	17.4	19.8	17.1	20.1	19.0	37.71%
							19.8	14.2	17.4	17.1	57.48%
Bookabourdie	Birkhead/ Hutton	2132	102	48	160	20.7	16.3	12.8	15.6	14.9	89.08%
							16.3	9.7	12.5	12.8	94.91%
Brolga	Patchawarra	2872	114	53	126	29.2	15.5	11.0	14.7	13.7	99.00%
							15.5	7.6	11.0	11.4	99.00%
Calamia West	Hutton	1476	99	43	196	15.1	24.1	21.7	22.1	22.7	0.85%
							24.0	21.0	21.4	22.1	1.82%
Calamia West	Murta	1204	81	42	211	12.3	21.8	20.1	19.4	20.4	3.62%
							21.7	17.7	17.5	18.9	9.76%

Cooper-Eromanga basin field % CO_2



CO2 EOR ROZ Conclusions

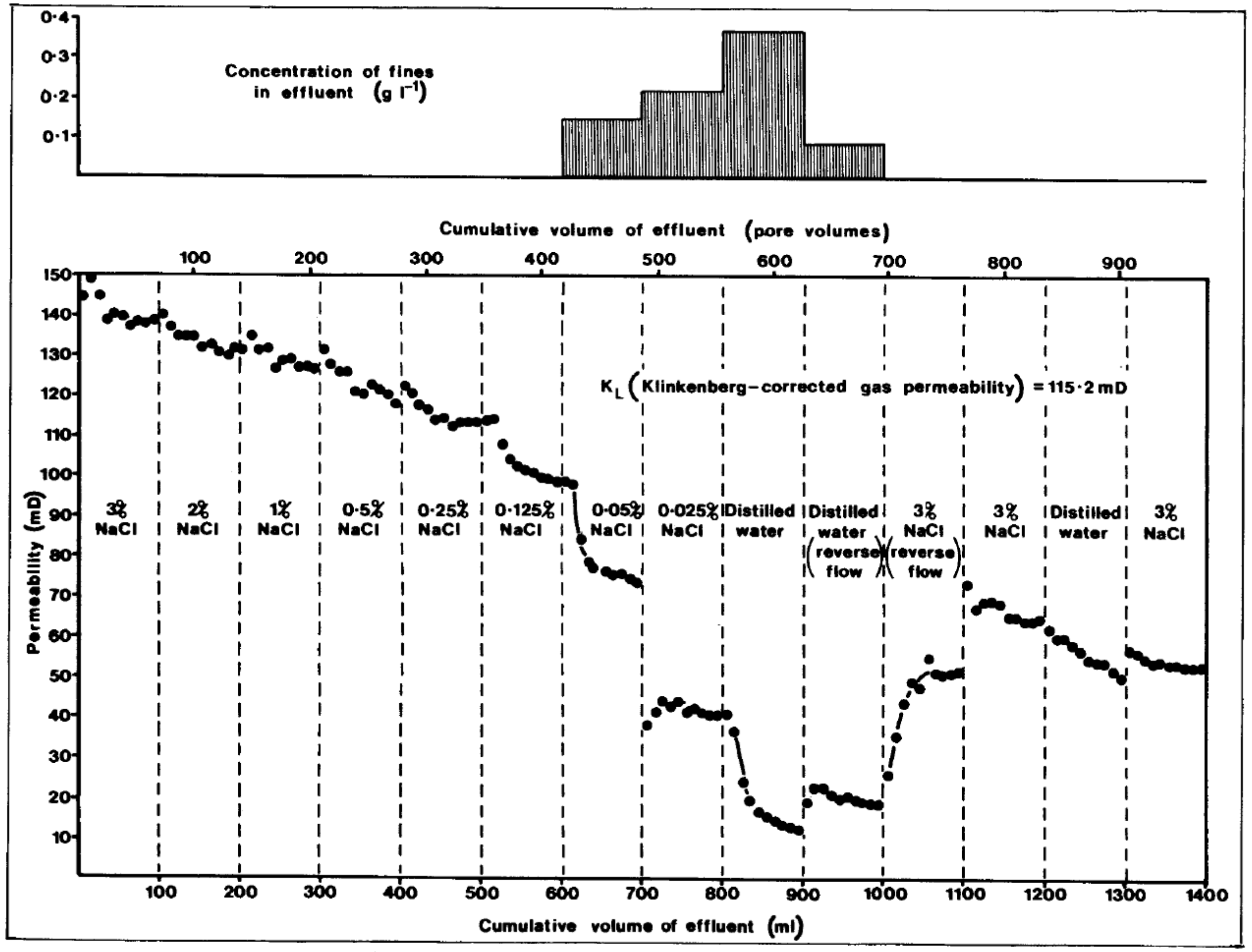
- All reservoirs in the Cooper-Eromanga Basin system passed the screening criteria of reservoir depth, reservoir temperature, and oil API gravity, established in previous literature.
- The Cooper-Eromanga Basin system appears to be well suited for CO_2 EOR.
- There is a significant amount of uncertainty associated with the current data. More accurate screening would require improved methods of data collection and analysis.
- Further work must be done in order to validate these results with laboratory studies.
- Field trials planned.

2.2. Fines-Assisted Low-Salinity Waterflooding (LSW) in Sandstone Reservoirs

- Classical Physics of LSW (N. Morrow, J. Buckley, T. Austad, T. Puntervold, S. Strand, H. Mahani, et al.) – Sor reduction by wettability alteration, i.e. LSW is a Chemical EOR

- Fines-Assisted LSW (P. Bedrikovetsky, A. Zeinijahromi, et al.) – sweep enhancement by induced fines migration and permeability decline, i.e. LSW is also a Mobility-Control EOR

Core permeability declines as salinity decreases



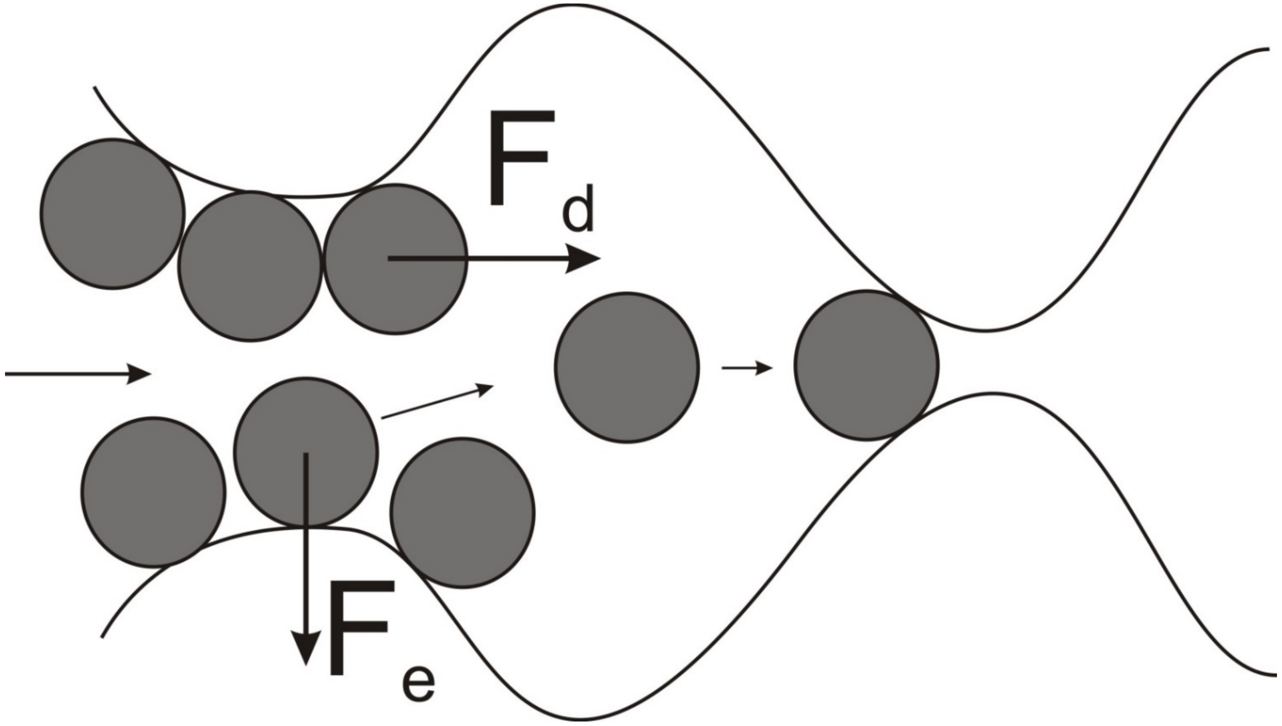
Lever and Dawe, 1984

- Sequential injection of water with decreasing salinity – drastic permeability decrease is accompanied by fines production

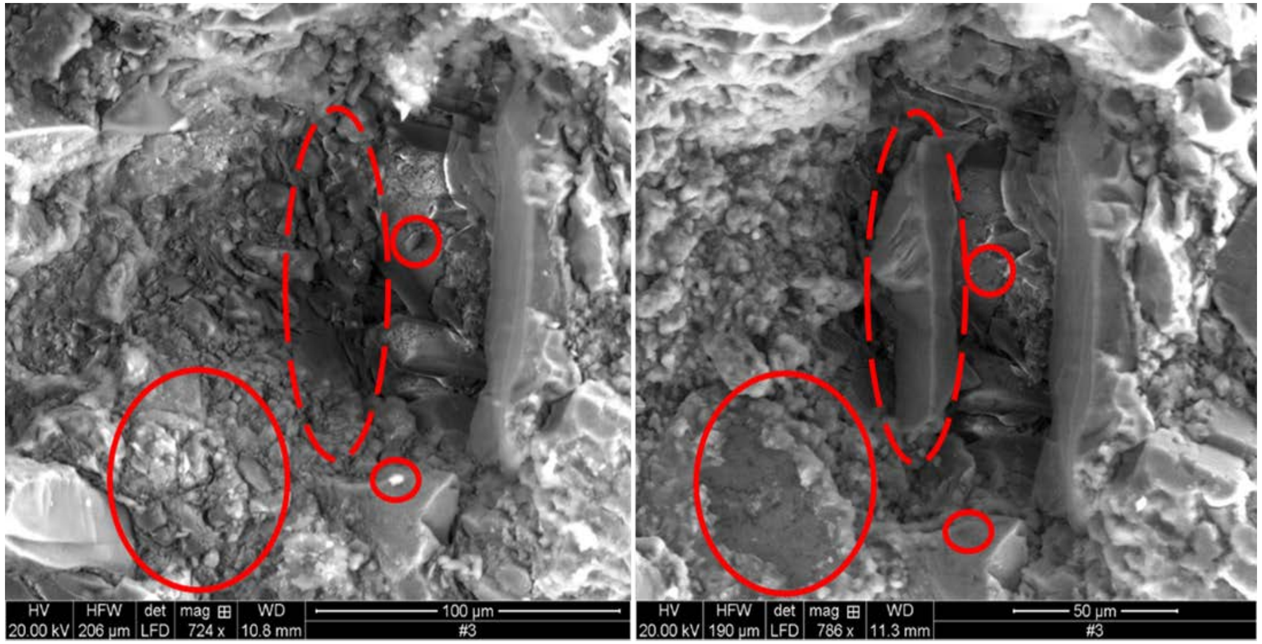
Permeability decline due to fines mobilization, migration and straining

- Plugging of thin pores by lifted and migrating fine particles; Fd – drag force, Fe – electrostatic force.

- Decreasing salinity weakens attaching Fe and lifts fines

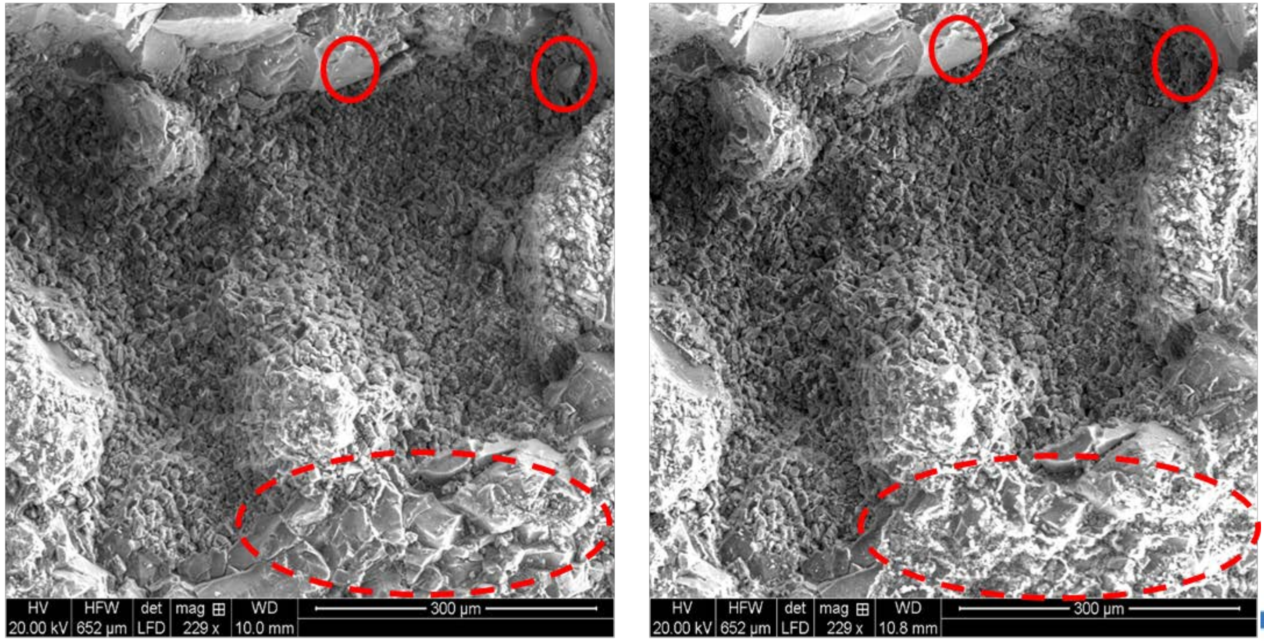


Muecke 1979; Sarkar, Sharma 1990; Khilar, Fogler 1994-1999; Civan 1996-2010



(a) (b)

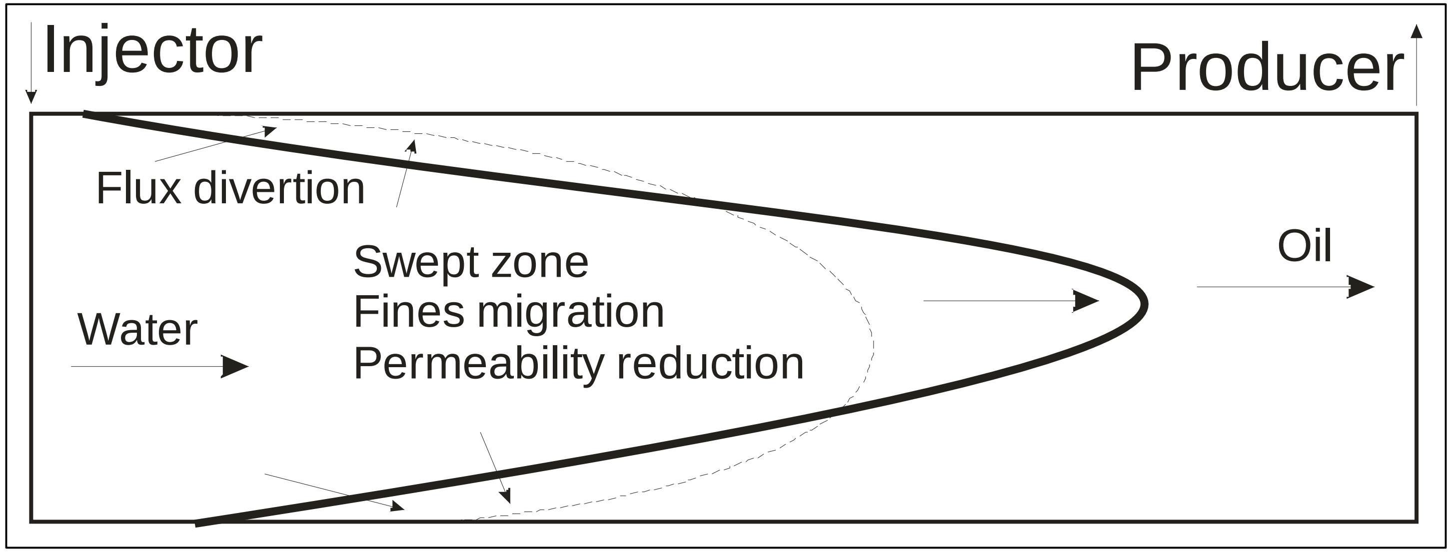
Inlet SEM images of Core 1: (a) taken before the coreflooding experiment and (b) taken afterwards. Here the solid circles show those particles that are present in (a) but have disappeared in (b). The dashed circle in (b), highlights a newly captured particle after the experiment.



(a) (b)

Inlet SEM images of Core 2: (a) taken before the coreflooding experiment and (b) taken afterwards. Here the solid circles show those particles that are present in (a) but have disappeared in (b). The dashed circle in (b), highlights newly captured particles after the experiment.

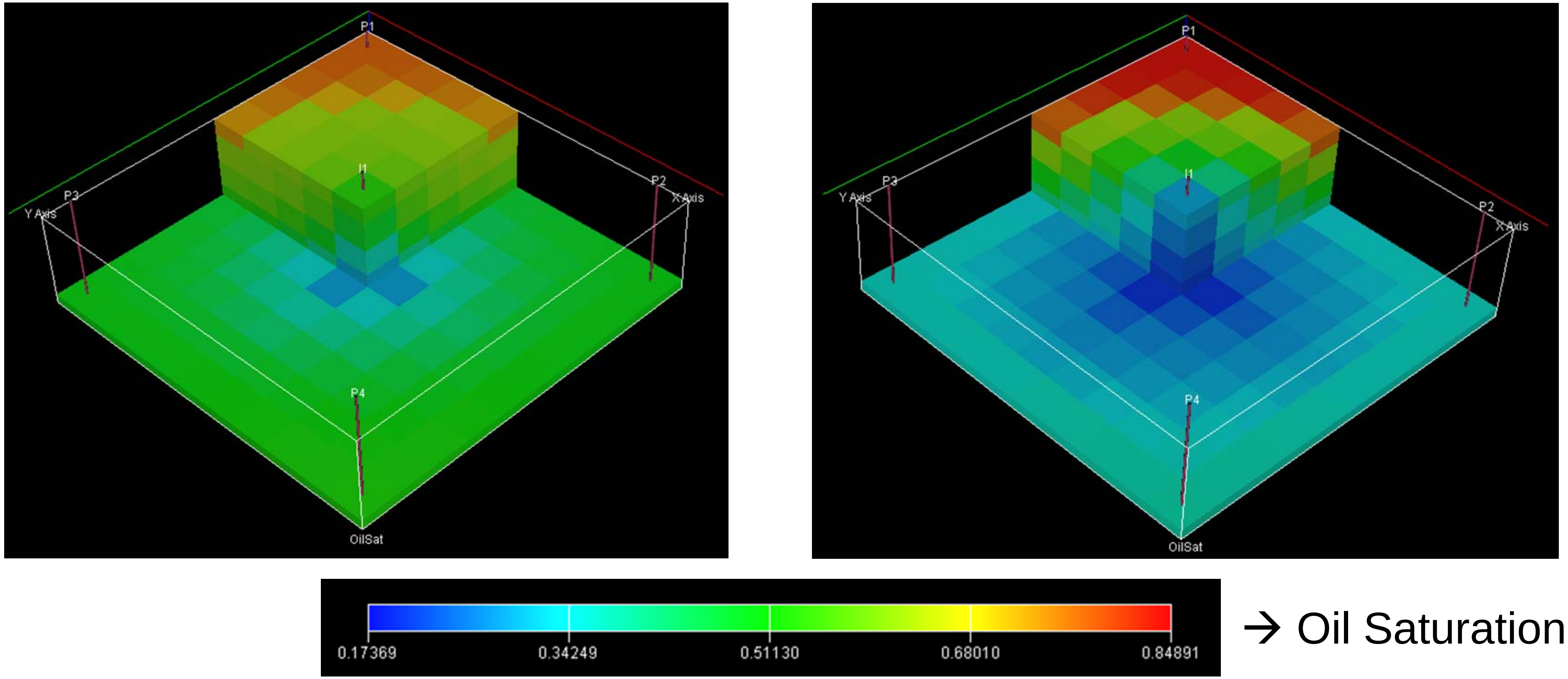
Fines-migration-assisted mobility control and produced water management



- Fines release yields the induced permeability decline in the swept zone, slowing water down and increase in sweep efficiency
- Analogy with polymer injection => mapping of fines migration equations on the polymer option of the Black-oil model

Zeinijahromi and Bedrikovetsky, J Canad Petr Techn Sept 2011

Improved sweep in 5-spot 5-layer-cake reservoir

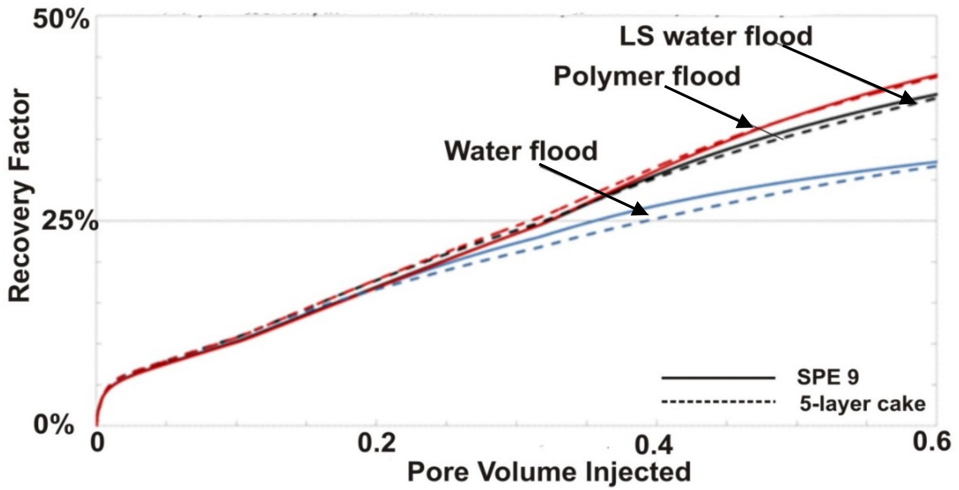


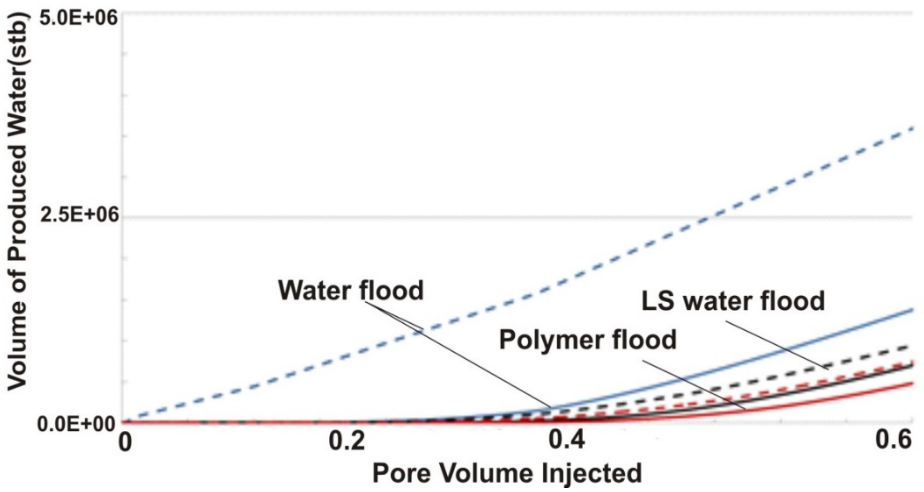
→ Oil Saturation

- Normal (left) and low-salinity (right) fines-assisted waterflooding after 0.4 PVI – results of 3D reservoir simulation by Eclipse

Yuan and Shapiro, J Petr Sci Eng 2012, Zeinijahromi and Bedrikovetsky, J SPEJ (19) 2013

Comparison between polymer flood, normal and fines-assisted waterfloodings (Daqing field)





- 8% incremental recovery with low-salinity fines-assisted waterflood if compared with normal waterflooding against 11% for polymer flooding

- 4-6 fold decrease in volumes of injected & produced water

Seright et al, J SPE REE 2008

Fines-Assisted Low-Salinity Waterflooding Conclusions

- Wettability alteration and fines migration are two independent processes. One, both or none of them can occur.

- Deliberate fines migration by low salinity waterflooding induces water blocking and formation damage yields:
  - sweep increase with 5-9% of incremental recovery and
  - 4-6-times reduction in injected and produced water volumes

- These conclusions are supported by micro-scale physics theory, mathematical modelling, laboratory experiments, field data and 3d reservoir simulation.

- Field pilots planned for the Cooper and Eromanga basins.

3. Summary

- Oil production in Australia is declining, however there is still a significant volume of oil remaining in-situ.

- Potential for various forms of EOR exists around Australia, in particular for the onshore Cooper and Eromanga basins.
  - CO_2 injection (including residual oil zones).
  - Fines-assisted low-salinity waterflooding.

- Research ongoing with pilots planned.

Thank you

Dominic Pepicelli, Principal Reservoir Engineer

Department for Energy and Mining

11 Waymouth Street
Adelaide, South Australia 5000

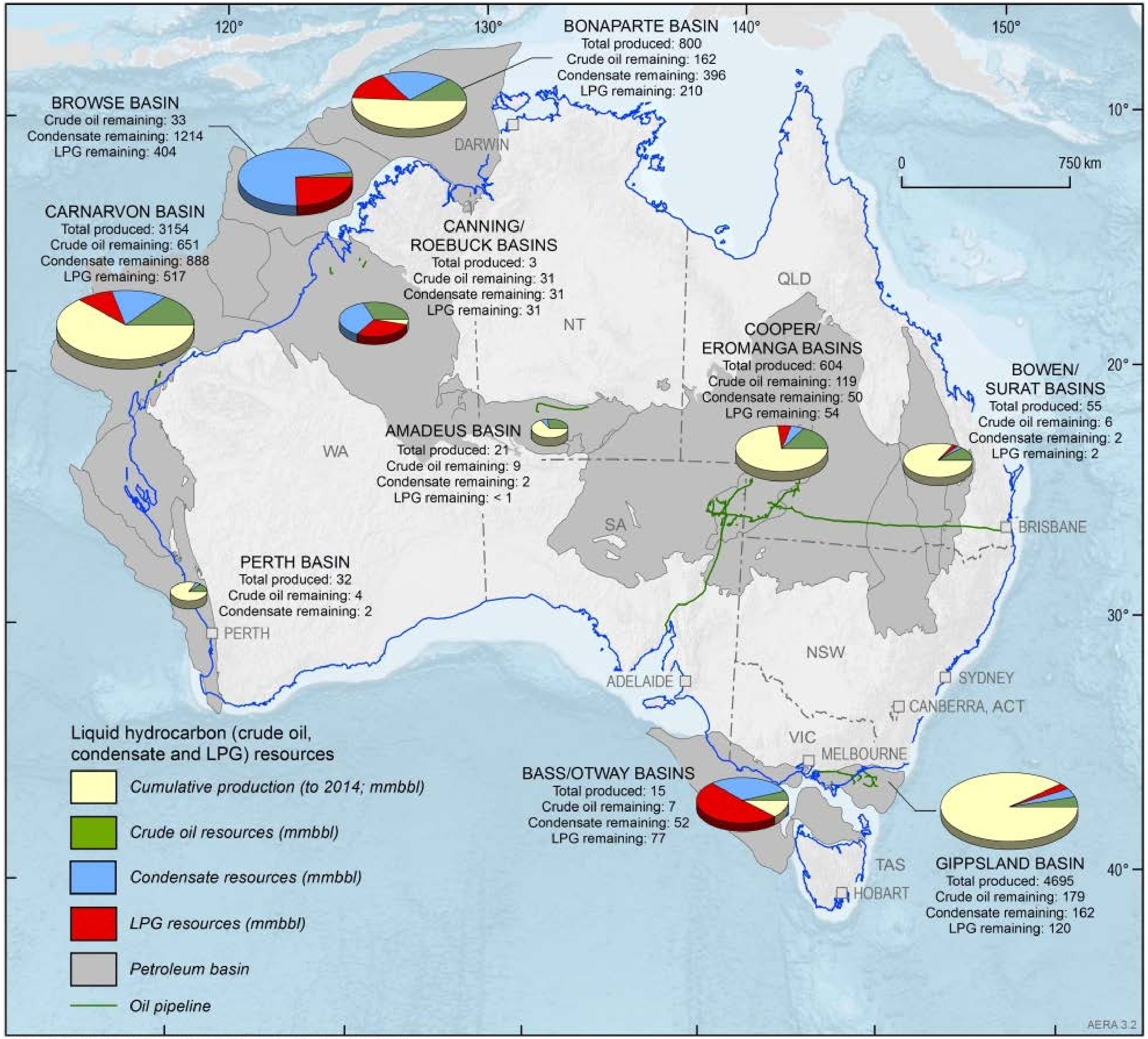
GPO Box 320
Adelaide, South Australia 5001

T: +61 8 8429 2619

E: dominic.pepicelli@sa.gov.au

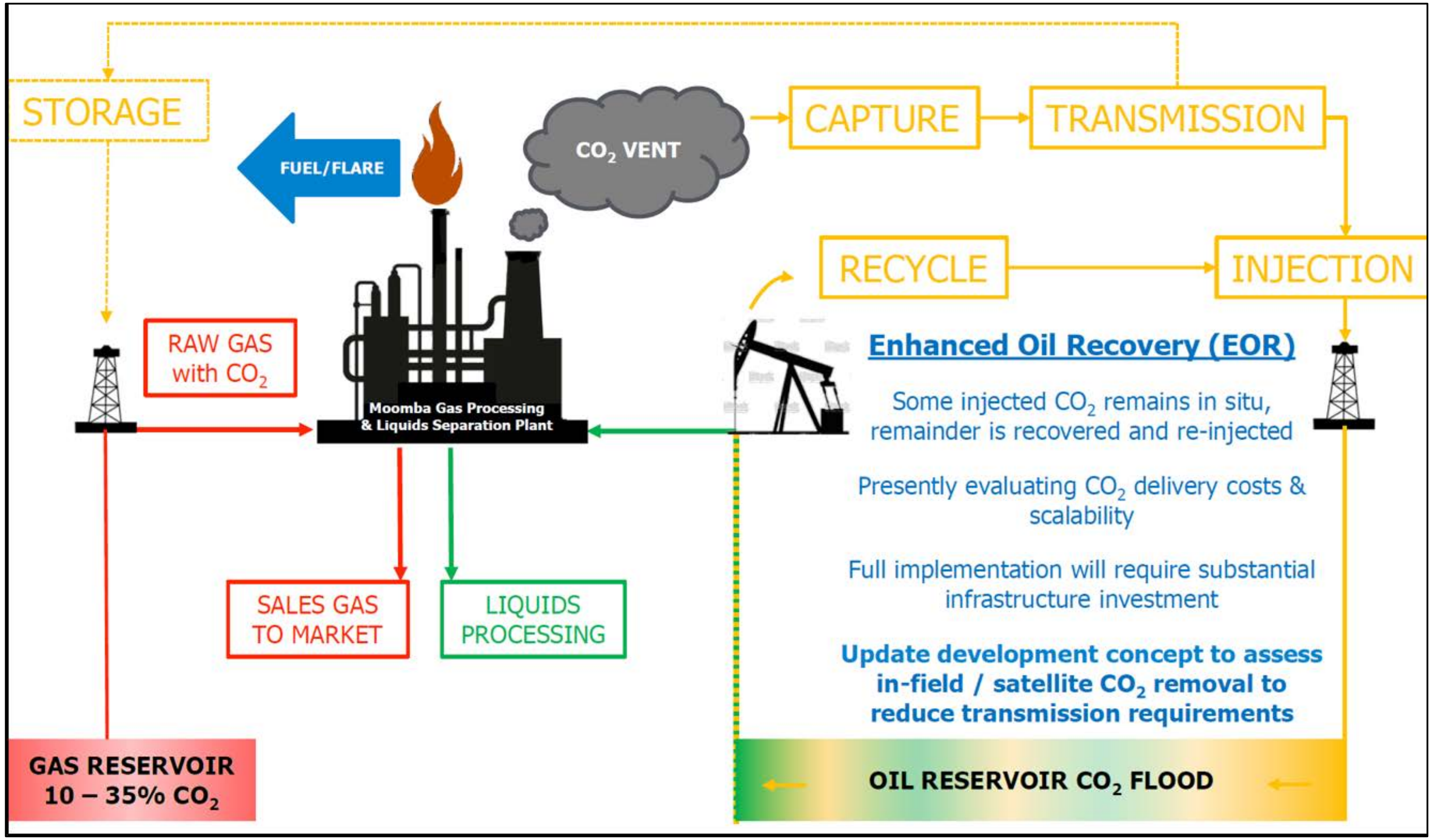
Government of South Australia
Department for Energy and Mining

Back up slides

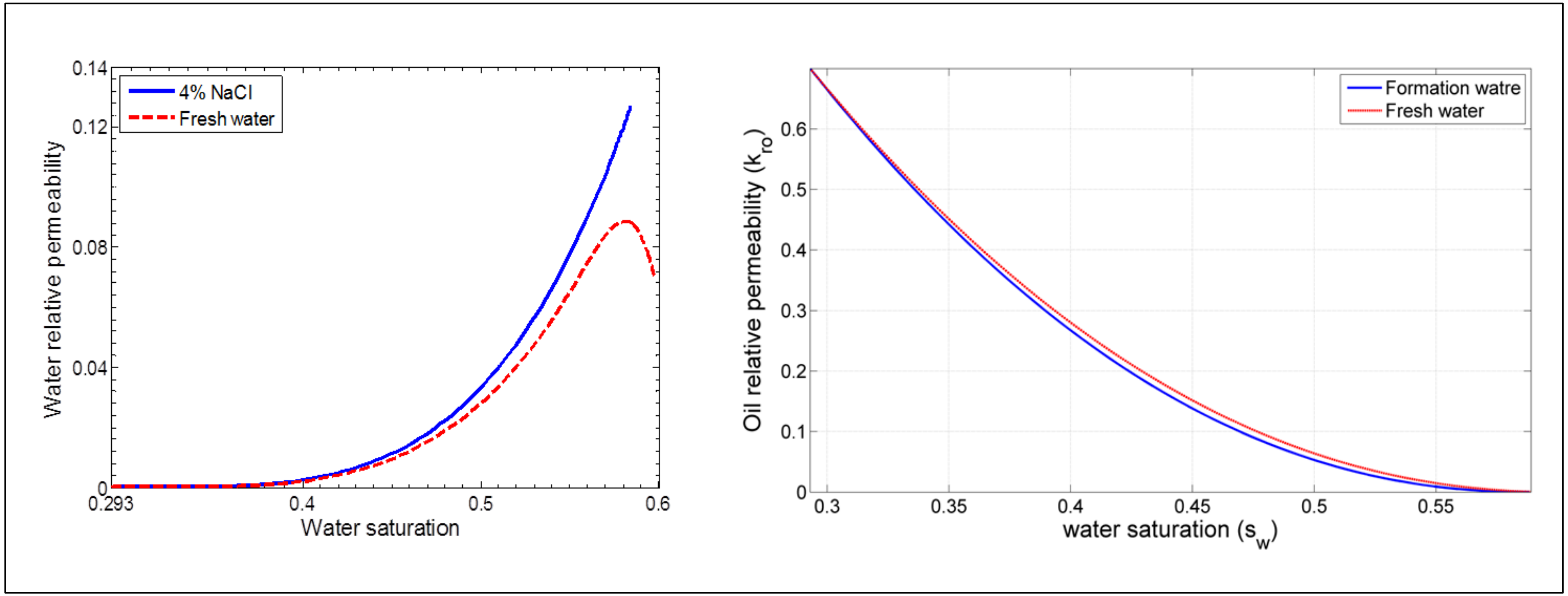


Source: Geoscience Australia, Encom GPinfo, a Datamine Australia Pty Ltd.
Whilst all care is taken in the compilation of the petroleum pipelines by Datamine, no warranty is provided re the accuracy or completeness of the information, and it is the responsibility of the Customer to ensure, by independent means, that those parts of the information used by it are correct before any reliance is placed on them. Accurate at August 2017.

CO2 EOR operational scenario

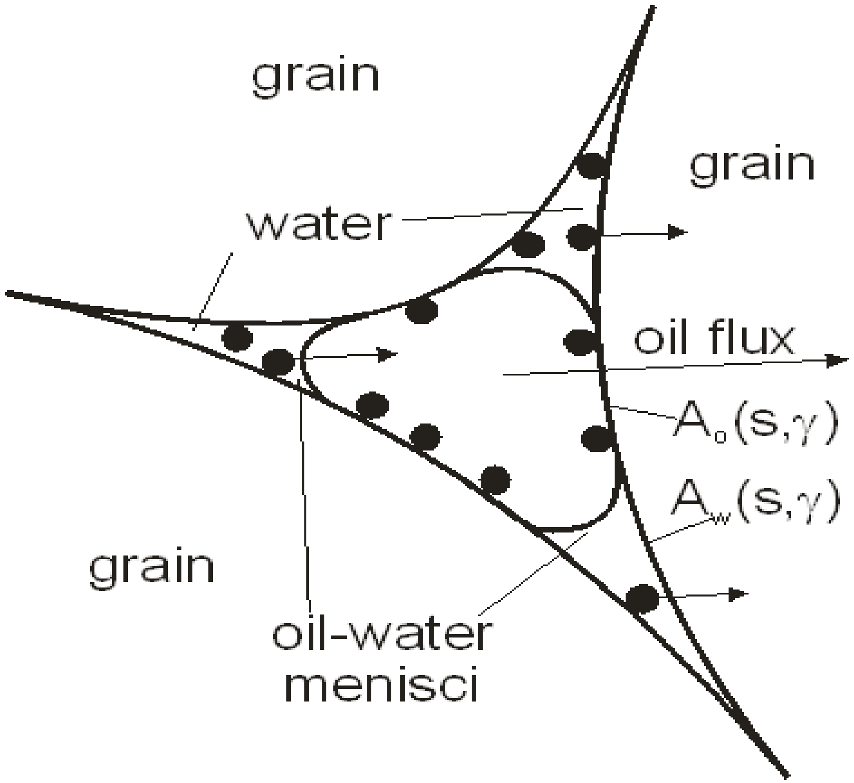


Results of coreflood data treatment



- Typical shape of rel perms during formation water flooding
- 2-10 times decrease of rel perm for water during low-salinity fines-assisted waterflood -> water deceleration, mobility control IOR
- How to explain non-monotonic rel perm for water?

Non-monotonic relative permeability for water during fines-assisted waterflood



- Gradual increase of water-accessible rock surface and continuous release of fines during low-salinity fines-assisted water flooding

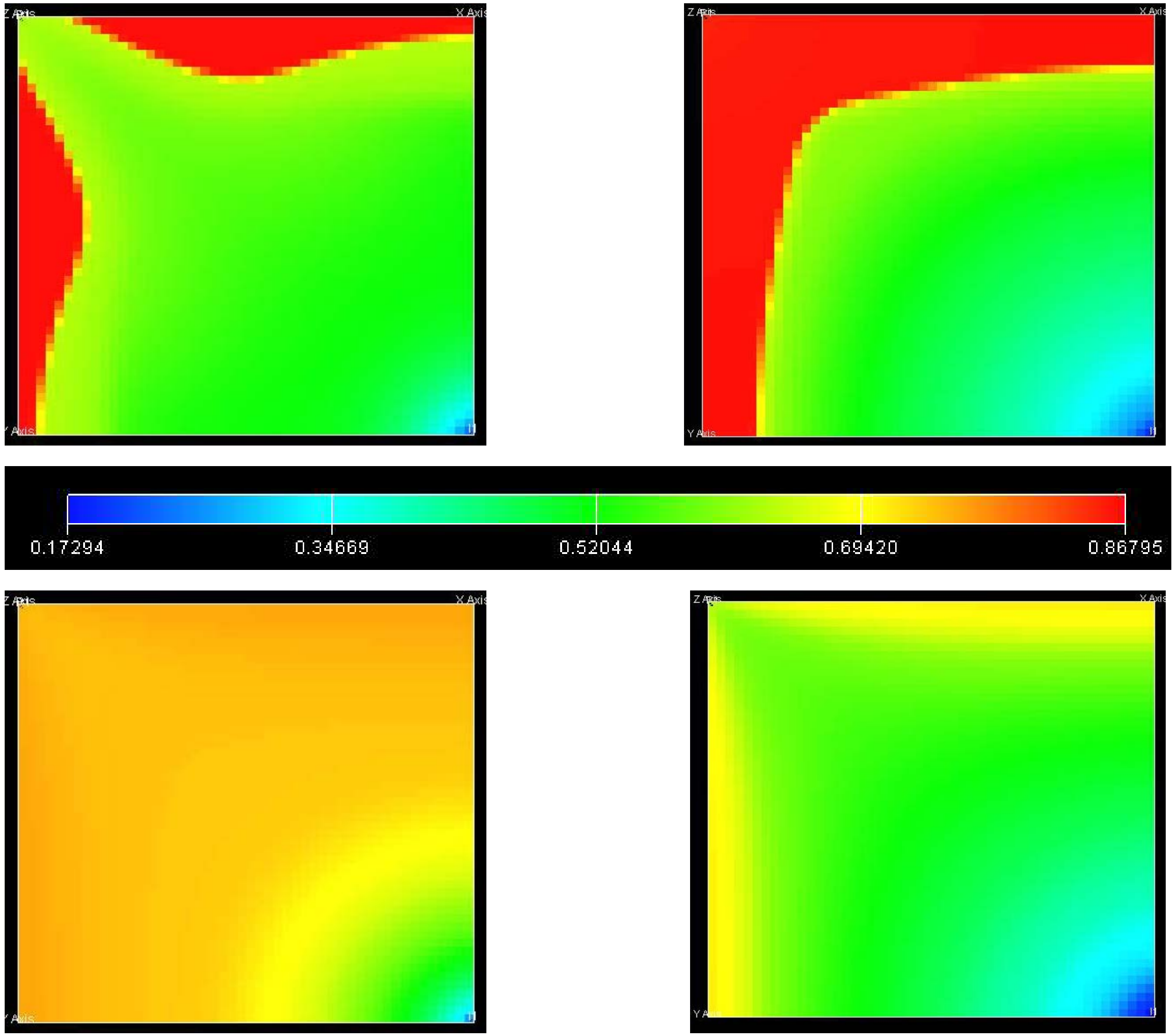
Yuan and Shapiro, J Petr Sci Eng 2012, Zeinijahromi and Bedrikovetsky, J SPEJ (19) 2013

Improved sweep in 5-spot

0.3 PVI

Fresh Water flooding

Normal Water Flooding



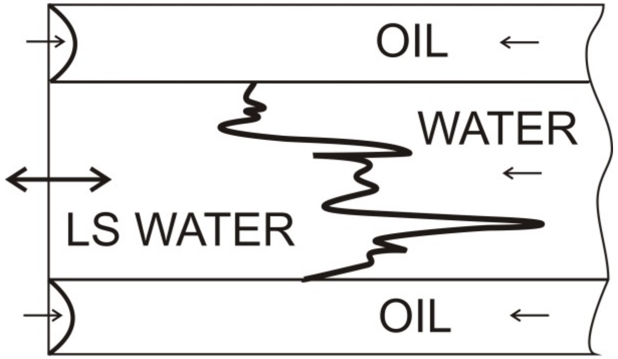
→ Oil Saturation

0.6 PVI

Water shut-off in oil and gas production by low-salinity water injection

- Rationale: fines mobilisation during huff; drastic permeability decline during both huff and puff

- High capillary pressure in low permeable layers prevents the water entering the “viscous-oil zones”. The injected water enters the water-production intervals



- Screening: best applied in mixed-wet and oil wet reservoirs with high viscosity oil (>20 cp)

- Results: 3 (4)-day injection of lake water caused water-cut reduction from 0.86 (0.84) to 0.71 (0.72). The effects last for 7 (4) months