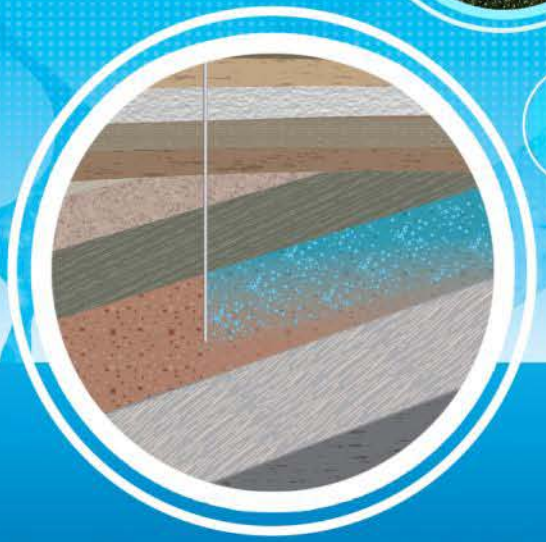
Physical exploration methods and site characterisation



Presenter
Dr Mark Bunch

Cooperative Research Centre for Greenhouse Gas Technologies (CO2CRC)

CAGS Summer School
Wuhan, Hubei province, China
1st November 2010

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China Australia Geological Storage of CO_2

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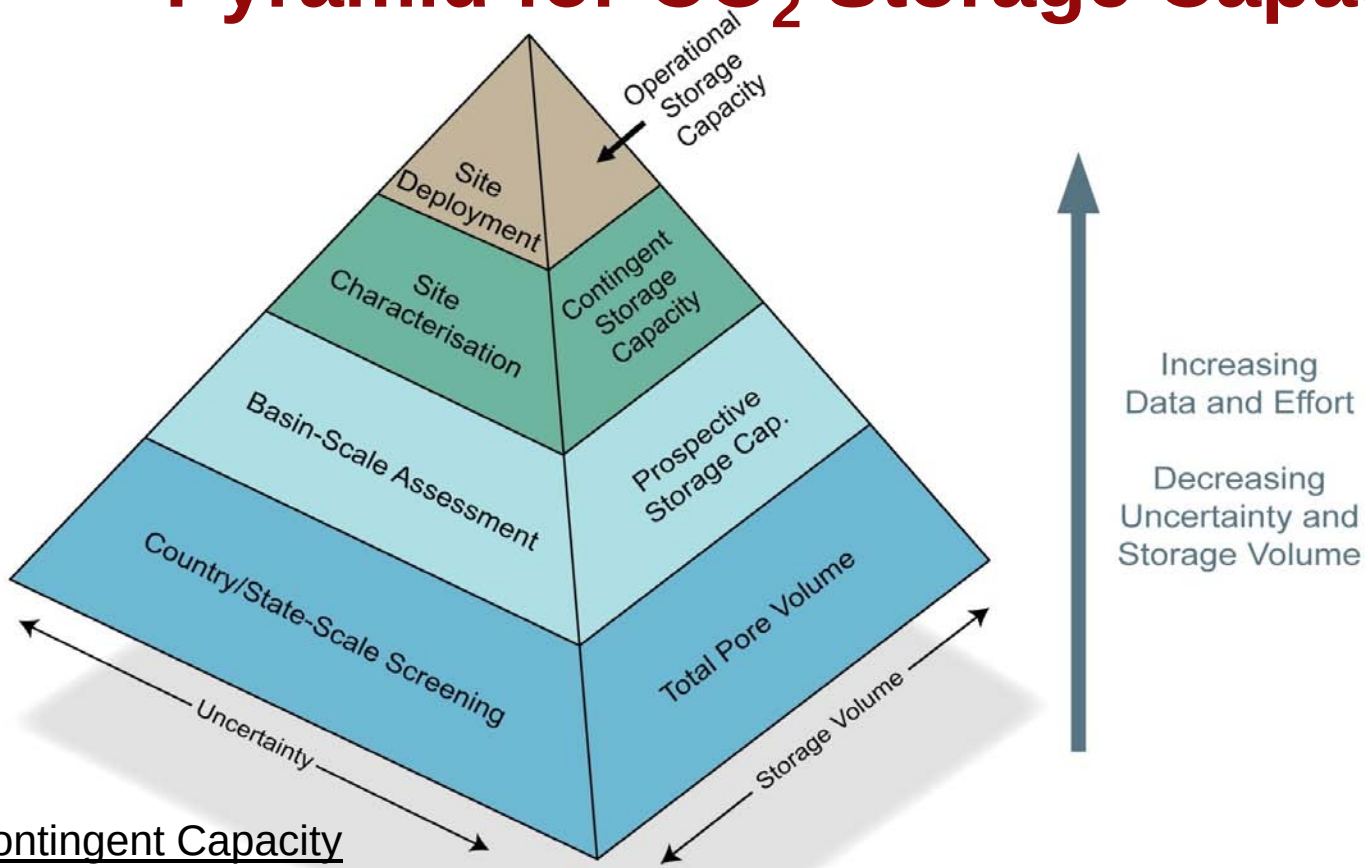
Techno-Economic Resource-Reserve Pyramid for CO_2 Storage Capacity



CO2CRC, 2008
Modified from Bachu et al., CSLF, 2005

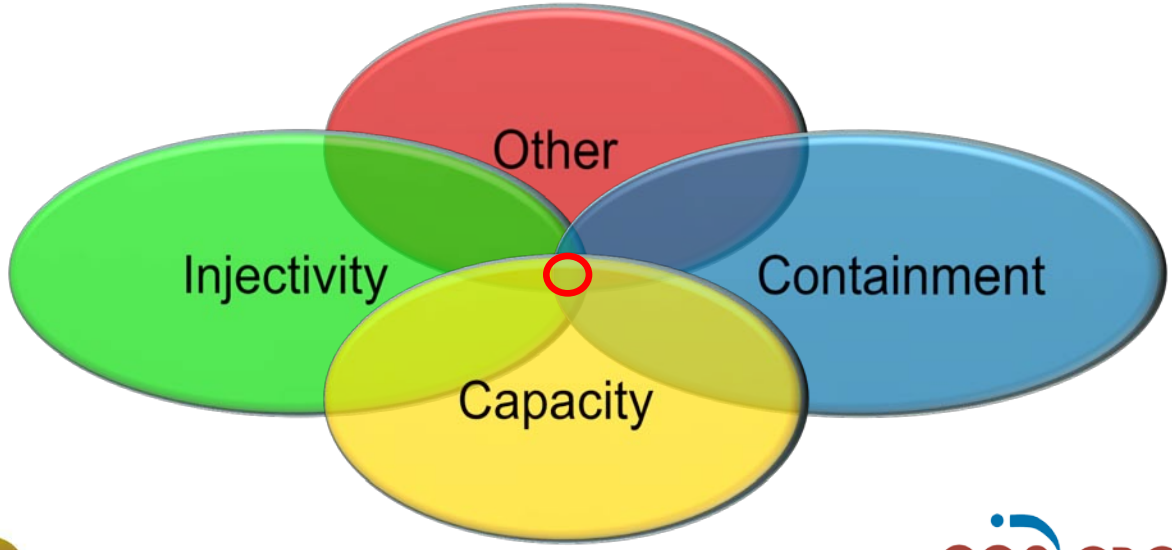
Contingent Capacity

- Subset of prospective capacity obtained by considering technical, legal and regulatory, infrastructure and general economic barriers.
- Value prone to changes as technology, policy, regulations and/or economics change.

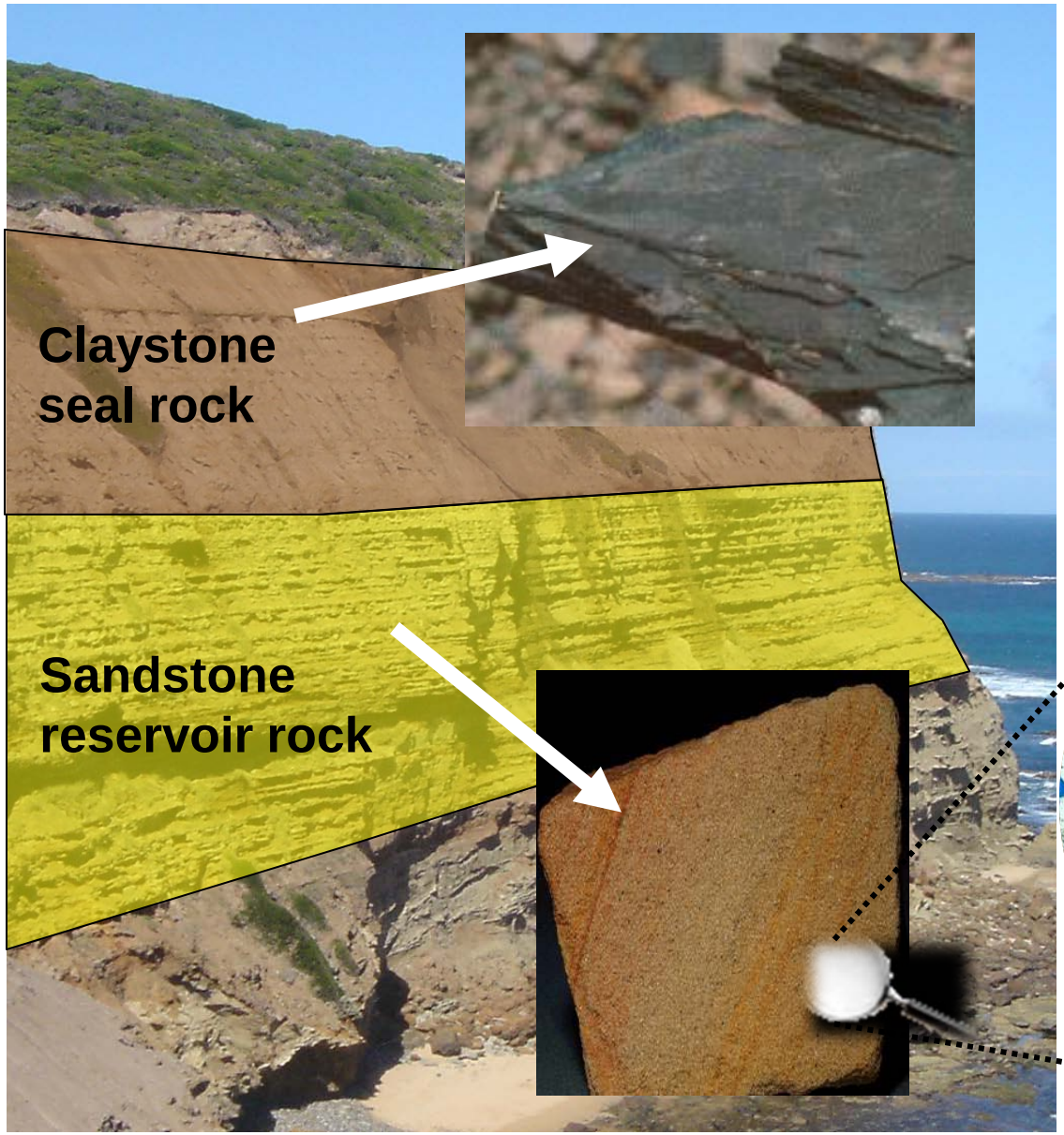
Corresponds to "Reserves" as used in energy and mining industries

Criteria for Site Selection (In All Geological Storage Systems):

- **Capacity (what volume of CO_2 can the rock hold?)**
- **Containment (can we keep the CO_2 in the rock?)**
- **Injectivity (can we put the CO_2 into the rock?)**
- **Other (Economic, Regulatory, Risk, Legal, Community…)**



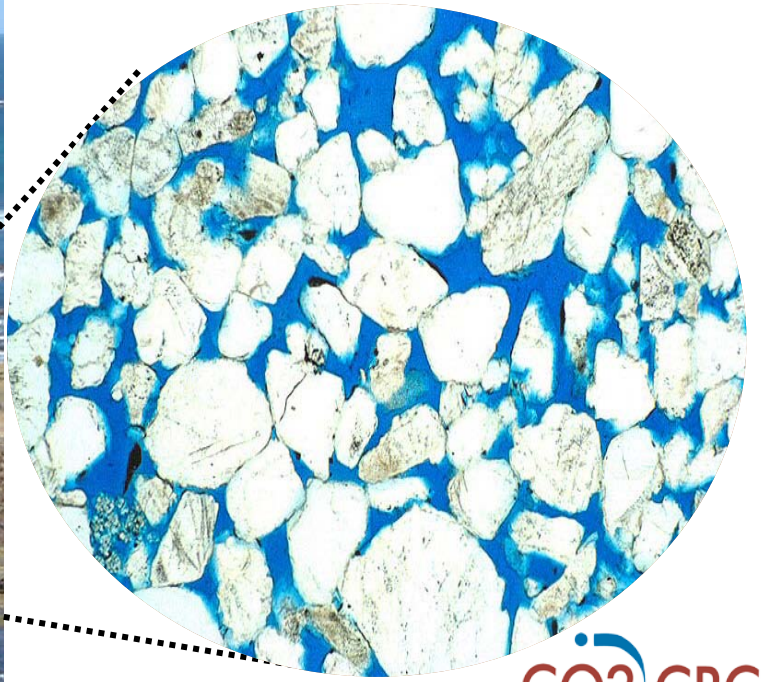
Geological storage of CO_2



What do we need?

SEAL ROCK – variable porosity, low permeability, e.g. claystone

RESERVOIR ROCK – porous, permeable, e.g. sandstone



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How do we know what's down there? (Sources of geological data)

- Geophysics
  - Seismic
- Drilled wells
  - Rock (core; drill cuttings)
  - Wireline logs
- Analogs
  - Outcrops
  - Modern depositional environments
- Integrated models

Onshore seismic

What is seismic?

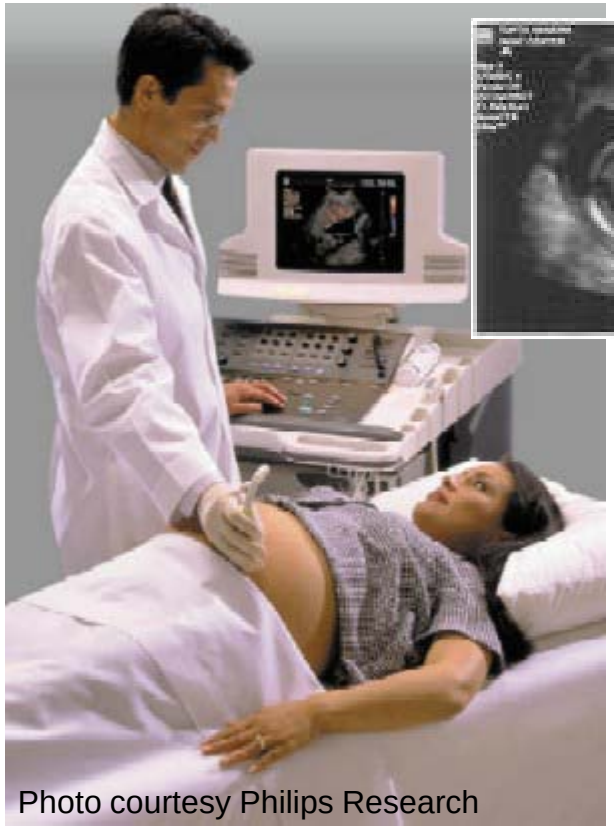
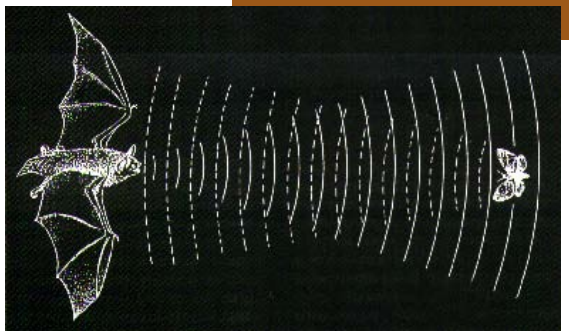
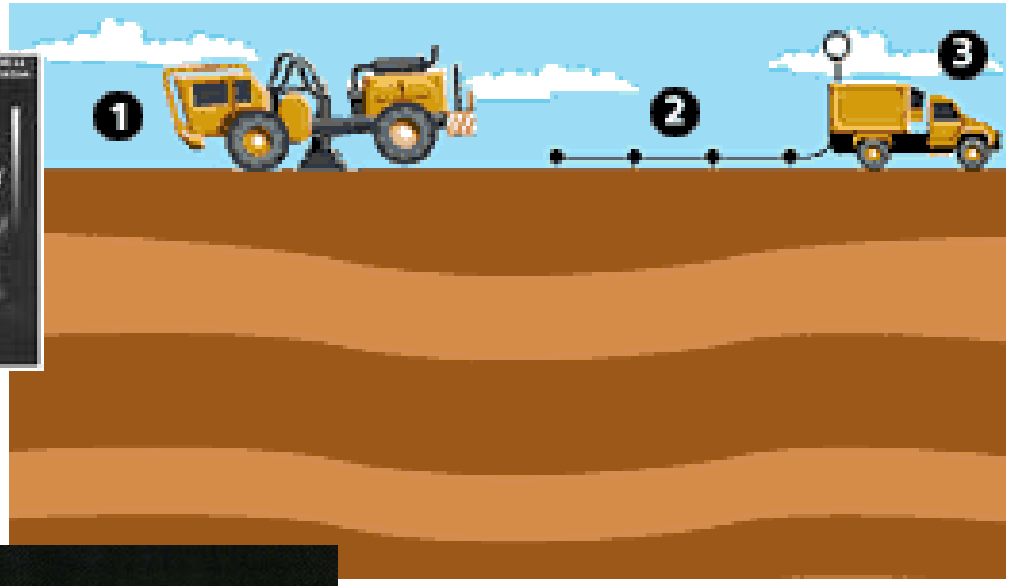


Photo courtesy Philips Research

Ultrasound examination during pregnancy





Animation courtesy US Department of Energy
Collecting seismic data on land

Seismic imaging uses reflected sound waves to create a picture of underground rock formations.

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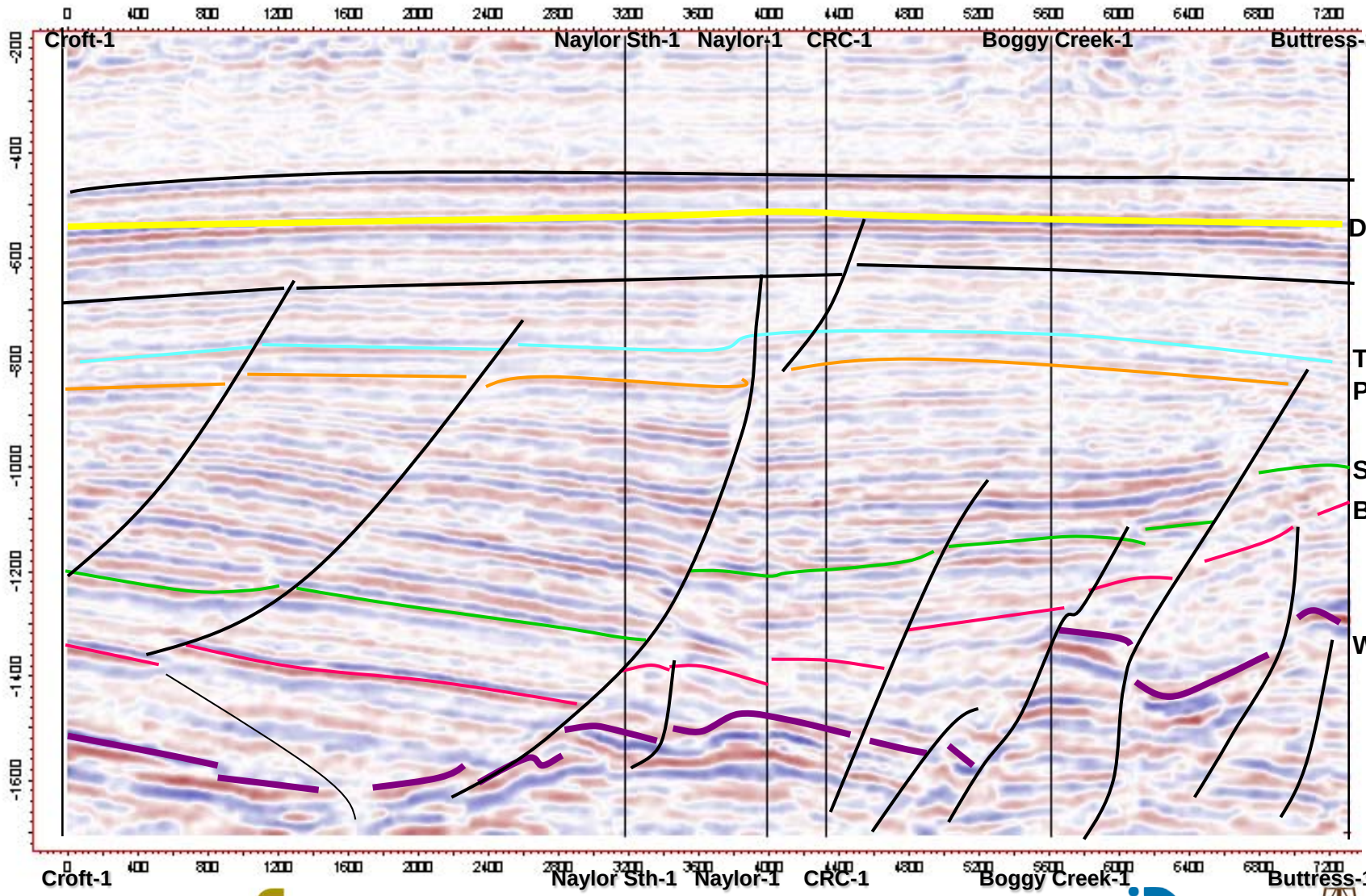
Seismic section

SW

NE



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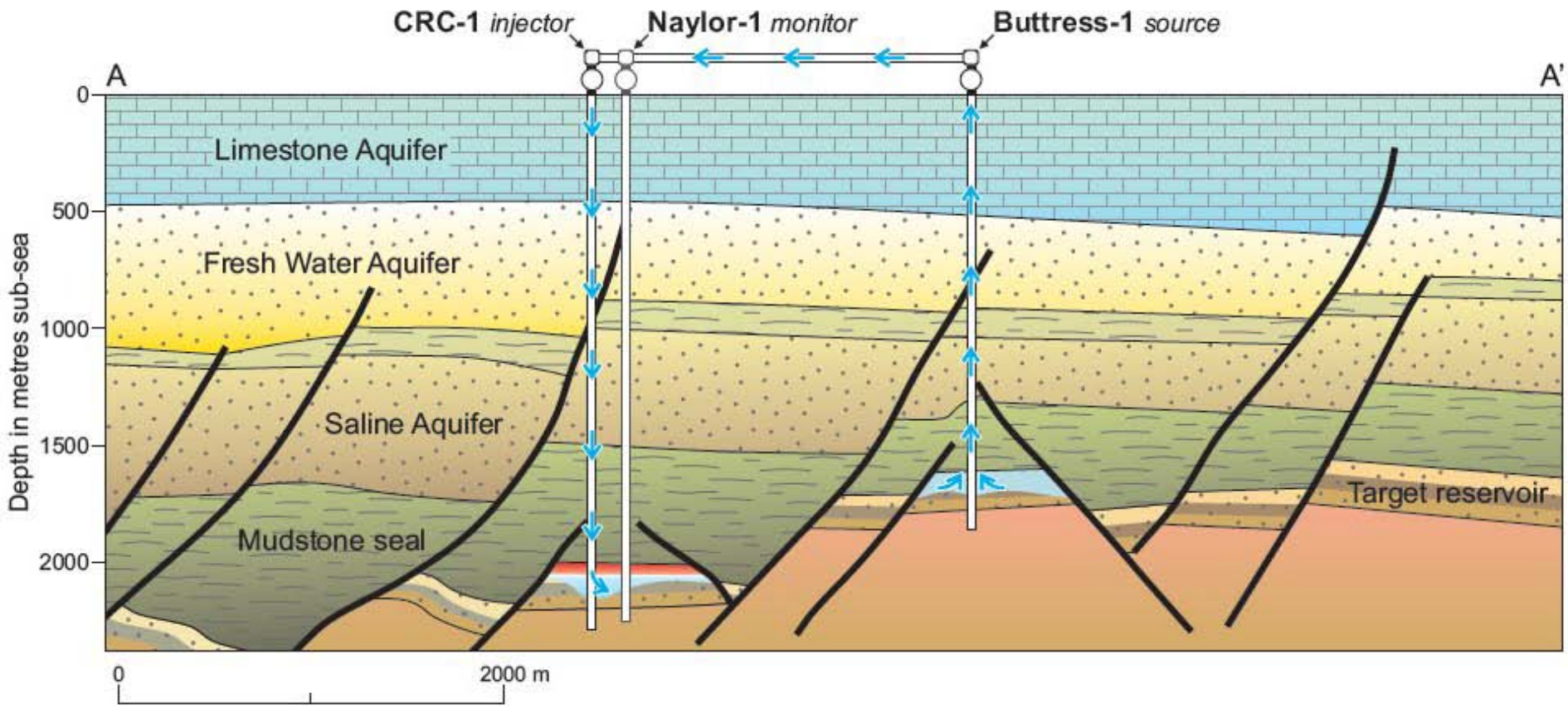
Geological model



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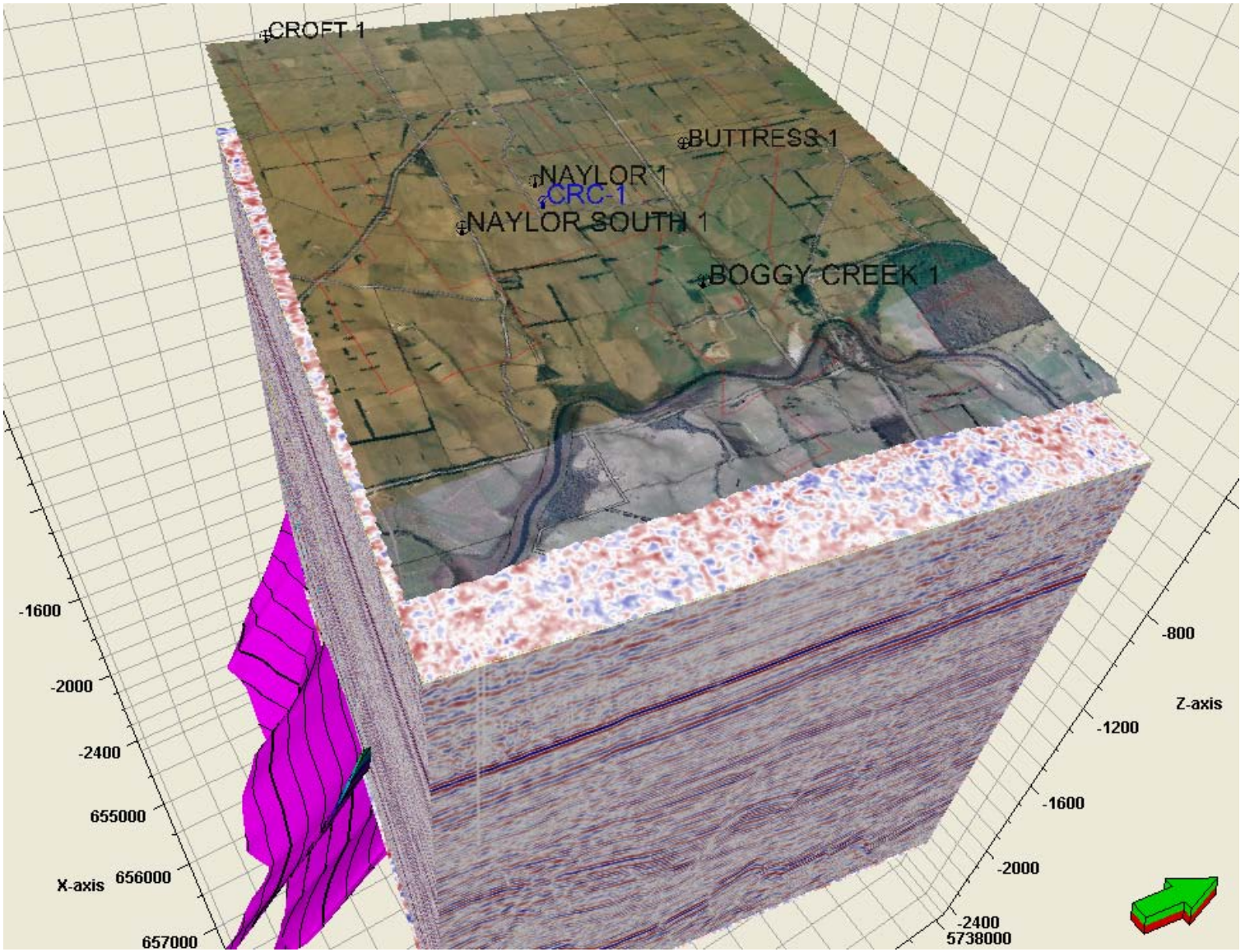
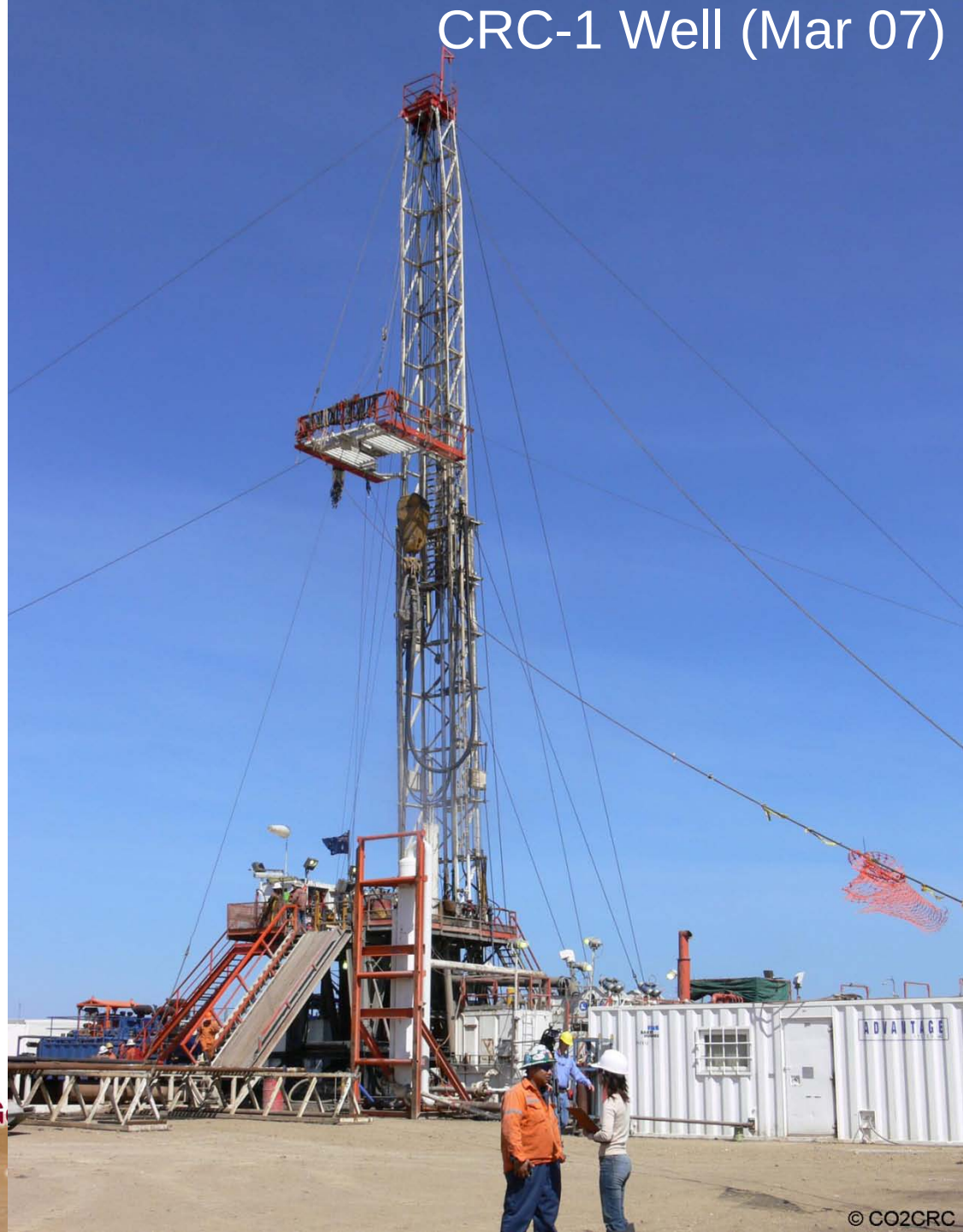
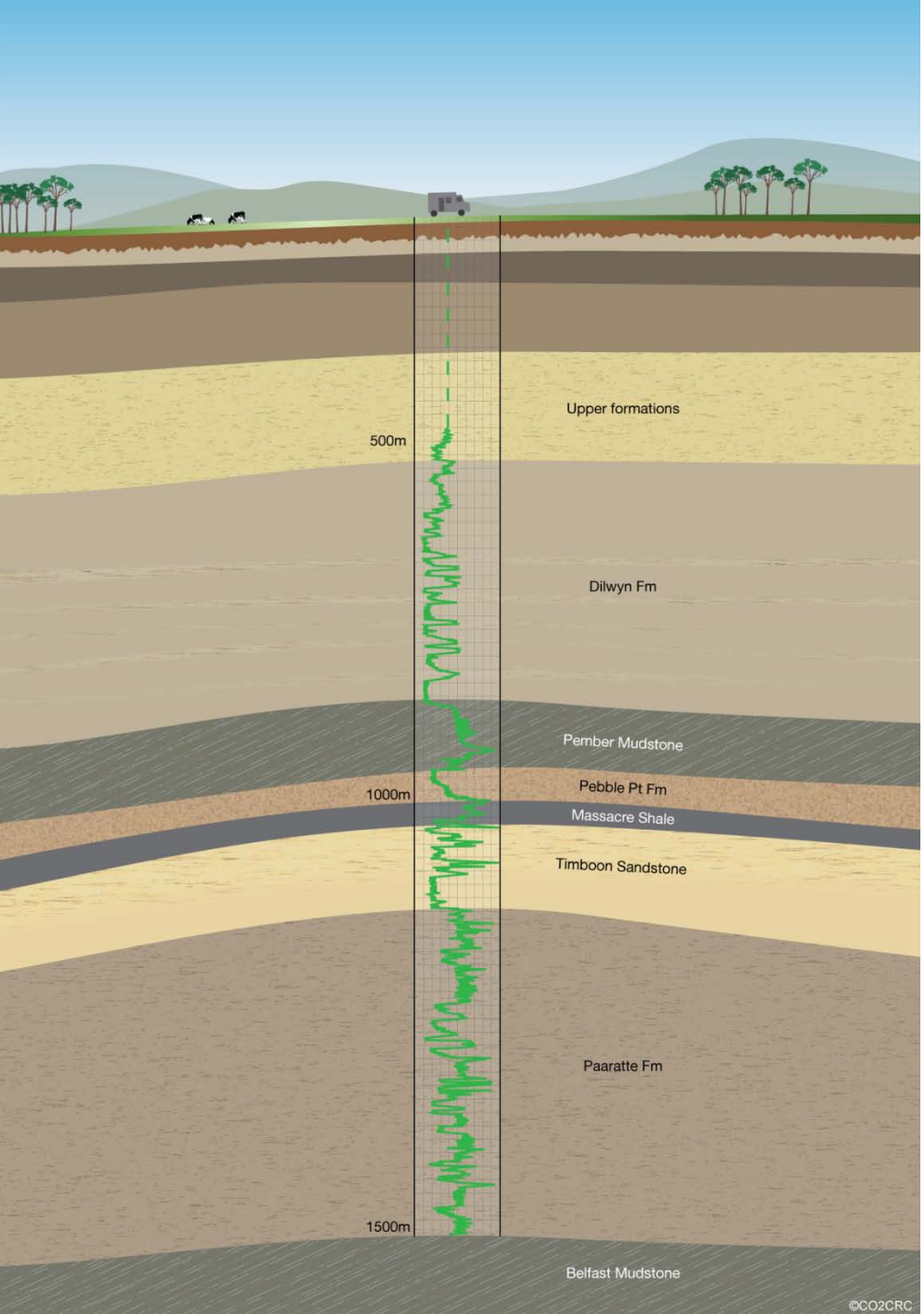
3D layered Earth model



Well data

Core is very important





Wireline well logging

- Gamma ray, neutron, density, resistivity and caliper log
- NMR
- ECS (elemental capture spectroscopy)
- FMI (image log)
- Sonic Scanner
- Formation tester
- 3D VSP

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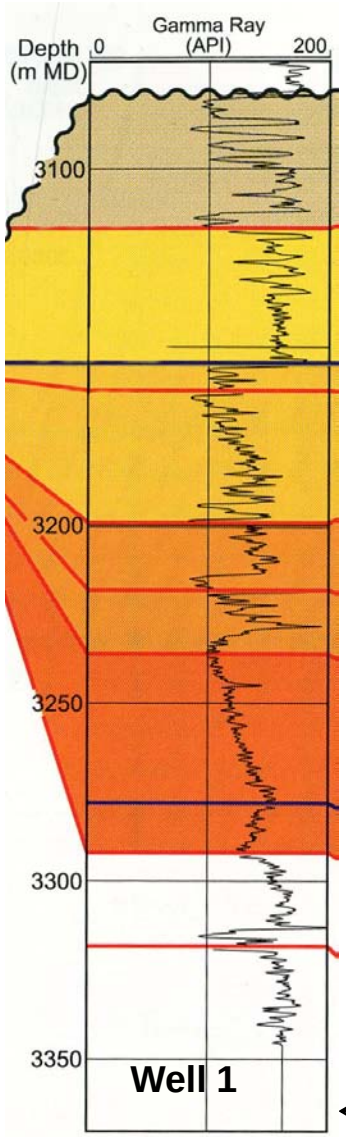
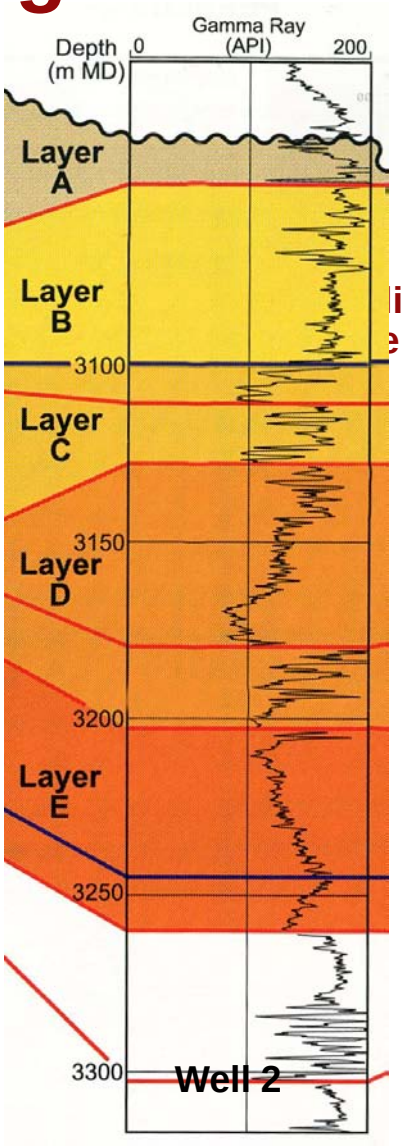
Wireline well log data

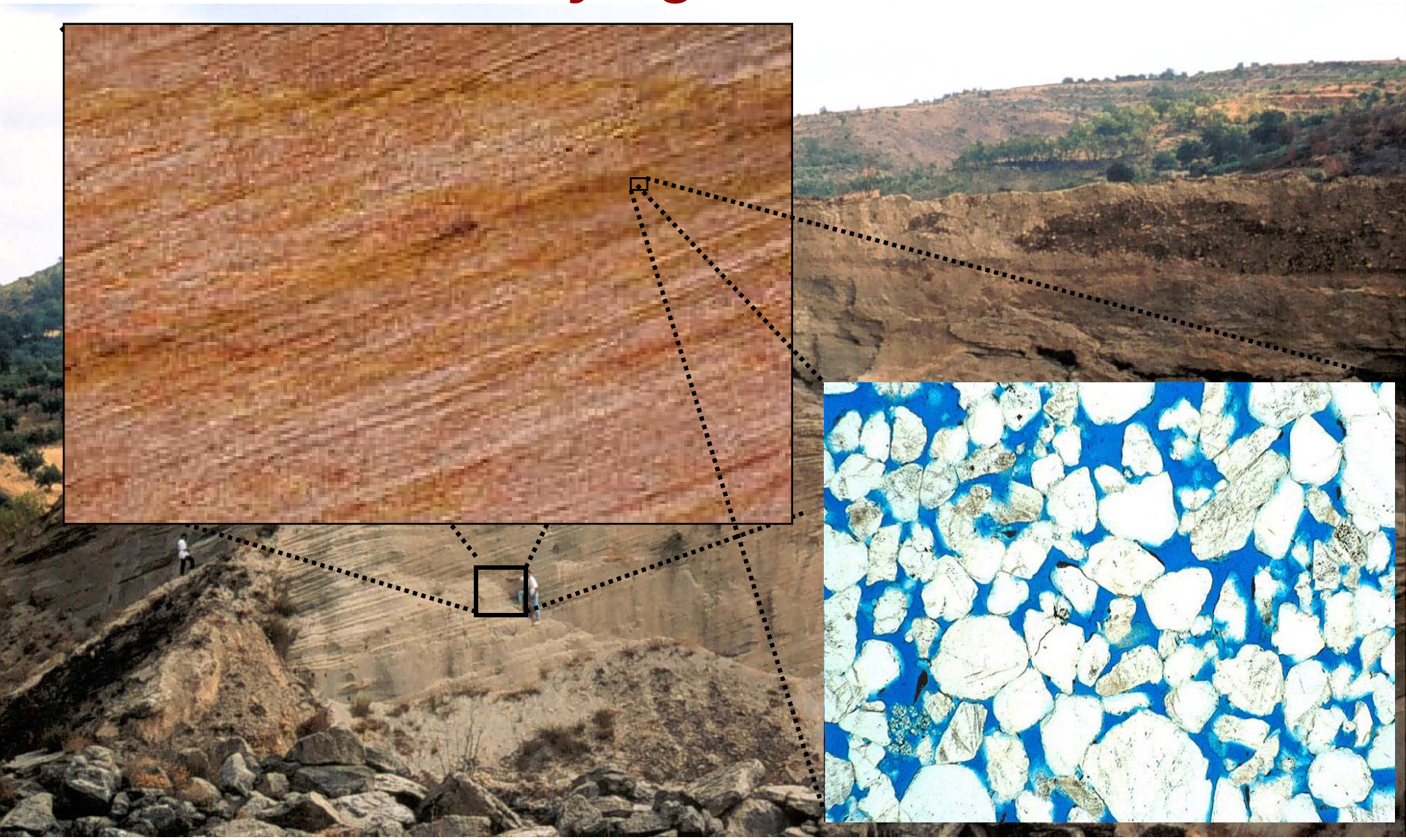


← 1 – 10's of km. →



ine log data
e between wells)

Studying the rocks



Identifying the likeliest depositional system

Transgressive Shoreface Model:~ from Buffin (1989)

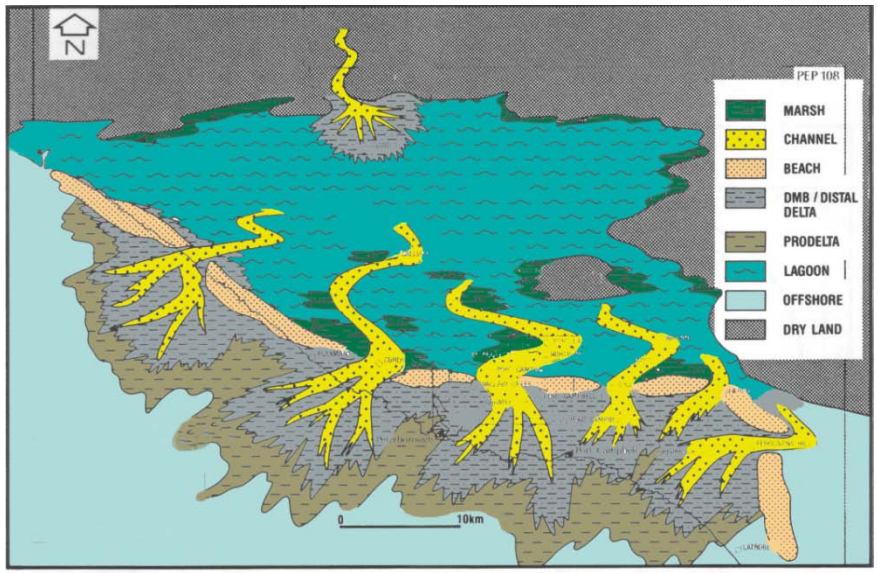
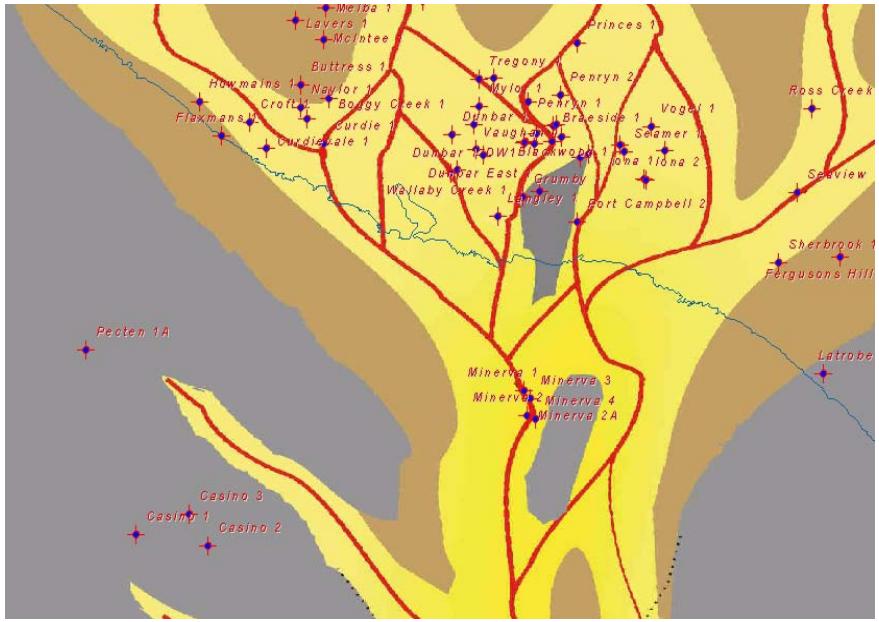


Figure 17. Facies distribution and depositional environments throughout the Port Campbell Embayment: during the Upper Waarre Formation.

Possible but unlikely
•Flaxmans A shale is now interpreted to never be time equivalent of Waarre C.

Regressive Braided Fluvial (Faulkner 2001)



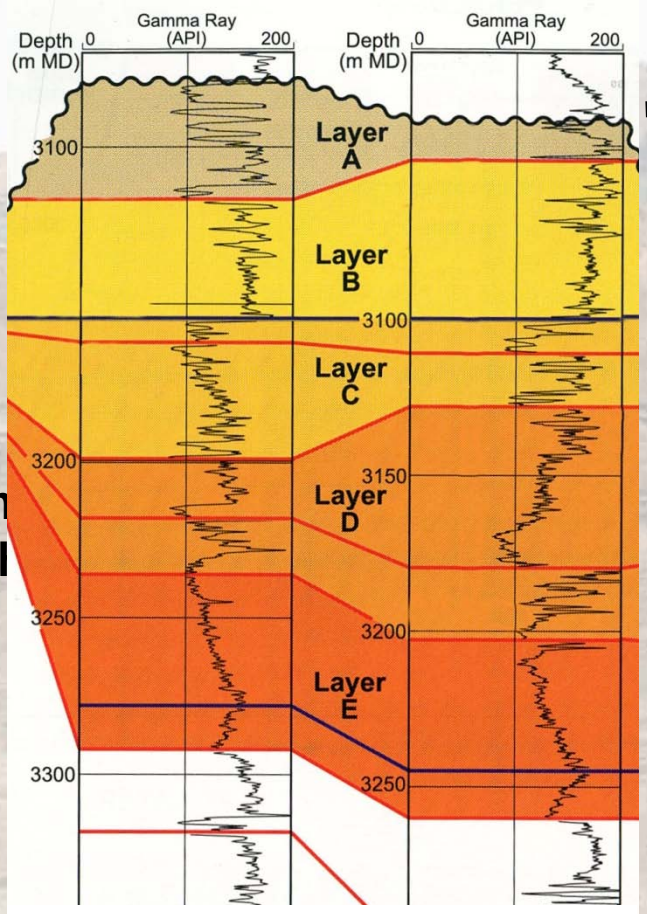
Most likely model imposes modeling constraints:
•channel orientation is grossly N-S.
•but ranges from SE-NW.

Integrated data sources

Core data

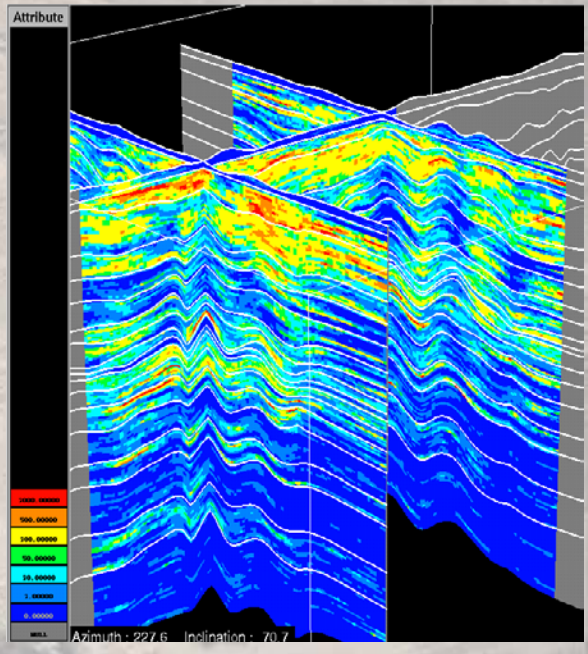
-Dep. Env.
- Poro/Perm
- Stratigrapl

Outcrop analogs



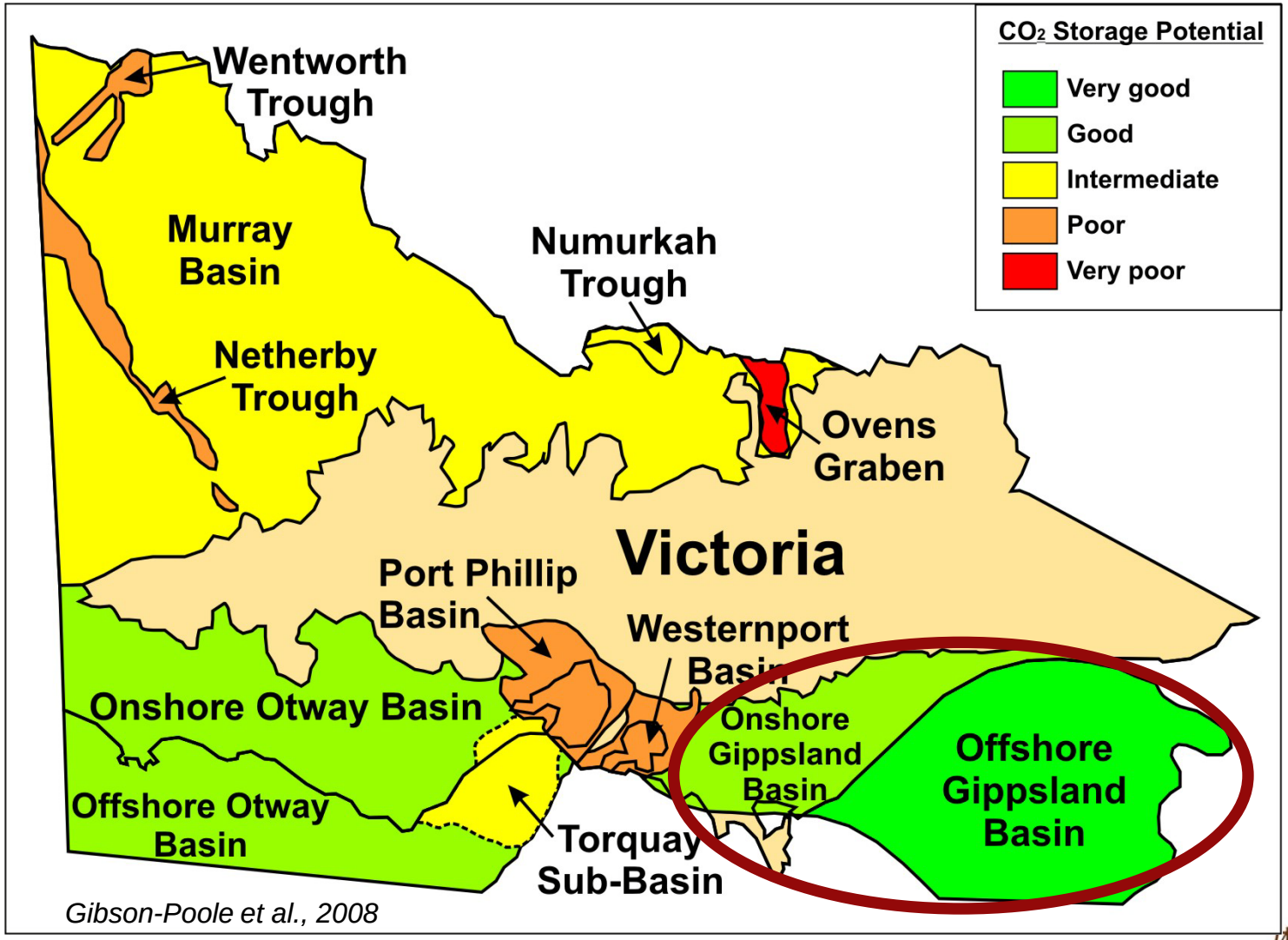
Wireline log data
(correlate between wells)

Seismic



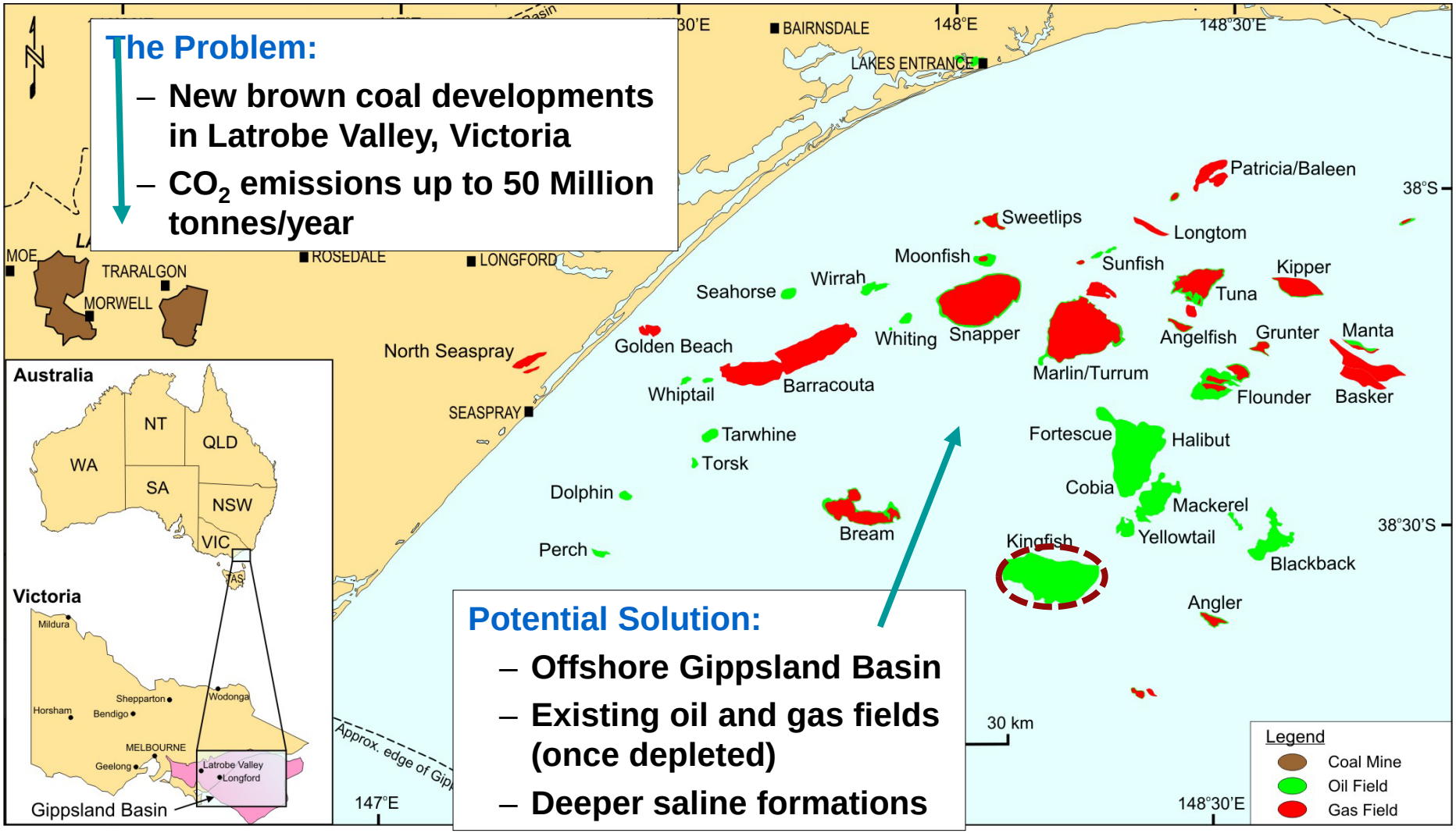
Static model

Qualitative basin ranking



Gibson-Poole et al., 2008

Gippsland Basin, Southeast Australia



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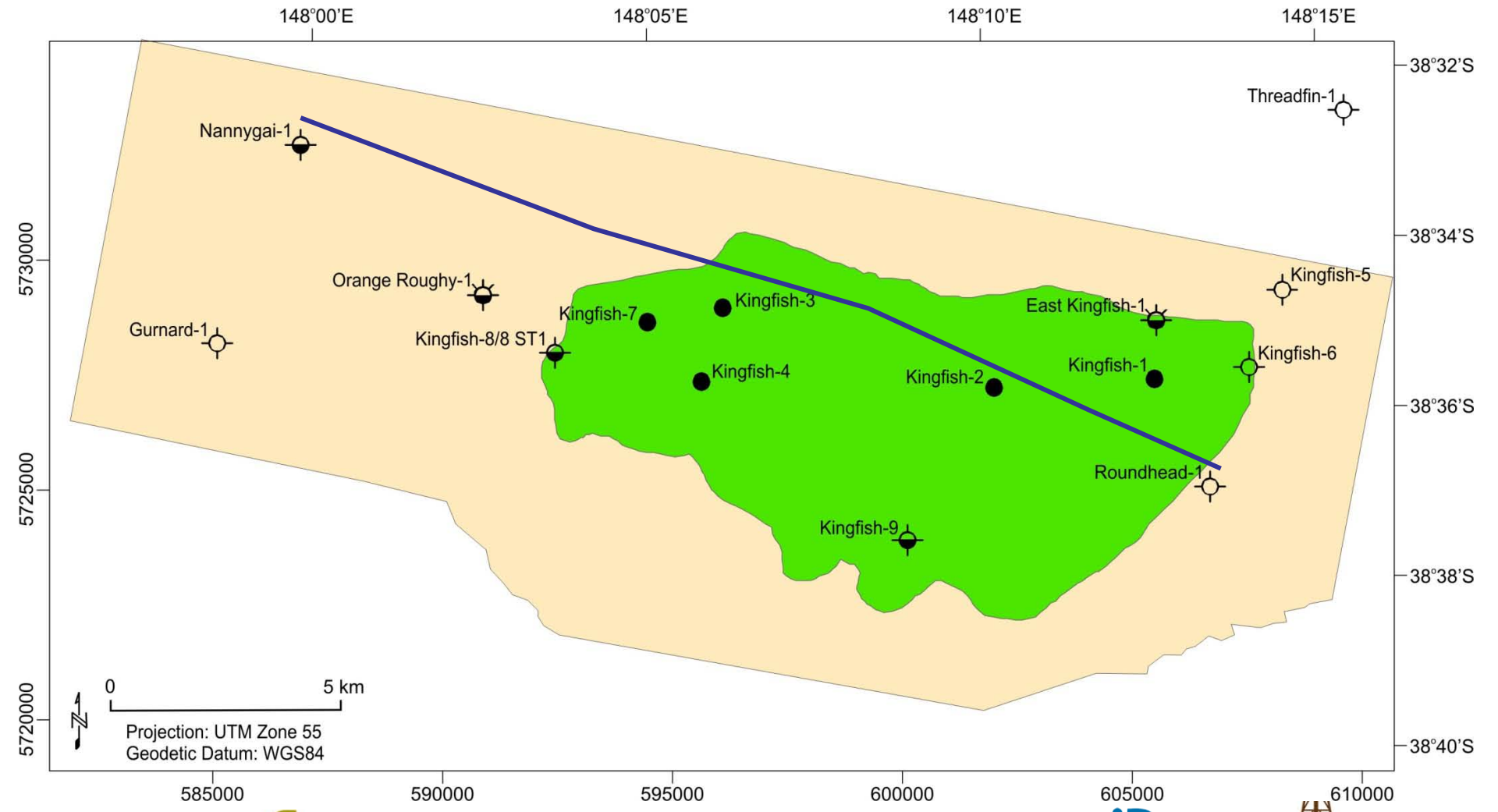
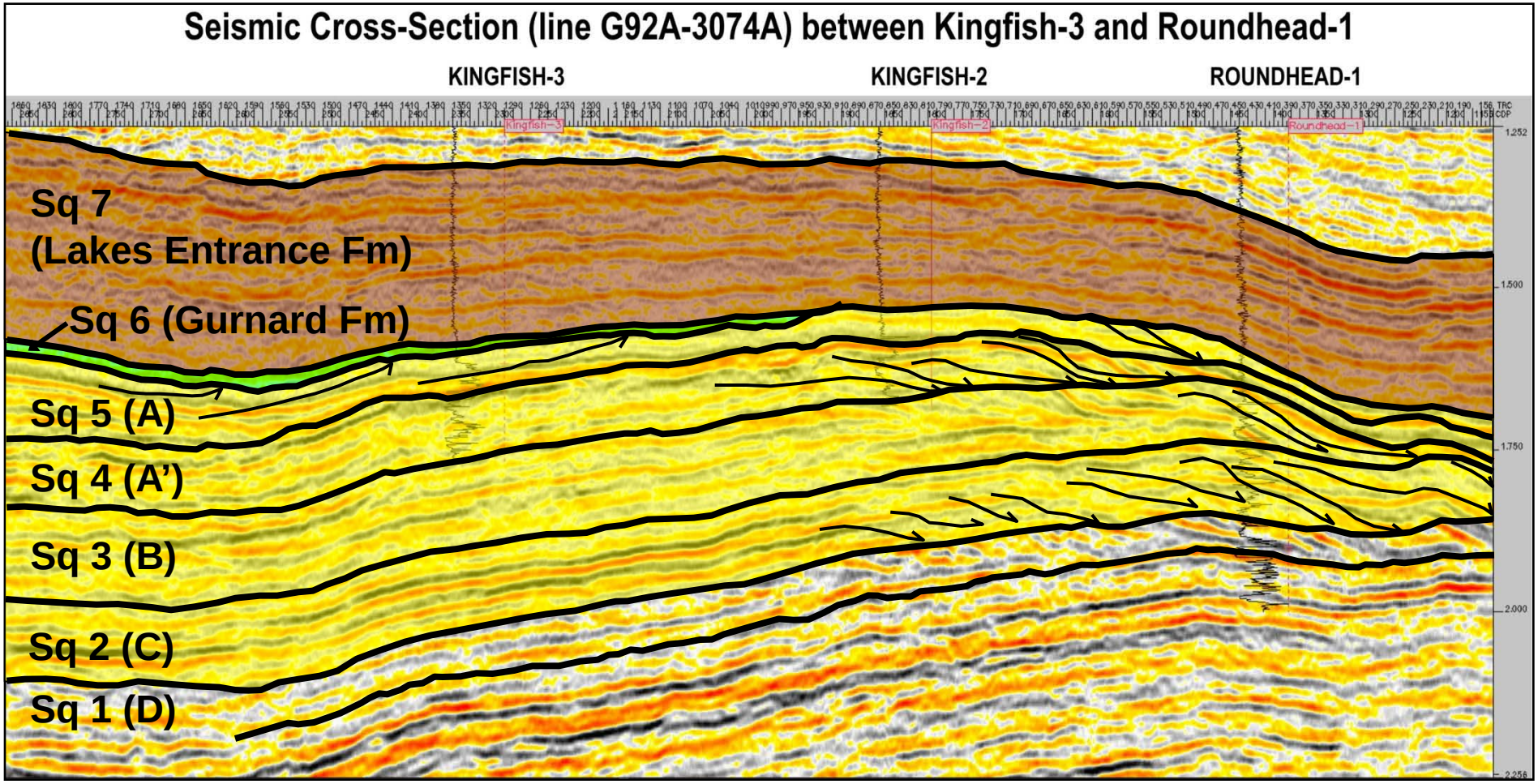
Map of the Kingfish field, Gippsland Basin

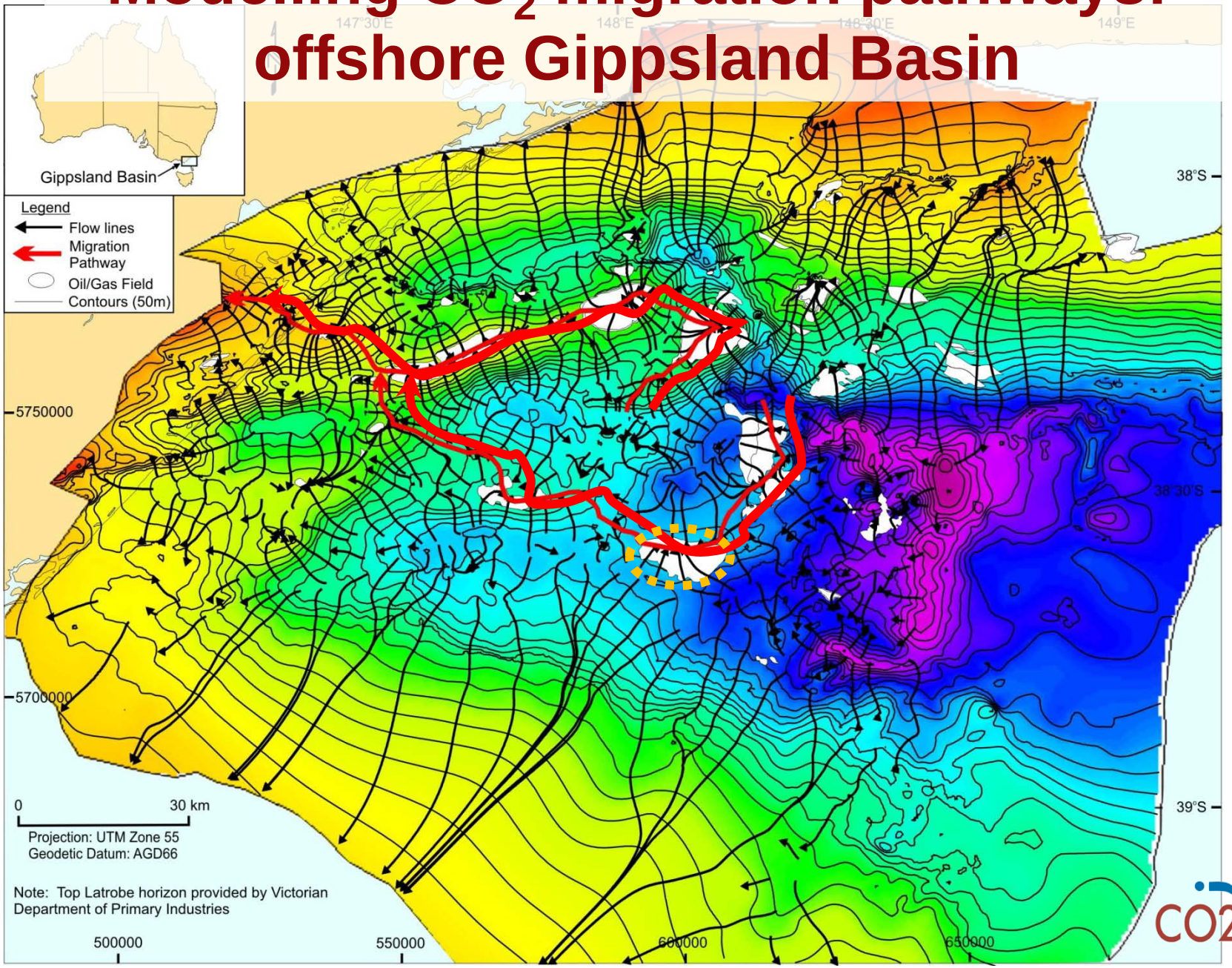


Seismic cross-section and geological interpretation:Kingfish field, Gippsland Basin

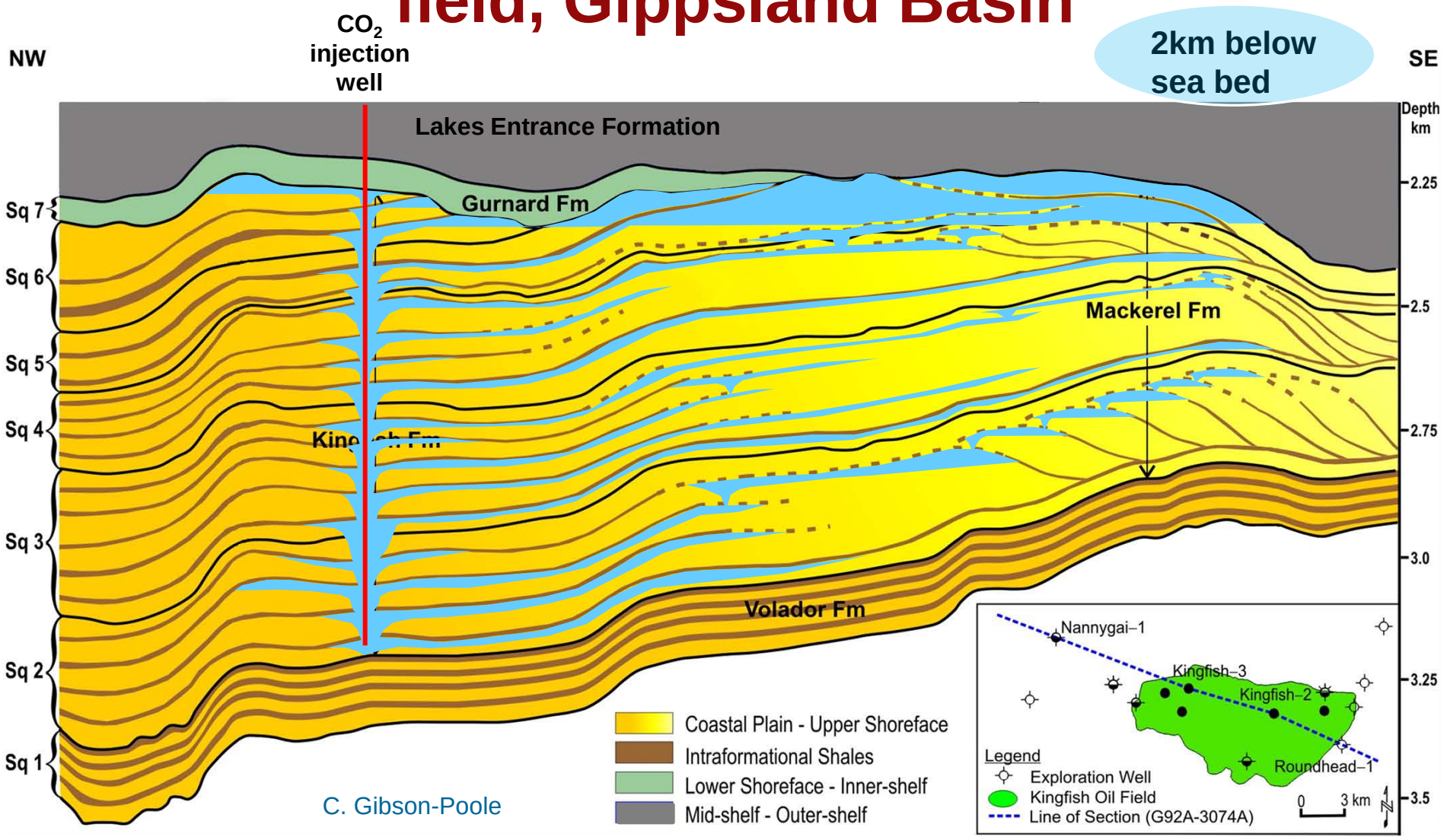


C. Gibson-Poole

Modelling CO_2 migration pathways: offshore Gippsland Basin

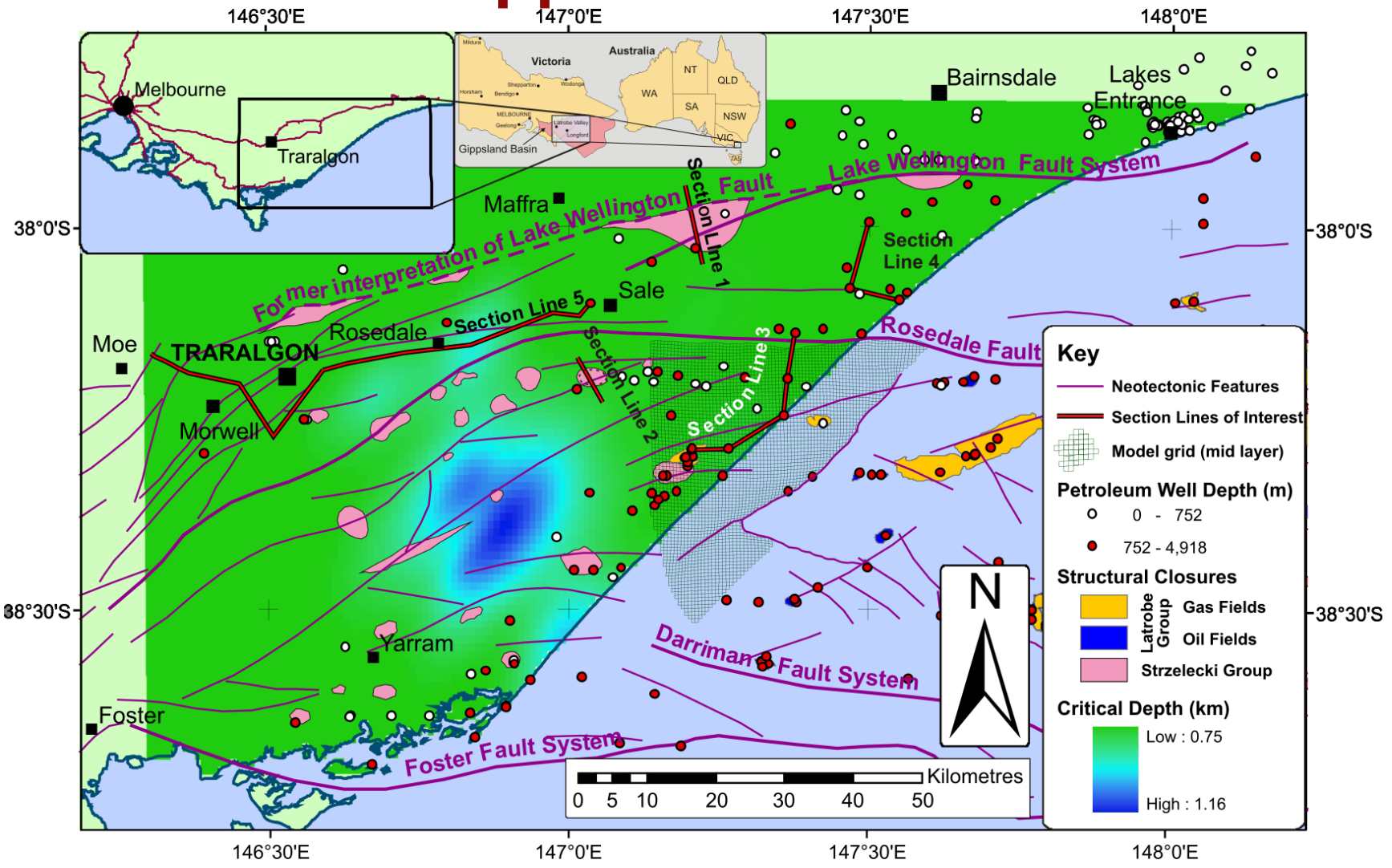


Modelling CO_2 migration pathways: Kingfish field, Gippsland Basin



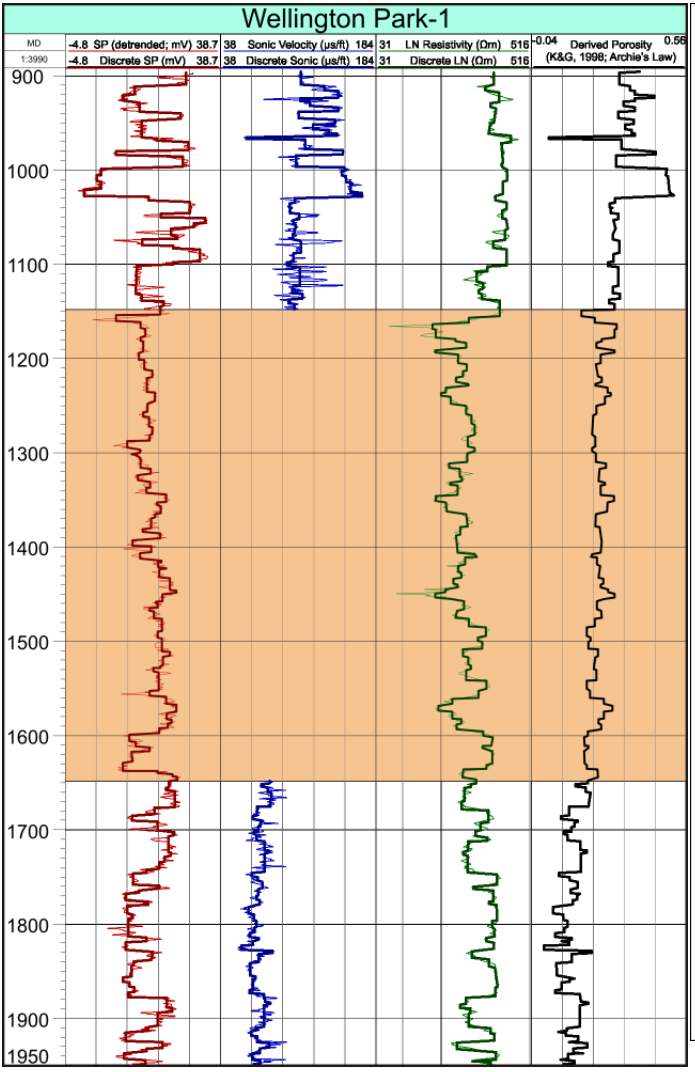
C. Gibson-Poole

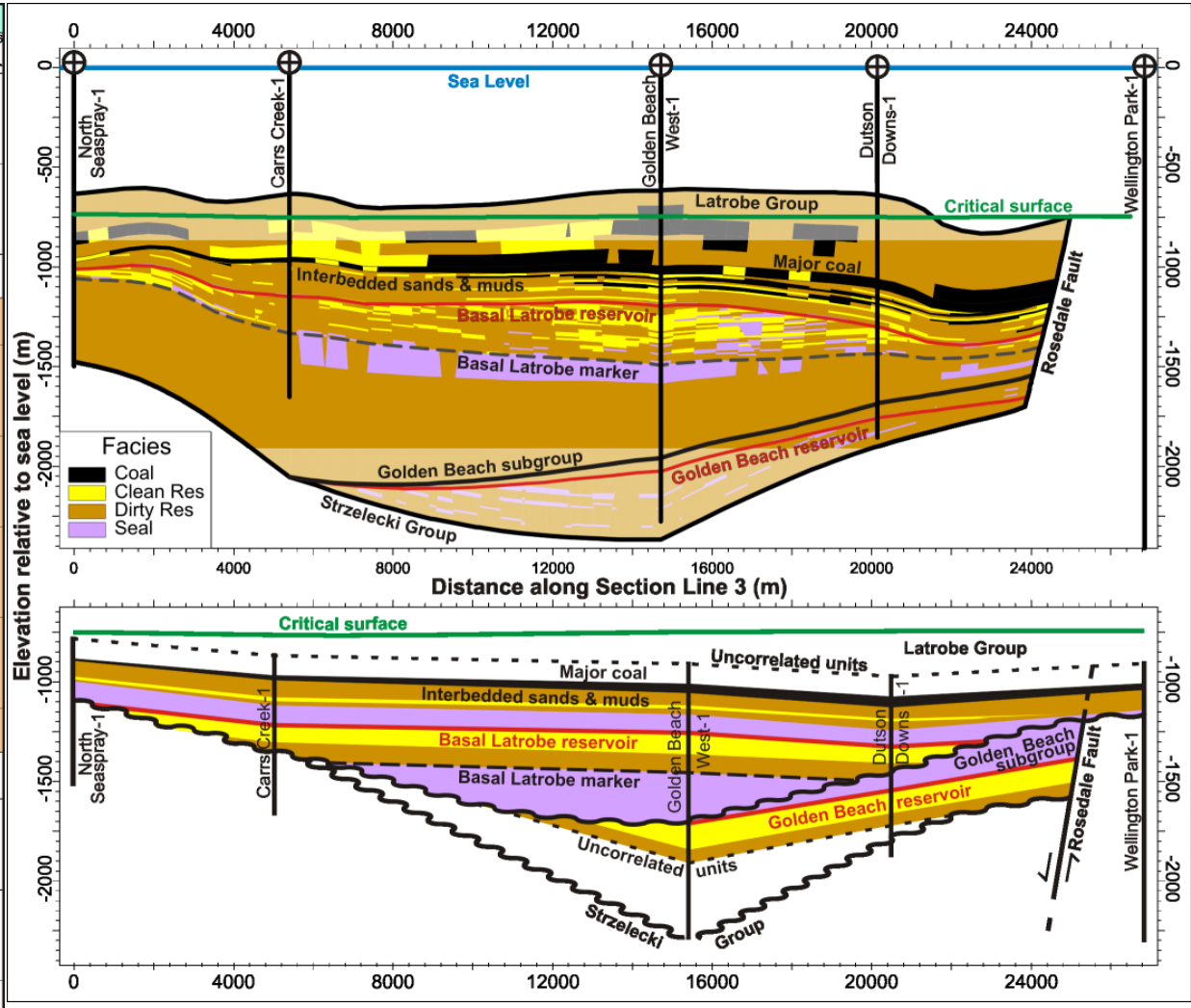
Modelling storage potential: onshore Gippsland Basin



Bunch et al., 2010

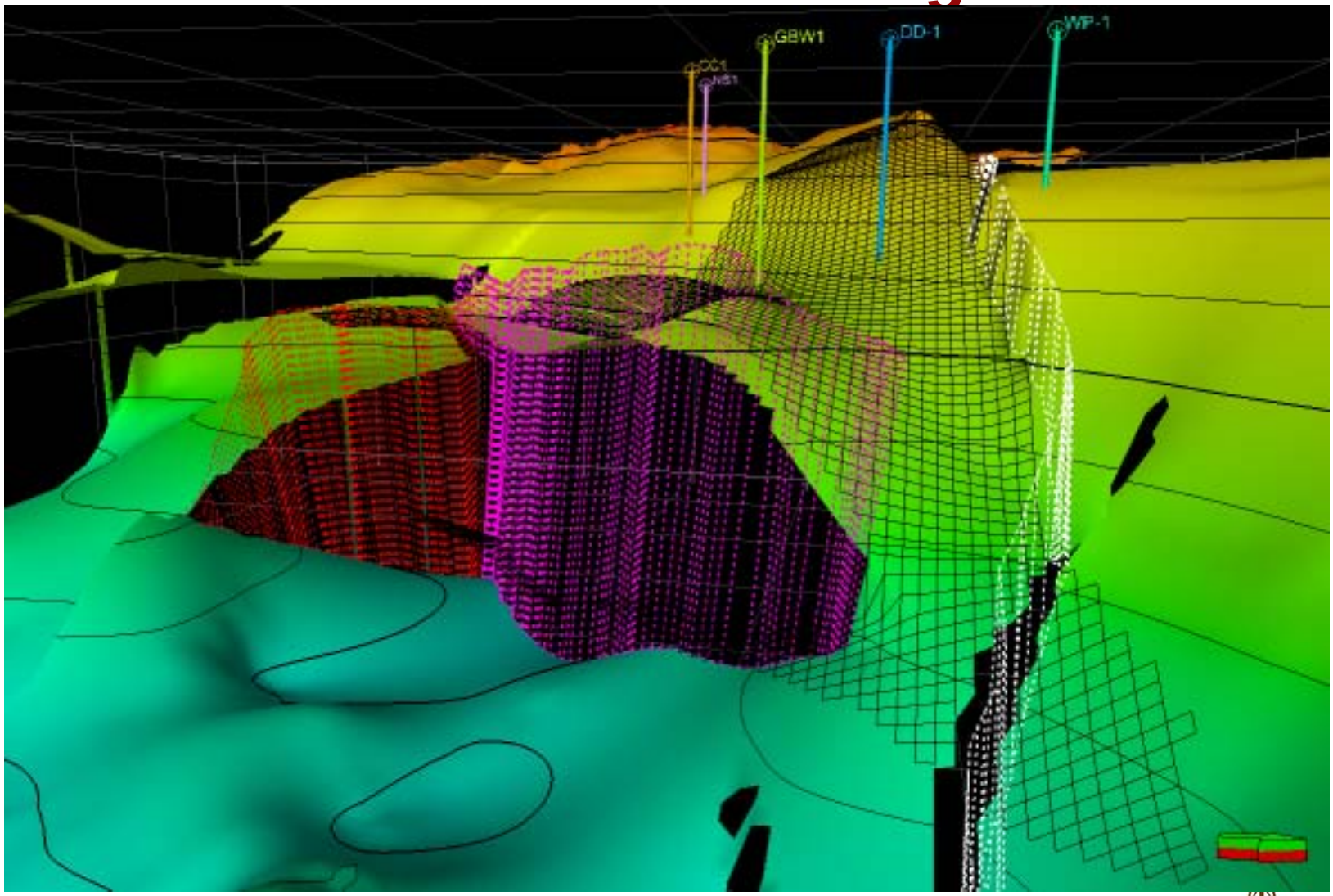
Comparison of storage litho-facies





Bunch et al., 2010 (GHGT-10)

Skeleton of the numerical geo-model



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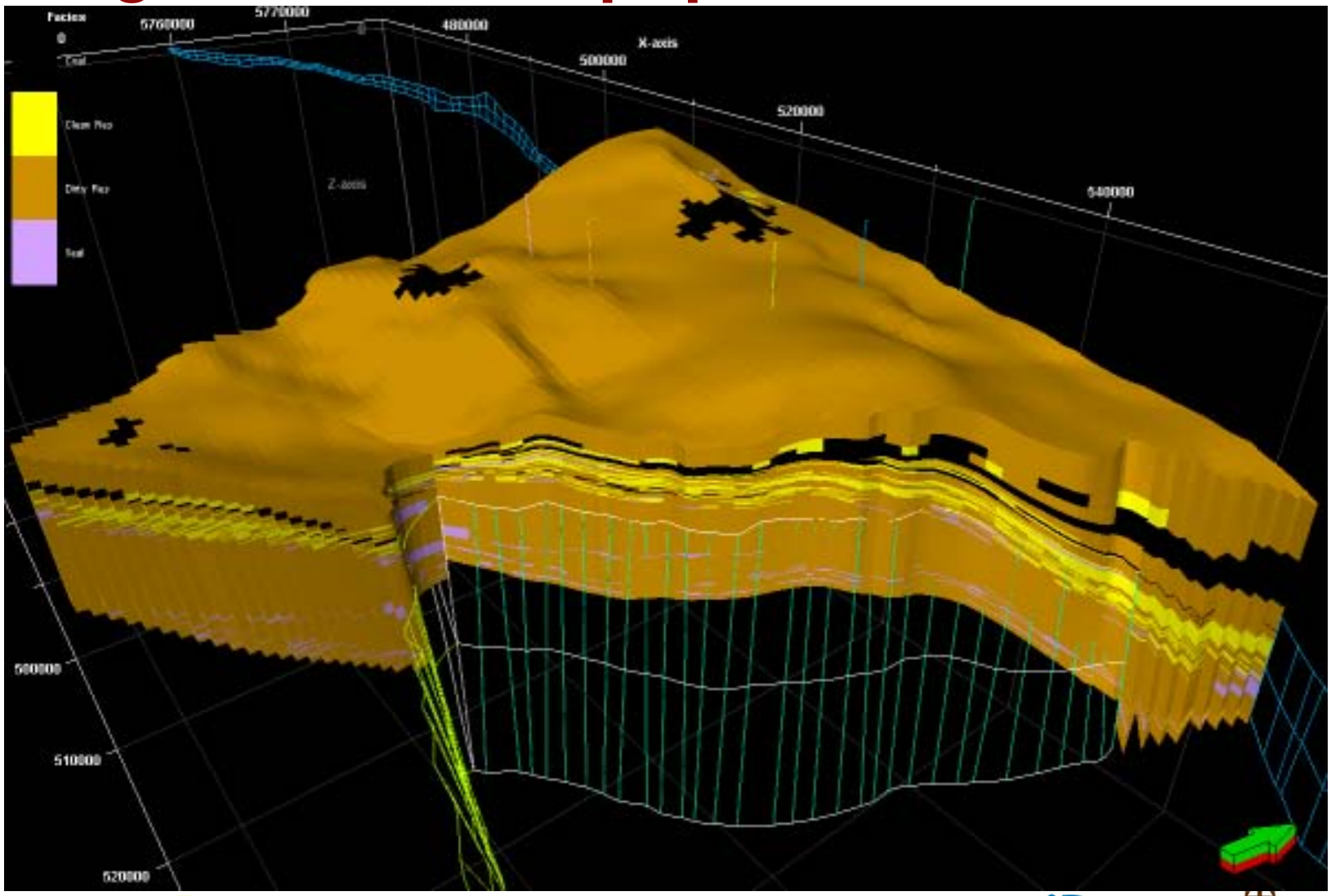
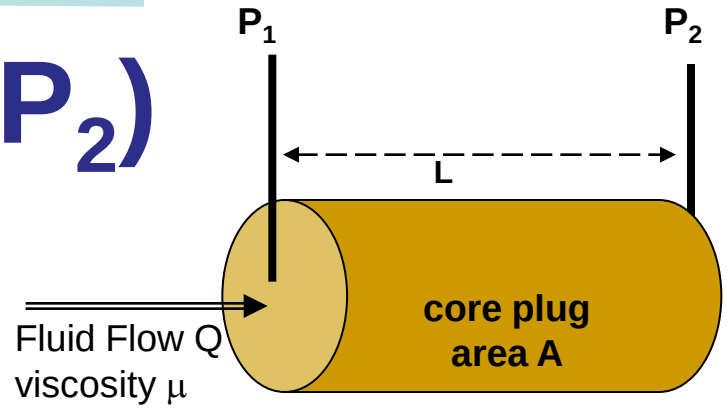
Storage litho-facies populated across model



Permeability

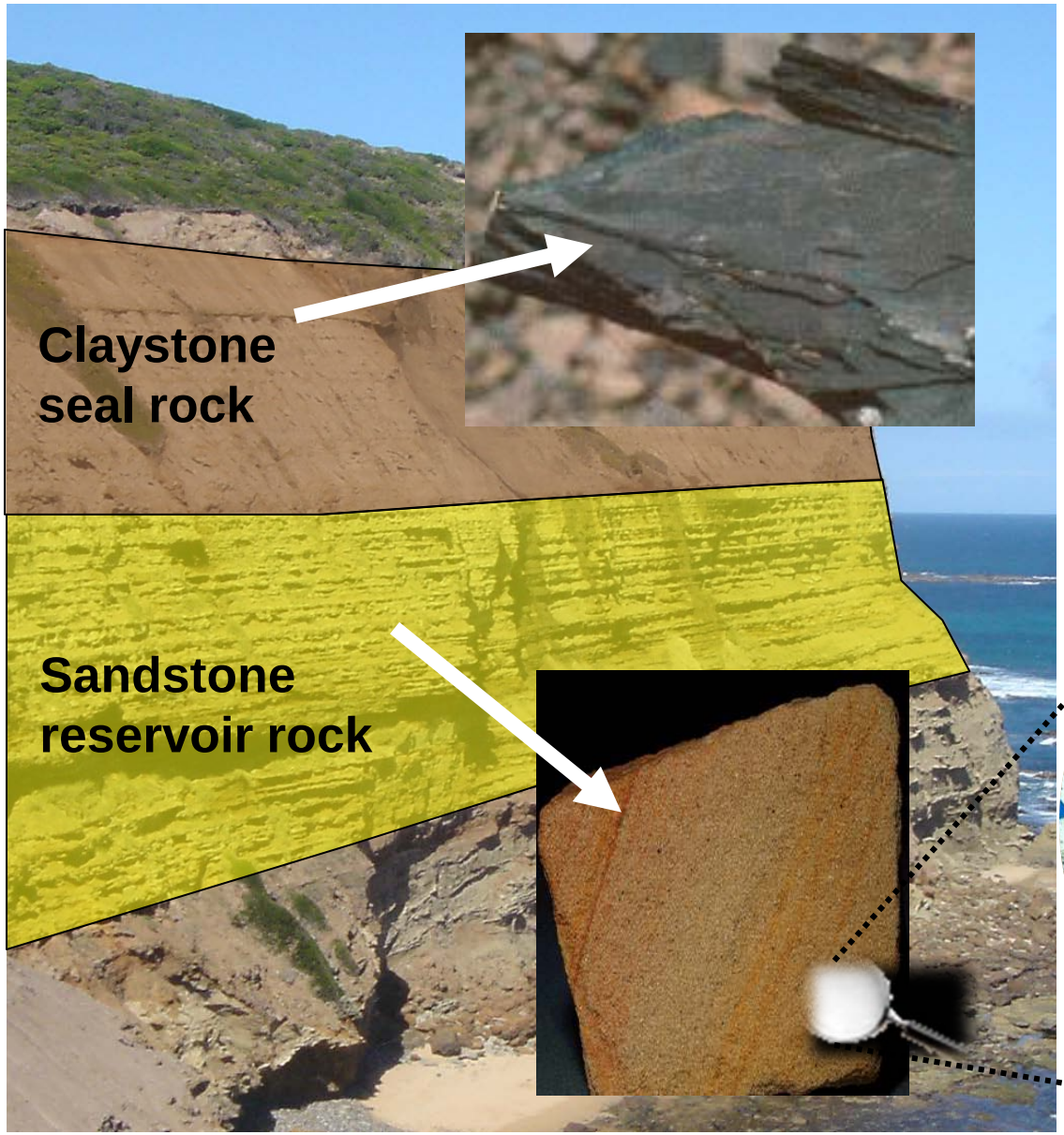
(measure of fluid connectivity)

$$K = \frac{Q\,\mu}{A} \frac{L}{(P_1 - P_2)}$$



Measured in Darcies (D) or millidarcies (mD)

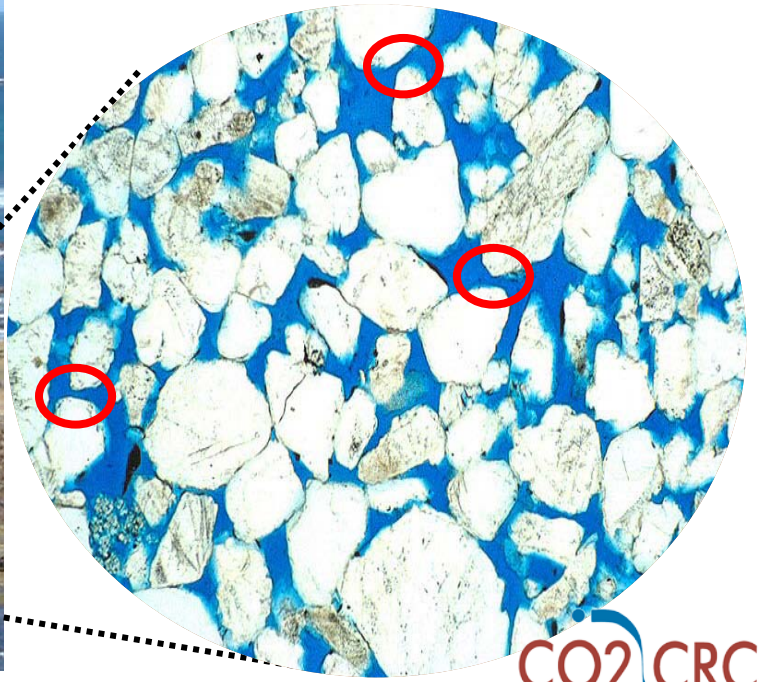
Porosity and permeability



Porosity is the storage space shown by the blue spaces in this thin slice through a reservoir sandstone.

Permeability is the ability of the rock to allow fluid flow from pore to pore. Permeability is strongly affected by the geometry of the pore throats (red circles).

Permeability is main control on injectivity



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Injectivity

$I_{v/t}$ depends on $A * P_i * k$

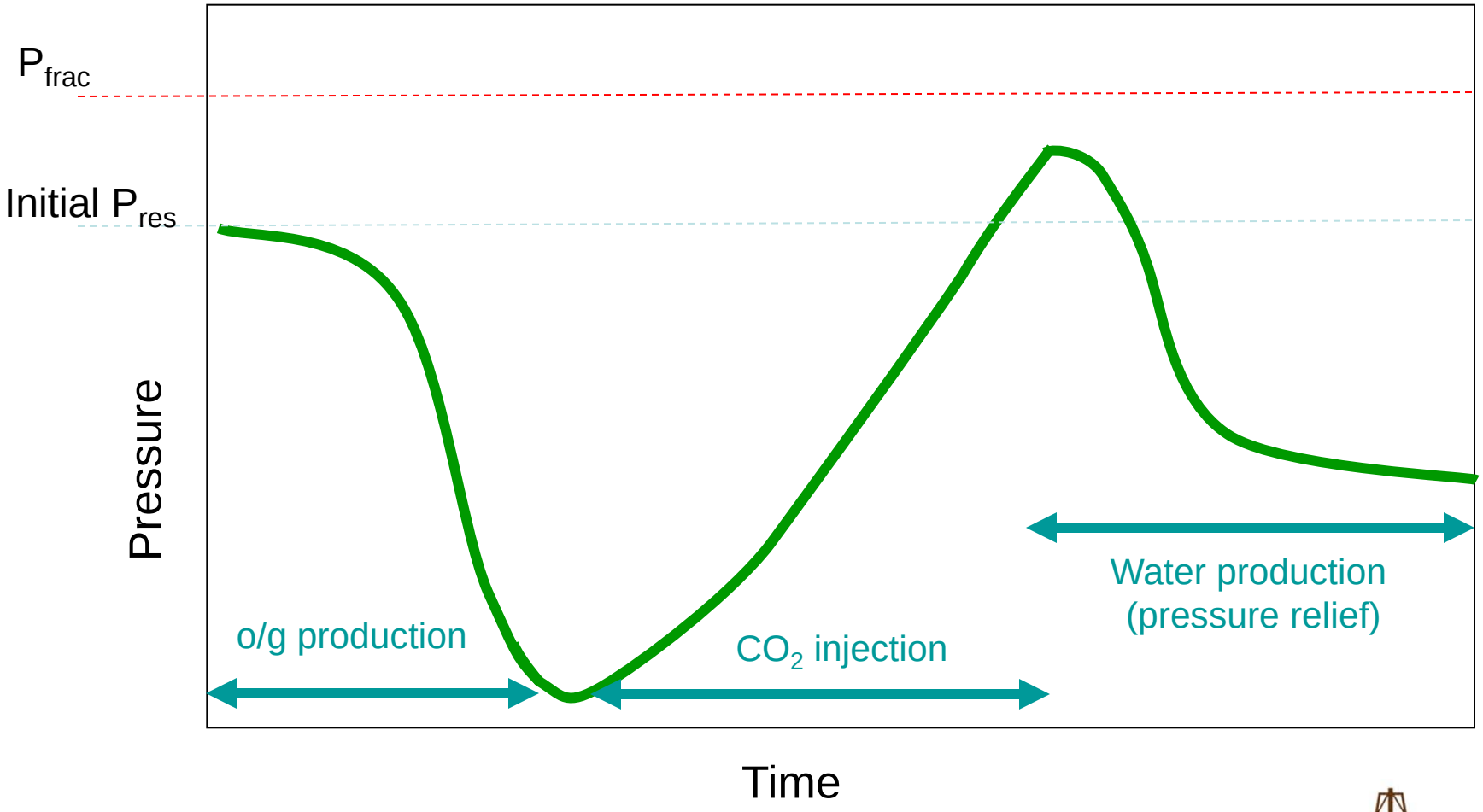
$I_{v/t}$ = Injection rate
A = Area (of wellbore in contact with formation)
P_i = injection pressure (below frac)
k = permeability

($I_{v/t}$ is proportional to number of wells)

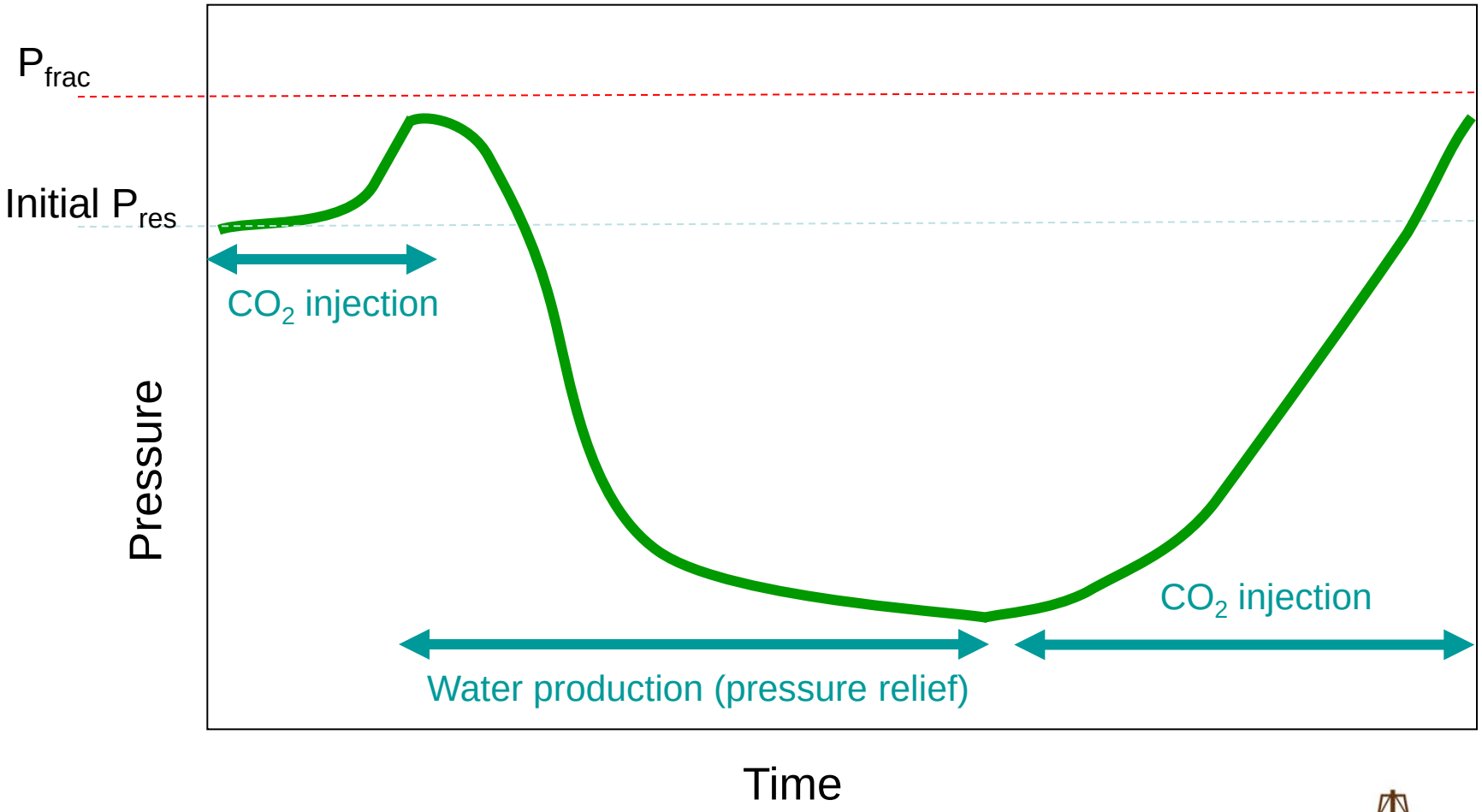
Injectivity / Pressure Considerations:

- Injection of fluids (eg CO_2) causes reservoir pressure build up
- In depleted fields, pressure build-up may be neutral or beneficial
- In both depleted fields and saline aquifers, pressure must remain below fracture pressure
- In low permeability reservoirs this may limit economic storage capacity due to decreased injection rate, requiring more wells
- Injection in saline formations may displace saline fluids & increase risk of possible mixing with a freshwater system
- Drilling pressure relief (water production) wells is a possible solution

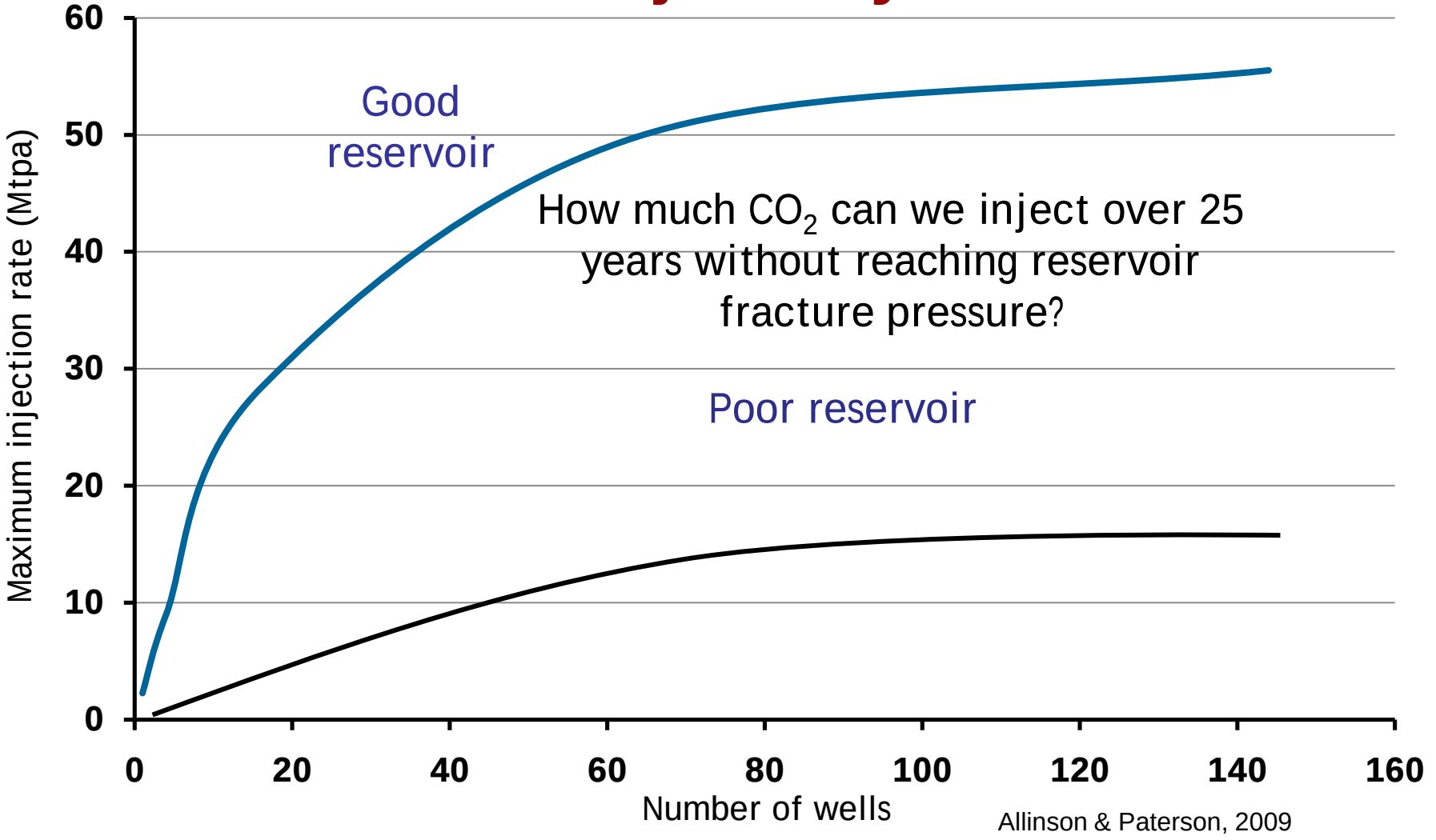
Depleted Field (Pressure v. Time)



Saline Aquifer (Pressure v. Time)



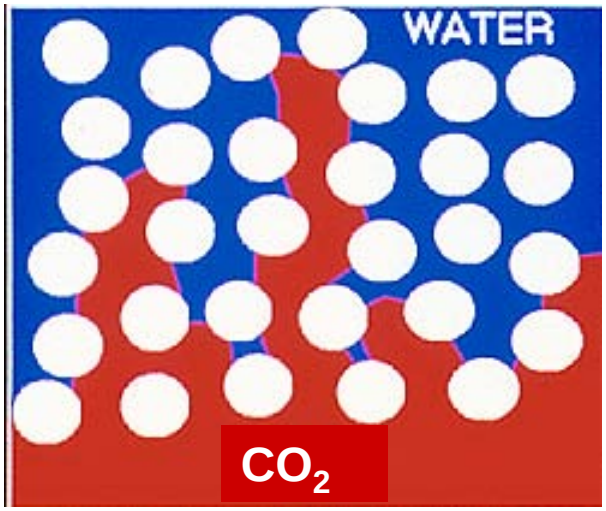
Modelling CO_2 storage capacity – the effect of injectivity on economics



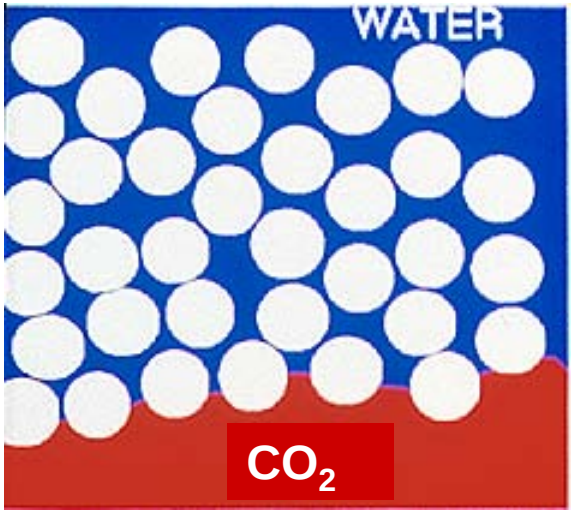
Allinson & Paterson, 2009

Containment

Buoyancy vs. capillary pressure



$P_b > P_c$

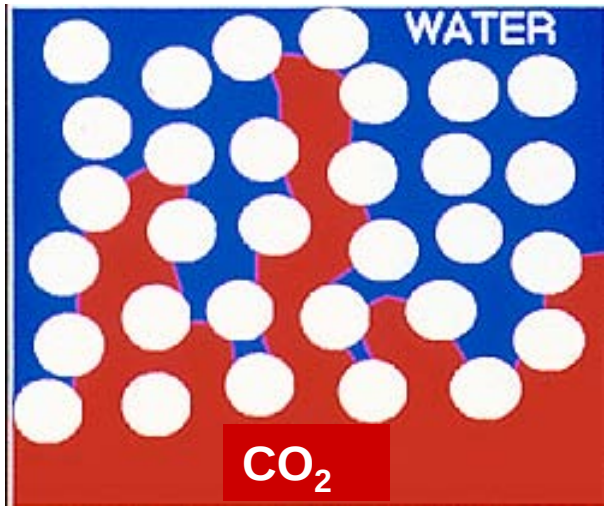


$S_w = 100\%$

$P_b < P_c$

$S_w < 100\%$

Mercury porosimeter



$P_m > P_c$

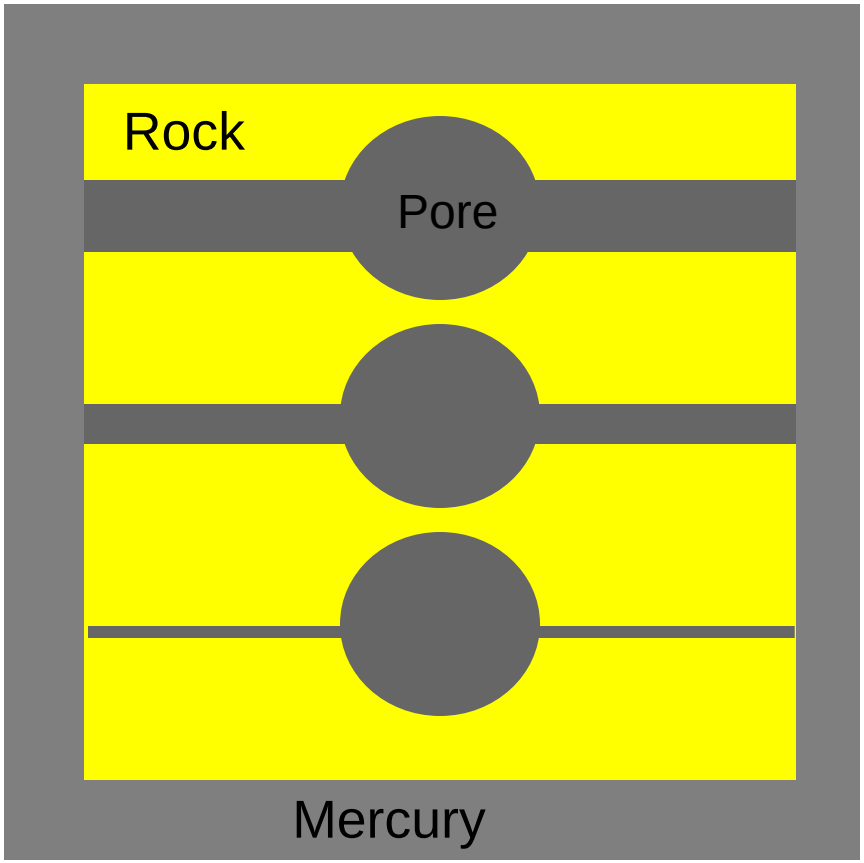
Mercury Capillary Pressure Experiment

0.0

Pressure (psia)

0.0

Rock pore volume saturated (%)



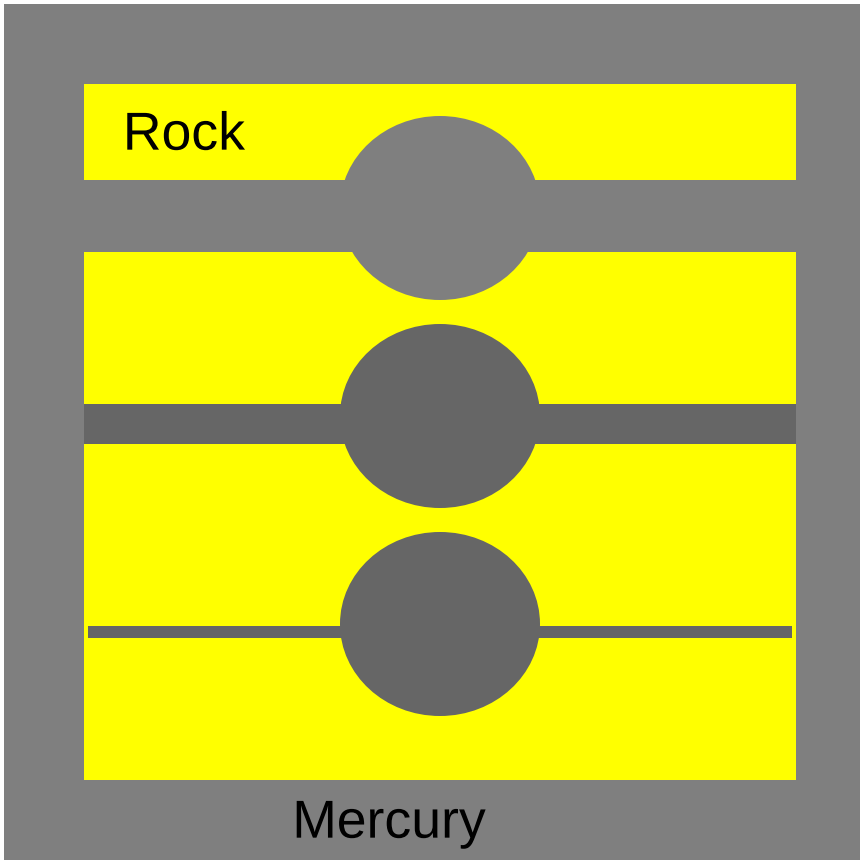
Mercury Capillary Pressure Experiment

10

Pressure (psia)

40

Rock pore volume saturated (%)



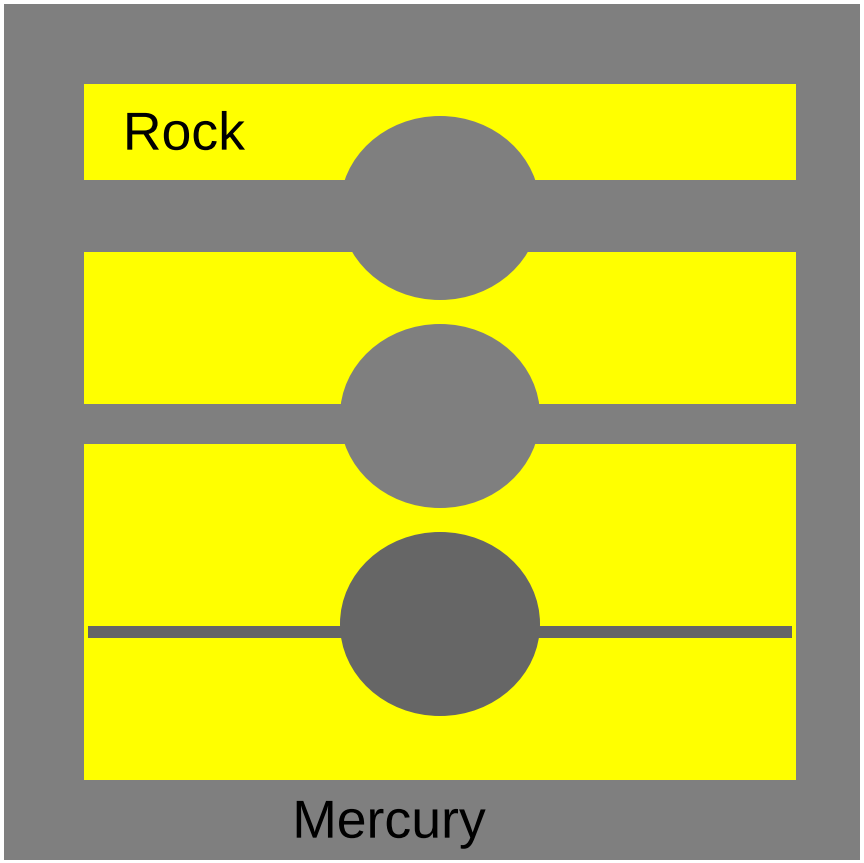
Mercury Capillary Pressure Experiment

100

Pressure (psia)

75

Rock pore volume saturated (%)



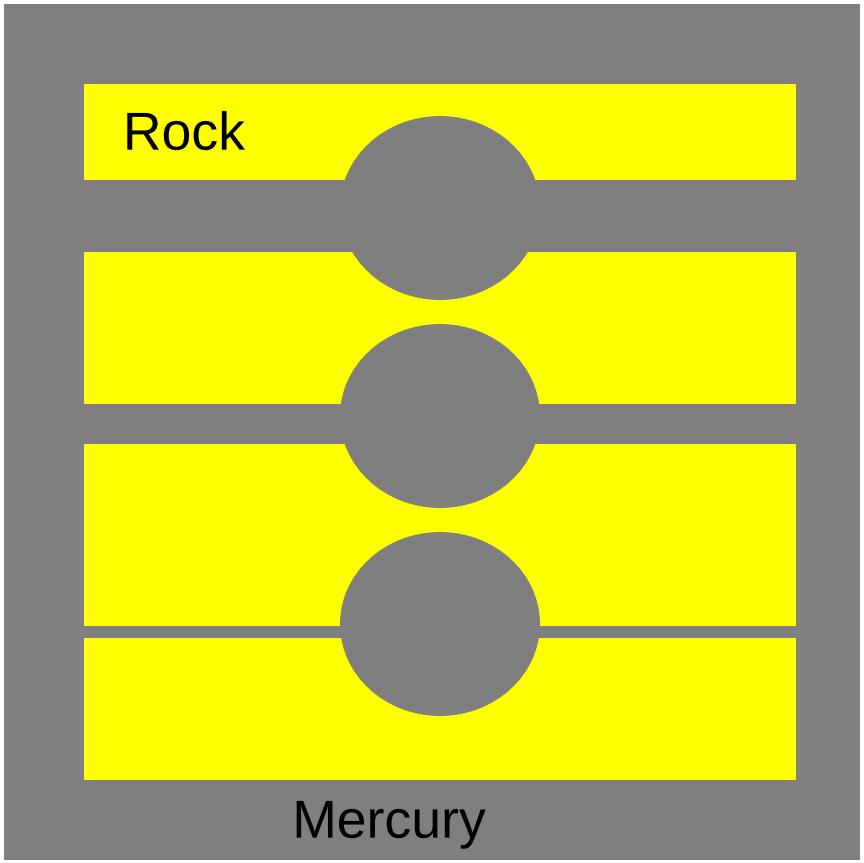
Mercury Capillary Pressure Experiment

500

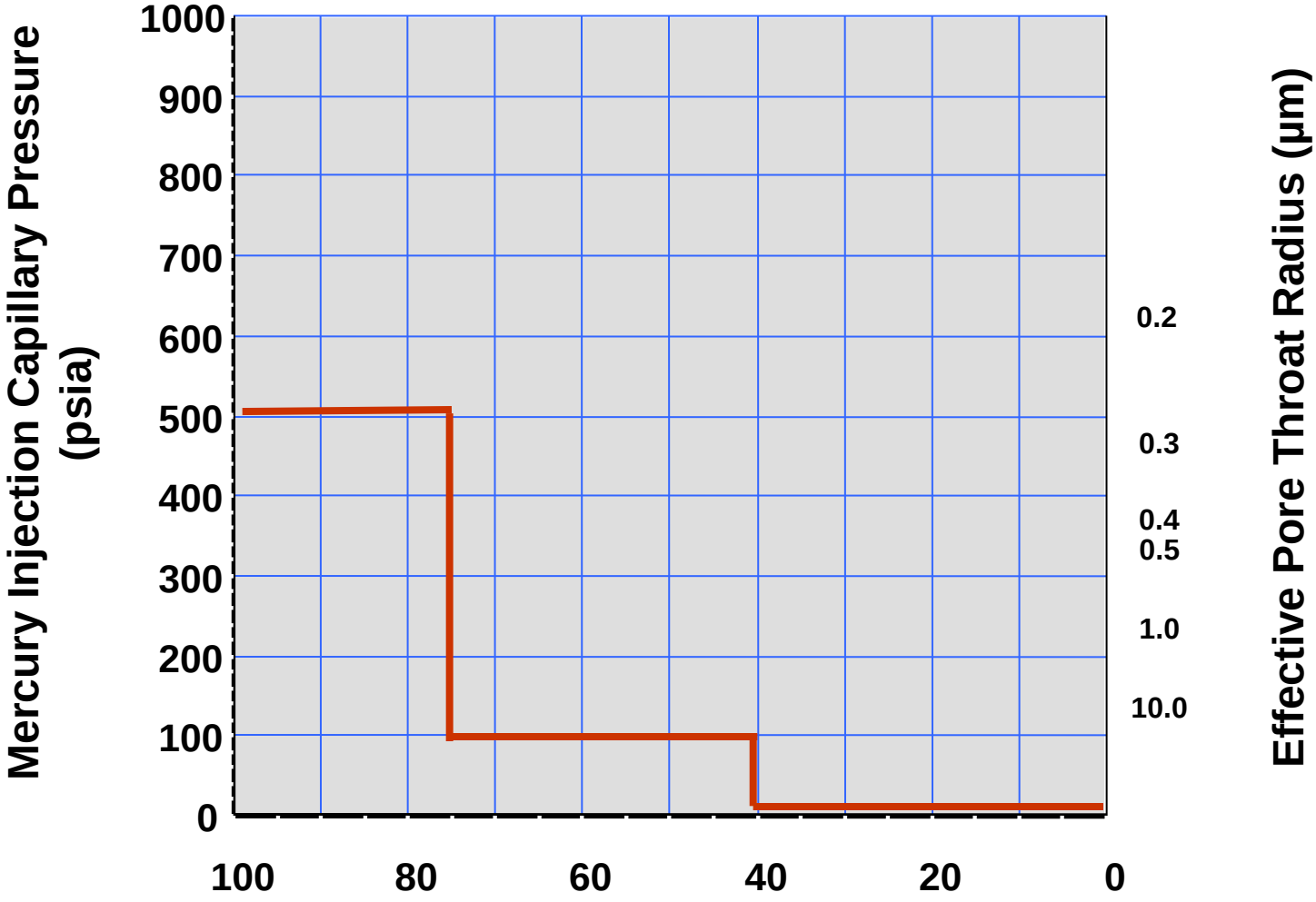
Pressure (psia)

100

Rock pore volume saturated (%)

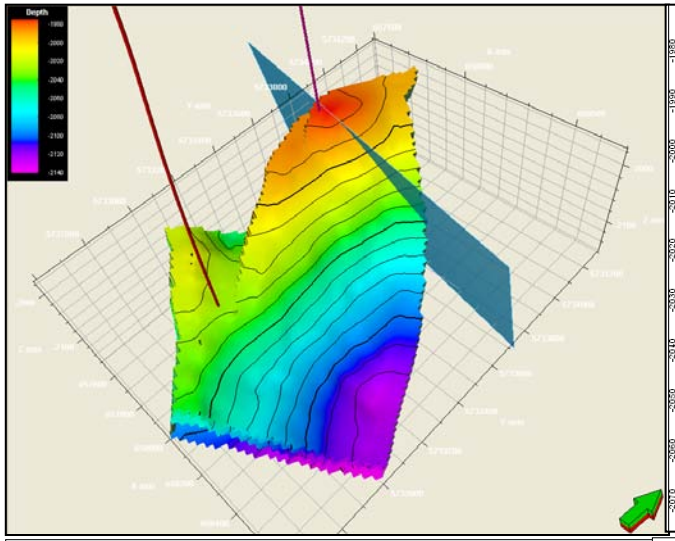


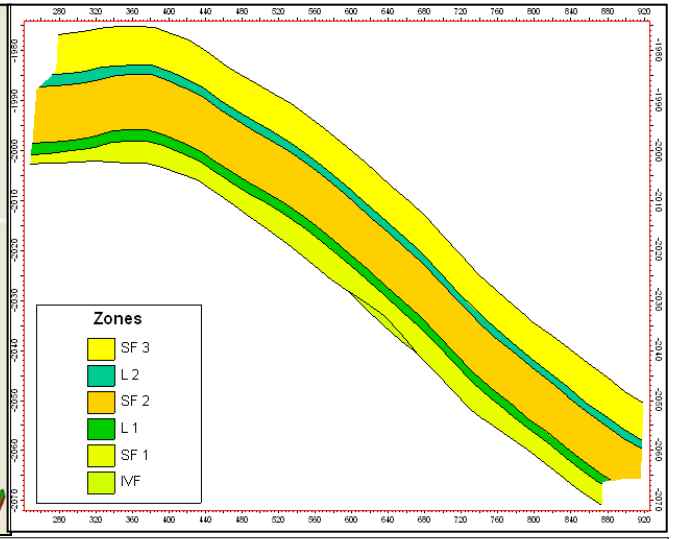
Mercury injection capillary pressure

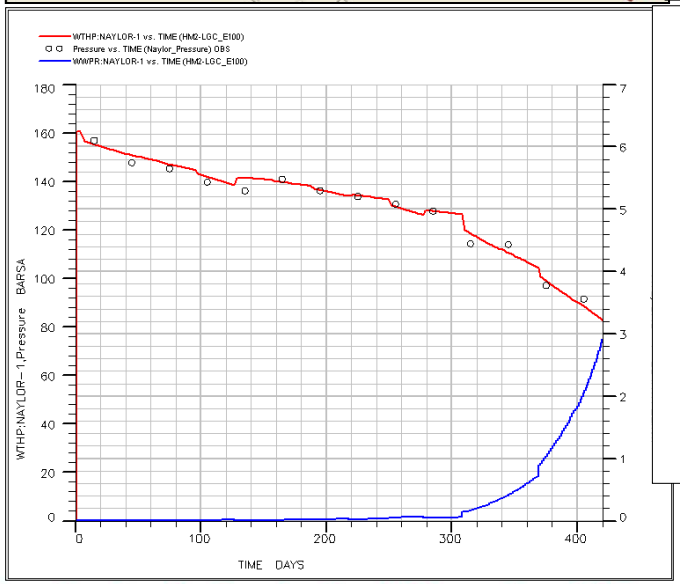


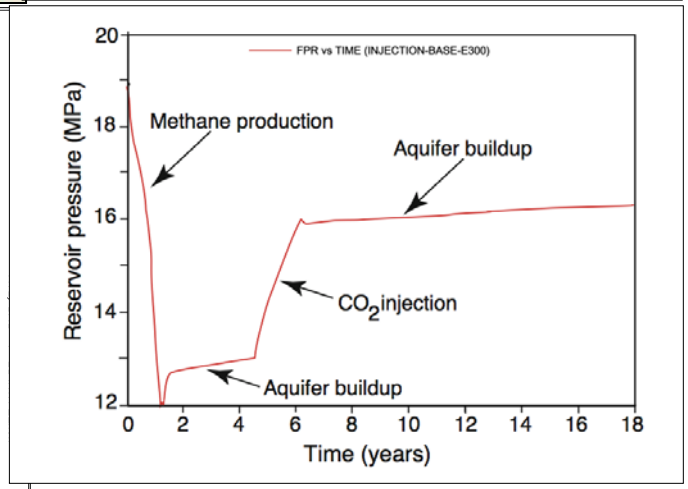
Site characterisation process

- Build detailed reservoir model using current state of the art modelling packages
- History match with actual production data to validate model.
- Predict future trend.

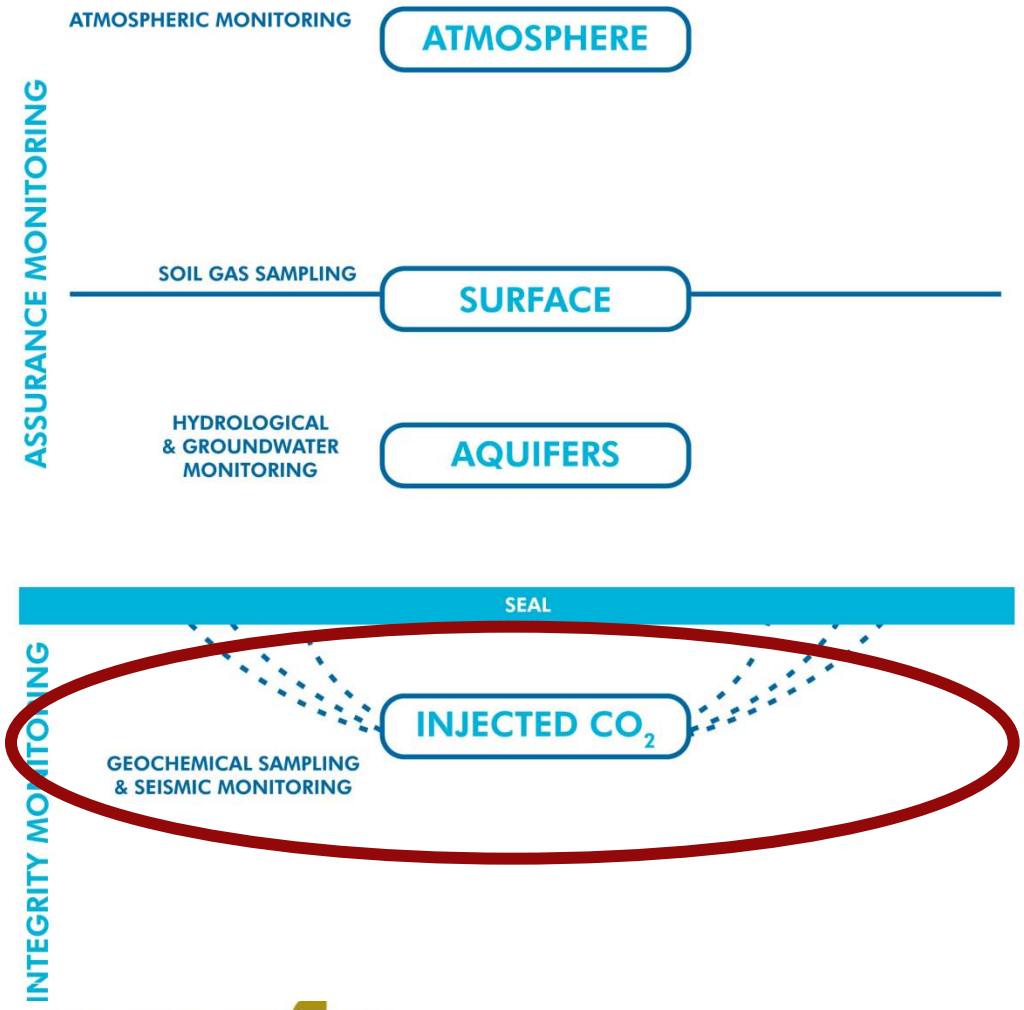








Monitoring the injected CO_2

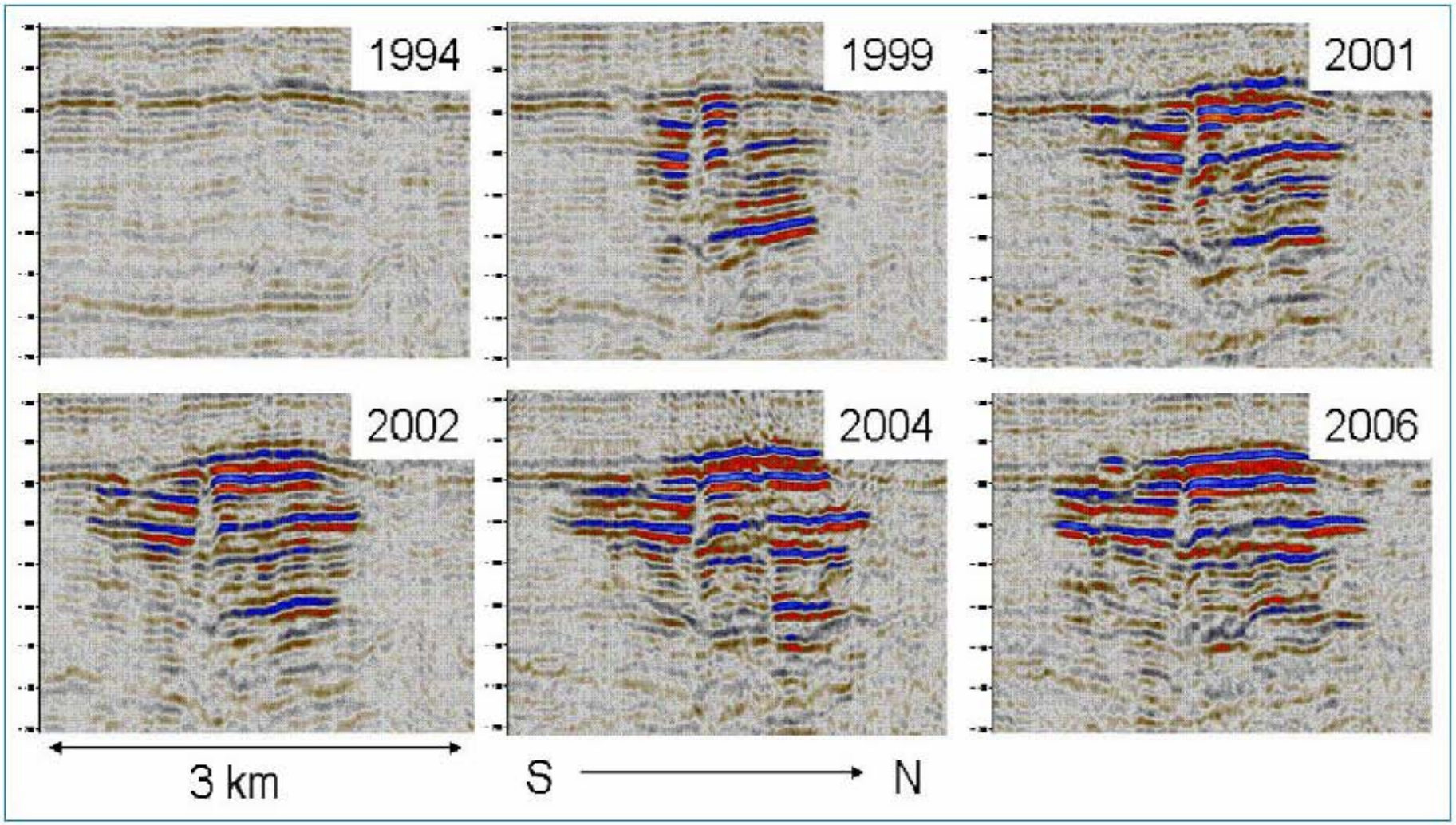


Measuring the temperature and pressure, recording sound waves and detecting chemical and electrical changes

Seismic monitoring

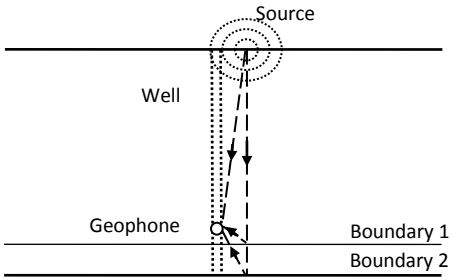
Image, CO2CRC

The Sleipner 4D seismics until 2006



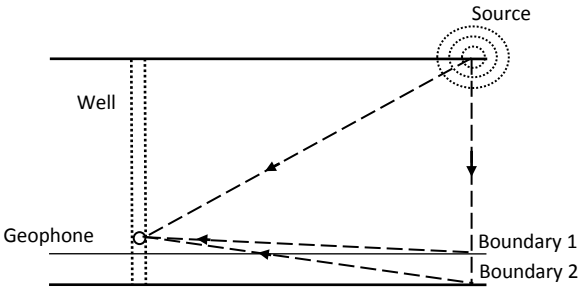
Vertical seismic profile monitoring

Zero offset VSP



The source is close to the well.

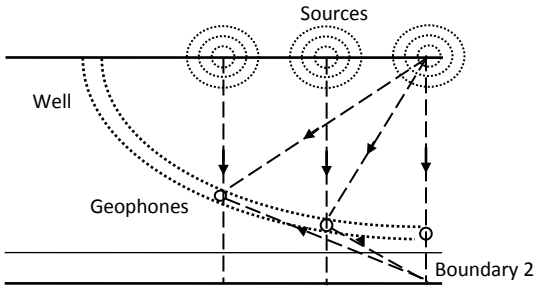
Offset VSP



The source is some distance from the well.

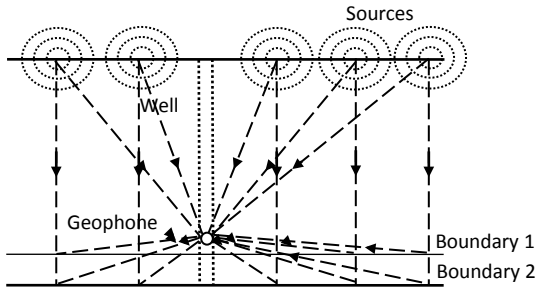
- VSP tomography
- High Resolution Travel time
- Microseismic surveys (measures creaks in the subsurface)

Deviated Well VSP (ZVSP)



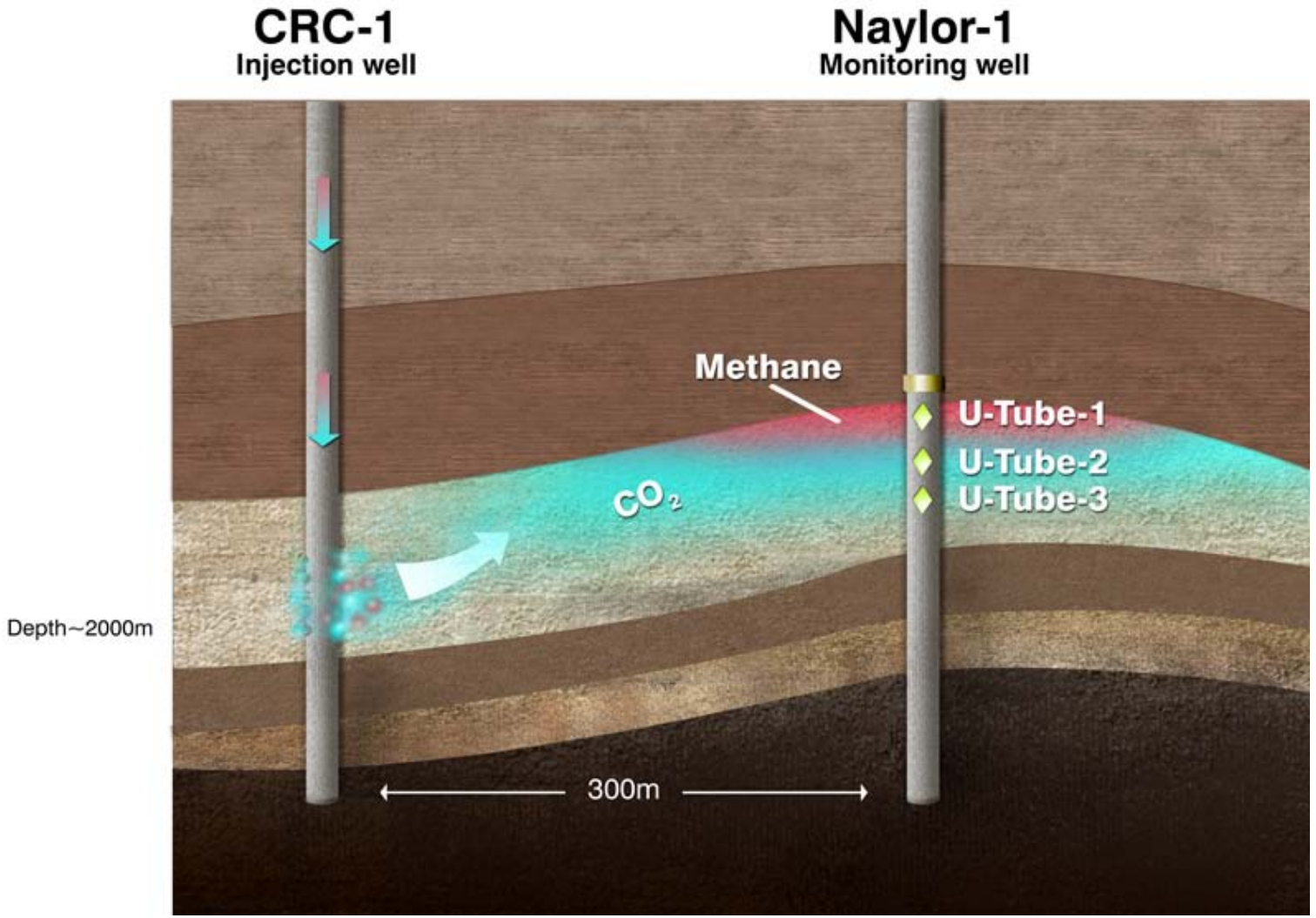
Multiple geophones are located in the well, with multiple source positions.

Walkaway VSP (WVSP)



The source is moved away from the well and signals are generated at regular spacings.

Downhole geochemical monitoring



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China Australia Geological Storage of CO_2

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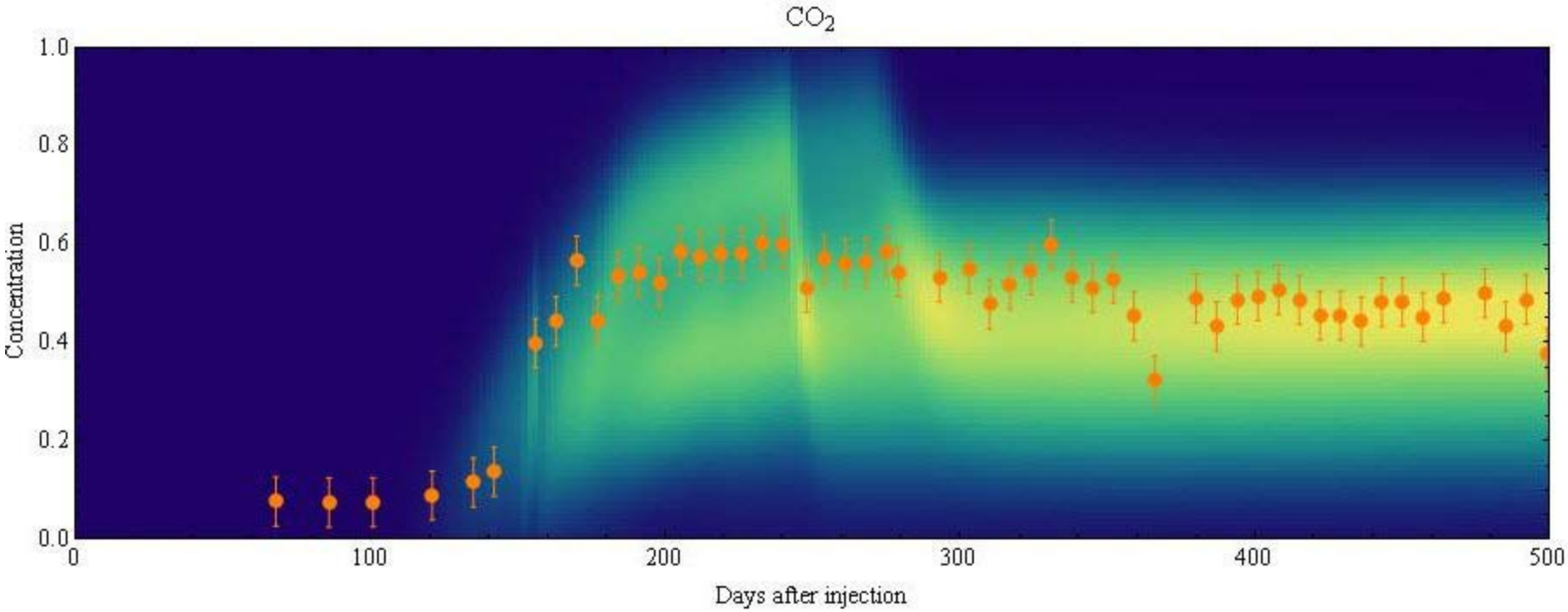
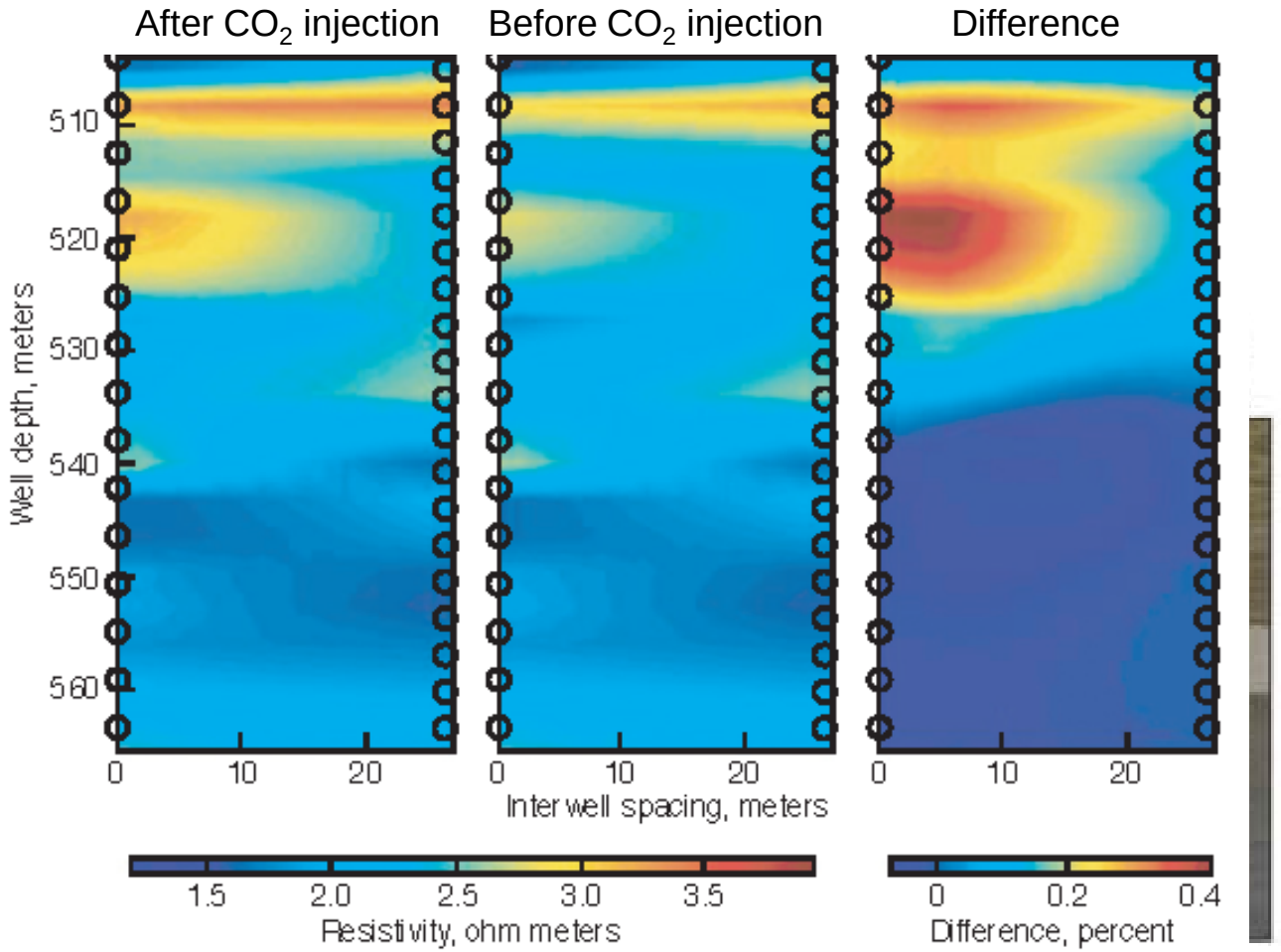
Model predictions



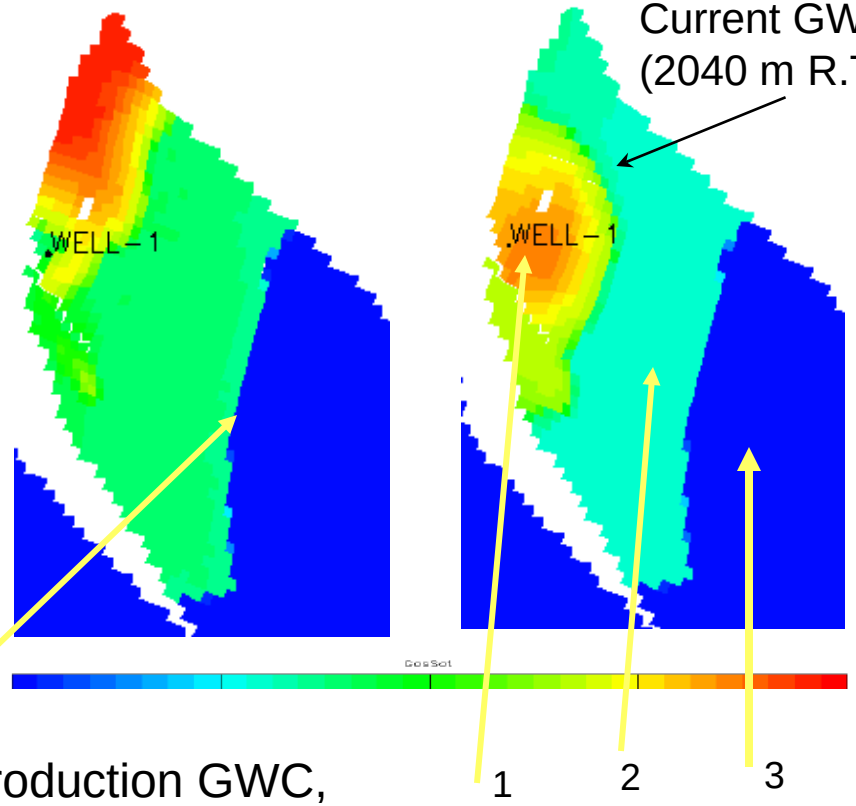
Cross-well electromagnetic tomography

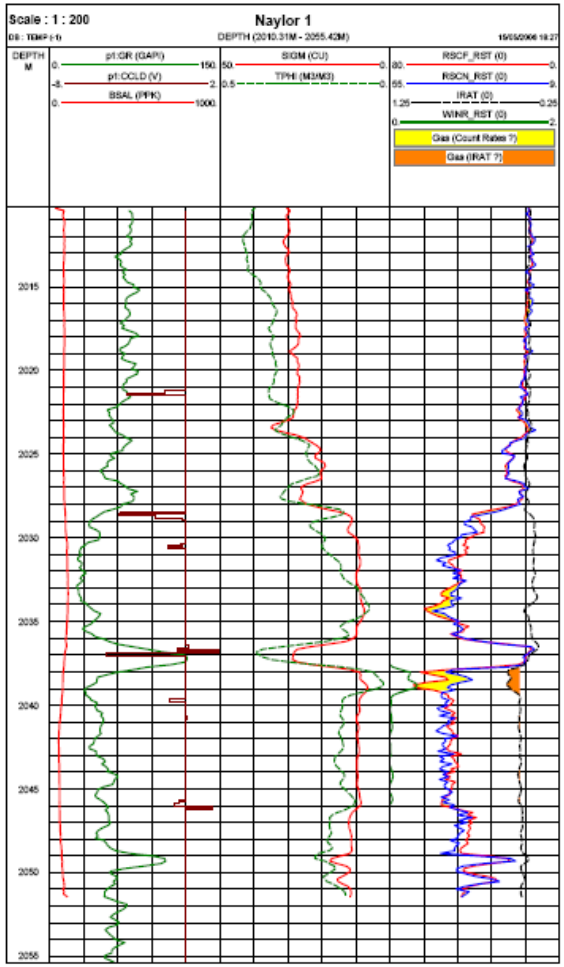


Schlumberger
S&TR, May 2005

Crosswell electromagnetic (EM) imaging of CO_2 sequestration at the Lost Hills field in central California—an enhanced oil recovery site operated by Chevron USA

Model validation through new data





1. Gas cap
2. Trapped gas (S_{gr}=0.25)
3. Aquifer (partial)

Other monitoring options…

- Microseismic activity, deep and shallow
- Pressure sensors in monitoring well
- InSAR to measure mm-to-cm scale surface deformation

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The authors would like to acknowledge the funding provided by the Australian Commonwealth through the CRC Program, and by both industry and state government partners to support CO2CRC research.

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CO2CRC Participants

Supporting Partners: The Global CCS Institute | The University of Queensland | Process Group | Lawrence Berkeley National Laboratory

Established & supported under the Australian Government's Cooperative Research Centres Program

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