# Cretaceous Stratigraphic Play Fairways and Risk Assessment in the Browse Basin: Implications for $CO_2$ Storage*

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## Abstract

The Browse Basin is a major Paleozoic to Cenozoic depocentre on Australia's Northwest Shelf that contains extensive petroleum reserves. Some of the gas accumulations have naturally elevated levels of $CO_2$ and future development of these gas fields may require sequestration options. A regional sequence stratigraphic analysis and geochemical study, using newly acquired geophysical data (from marine seepage and aeromagnetic surveys) and sediment samples, were undertaken to provide an updated basin framework and a better understanding of the potential of Cretaceous supersequences for both $CO_2$ storage and hydrocarbons. Updated biostratigraphy, well correlations, seismic, paleogeography interpretation and play fairway mapping were completed for seven supersequences, from the Berriasian to Maastrichtian. This analysis shows that entrenched fluvial systems flowing from the Kimberley Paleoproterozoic Basin on the inner-shelf formed a complex network of sedimentary inputs that operated throughout the Cretaceous. These fluvial systems fed numerous large submarine fan complexes of variable reservoir quality that are potentially isolated from the deltaic systems. These were deposited with N-NW progradation in the central and northern depocentres during sea level falls in the Berriasian, Valanginian, Barremian, Campanian and Maastrichtian.

A risk assessment was carried out to better understand the suitability of these fans for $CO_2$ storage, including reservoir quality characterisation using well log analysis and key containment constraints. The constraints investigated include fault reactivation, connectivity between sand bodies, hydrocarbon presence and indications of present-day or palaeo-seepage. Geochemical analysis and Grains with Oil Inclusions (GOI) techniques were used to assess the seal integrity. Contemporary stress field indicators suggest that the basin is most likely in a strike-slip

faulting regime, with the main compression direction oriented E-W. Seal integrity modeling predicts that faults trending WSW–ENE and WNW–ESE are most prone to reactivation in response to $CO_2$ injection. Common risk element maps allow characterisation of reservoir and seal pairs away from these key containment risks and prioritisation of areas that are located within Upper Cretaceous submarine fans. This study provides a framework for further work which will help determine the suitability of potential $CO_2$ storage sites, which are not in direct conflict with hydrocarbon prospectivity.

## References Cited

Blevin, J.E., H.I.M. Struckmeyer, C.J. Boreham, D.L. Cathro, J. Sayers, and J.M. Totterdell, 1997, Browse Basin high resolution seismic study, North West Shelf, Australia, Interpretation Report: Australian Geological Survey Organisation, Canberra, Record 1997/38, 282 p.

Chirinos, A., G. Morgan, A. Patchett, and A. Lahtinen, 2008, Site characterisation analysis for potential $CO_2$ storage in the Browse Basin, North West Shelf, Australia: Cooperative Research Centre for Greenhouse Gas Technologies, Canberra, Australia, CO2CRC Publication Number RPT08-1014, 139 p.

Australian Government
Geoscience Australia

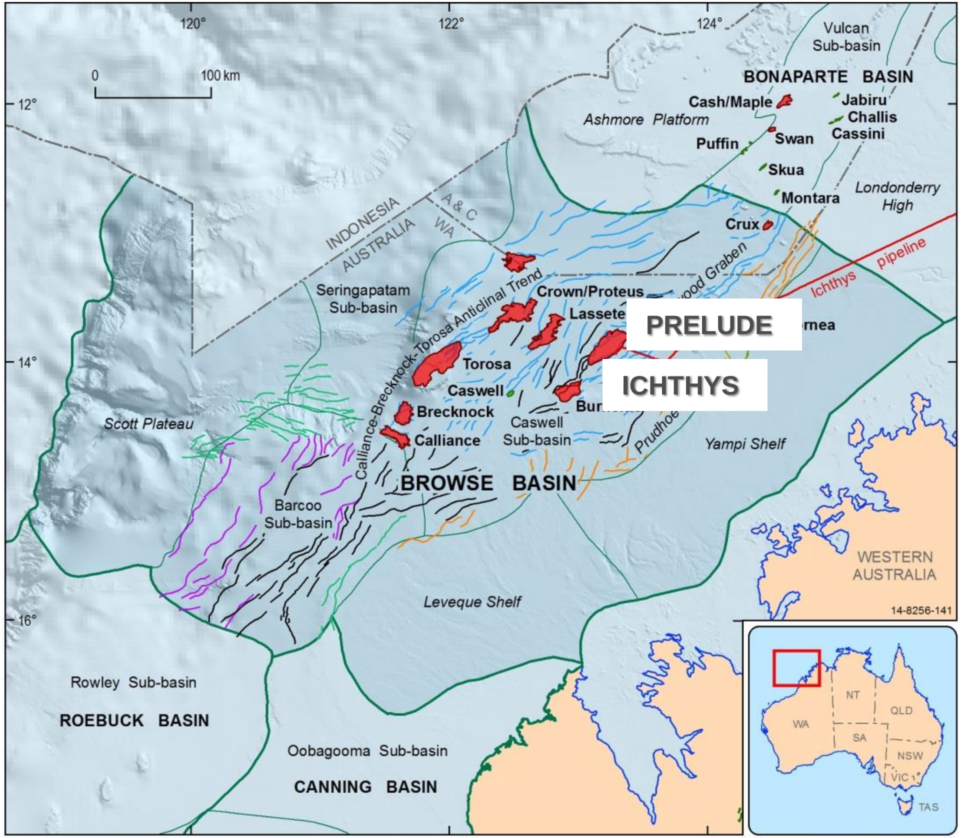
# Cretaceous Stratigraphic Play Fairways and Risk Assessment in the Browse Basin: Implications for $CO_2$ Storage

**GEOSCIENCE AUSTRALIA:** Nadege Rollet, Steve Abbott, Rowan Romeyn, Megan Lech, Kamal Khider, Emmanuelle Grosjean, Dianne Edwards, Chris Nicholson, Jennifer Totterdell, George Bernardel, Eric Tenthorey, Duy Nguyen, Luiqi Wang, David Caust and Ron Hackney

**FROGTECH:** Karen Romine, Jane Blevin

**CSIRO Energy Flagship:** Richard Kempton

# Browse Basin Regional Context

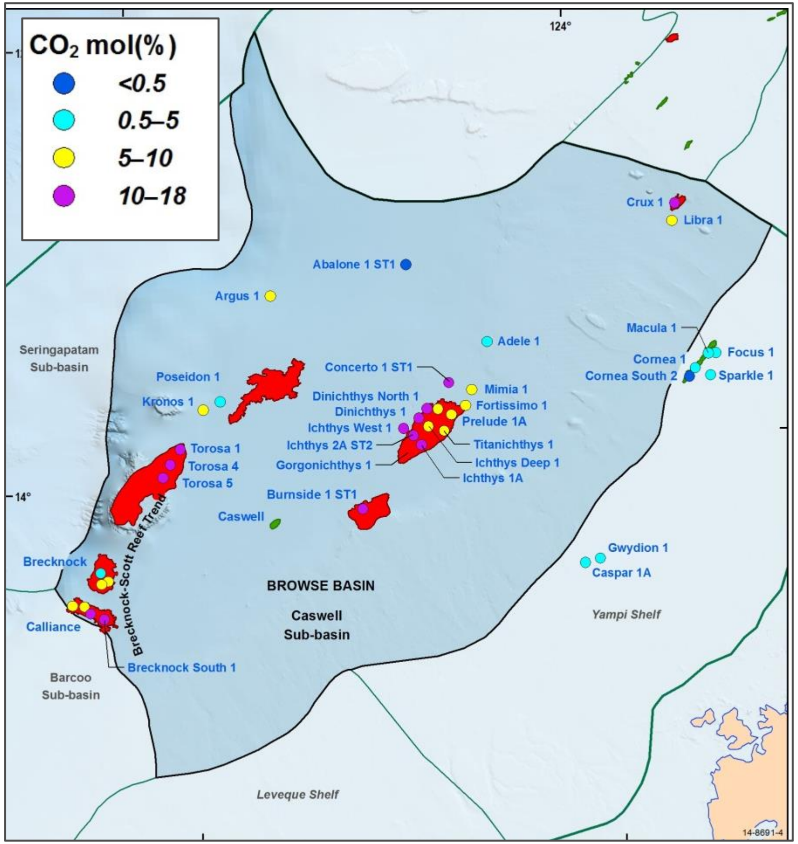



- Hosts large undeveloped gas resources

  (36 Tcf of gas and 1148 MMbbl of condensate)

- Next LNG province on the North West Shelf

# Browse Basin Regional Context

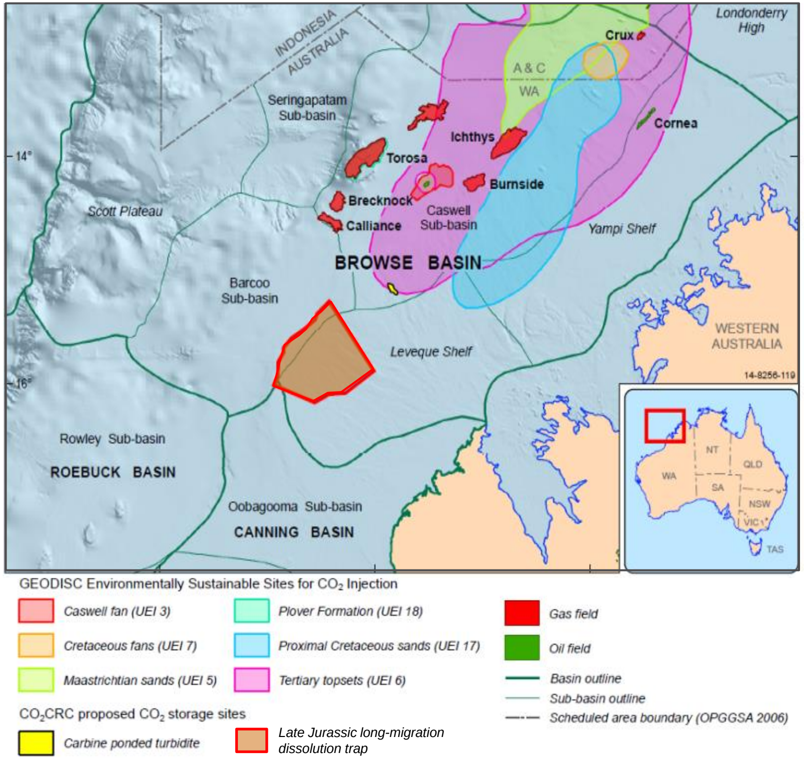



- Accumulations are high in $CO_2$ (~ 8%) → Carbonate origin
- Sequestration options may be required in the future

# Previous studies

- Previous studies identified Environmentally Suitable Sites for $CO_2$ injection (ESSCI)
- Based on GA's previous regional geological study (Blevin et al., 1997)

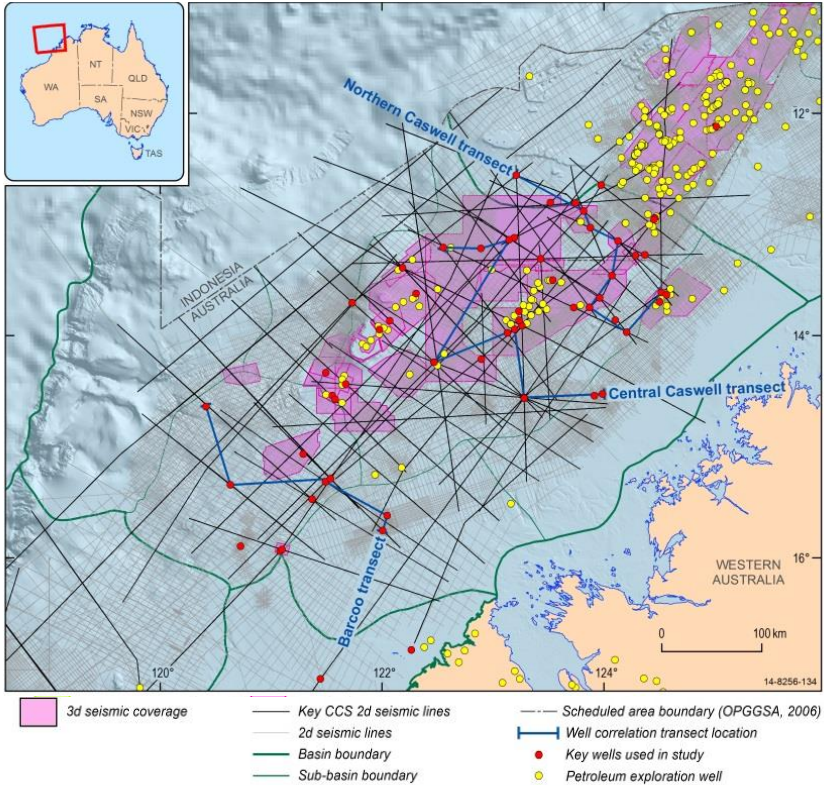
BBHR (1997); GEODISC (1999-2003); CO2CRC (2007-2008)



# Aims of the study

- Improve understanding of basin evolution, sequence stratigraphy and architecture
- Update basin framework, palaeogeography and play fairways
- Identify and prioritise suitable areas for $CO_2$ storage that are NOT in conflict with hydrocarbon exploration

Abundant new data: 60 key wells and regional 2D and 3D seismic

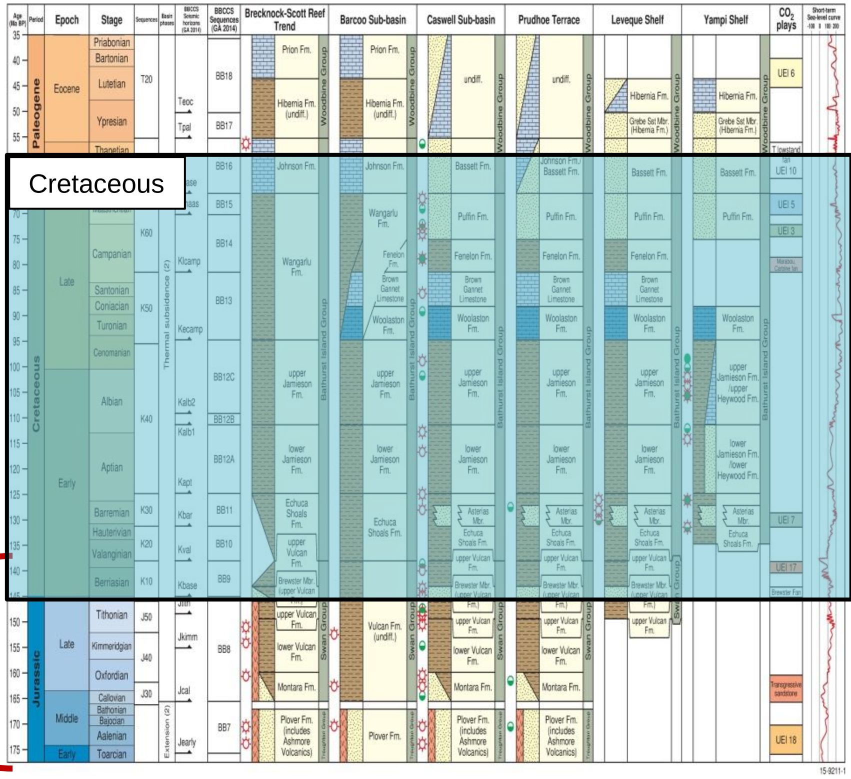


# Focus of the study

- Minimise resource conflicts risk: hydrocarbon targets in Jurassic–Lower Cretaceous

- Study focused on Cretaceous successions for potential CO2 storage

High hydrocarbon prospectivity conflict + high $CO_2$ content



# Assessment Workflow

**OUTCOME**

## $CO_2$ STORAGE POTENTIAL ASSESSMENT

- High grading plays of interest
- Common risk element mapping
- Constraints to containment

**OUTPUT**

## Palaeogeographic and play fairway mapping

- Sequence stratigraphy
- Structure
- Petroleum systems

**INPUT**

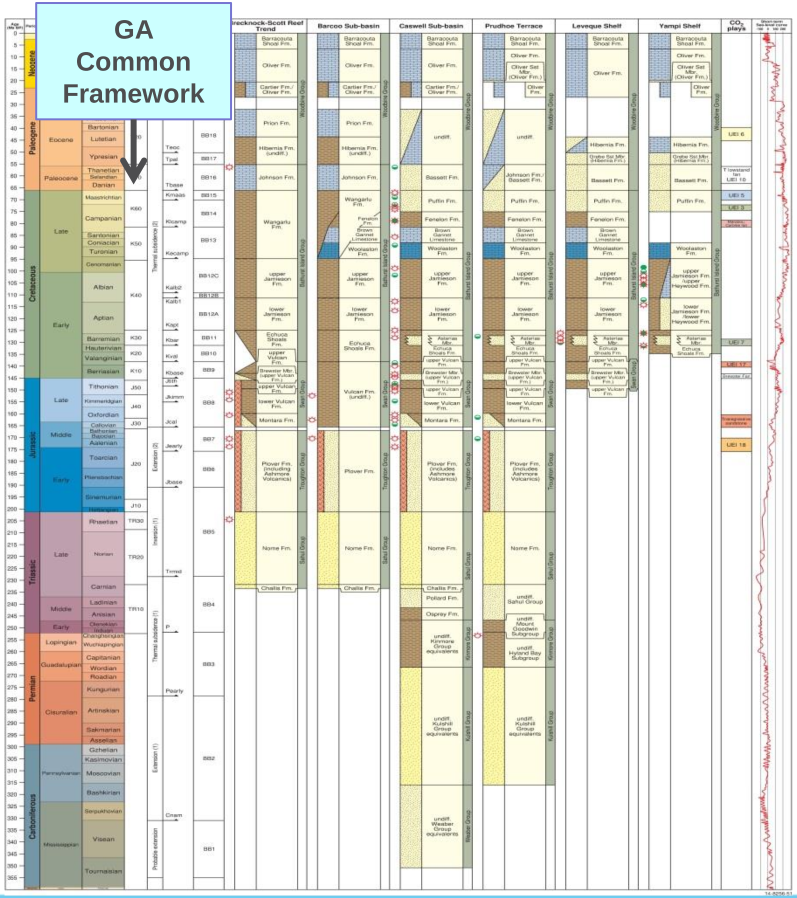
## Data capture and knowledge gap analysis

- **Well data:** biostratigraphy, well composites, time-space plots, synthetics, petrophysical analysis
- **Seismic:** 2D, 3D
- **Potential field:** gravity, magnetic
- **Geochemistry:** fluid inclusions, source rock & fluid analysis
- **Exploration:** hydrocarbon shows and accumulations

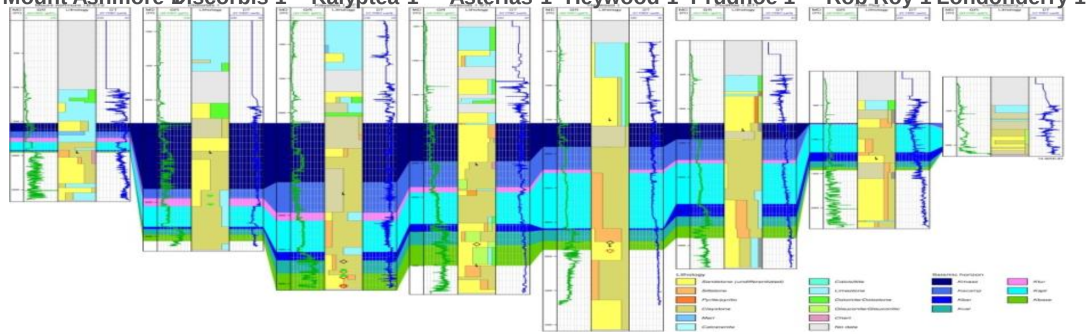
## New Pre-competitive data

- **Potential field:** aeromagnetic
- **Marine environmental:** seabed, biota and seepage
- **Geochemistry:** source rock sampling and analysis

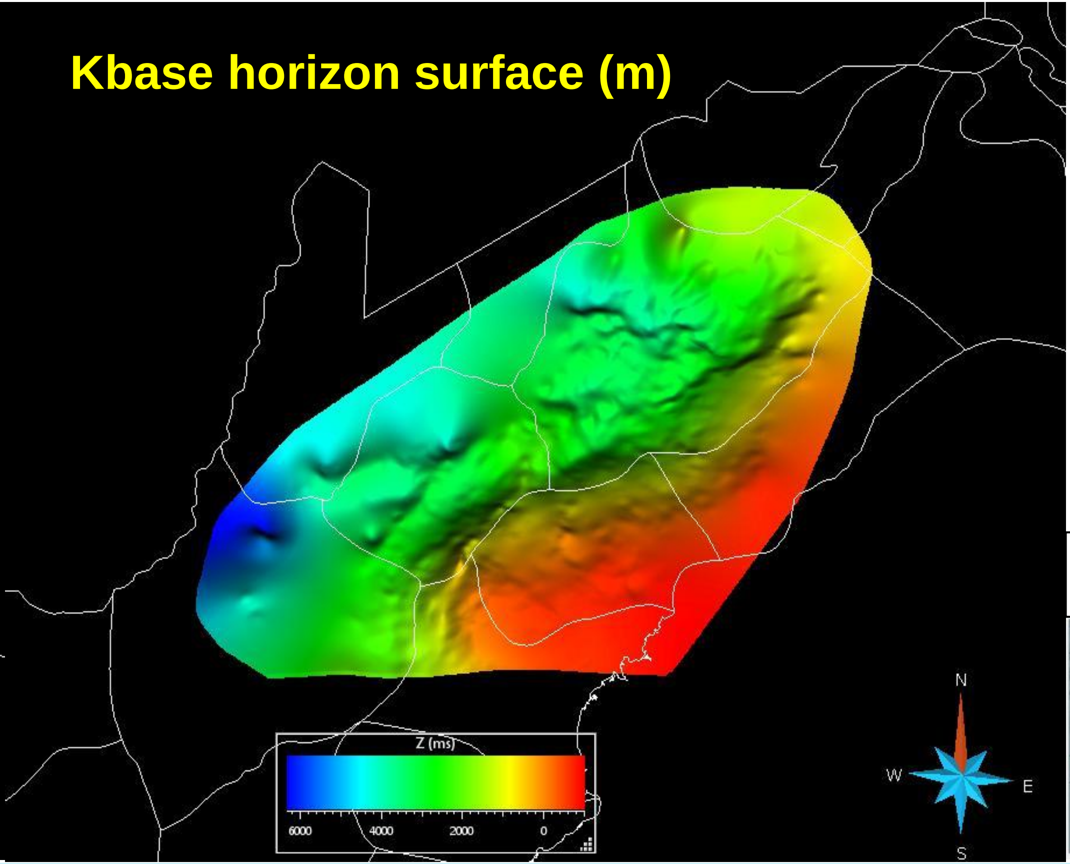
# NWS common stratigraphic framework



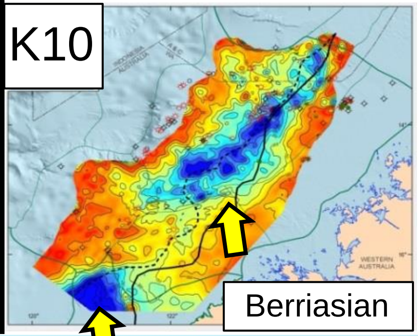

- Updated Browse Basin tectonostratigraphic framework
- Adopted a common NWS framework with industry aligned on Geologic Time Scale 2012
- Will assist industry and benefit exploration through a common ‘stratigraphic language’

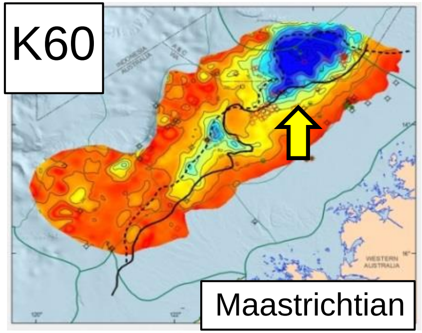


# Mapping faults and key seismic surfaces



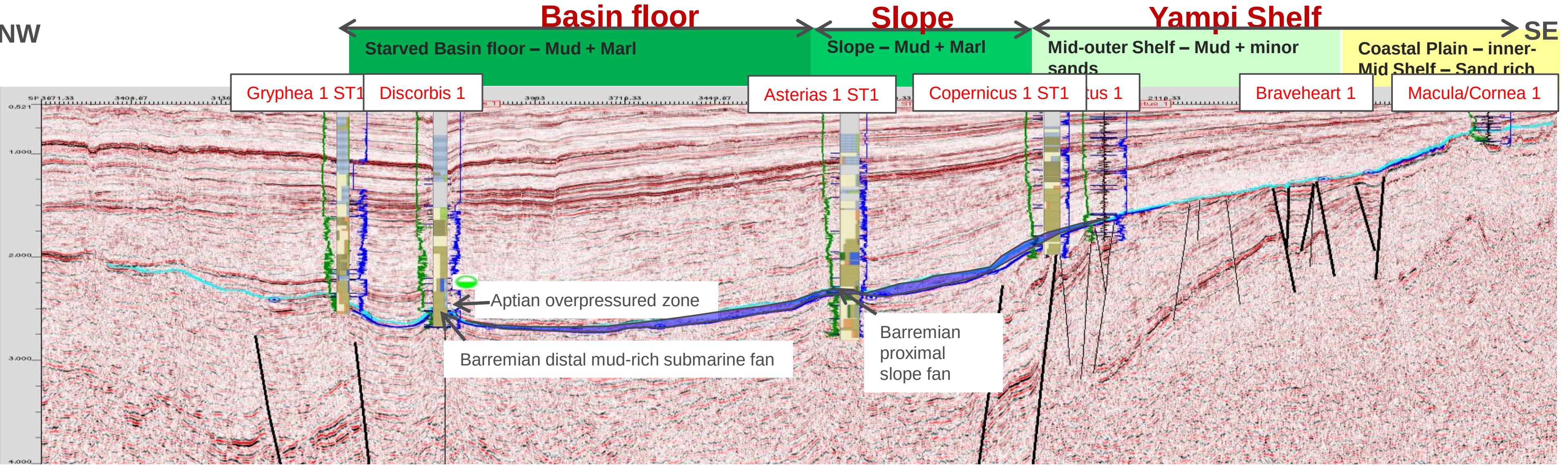

- Horizon surface grids. Time-Depth conversion using HiQbe velocity model
- 3D visualisation in GOCAD
  - → 7 supersequences (Berriasian–Maastrichtian)
  - → basin and sequence geometry through time (N/NW progradation)



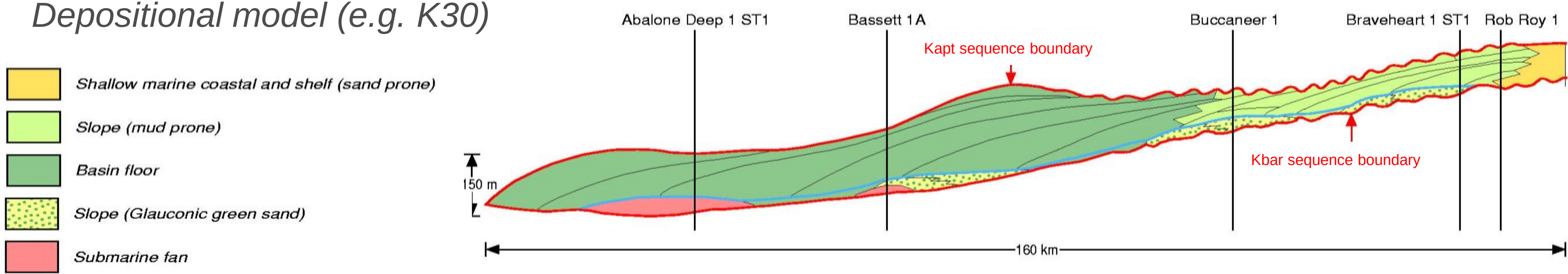



# Sequence stratigraphy and depositional models

*e.g., Caswell Sub-basin – Lower Cretaceous*

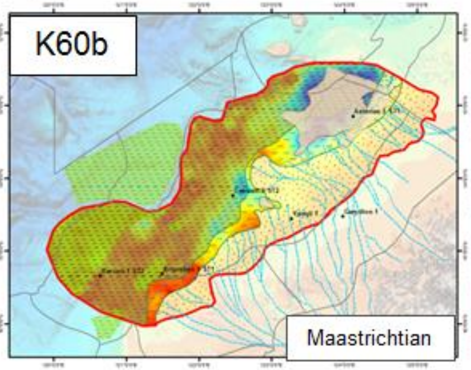


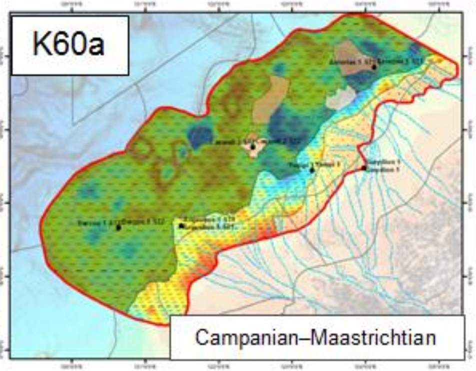

*Depositional model (e.g. K30)*

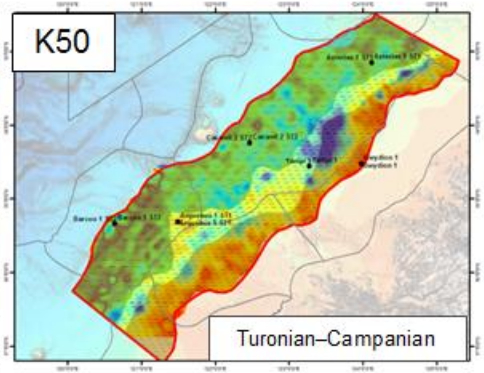


# Palaeogeographic mapping

## Upper Cretaceous

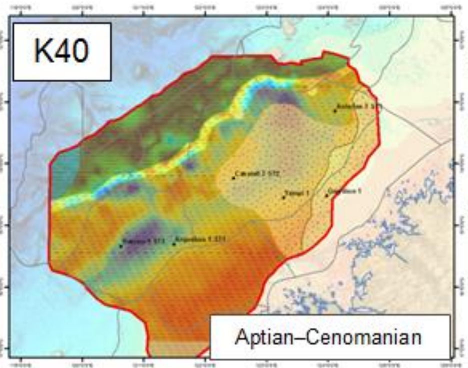


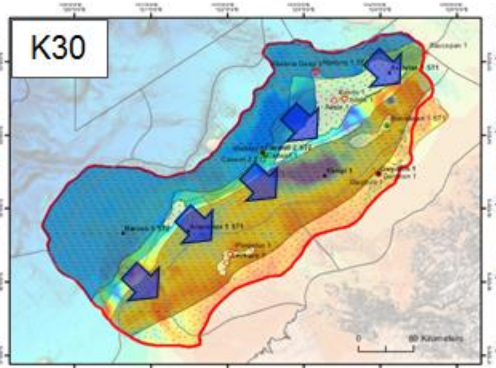



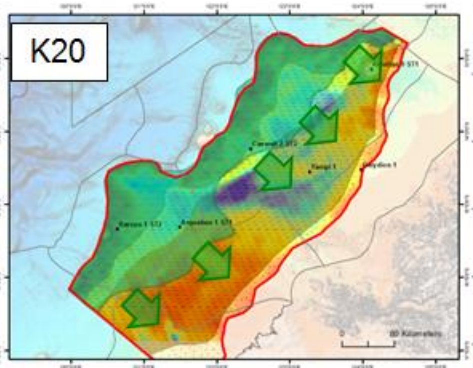



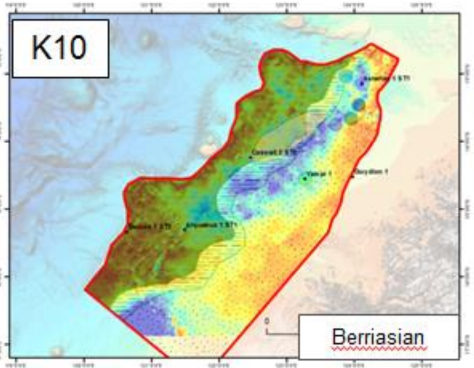

- Coastal plain and shelf (mud prone)
- Coastal plain and shelf (sand prone)
- Slope
- Basin floor

## Lower Cretaceous



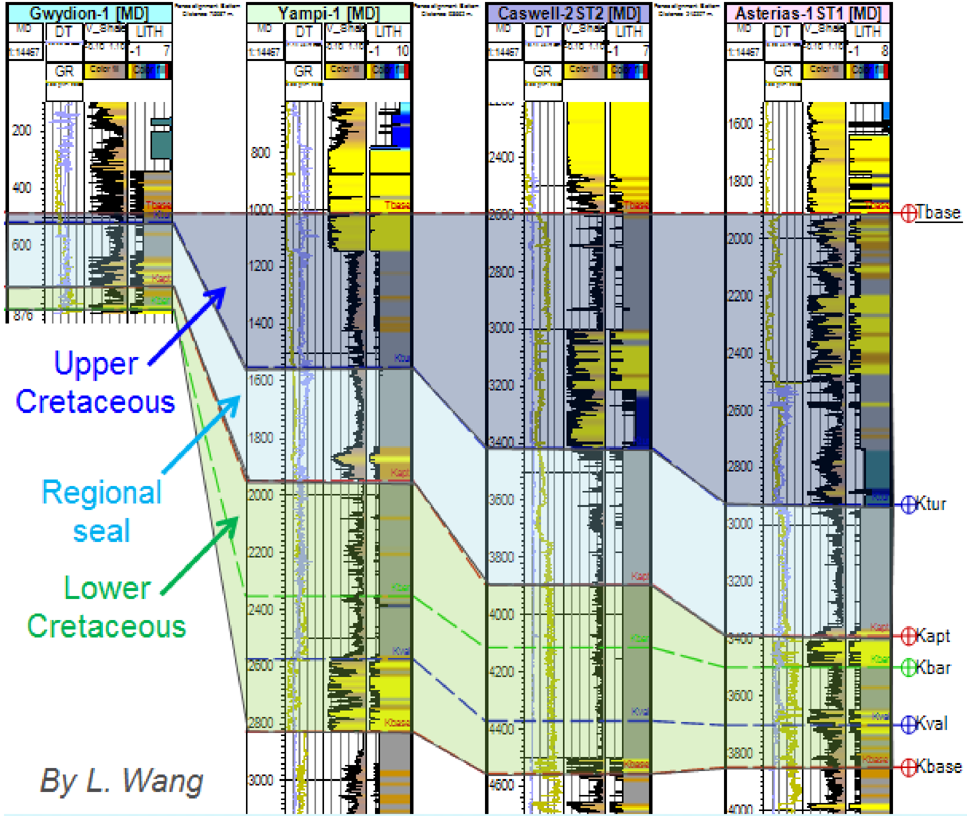



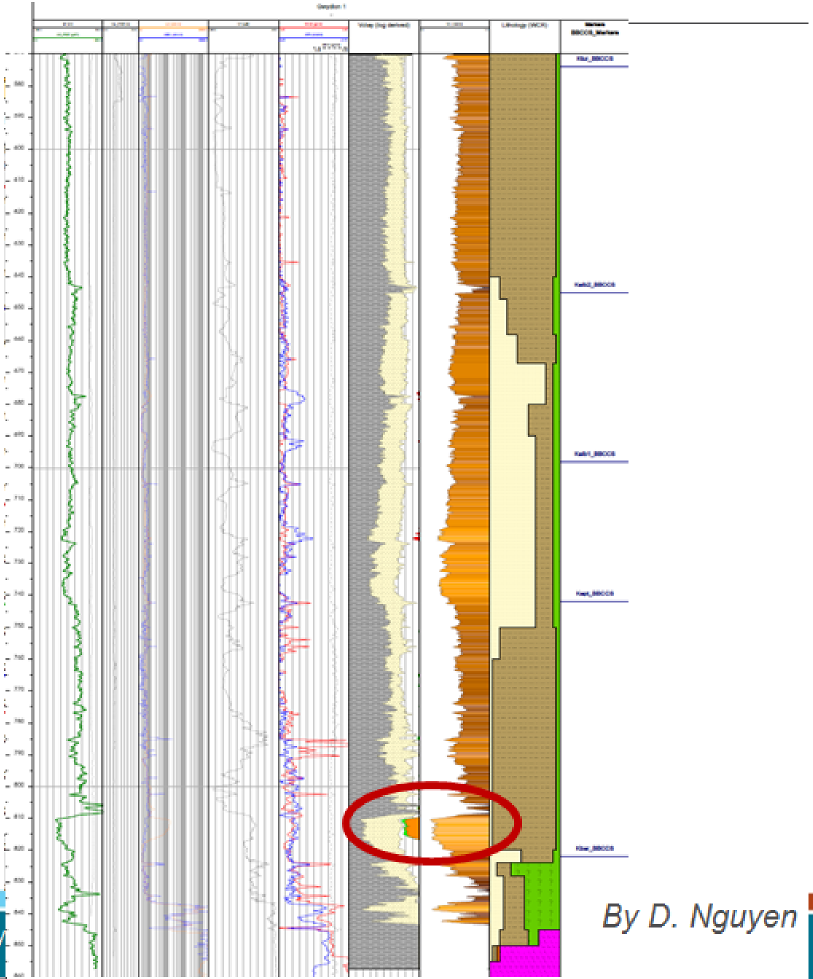
# Reservoir and seal analysis

*Caswell Sub-basin*




*By L. Wang*

→ For areas of interest

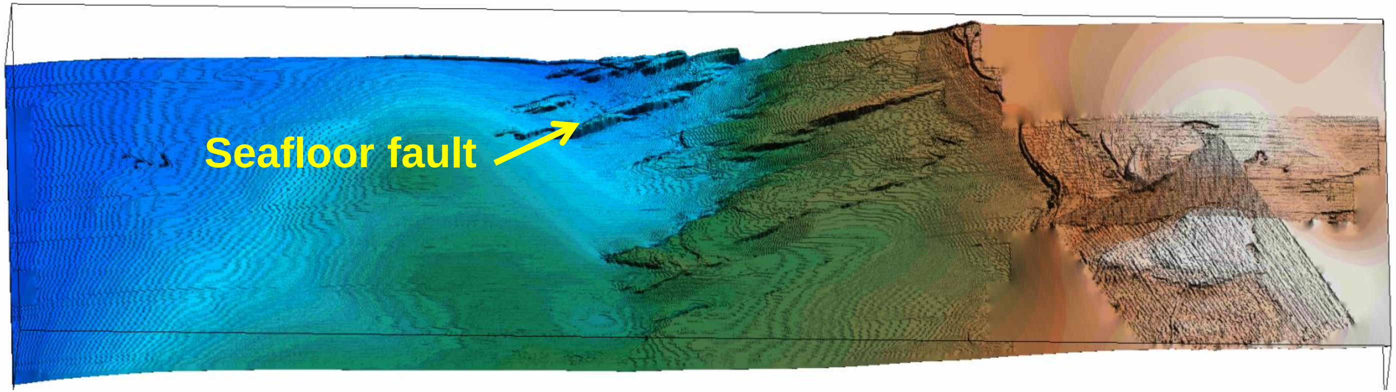


*By D. Nguyen*

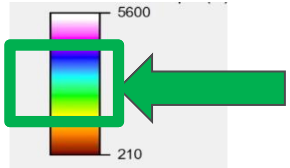
# Limiting factors for $CO_2$ containment

1. High-quality reservoir at 800–3000 m depth
2. Seal distribution
3. Seal integrity (e.g. fault reactivation)
4. Hydrocarbon conflicts

→ **Risk Matrix**



Surface Depth (m)

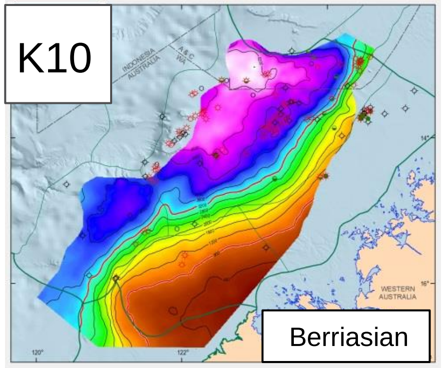


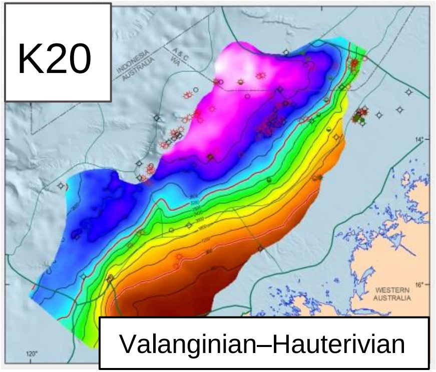

# 1- Reservoir Depth

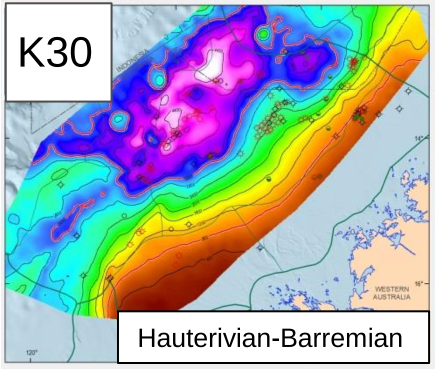
**Reservoir depth suitable for $CO_2$ storage: 800–3000 m**

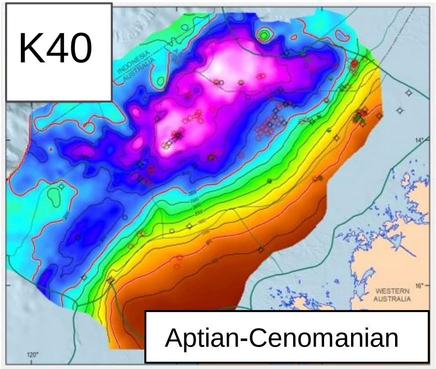
## Lower Cretaceous

K20 (Valanginian-Hauterivian)

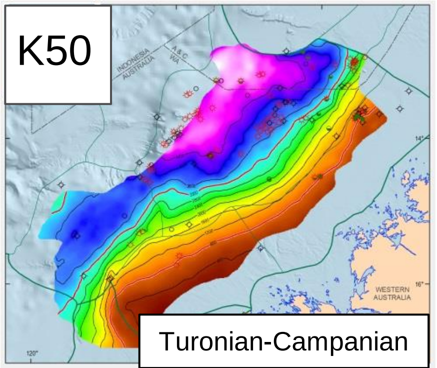


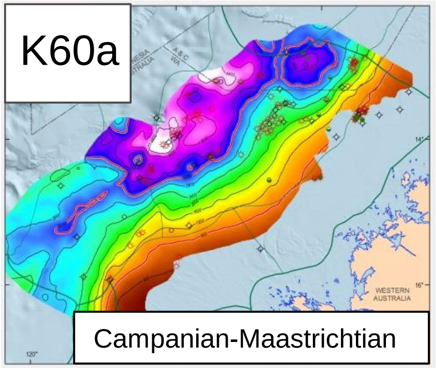



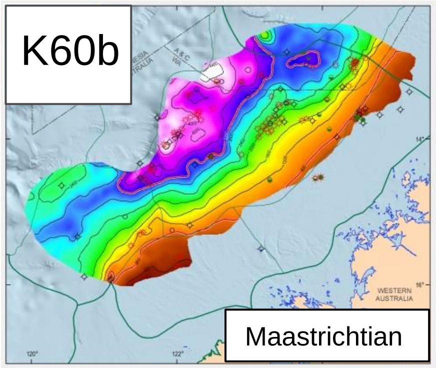



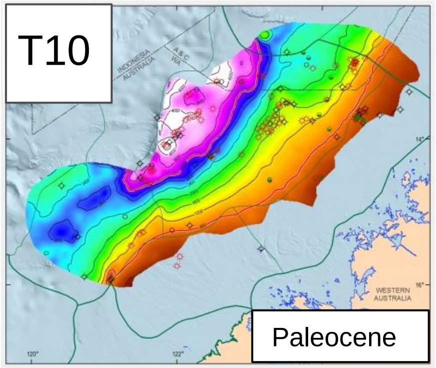




## Upper Cretaceous



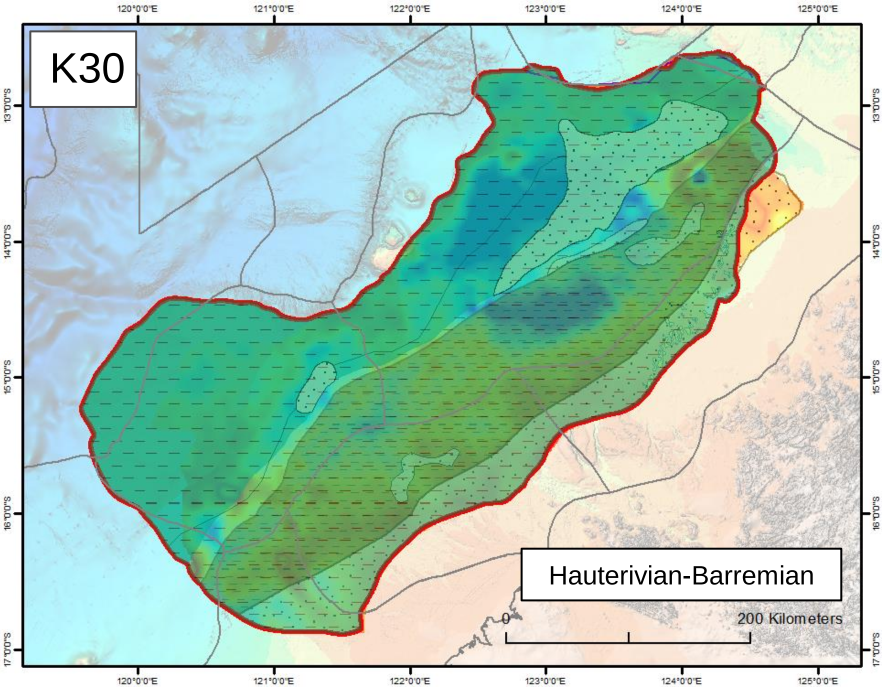



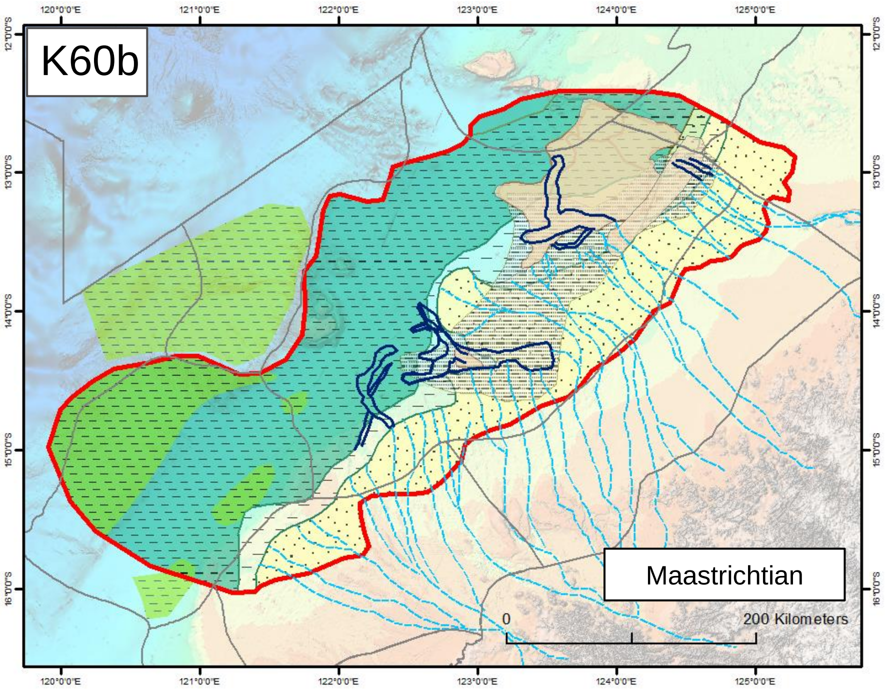
# 2- Top seal distribution and characteristics

## Lower Cretaceous




High-quality thick claystone regional seal (80–200 m); inboard pinchout against basement

## Upper Cretaceous

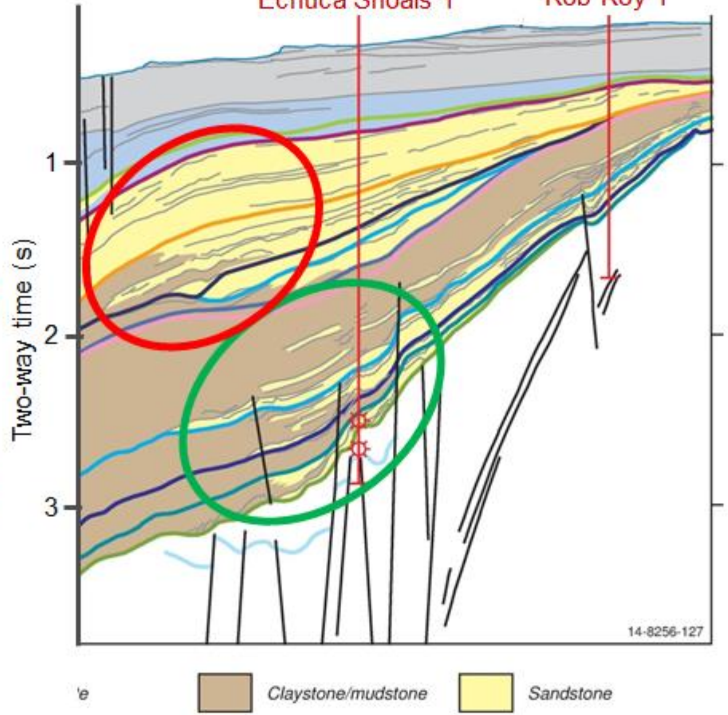



Variable seal quality (basin floor mud-prone; slope mud/silt-prone; shelfal progrades with sand/silt/mud

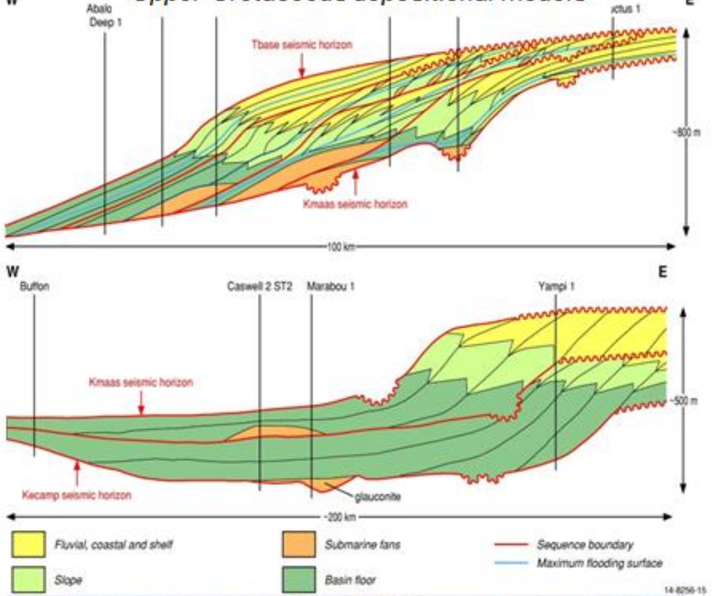
# 2- Top seal characteristics – Sand connectivity

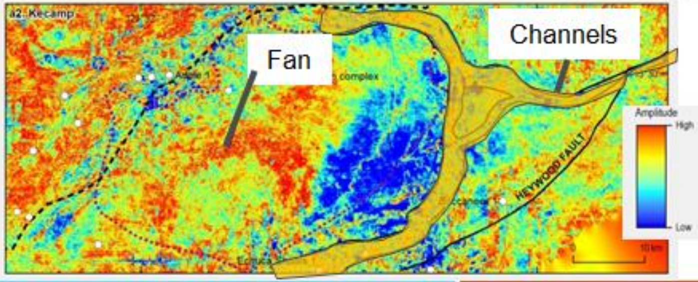
Upper Cretaceous
Higher connectivity

Lower Cretaceous
Lower connectivity




Upper Cretaceous depositional models

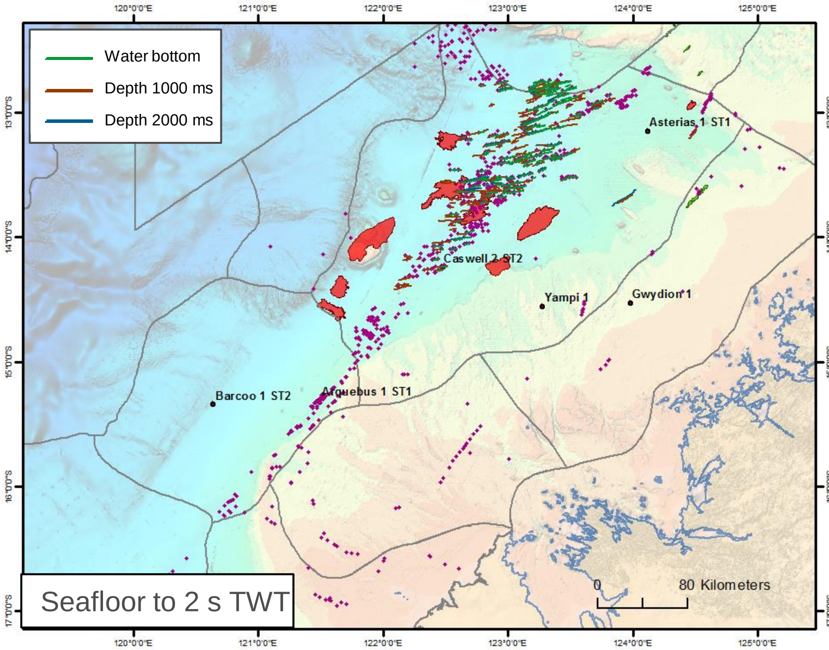


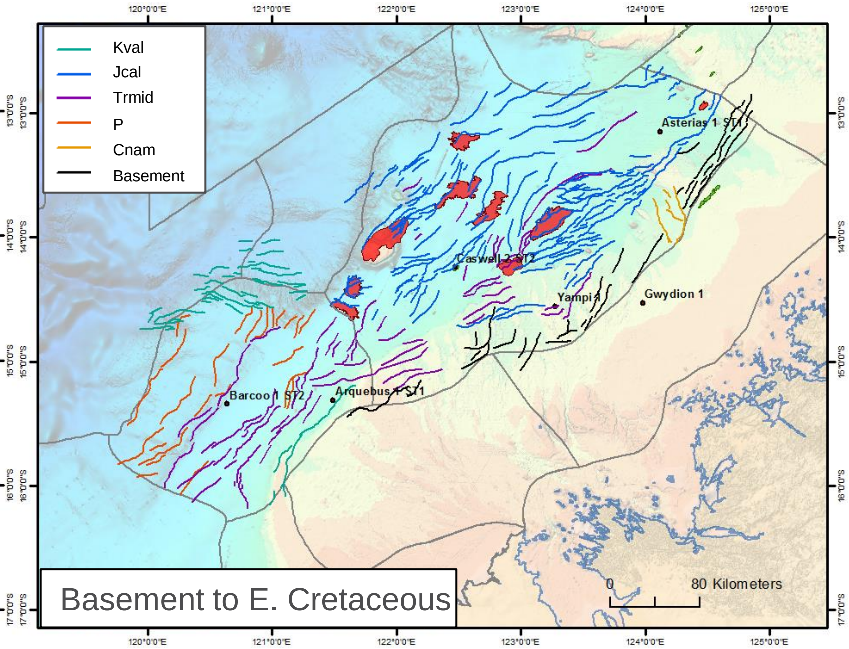

→ Connectivity between stacking patterns?
→ Connectivity between submarine fans and shelf?
→ Submarine fans fed by entrenched fluvial systems

# 3- Seal integrity – Fault presence

## Shallow faults

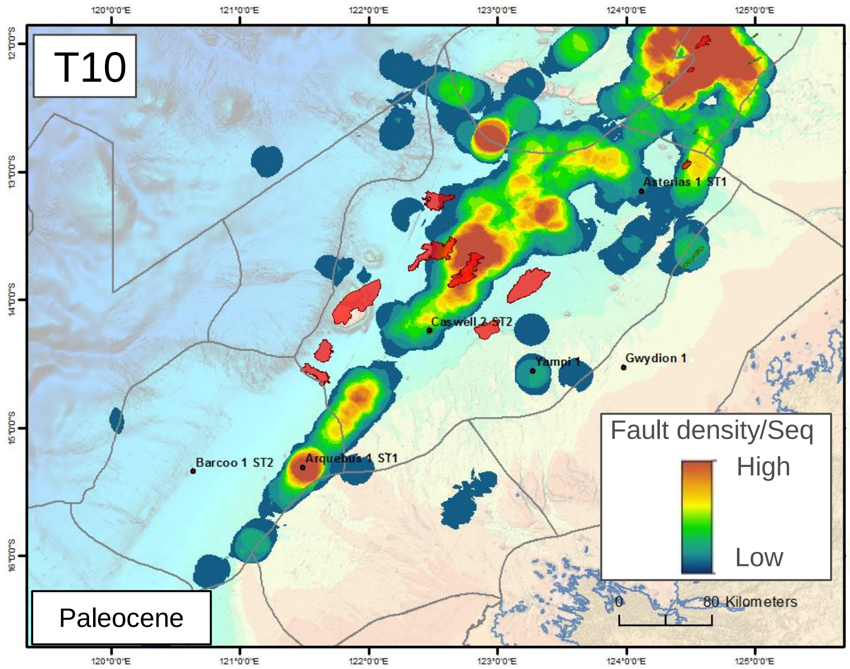



## Regional deep faults



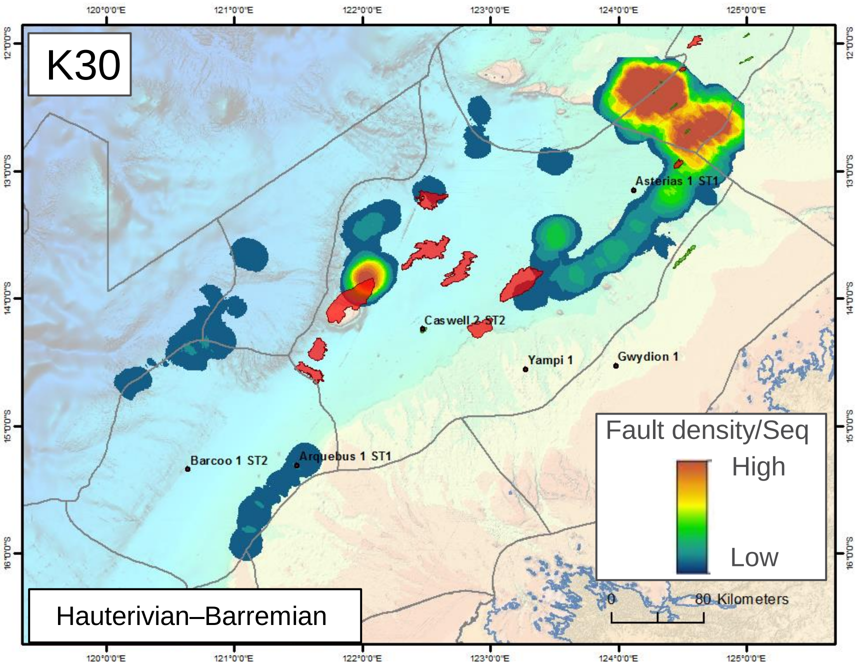
# 3- Seal integrity – Fault density

Upper Cretaceous



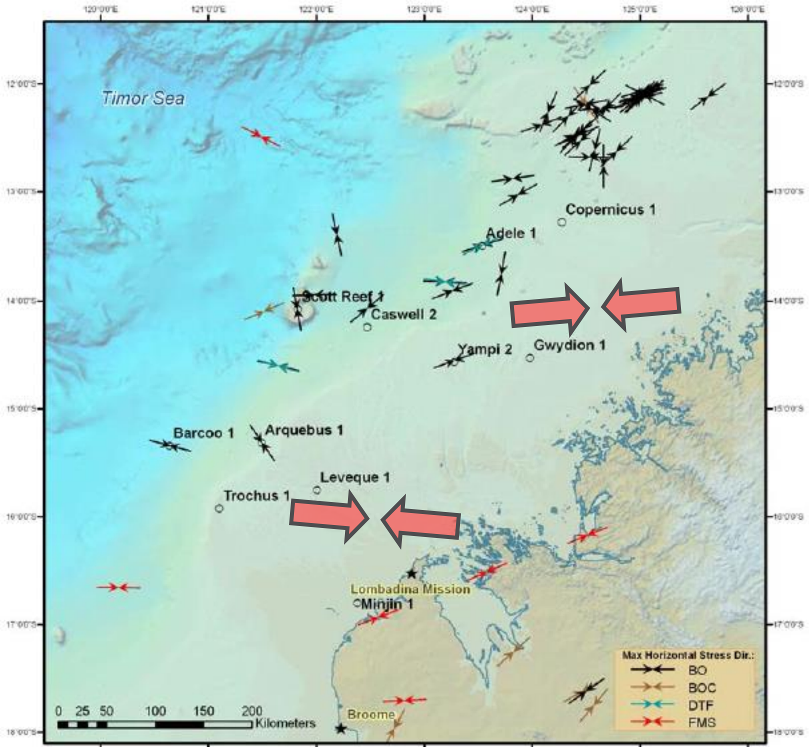

→ Shallow faults

Lower Cretaceous




→ Regional deep faults

# 3- Seal integrity – Geomechanical analysis




*By E. Tenthorey*

→ Current Stress Field -

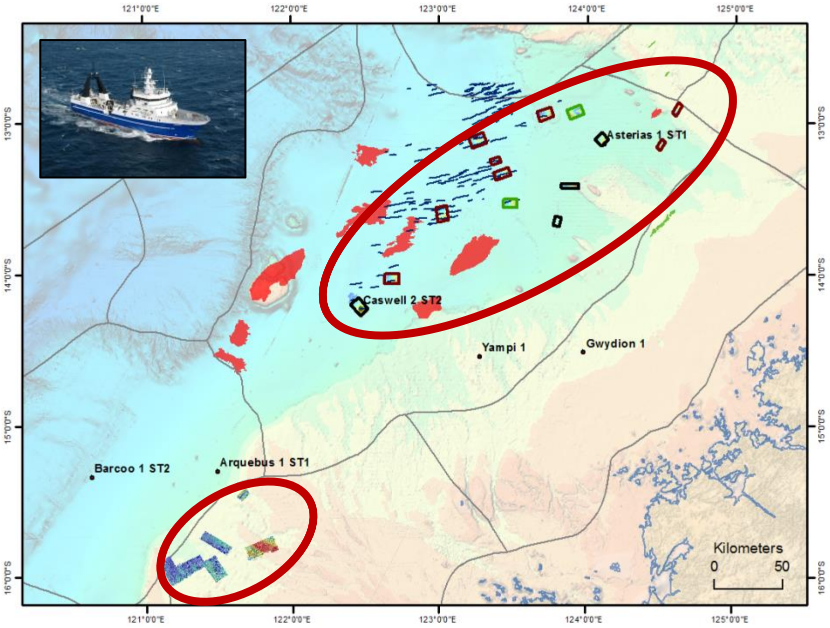
$S_{Hmax}$ Orientation

→ ESE- and ENE-trending faults have the highest reactivation risk

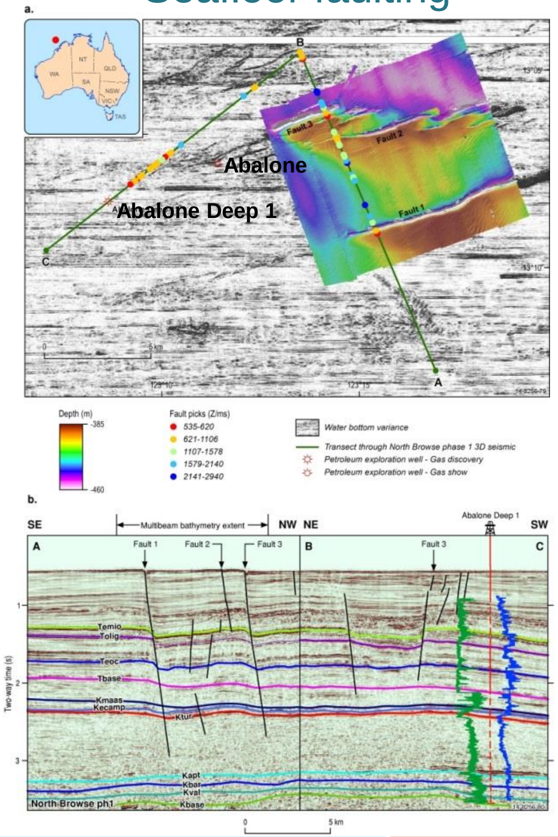
# 3- Seal integrity – Fault reactivation and leakage?

## → Marine survey data:

- Investigate modern seepage that may compromise storage prospectivity or help better understand petroleum systems
- Collect environmental baseline data before storage activities



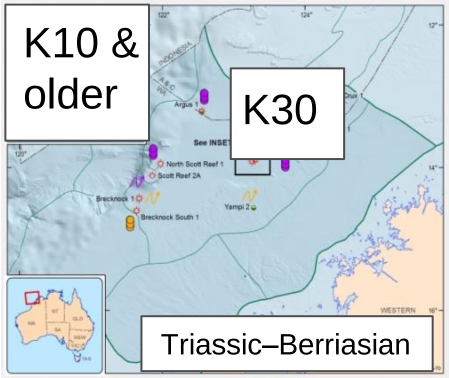

## Seafloor faulting

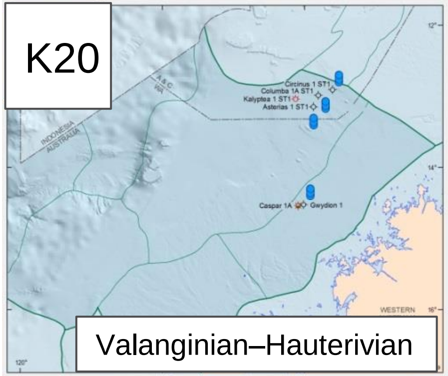


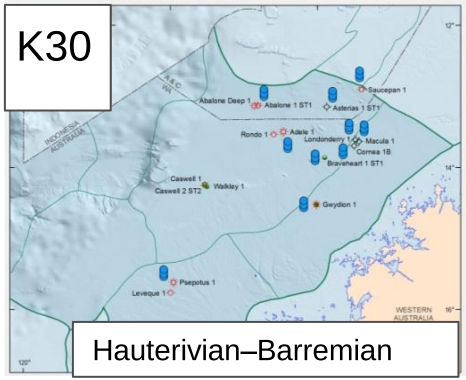
# 4- Hydrocarbon Shows and GOI

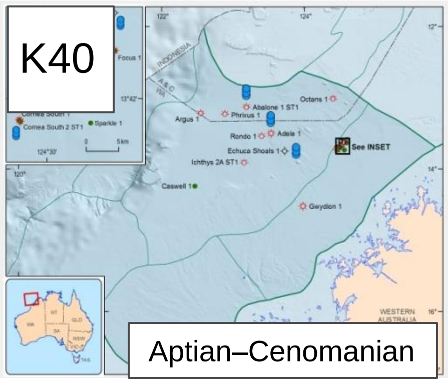
→ Gas and oil accumulations/shows in K10–T10 and palaeo-oil migration up to K60b (GOI)

## Lower Cretaceous

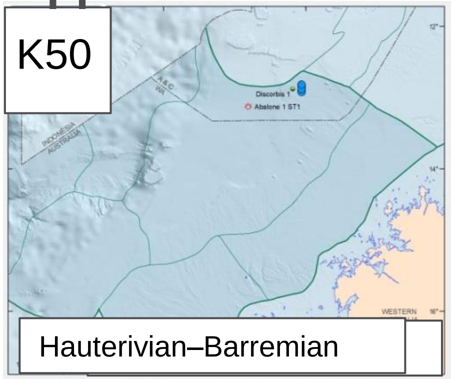


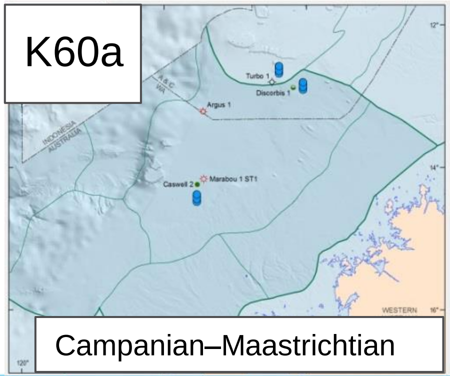



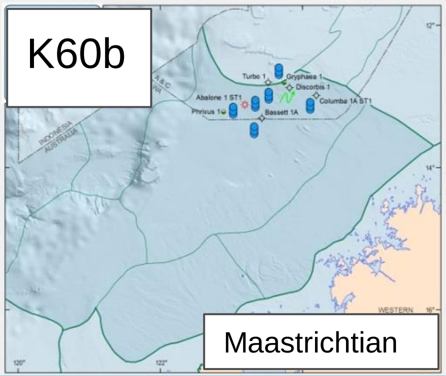



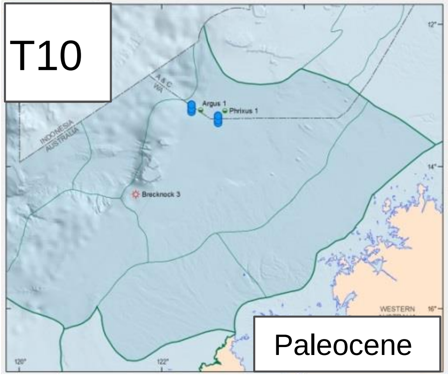




## Upper Cretaceous



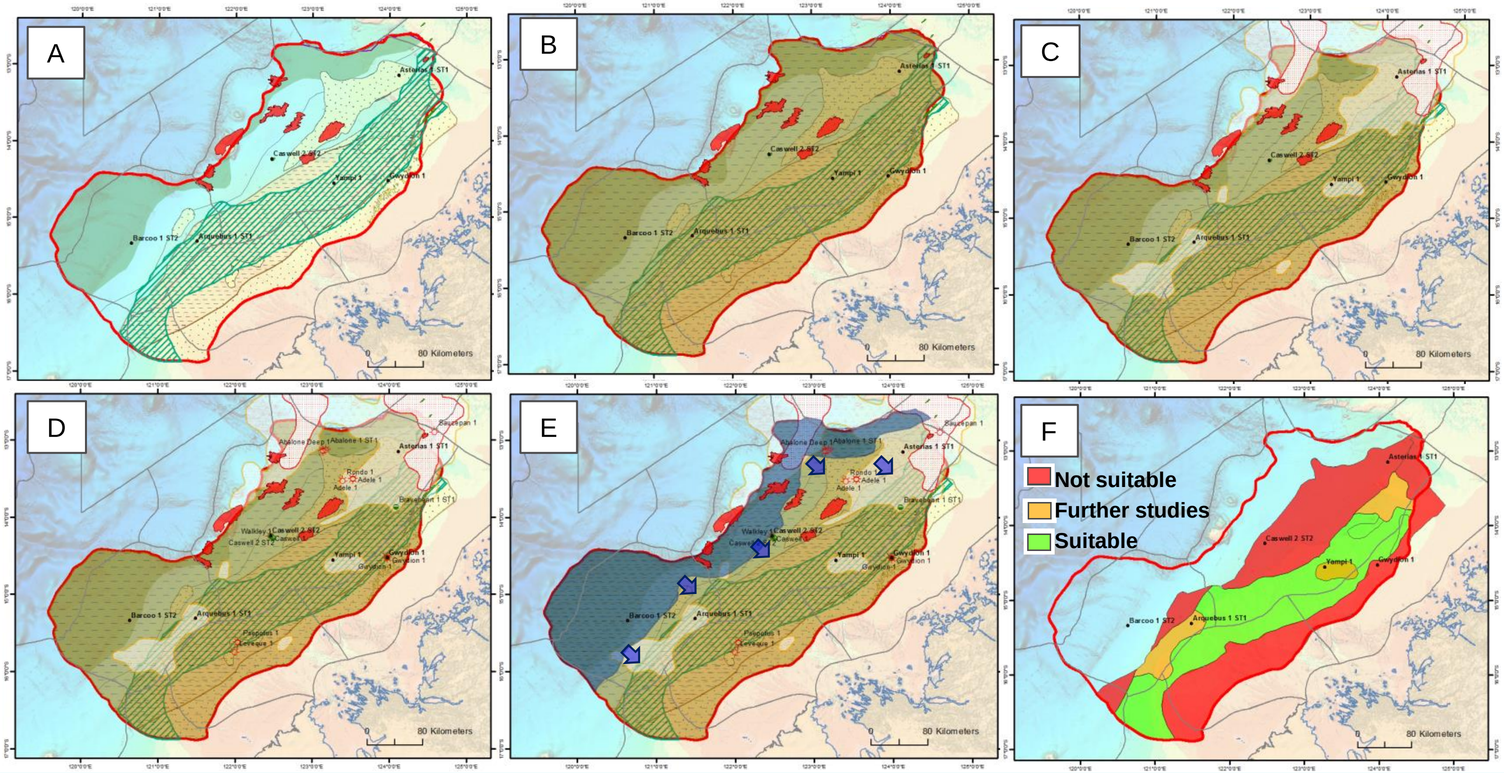



# Common Risk Elements

→ Eliminate areas with high level containment constraints per supersequence

*Example for K30 Palaeogeography*




A- Reservoir depth

B- Seal extent

C- Fault density

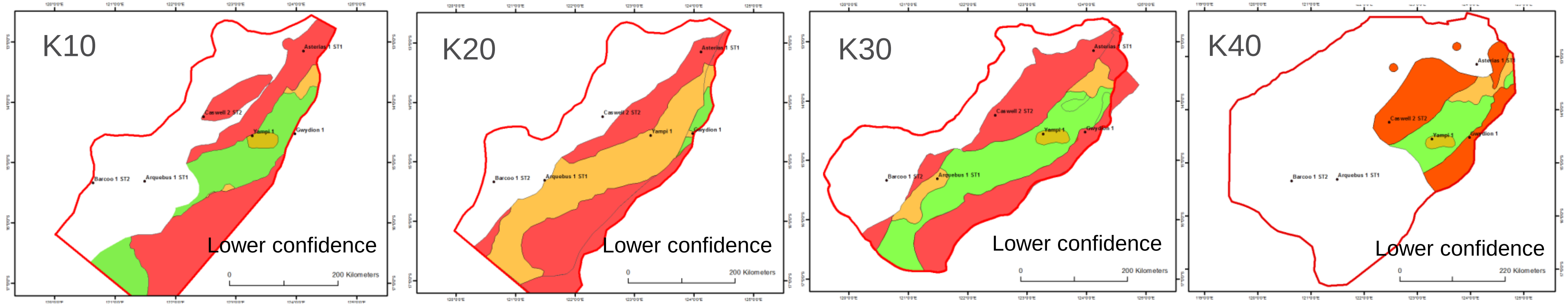
D- HC shows

E- Condensed section

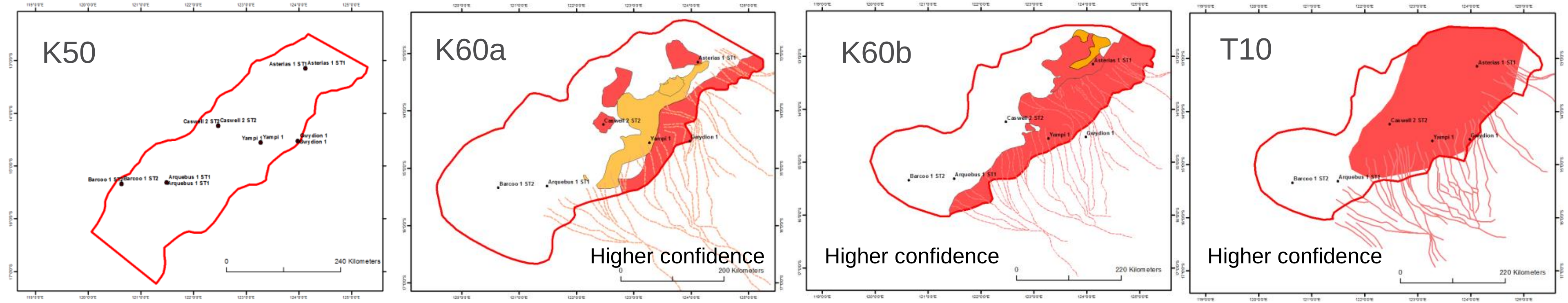
F- Traffic light colours results (with various confidence levels)

# High-grading plays for potential $CO_2$ storage

Not suitable
Further studies
Suitable




## Lower Cretaceous: potentially more prospective for $CO_2$ storage




## Upper Cretaceous: potentially less prospective for $CO_2$ storage

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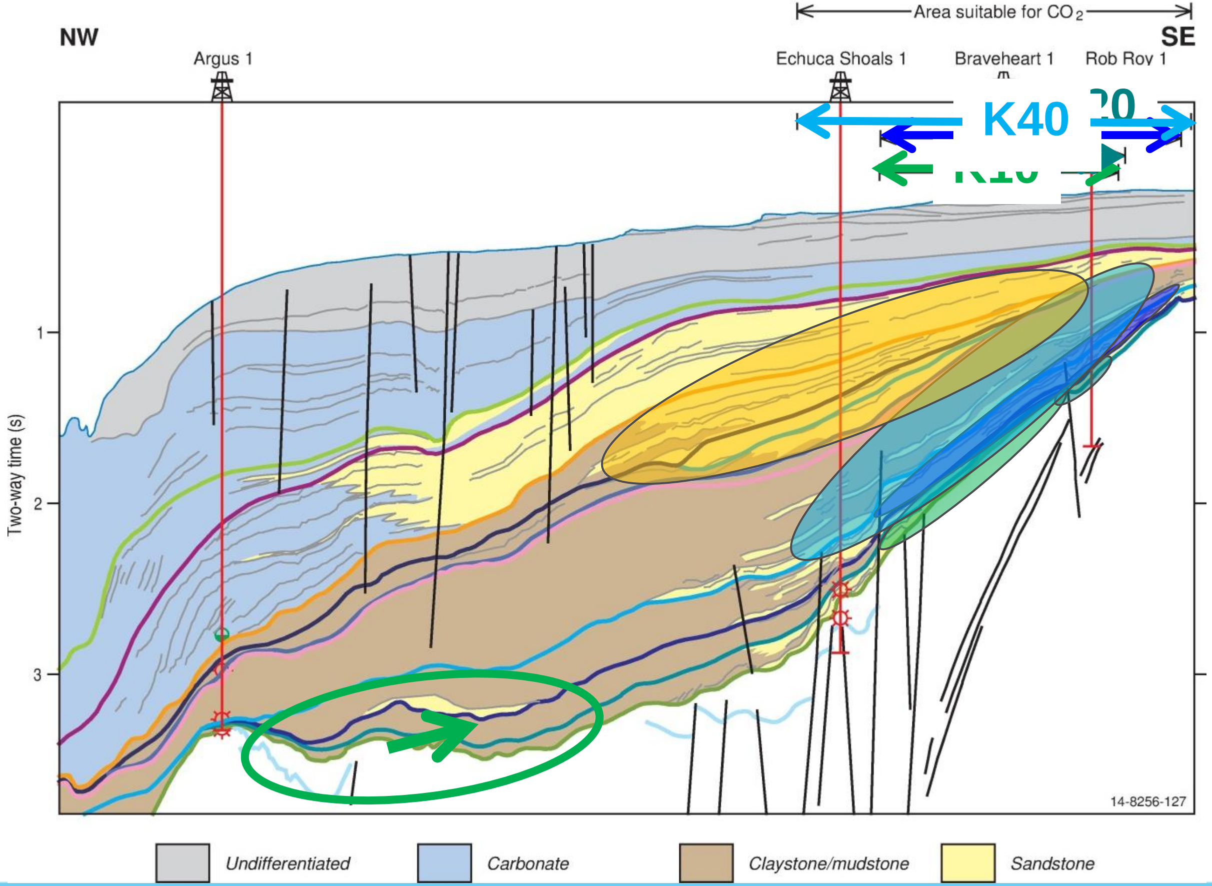
# Areas more suitable for $CO_2$ storage

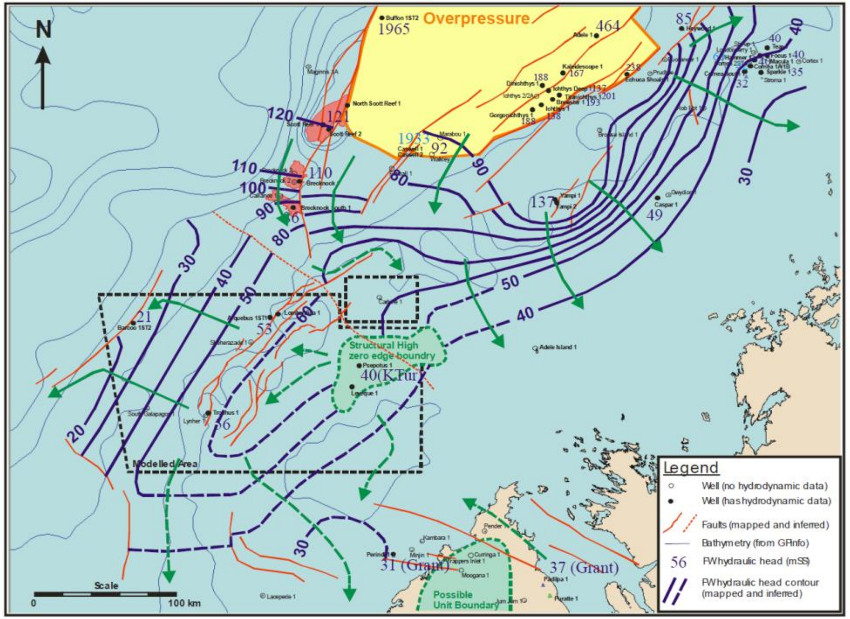



- Upper Cretaceous abundant and high-quality sands; Submarine fans and topsets
- Lower Cretaceous lower sand volume and quality; Lowstand wedges & topsets
- Updip HC migration

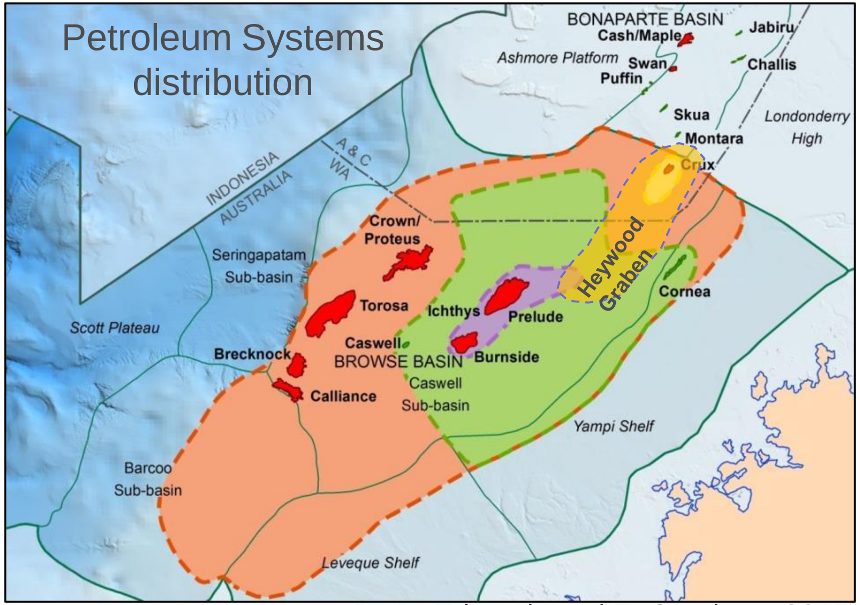
# Future – Overpressure and hydrocarbon generation

→ Fluid flow, hydrodynamic and petroleum system modellings

Freshwater Hydraulic Head (m) distribution
(Kbas-Jcal interval)




*After J. Underschultz in Chirinos, 2008*




*By D. Edwards and E. Grosjean, 2015*

- Westralian 3 – Early Cretaceous Echuca Shoals
- Westralian 1 + 2 – Jurassic – Early Cretaceous Plover + Vulcan (thick)
- Westralian 1 + 2 – Jurassic Plover + Lower Vulcan
- Westralian 1 – Early – Middle Jurassic Plover

# Conclusions

- Regional basin-scale conceptual models and risk assessment
- Revised  tectonostratigraphic framework – NWS common framework
- Updated Cretaceous stratigraphy, regional structure and petroleum systems
- Identified containment constraints and common risk elements
- Recognised areas with potential hydrocarbon resource conflicts
- Prioritised areas potentially suitable for geological $CO_2$ storage
- Future work required at prospect scale using 3D interpretation and modelling

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# Related AAPG|SEG-ICE 2015 presentations and poster

S. T. Abbott, D. Caust, N. Rollet, M. E. Lech, R. Romeyn, K. Romine, K. Khider, J. Blevin, 2015. Seven Cretaceous Low-Order Depositional Sequences From the Browse Basin, North West Shelf, Australia: A Framework for CO2 Storage Studies, In Seismic Stratigraphy Tuesday afternoon (presentation)

E. Grosjean, D. S. Edwards, T. J. Kuske, L. Hall, N. Rollet, J. Zumberge, 2015. The Source of Oil and Gas Accumulations in the Browse Basin, North West Shelf of Australia: A Geochemical Assessment, In Geochemistry Monday afternoon (presentation)

M. E. Lech, N. Rollet, D. Caust, K. Romine, 2015. Paleogeographic Evolution of Early Campanian to Maastrichtian Supersequences in the Caswell Sub-Basin—Implications for CO2 Storage and Hydrocarbon Entrapment, In Marita Bradshaw – Palaeographic Evolution of Oz Tuesday morning (poster)

C. Nicholson, R. Romeyn, M. Lech, S. T. Abbott, G. Bernardel, A. Carroll, D. Caust, E. Grosjean, R. Hackney, F. Howard, R. Melrose, S. Nichol, L. Radke, N. Rollet, J. Siwabessy, J. Trafford, 2015. Browse Basin 2014 Marine Survey—Investigating Containment for Potential Late Cretaceous CO2 Storage Plays, In $CO_2$ Storage: Results Thus Far Tuesday morning (presentation)

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