Basin-Scale Fluid Flow, Sealing, Leakage and Seepage Processes in the Gippsland Basin, Australia*

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Abstract

A multi-disciplinary study of the regional fluid flow, charge, sealing and leakage and seepage processes has been undertaken on the prolific Gippsland Basin, south-eastern Australia. The far offshore and onshore elements of the central basin, where most of the hydrocarbons are trapped, are linked by two prominent, east-west trending, fill-spill chains (the northern and southern fill-spill chains; NFSC, SFSC) which converge in the far eastern part of the offshore basin and then extend onshore. North and south of the central basin, on the flanking terraces, migration is typically to the northeast and southwest respectively. Charge history and 2D and 3D modelling have shown that the first hydrocarbon charge into all of the giant fields in the basin, including the gas fields, was oil. In the late Neogene, progradation of carbonates from the northwest increased the thermal maturity of the source kitchens, resulting in strong gas generation, the flushing of the pre-existing oil charge from many traps and its displacement further up the respective chains. Top seal containment is lost around the flanks of the offshore basin and also across much of the onshore.

Consequently, the migrating hydrocarbons begin leaking along zones of failing top seal integrity. Prominent suites of gas chimneys occur along these zones; onshore, this seepage is detectable as a prominent zone of surface seepage and uranium enrichment at the terminal edge of the major fill-spill chain. Offshore, on the northern and southern terraces, these leakage zones have been characterised by the integration of gas chimney mapping, and sniffer and SAR data. This study has allowed the development of a robust understanding of the basin-scale fluid flow processes within the Gippsland Basin and the observations and approaches can be applied to the assessment of other basins for both the evaluation of hydrocarbon potential and geological carbon storage potential.

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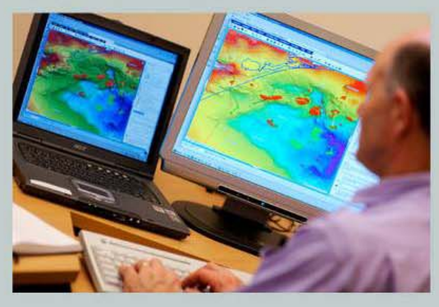

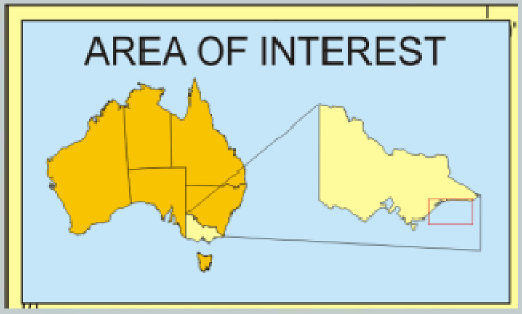

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Victoria
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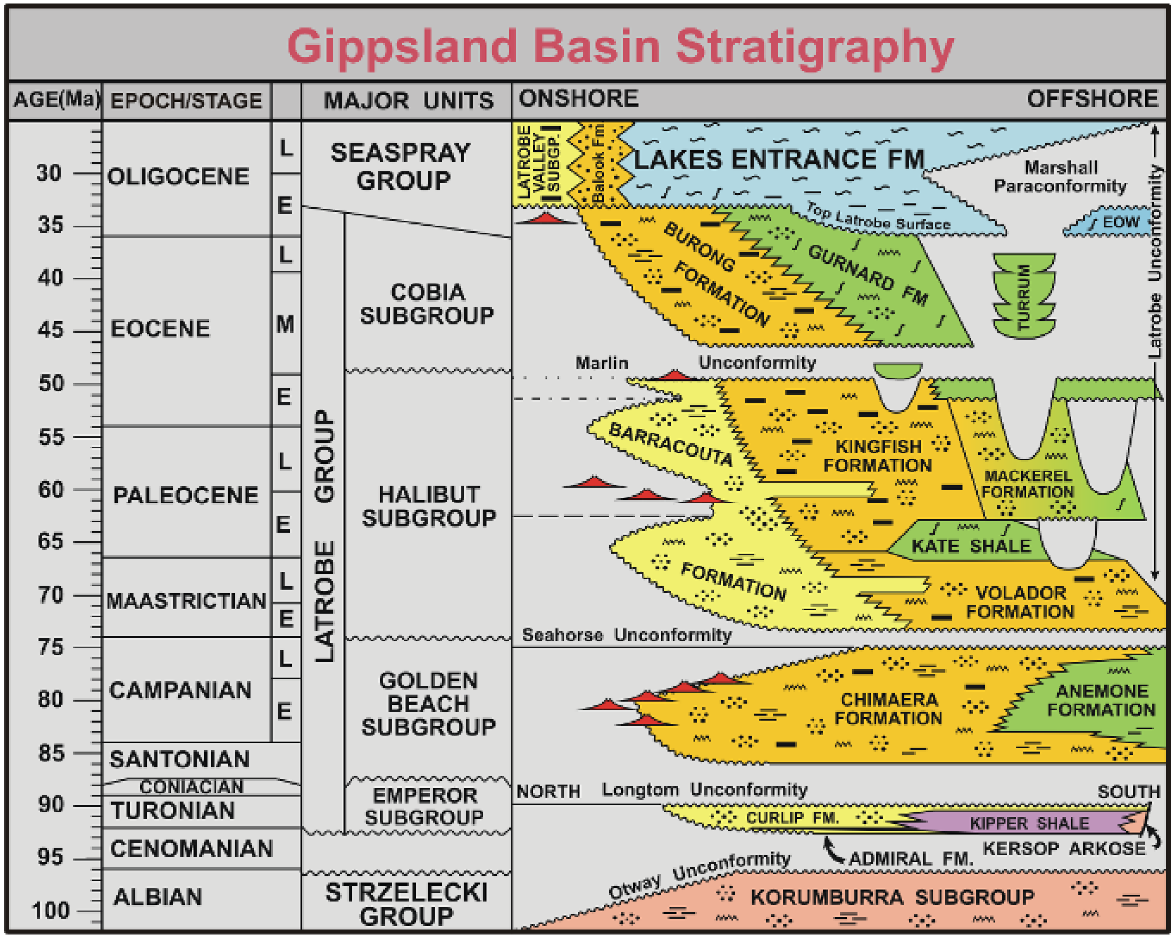
Objectives

- **Take a new look at a mature basin**
- **Evaluate the primary fluid flow pathways**
- **Determine the relationships between these pathways and the first-order charge, sealing and leakage-seepage processes**
- **Use this improved understanding to better assess and manage the basin for petroleum exploration and geological carbon storage**

Outline

- **Regional setting**
  - Distribution of oil and gas
  - Reservoirs and seals
- **Top seal potential assessment**
- **Charge history**
  - Fluid inclusion analysis
- **First-order 3D generation-migration processes and architecture**
  - Fill-spill architecture
- **Leakage and seepage indicators**
- **Integration**

Gippsland Basin



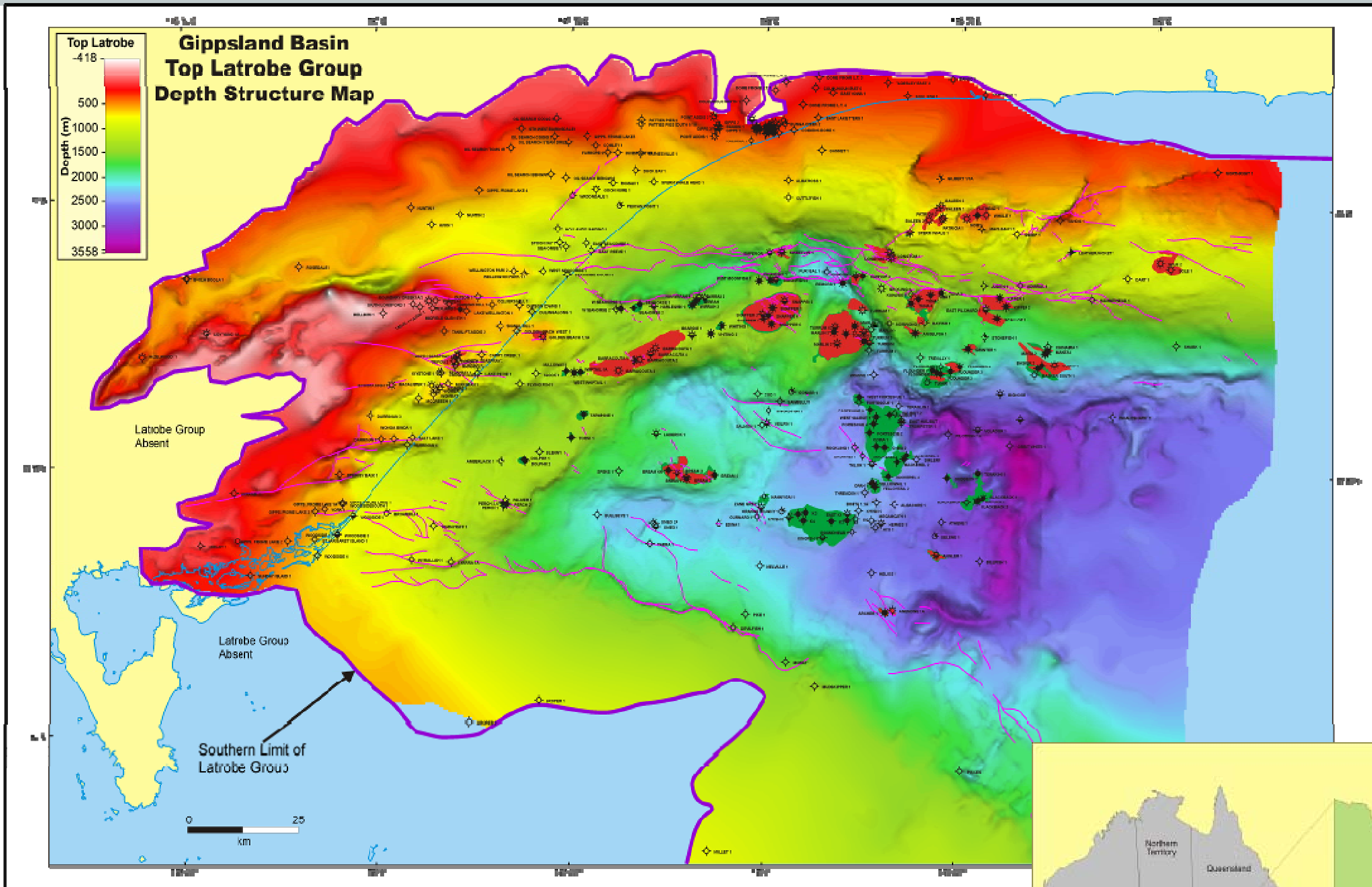
- Cretaceous-Tertiary rift basin
- Giant oil and gas fields
- Strongly compartmentalised distribution of oil and gas

- Hydrocarbons reservoired within siliciclastics - principally (>85%) at the base of the regional seal
- Traps filled to spill
- Large Neogene loading by shelfal carbonates probably important for hydrocarbon generation

Key Technical Approaches

- Map regional top seal potential
- Evaluate charge history of major traps using fluid inclusion analysis
- 3D model of hydrocarbon generation-migration
- Combine with leakage and seepage assessments

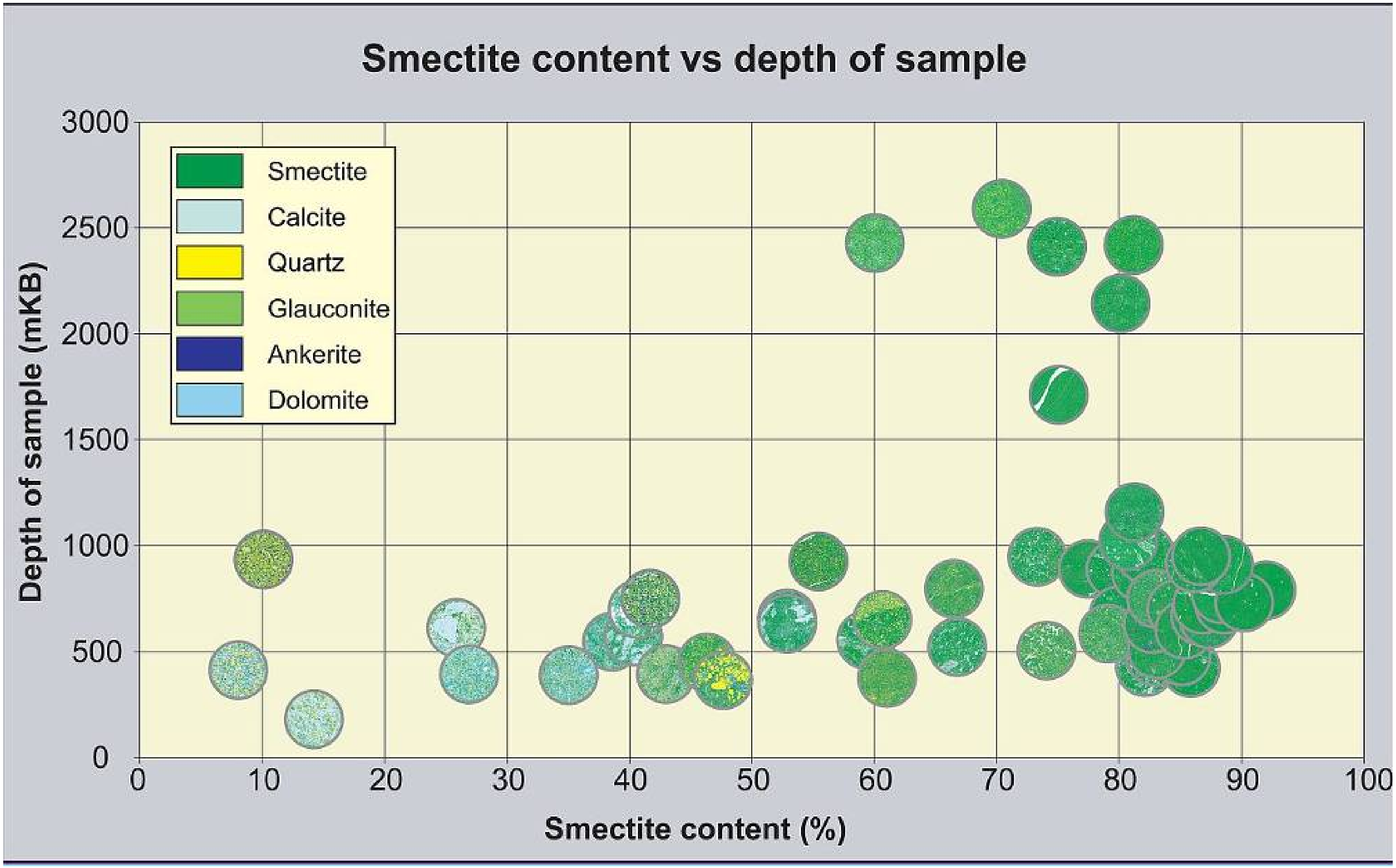
Gippsland Basin



Regional Top Seal

- Lakes Entrance Formation
- Consists of claystones, mudstones and marls
- Deposited ~30 Ma across the post-rift Latrobe unconformity topography

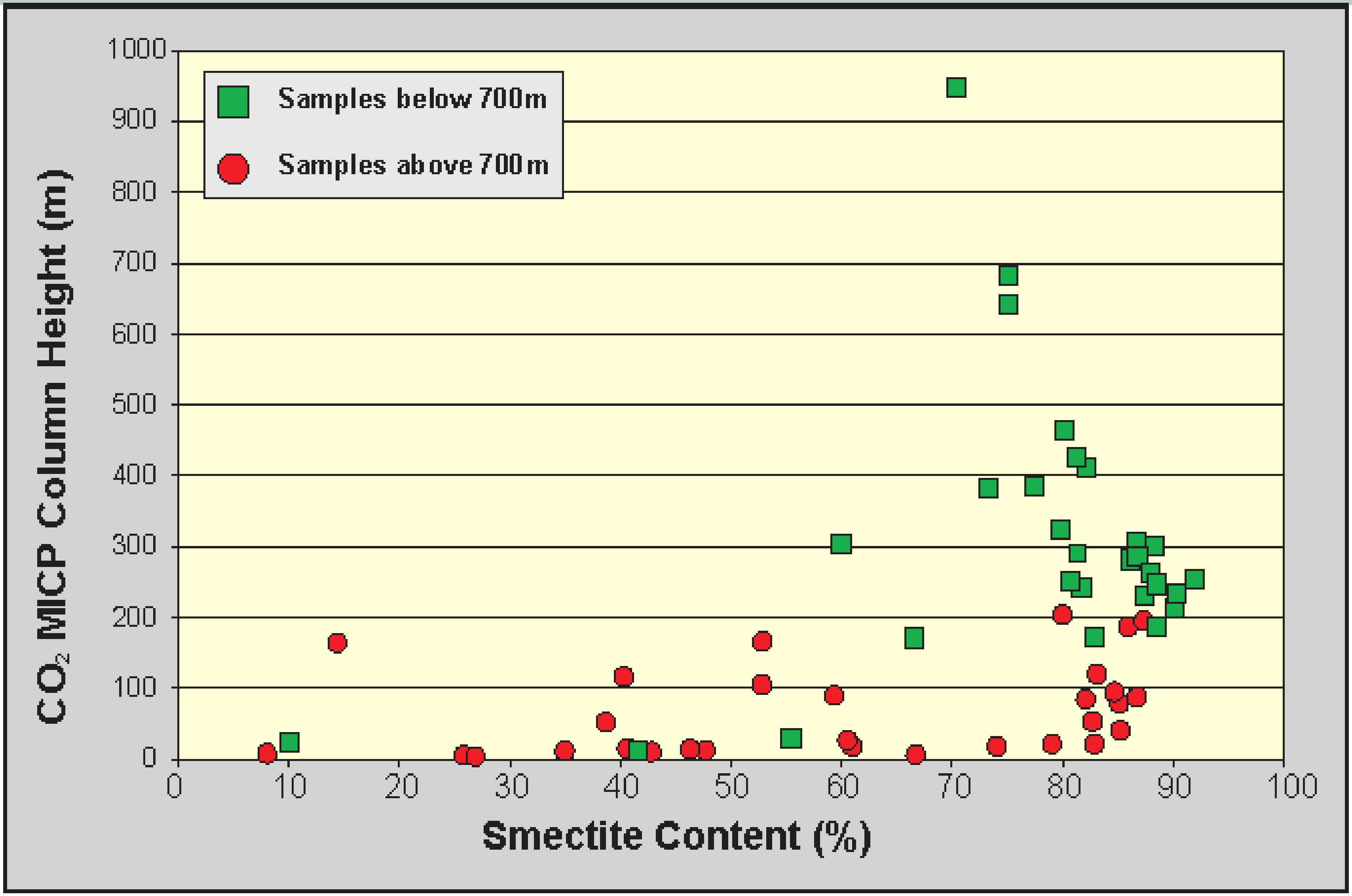
Top Seal Characteristics



Deeper samples are smectite-rich

Shallower samples are richer in carbonate and quartz

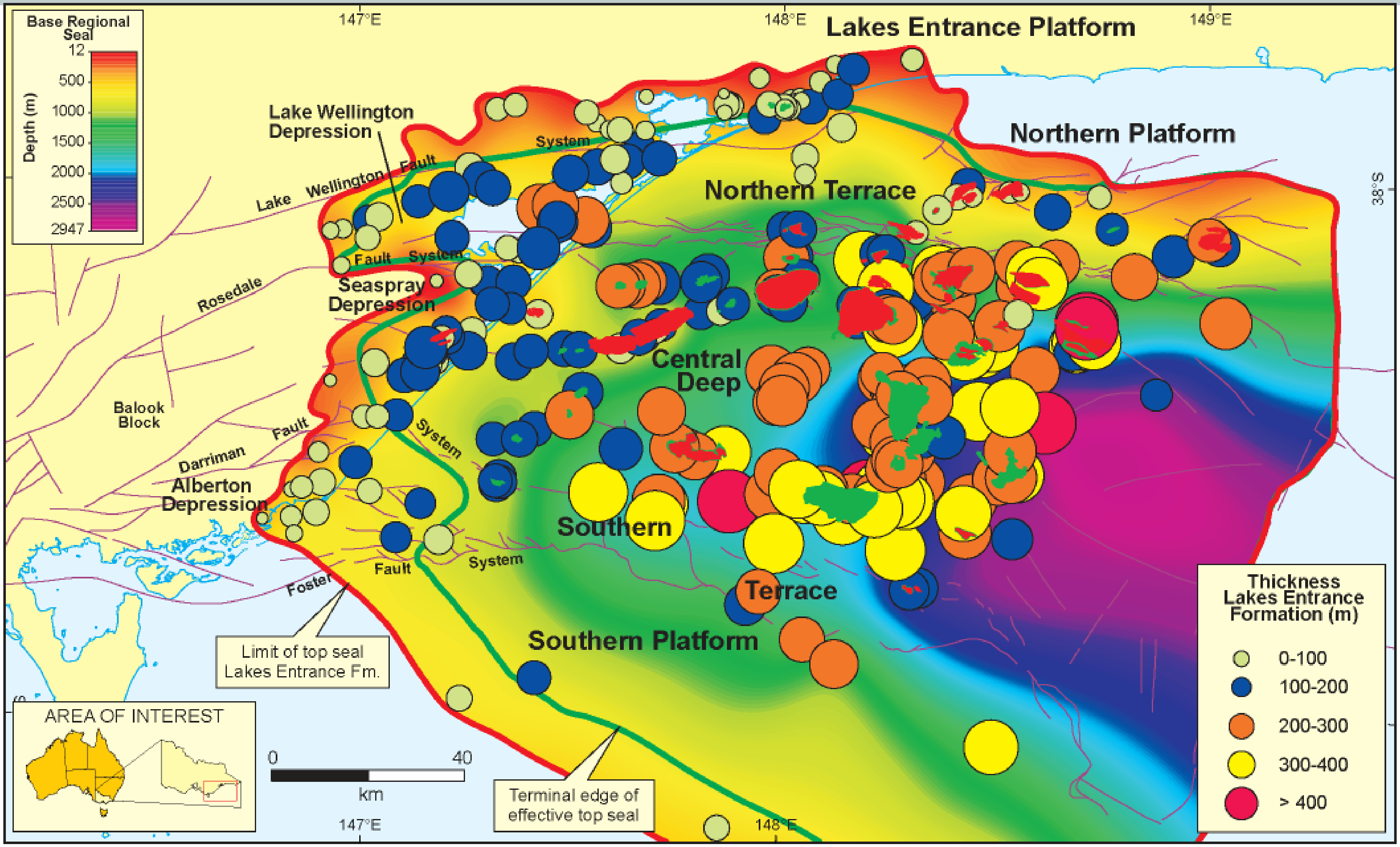
Top Seal Characteristics



Mercury Injection Capillary Pressure Data

deeper samples have larger column heights for retained oil, gas + CO_2

Top Seal Characteristics



thick, deeply buried and high quality in depocentre

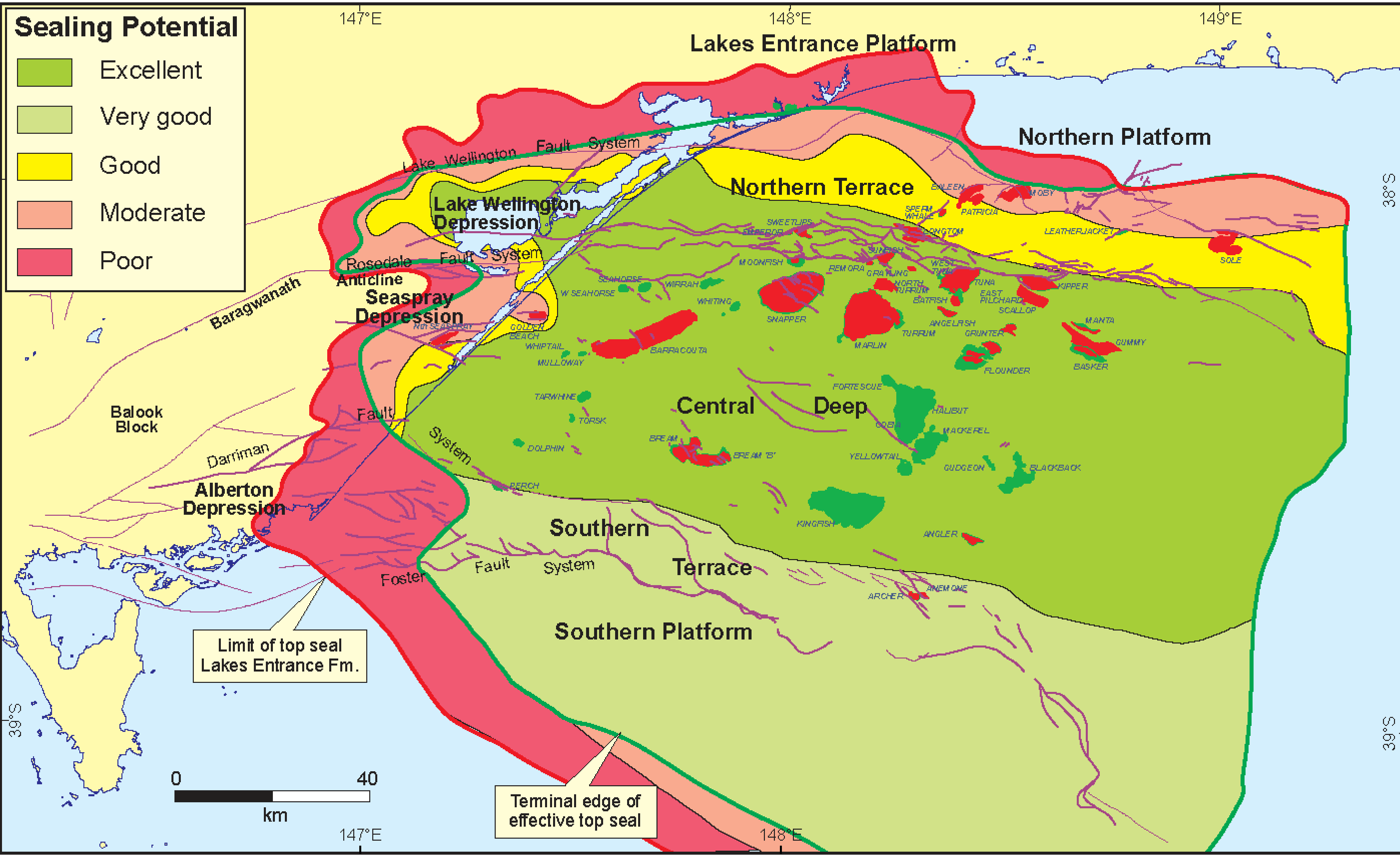
thinner, shallower and much poorer around margins

map zero and edge of effective seal to define limit of prospective basin

Basin-Scale Top Seal Potential

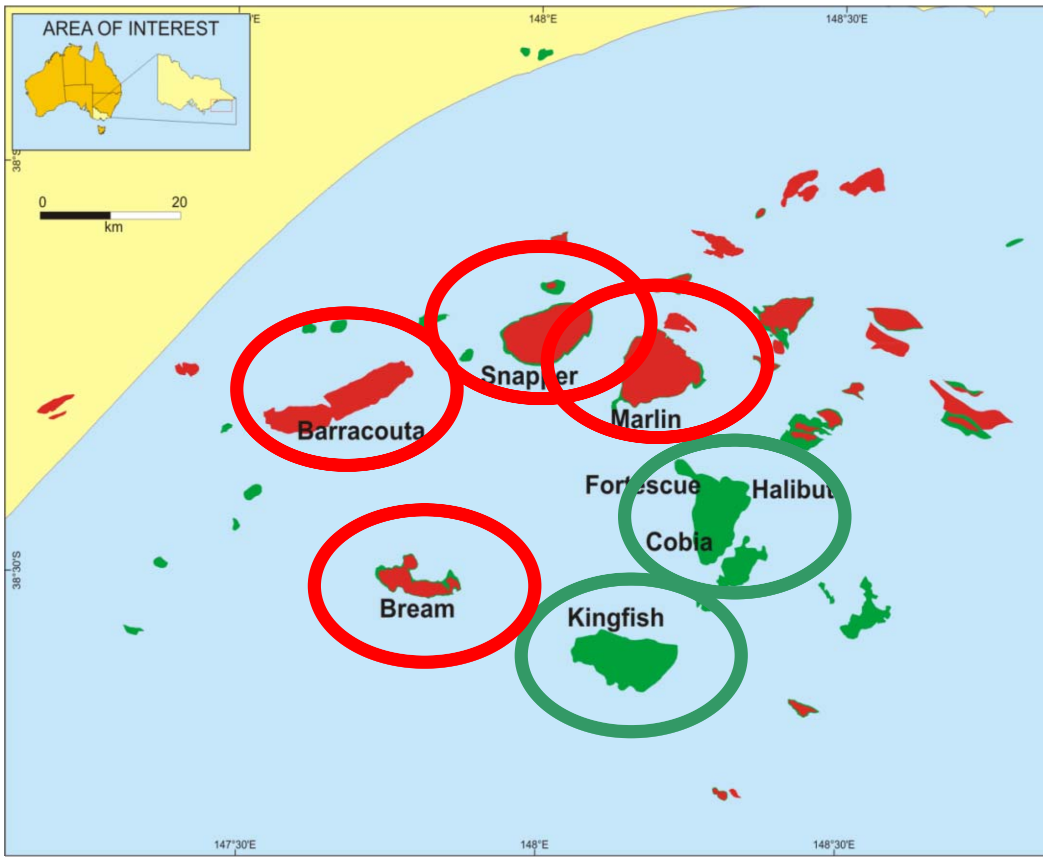
- Excellent – Central Deep
  - depth to base >800m
  - vertical column heights >100m
- Very Good
  - Southern Margin Offshore (cf Central Deep)
  - uncertainty due to lack of data coverage
- Good
  - depth to base <700m
  - vertical column heights 10 – 190m
- Poor
  - depth to base 300–400m, v. low MICP values

Basin-Scale Top Seal Potential



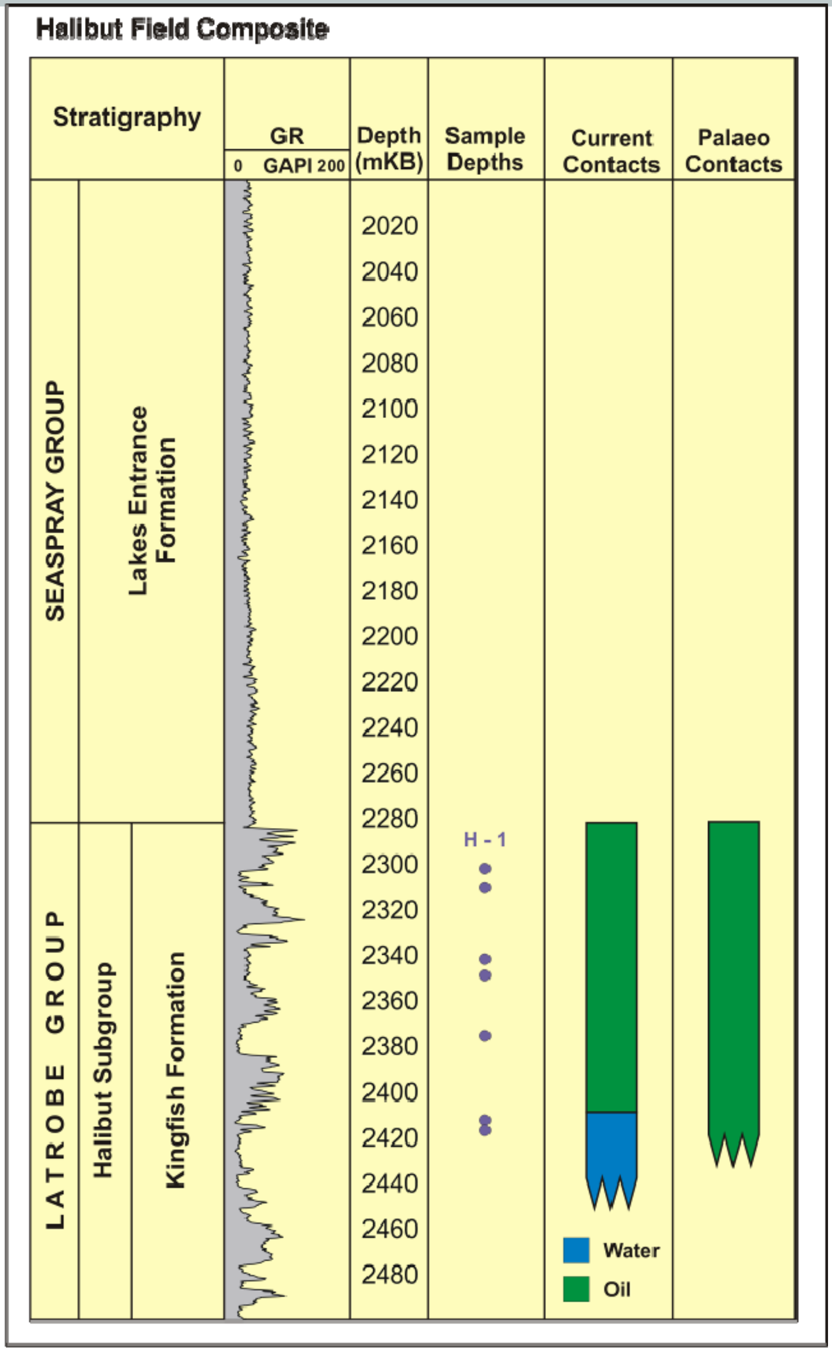
Palaeo-Charge Analysis

6 giant fields (4 gas, 2 oil) analysed for palaeo-charge analysis by QGF and QGF-E techniques by CSIRO Petroleum



- QGF = Quantitative Grain Fluoresence = fluorescence from oil inclusions after solvent extraction of adsorbed oil
- QGF-E = fluorescence intensity of solvent extract
- Use to detect palaeo-oil zones in current water and gas legs

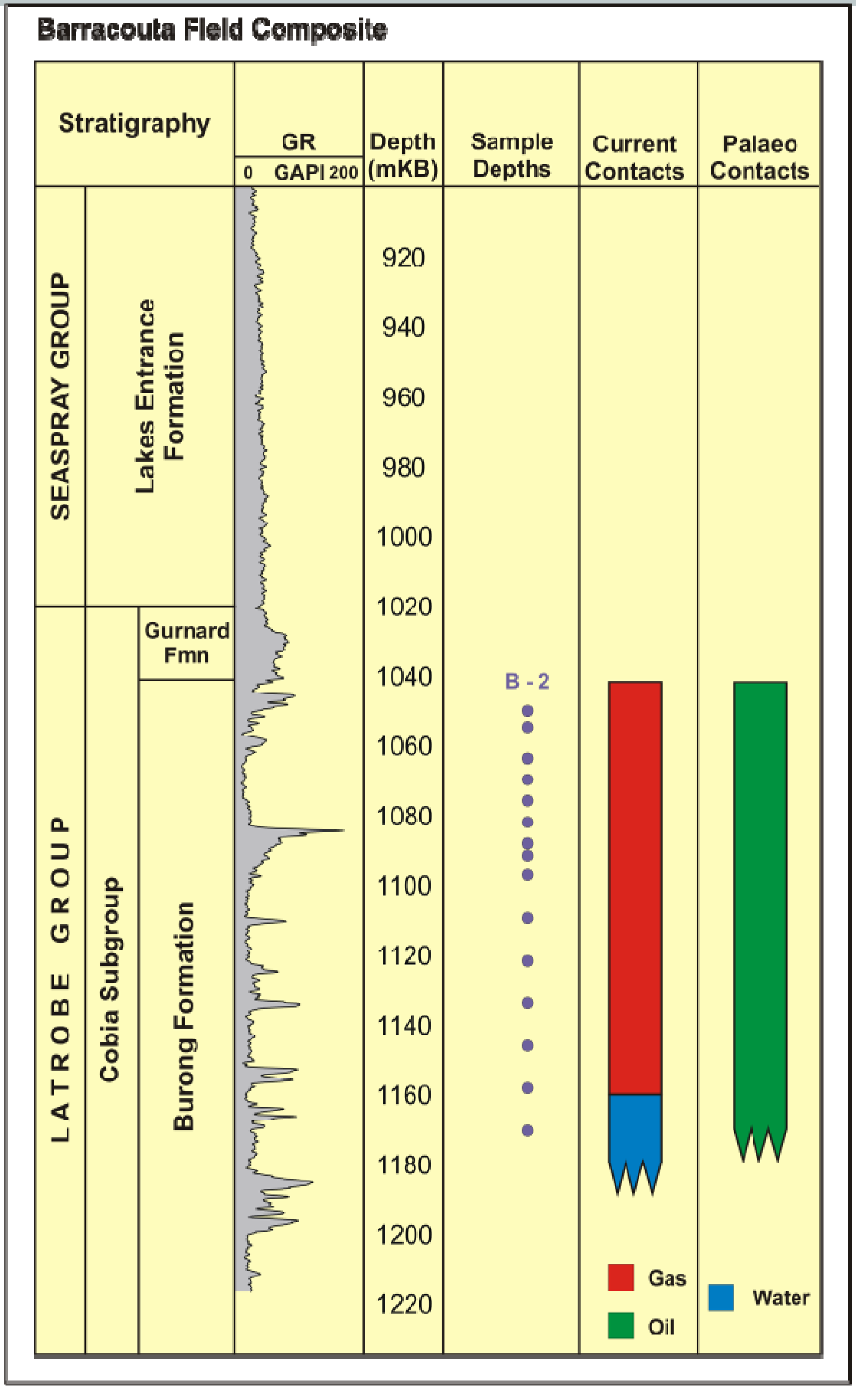
Palaeo-Charge Analysis:



Halibut

No evidence of paleao-gas column in Halibut (or Kingfish) as would be evidenced by low QGF at top of current oil zones

Palaeo-Charge Analysis:



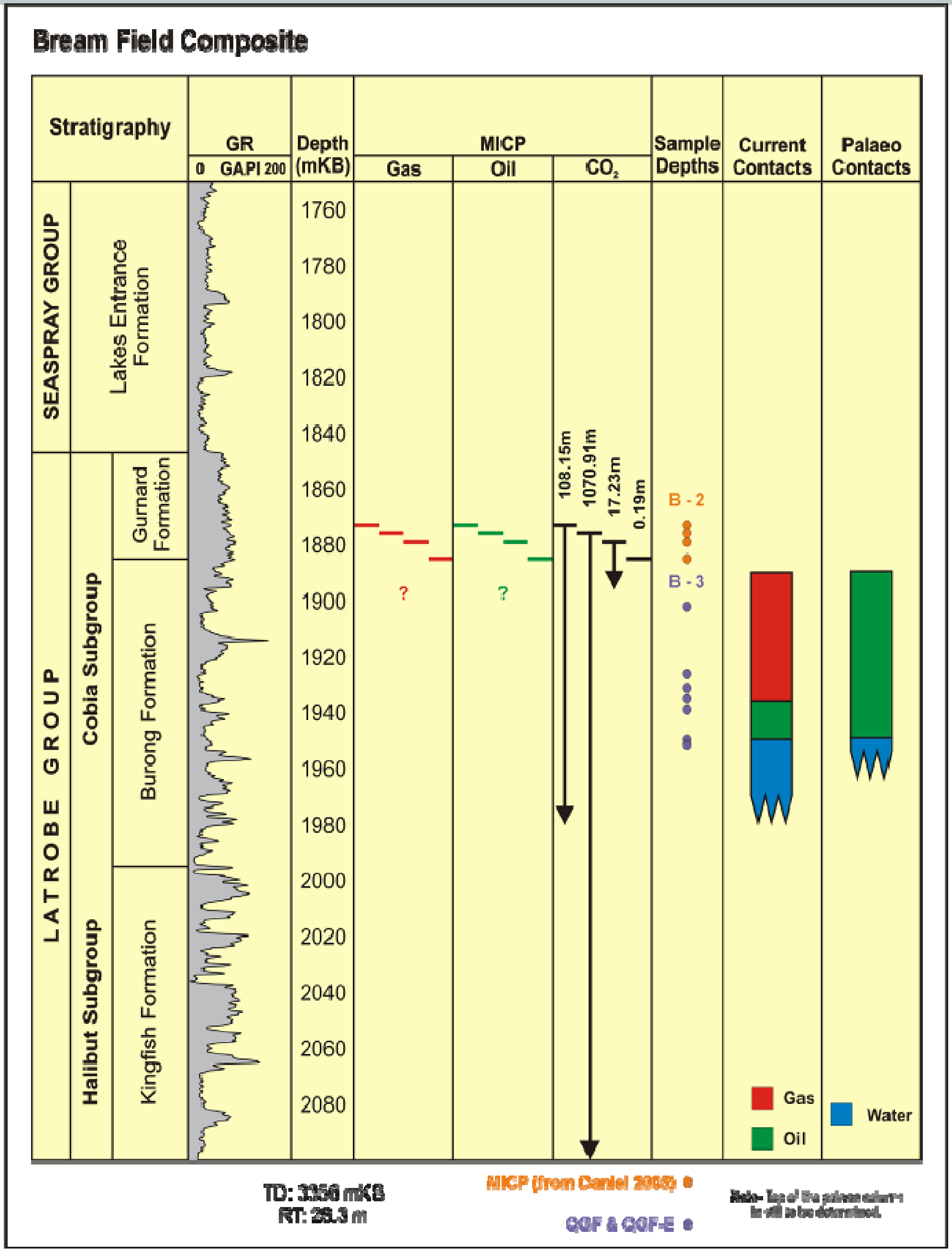
Barracouta

Prior existence of an oil column >100m

Extended across current GWC

Later gas displaced all of palaeo-oil

Palaeo-Charge Analysis:



Bream

Palaeo-oil column of 60m

Extended across current OGC

Later gas displaced most of palaeo-oil

Gurnard Formation - wide MICP range = poor quality seal and reservoir

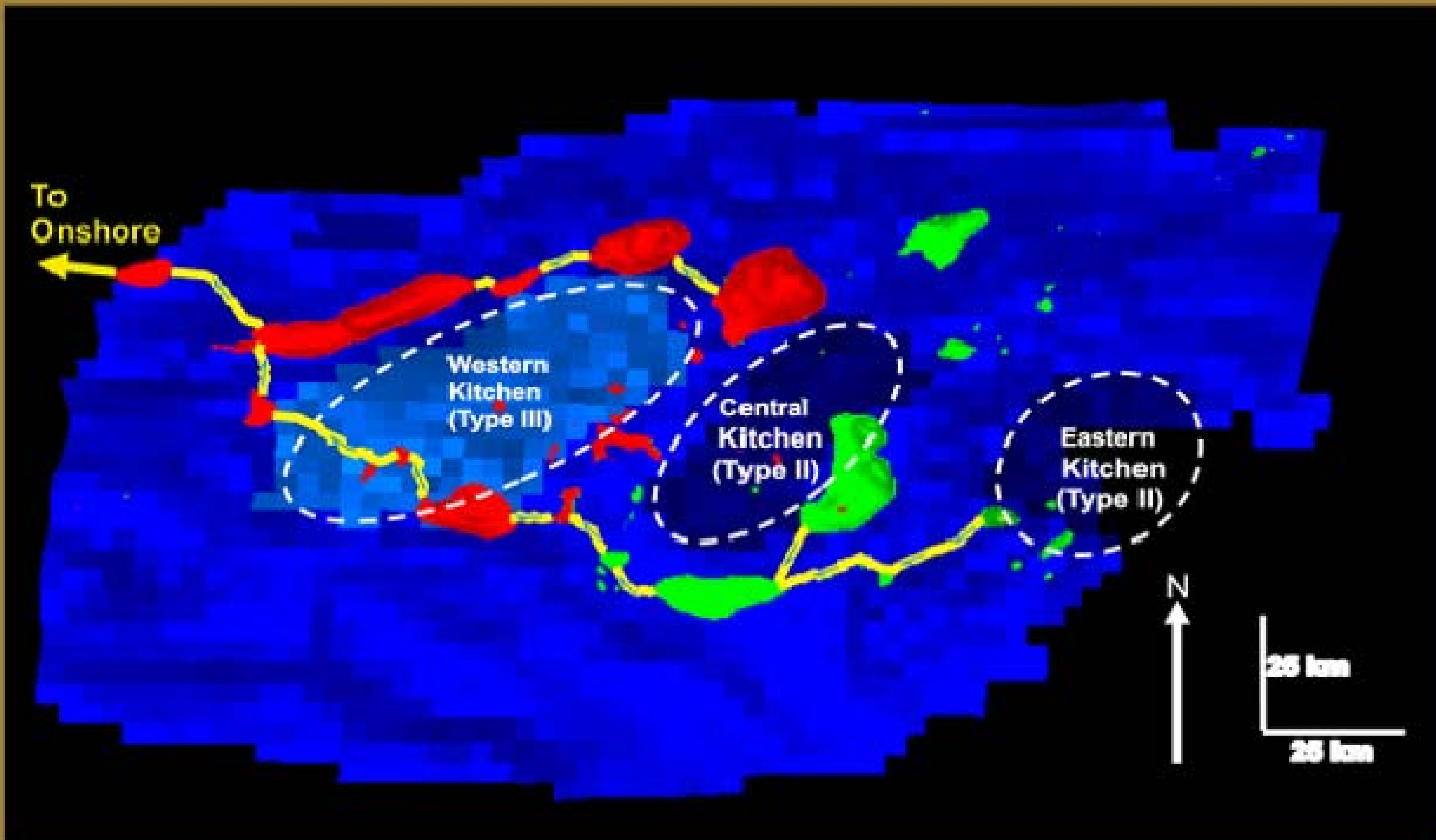
Palaeo-Charge Analysis: Summary

Oil Dominates Early Charge, Even In Giant Gas Fields

In Northern gas fields (Barracouta, Bream, Marlin, Snapper) later gas displaced all/most of palaeo-oil

Giant oil fields only charged with oil

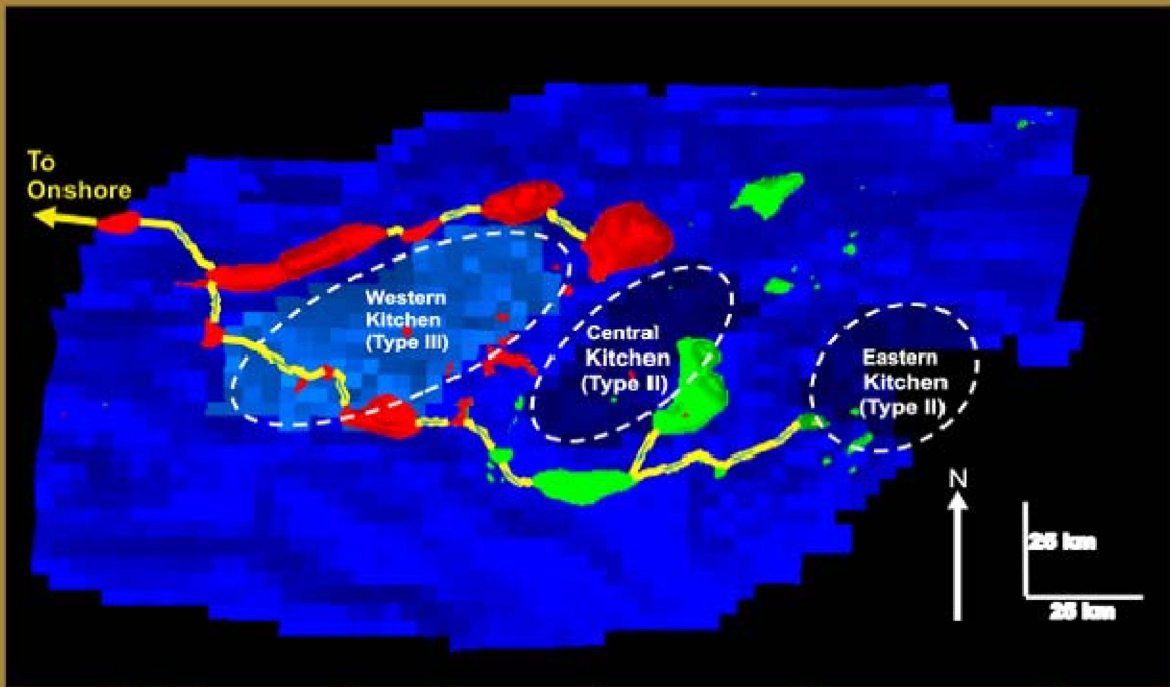
Migration Modelling



Offshore migration pathways and source rock distribution used in the model

3 kitchens centred on depressions in top-Lower Paleocene surface

Migration Modelling



Offshore migration pathways and source rock distribution used in the model

Generate hydrocarbons according to kerogen type

Migrate under buoyancy to regional top seal

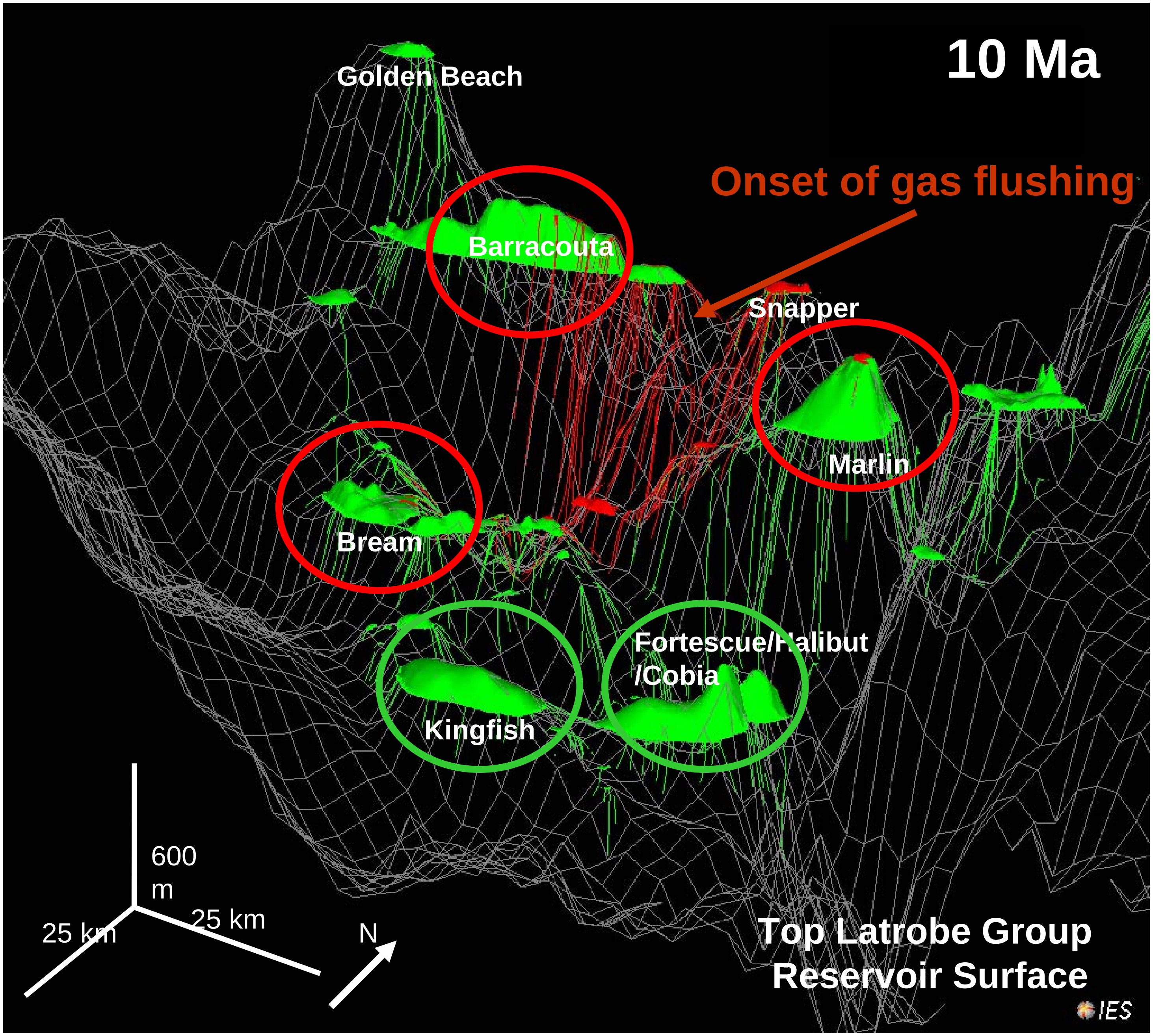
Migrate laterally

Palaeo-charge history: 10 Ma

Gippsland Basin actually looked like this at 10 Ma

Current day giant gas fields were filled with oil, probably sourced from an outboard (to SE) oil kitchen, with charging via linked fill-spill chains

These were subsequently flushed with gas in the late Neogene from a gas kitchen located immediately south of Barracouta



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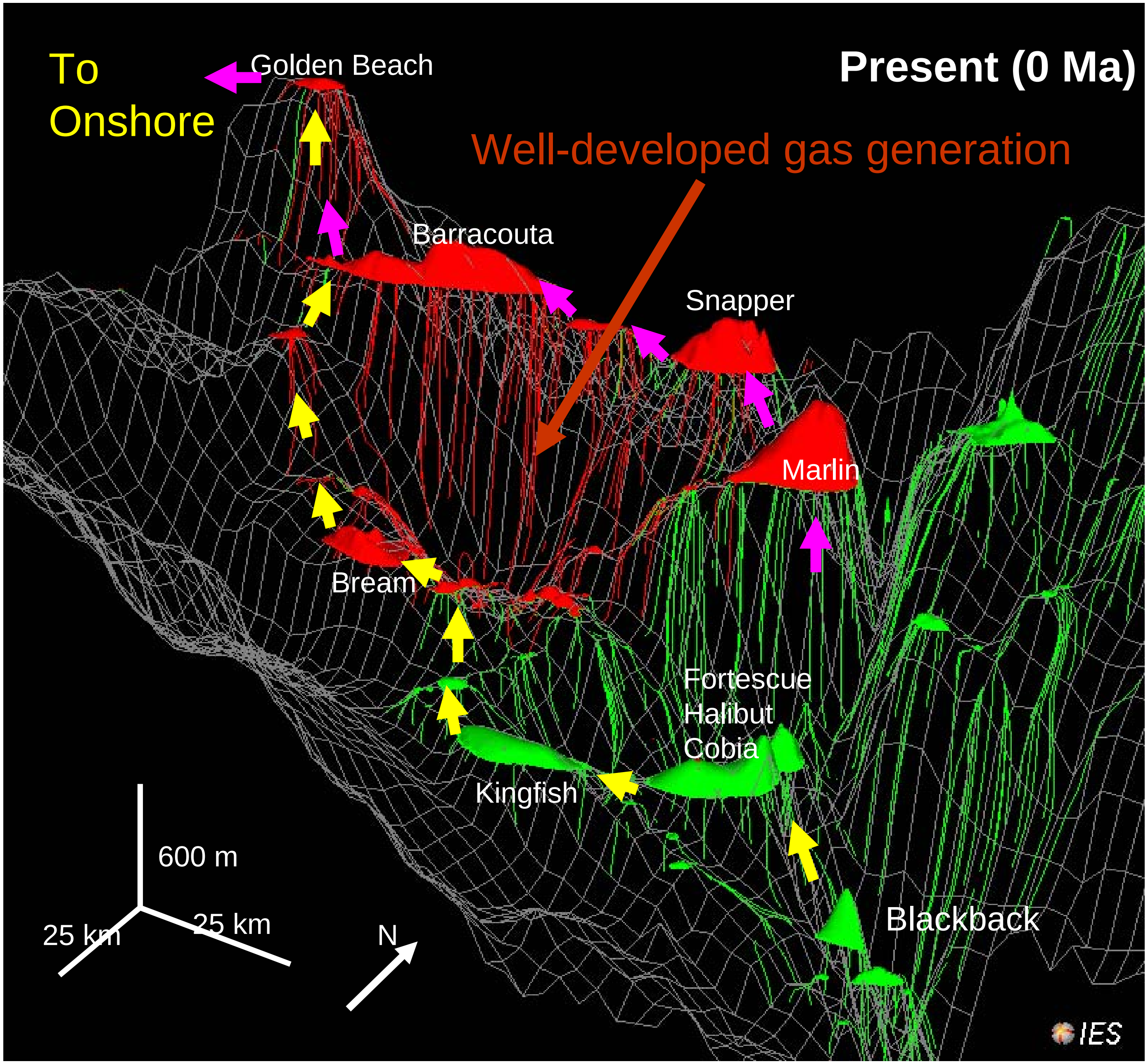


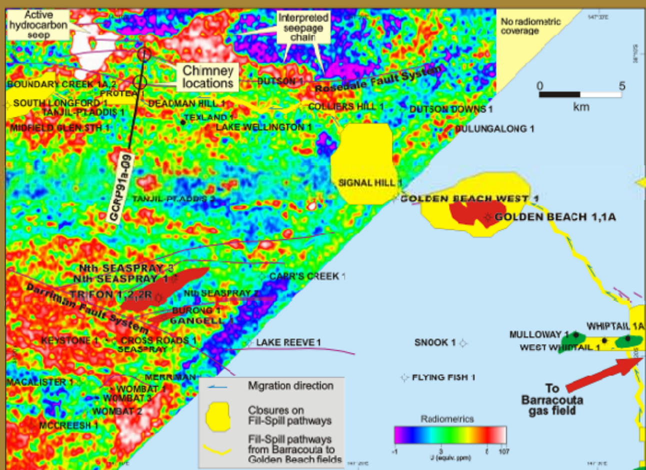
•Prominent, completely filled fill-spill chains evident in the Gippsland Basin, with focused hydrocarbon migration

•Charge history data show evidence for early major oil charge with oil migrating through major fields via fill-spill chains

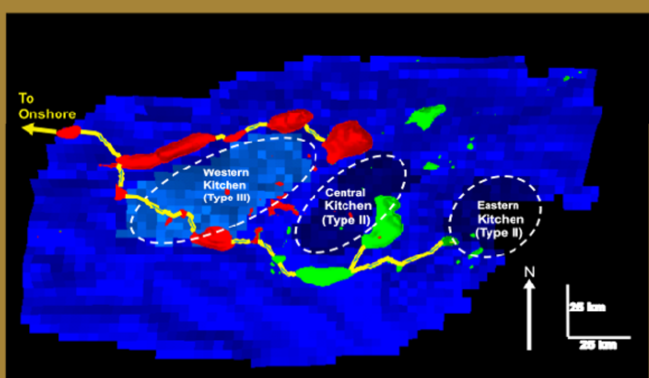
•Where did (and does) this massive volume of hydrocarbons go?

–Leakage and seepage

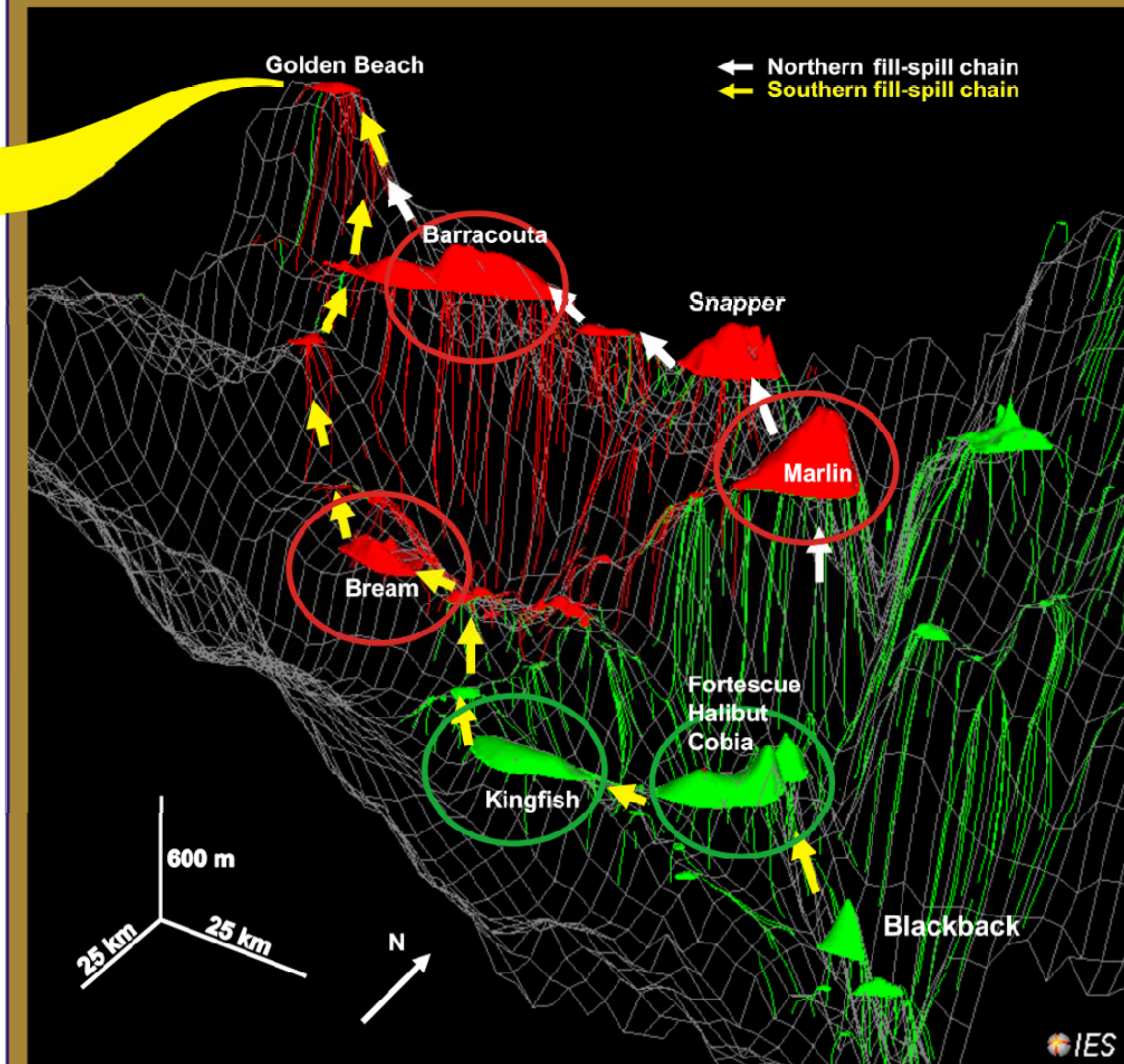
Basin-Scale Fluid Flow Exit Point



Migration pathway and seepage indicators



Offshore migration pathways and source rock distribution used in the model

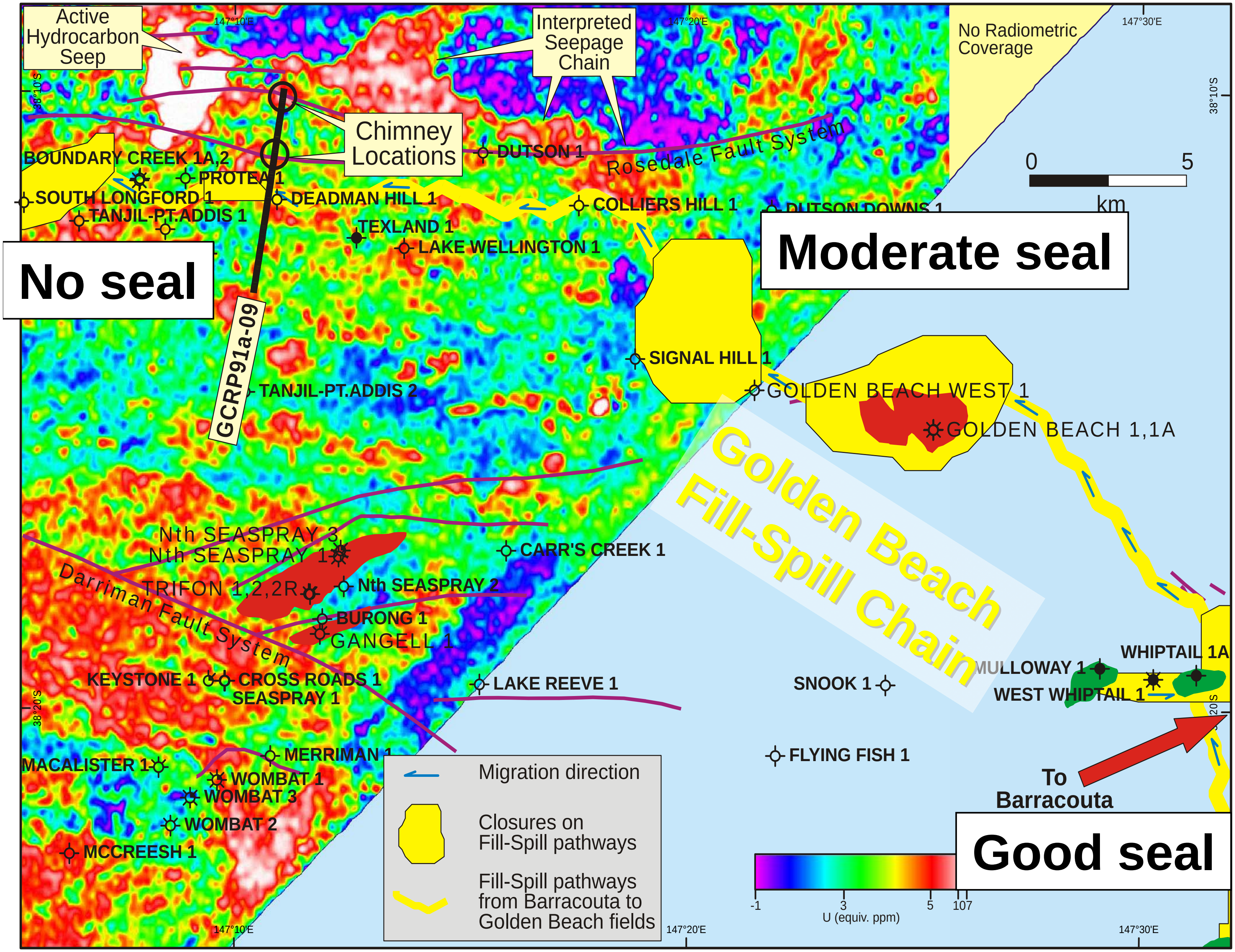


Current Top Latrobe accumulations & migration paths

Radiometrics data, active seeps and gas chimneys reveal where the hydrocarbons have gone

- Active zones of confirmed hydrocarbon seeps, hydrocarbon seepage and prominent gas chimneys occur where primary fill-spill chains intersect zones of progressively decreasing top seal integrity

- Seepage is evident in uranium channel of radiometrics data, due to uranium concentration via hydrocarbon-related U^{6+} reduction to insoluble U^{4+}



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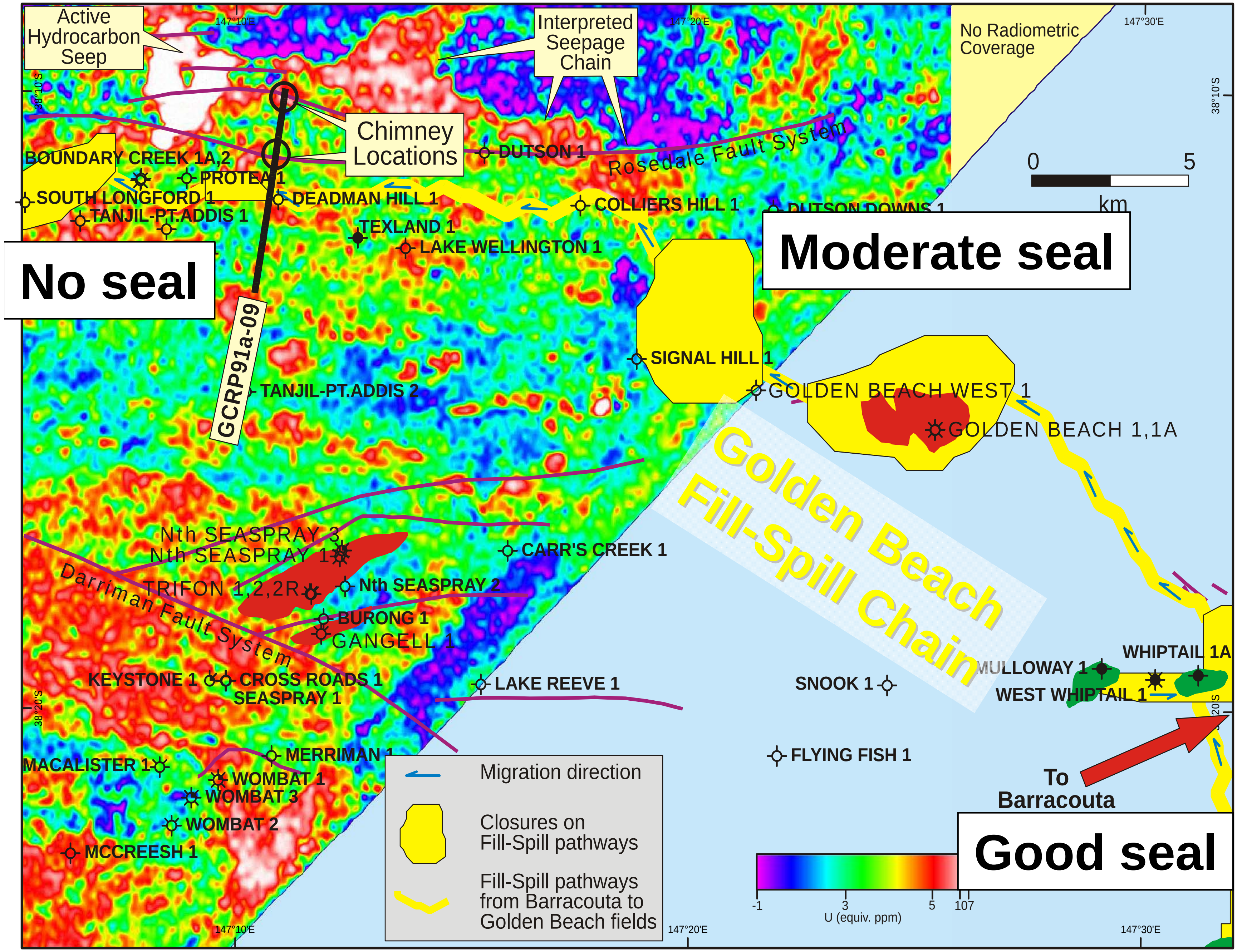
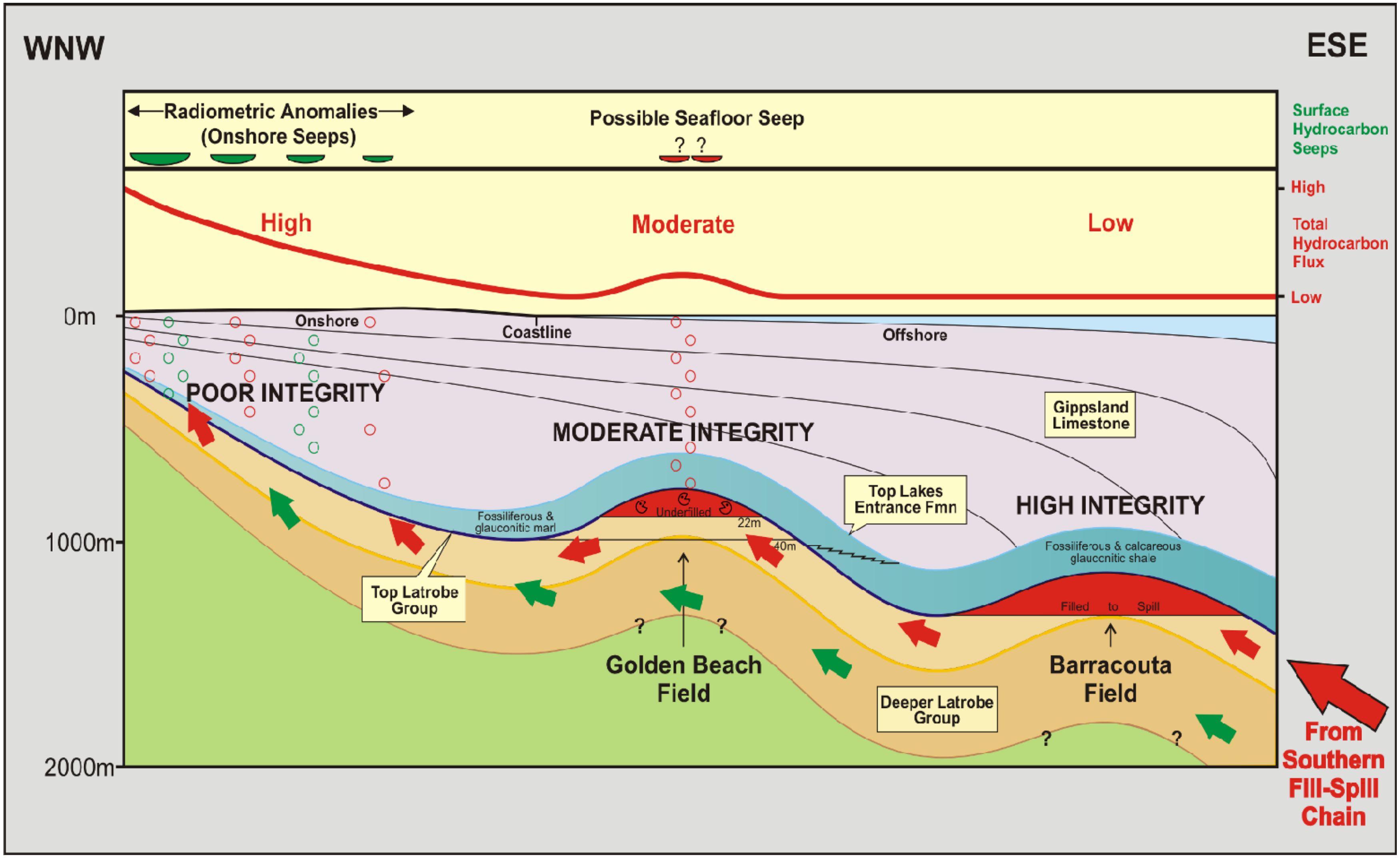


Styles of Leakage & Seepage: Fill-Spill Chains



The Golden Beach Fill-Spill Chain (GBFS Chain) is the primary fluid flow exit point

Decreasing seal integrity along the GBFS chain results in progressive loss of hydrocarbons through the top seal, which is expressed as leakage zones and seeps

This seeping inventory was once dominated by oil but is now dominated by condensate

Integration

First order sealing characteristics of region established

Early oil charge was dominant

This oil was displaced by later gas charge in the late Neogene

Gas charge lead to oilfield vs gasfield distribution in the basin

Highly connected fill-spill chains provide focused, fluid flow pathways that link offshore and onshore parts of the basin

Integration

The major fill-spill chains = primary fluids exit points from the basin

Leakage+seepage over flanking terraces and platforms offshore and onshore correlate with confluence of fill-spill chains and decreasing top seal integrity

The onshore and nearshore areas on the primary fill-spill chain might act as a potential “canary” for the monitoring of future CO_2 injection and migration in the basin

Future work is focused on building a more detailed 3D generation-migration model fully matched to both the palaeo-charge and the composition of the present-day hydrocarbon inventory, to provide insights into both untapped petroleum prospectivity and geological carbon storage potential

There are always lots of surprises, even in a “well-understood”, mature basin like the Gippsland Basin