Fault Seal Analysis through Geologic Time Using an Integrated Petroleum Systems Approach*

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Abstract

A workflow is presented to improve the understanding of fault seal behavior through geologic time at a basin scale. The dataset used in this workflow was compiled from Geoscience Australia and covers the Gippsland Basin. Five major faults have been interpreted from seismic and modelled including the major normal faults that form the Northern and Southern terraces. The first part of the workflow describes the present-day geometry definition and detailed structural interpretation based on an existing Earth model and interpretations. The second part covers the petroleum systems simulation to generate a full 3D pressure-temperature controlled, back stripped model through geologic time. In the third part, using fault interpretation and basin geometries at selected time steps, a fault seal analysis is performed on the geometries in the geologic past. In the final step, the results of the fault seal analysis are used in the petroleum systems model to control fault related hydrocarbon migration and pressure compartmentalization.

Using the described workflow, it is possible to reproduce the observed distribution of hydrocarbons and pressure in the Gippsland Basin more accurately. The iterative approach of basin analysis, restoration, and fault seal analysis directly leads to a better understanding of fault activity through geologic time. The results of the back stripped models are used to analyze the fault seal behavior related to the period of activity and affected lithology at a particular age. The combination of fault seal analysis and petroleum systems modeling improves the understanding of fault dominated extensional basins. It needs to be considered that this workflow requires regional data with significant offset along faults to work on a basin scale. The workflow demonstrates that the combination of back stripping and fault seal analysis in petroleum systems modeling can be used to achieve a better analysis of basin scale pressure and hydrocarbon distribution through geologic time. This workflow can be applied in frontier areas where no structural restoration was done before and only regional data is available. The demonstrated workflow can be performed on one single platform without the need of data transfer between software.

Acknowledgement

We thank Geoscience Australia for the permission to use the data and Schlumberger to publish this workflow.

References Cited

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ICE 2016 Barcelona

"Fault Seal Analysis Through Geologic Time Using an Integrated Petroleum Systems Approach"

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Schlumberger

Agenda

- Objectives
- Dataset
- Method
- Results
- Conclusions

Objectives

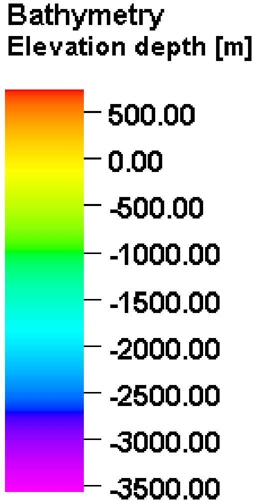
To test the application of fault seal analysis through geologic time, on a basin scale.

- Definition of Workflow:
  - Structural interpretation
  - Fault seal analysis
  - Petroleum Systems Modeling

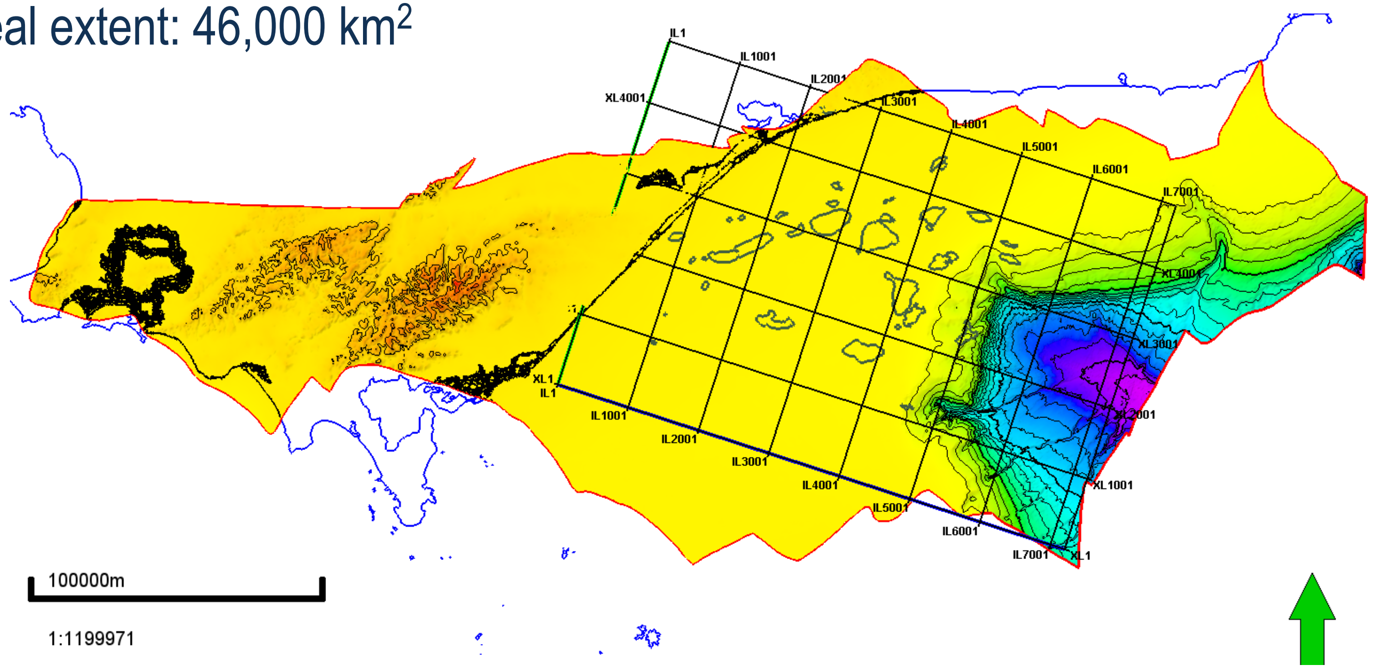
Dataset: Study Location

Gippsland Basin

- Location: 200 km east of Melbourne
- Producing Hydrocarbons: Oil and Gas
- Structure: Passive Margin, 2 rift phases
- Sedimentary Thickness: 11, 000 m
- Water Depths: 1000 - >4000 m
- Areal extent: 46,000 km^2



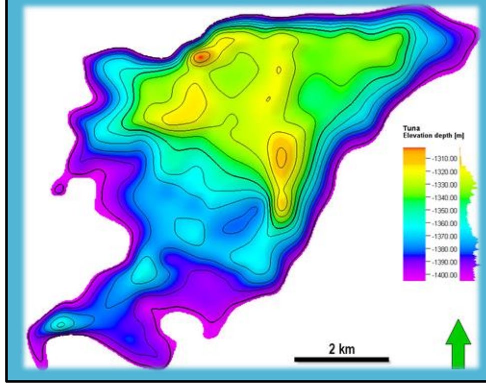
Australian Government
Geoscience Australia



Dataset: Exploration History

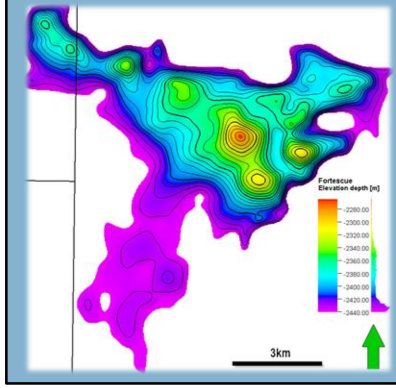
1965	1966	1967	1968	1969	1970	1972	1975	1978	1981	1983	1985	1986	1992
Barracouta	Marlin	Halibut Dolphin Kingfish	Snapper Flounder West Tuna Tuna	Bream Mackarel Perch	Batfish Emperor	Cobia	Blackback	Seahorse Fortescue	Tarwhine	Whiting	Angelfish	Kipper	Moonfish

Tuna



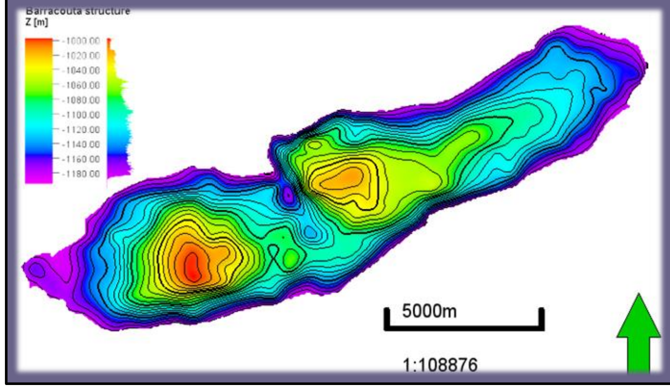
Discovered **1968**
Production **Oil**
Reservoir **Latrobe Group**
Trap **Combined**

Fortescue



Discovered **1978**
Max. Production **Oil**
Reservoir **Latrobe Group**
Trap **Unconformity**

Barracouta

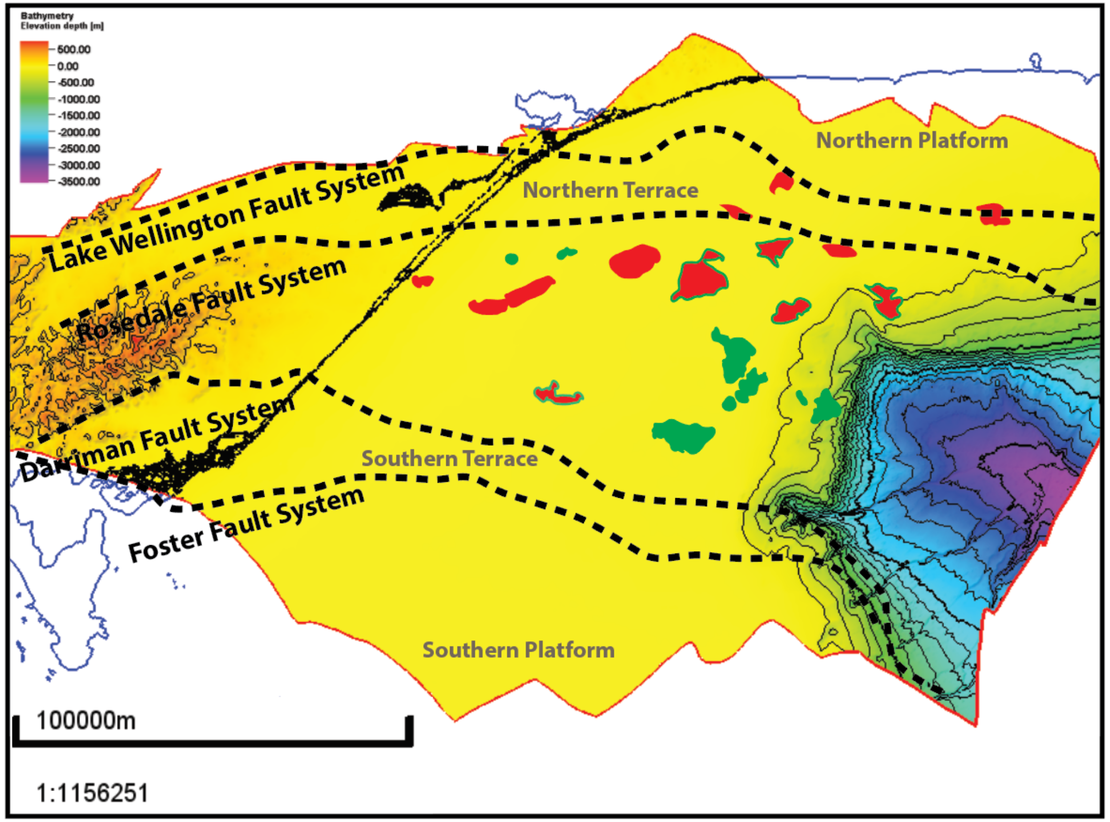


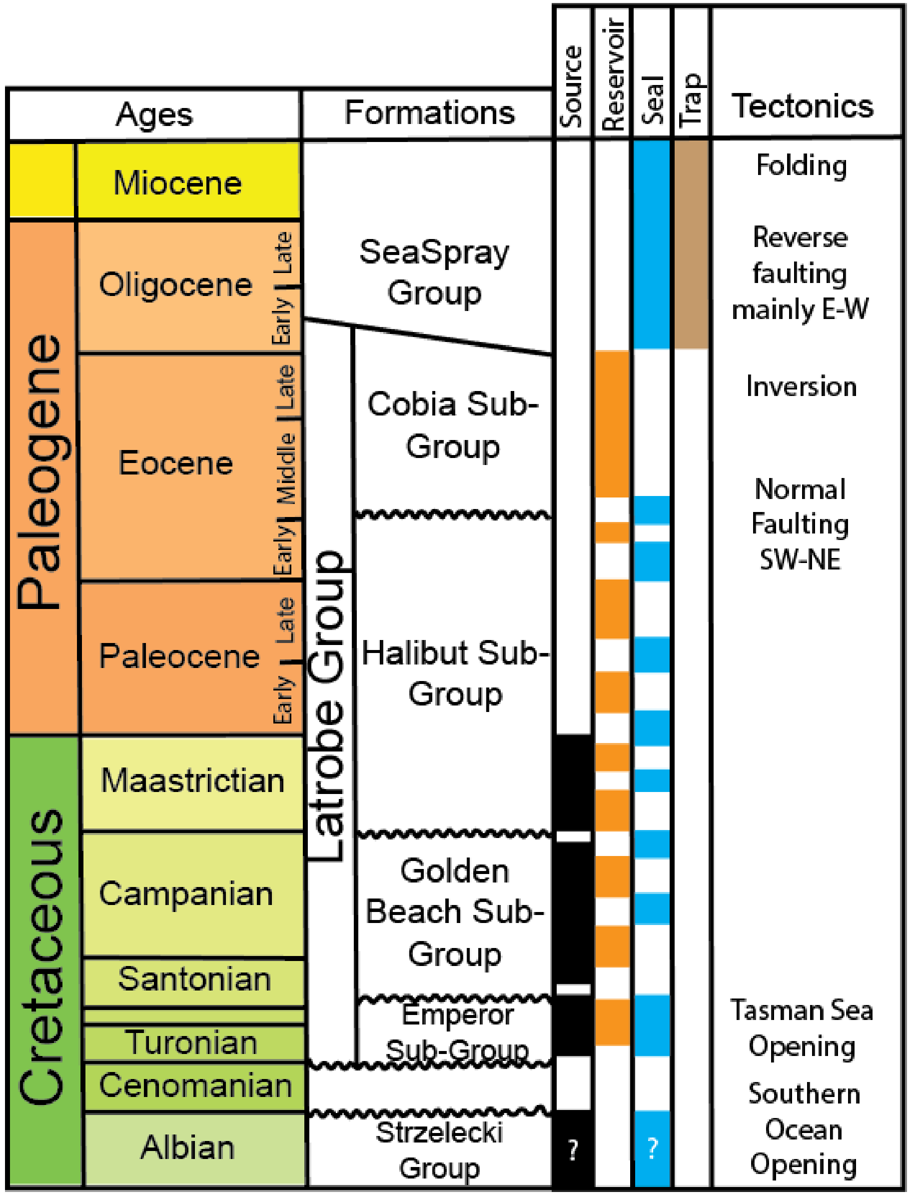
Discovered **1965**
Max. Production **Gas**
Reservoir **Latrobe Group**
Trap **Faulted Anticline**

- Gippsland Basin has a vast exploration history dating back to 1965 when exploration began
- It is a highly prospective basin
- The basin is producing oil and gas
  - 11 oil producing fields
  - 7 gas producing fields

Dataset: Geological History

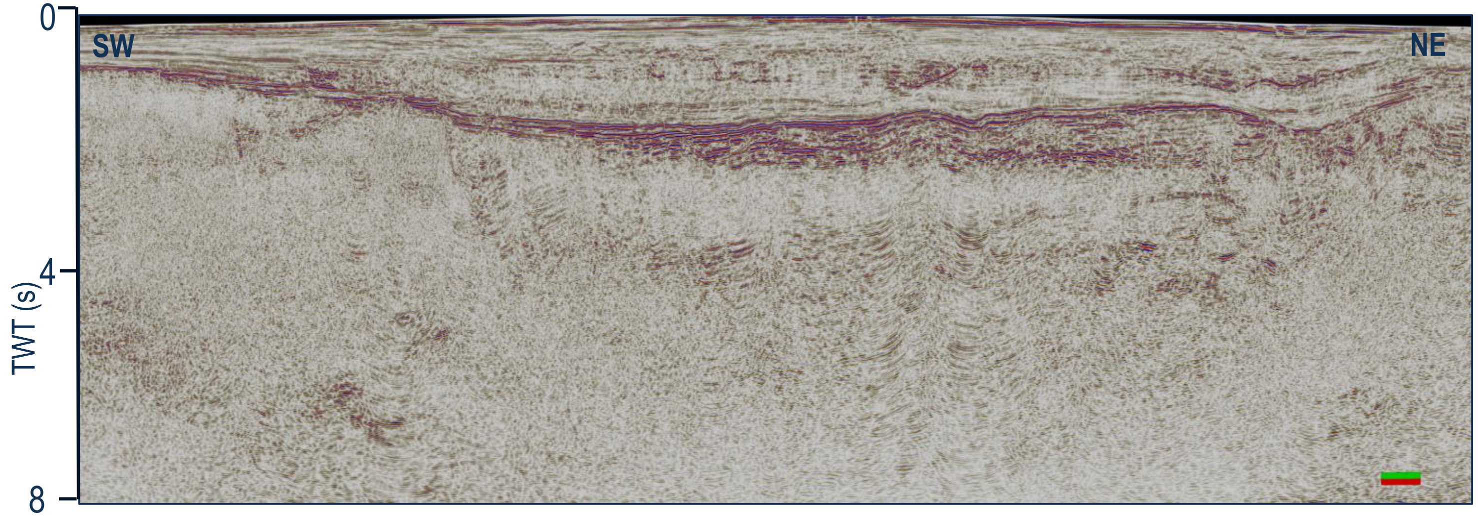
- Depocentre is bounded by many fault complex's
  - Initial rift phase; Extension between Australia and Antarctica
  - Second rifting phase; Opening of the Tasman Sea
  - Inversion related to the continued northwards movement of Australia
  - Throughout the basin history; strike slip influence

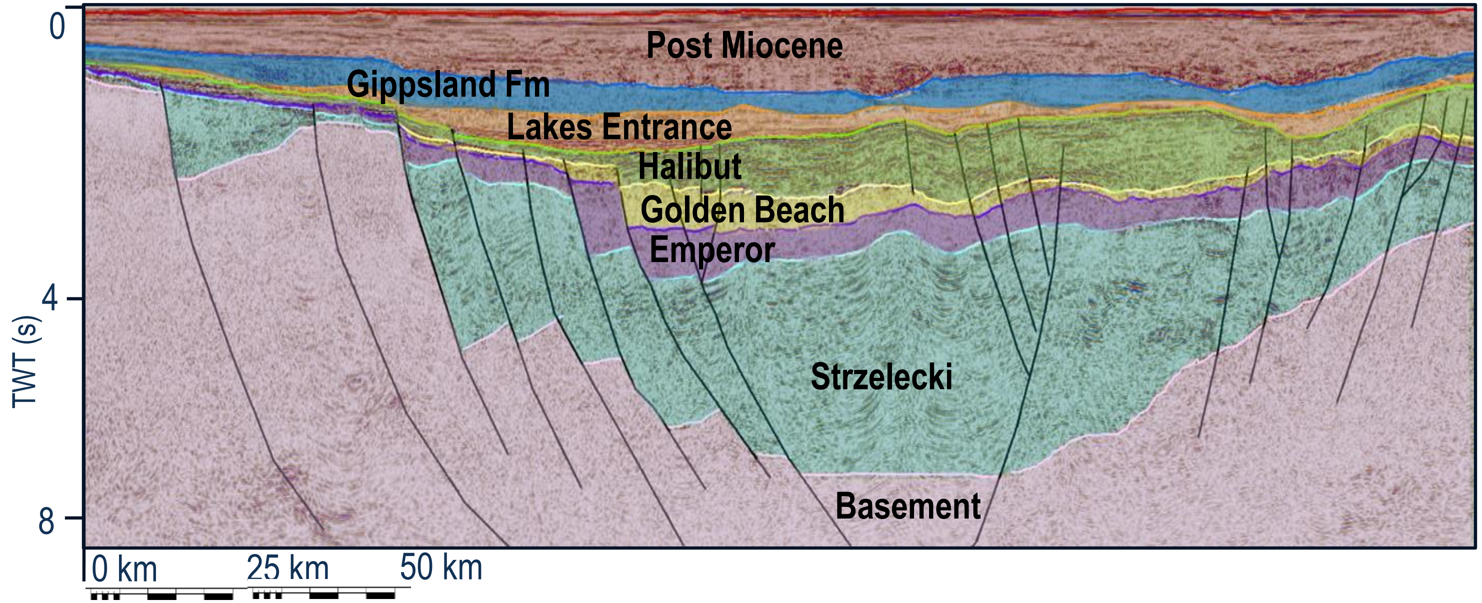


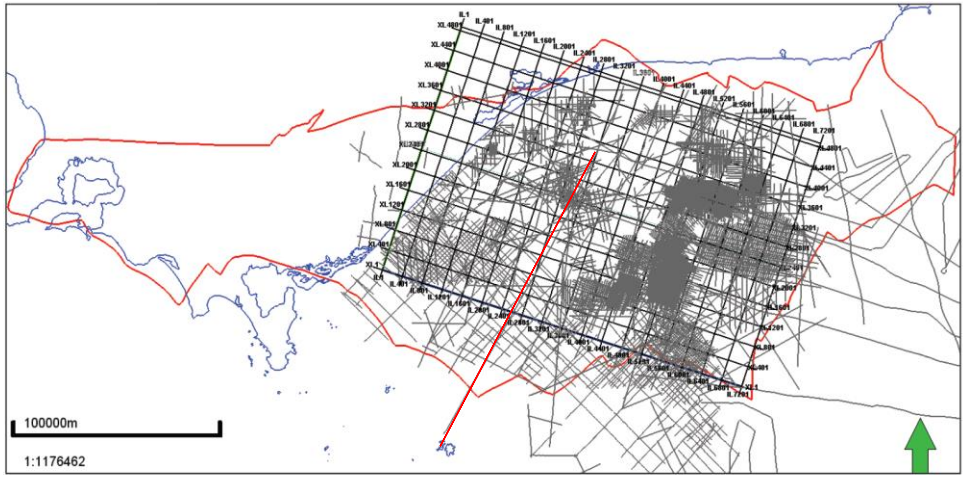


Dataset: Structural Interpretation

Regional Cross line: s_90_90_13





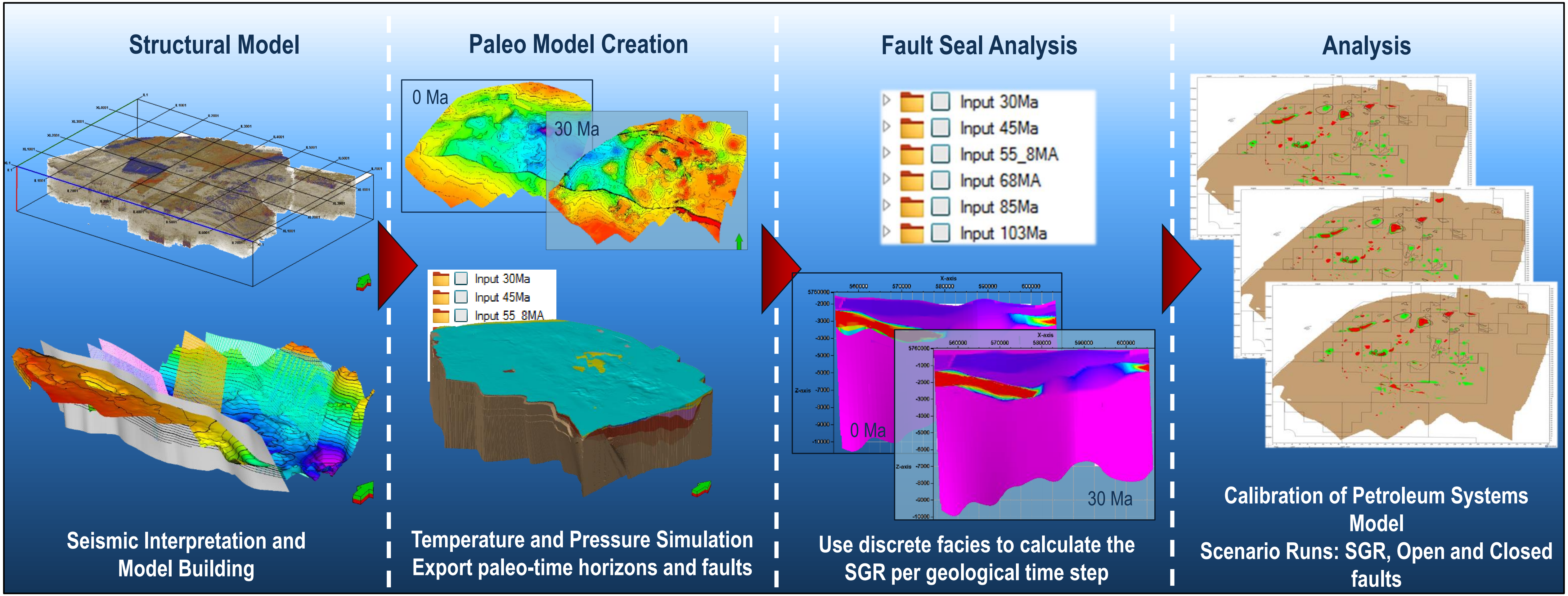


Distribution of available 3D and 2D seismic data

- Asymmetrical basin
- First rift phase forming NW-SE trending Grabens High angled normal faults
- Many faults interpreted but only the regional faults were incorporated into the basin model

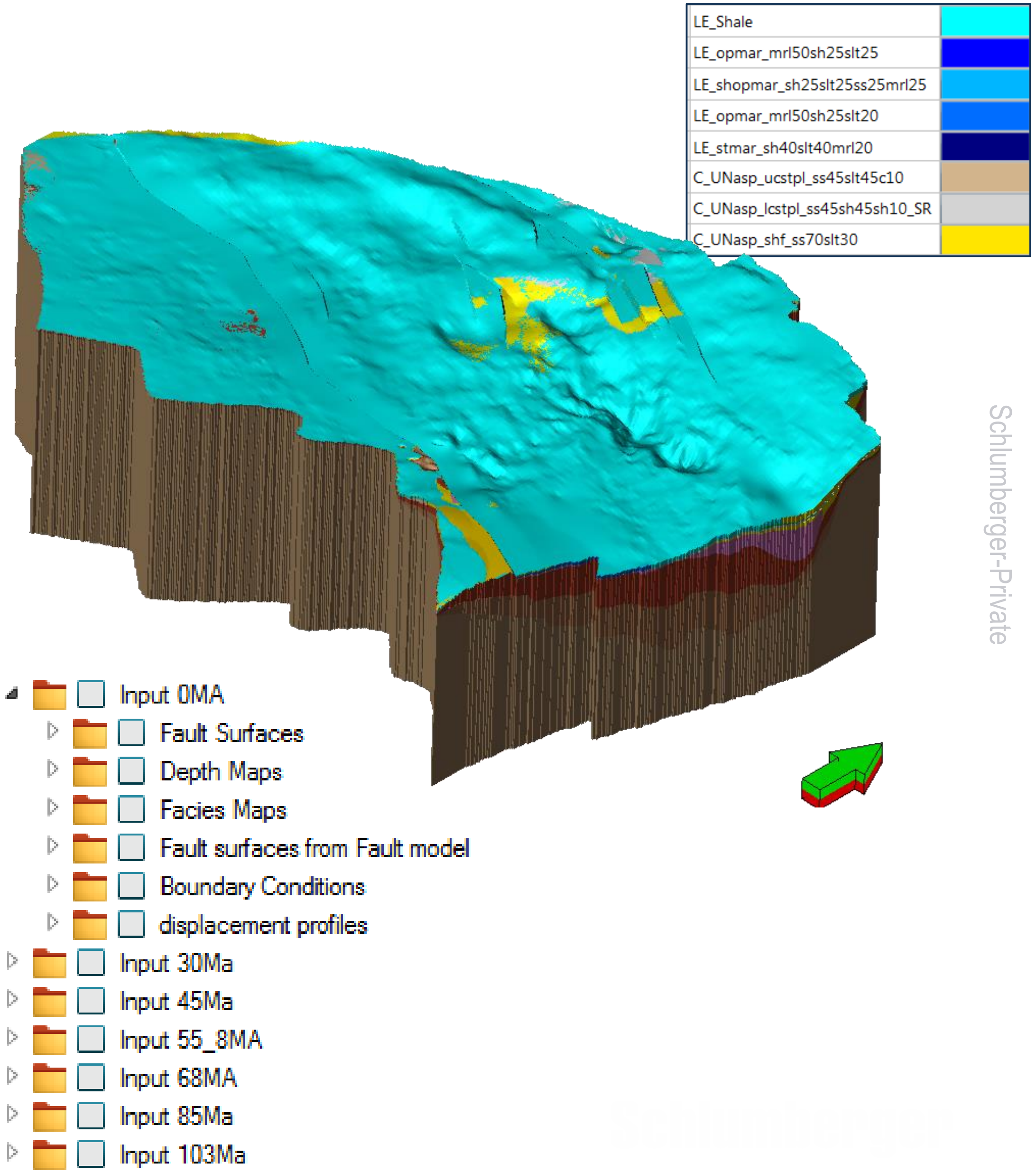
Method: Fault Seal Analysis to Petroleum Systems Modeling

Fully integrated approach between structural interpretation and petroleum systems modeling

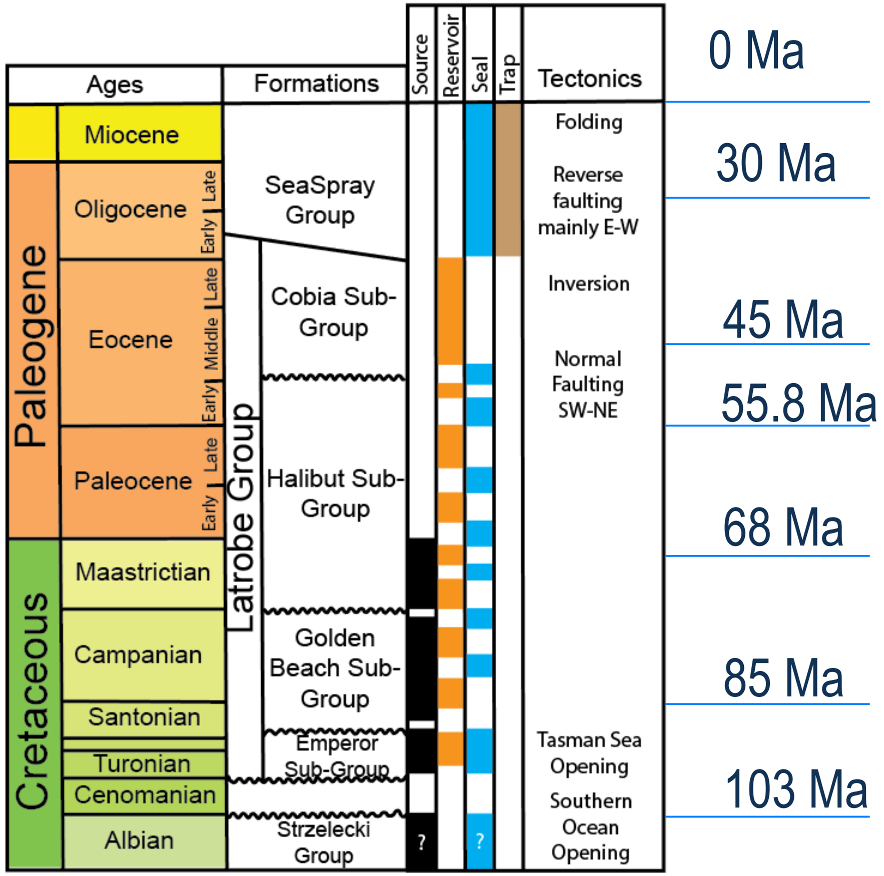


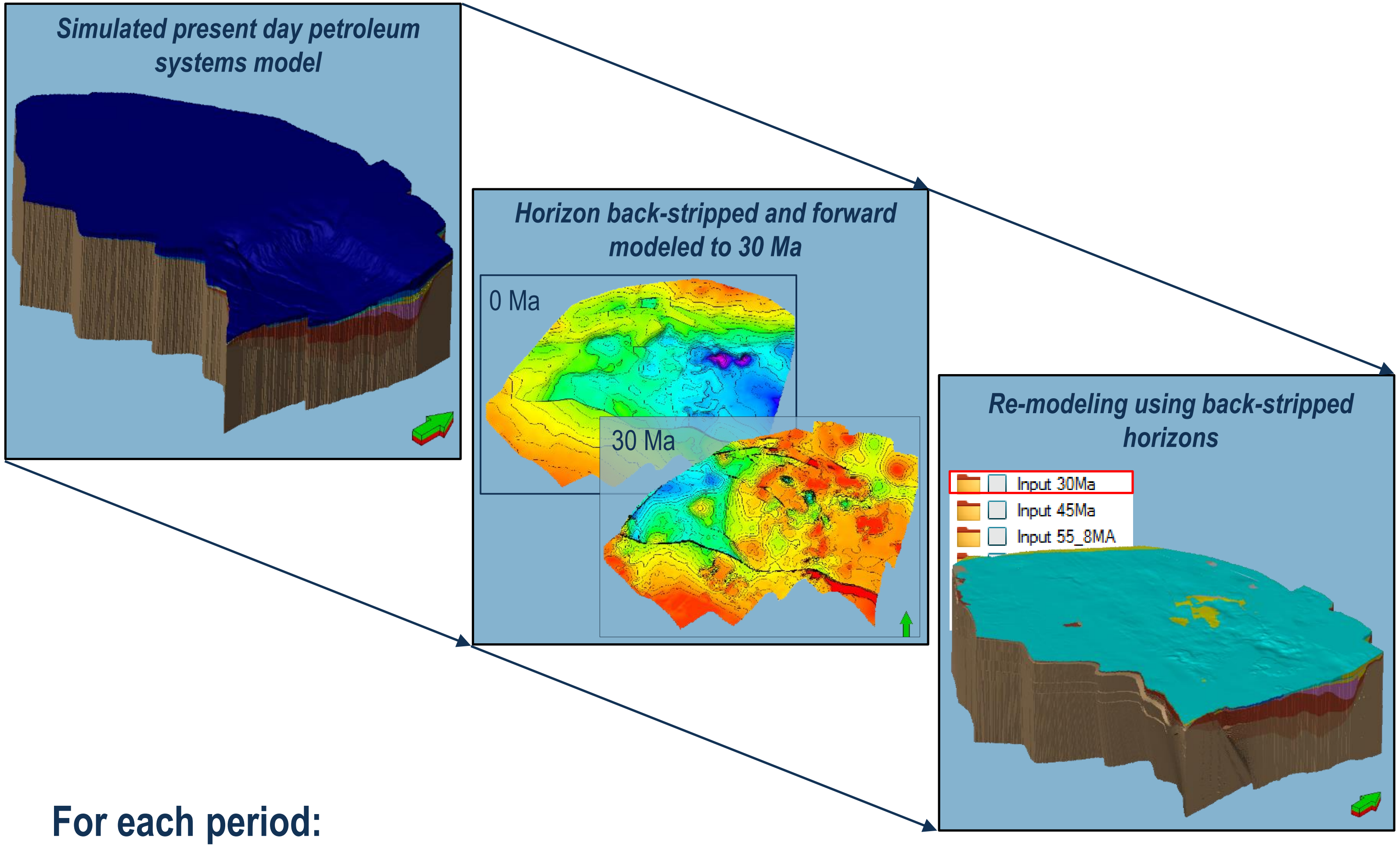
Method: Initial Basin Model

- Initial present day model provides back-stripped geometries through time:
  - 4.8M cells
  - 500m grid
  - 22 geologic horizons
  - Total of 38 sublayer(PM)/layer(Petrel)
  - Full 3D P/T simulation
  - Migration simulation run
- Facies & lithology definition based on basin stratigraphy in petroleum system model.
- Extraction of model geometry at specific time steps provides juxtaposition of geologic layers in history.



Method: Horizon Modeling





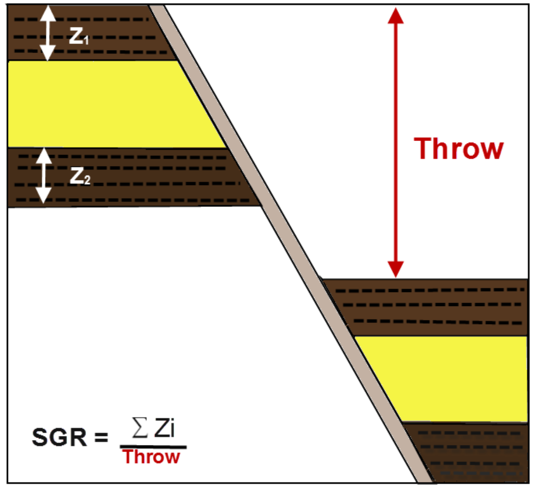
For each period:

- Horizon and fault definition from petroleum systems simulation results (3D P-T compaction effects included in back-stripping & forward modelling)
- vShale property from basin model facies definition

Method: Fault Modeling

Faults:

- 6 Basin scale fault zones from structural interpretation.
- Extending from Basement into Paleogene
- 3 Scenarios: open, closed, shale gauge ration definition
- Definition of seal behavior by shale gauge ratio modelling
- vShale for SGR from regional petroleum systems facies definition

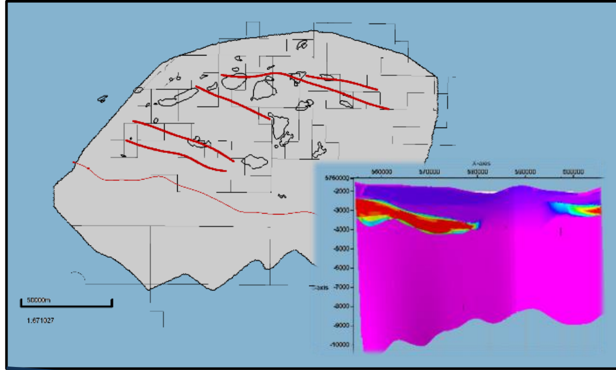


The SGR is the percentage of shale or clay in the slipped interval

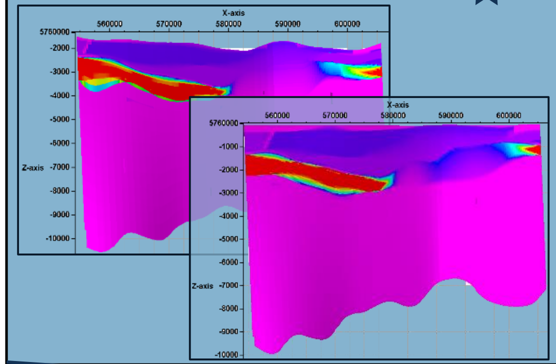
The SGR value assigned in PetroMod is converted to FCP and to permeabilities for fault migration simulation.

Yielding et al. (1997)

Fault Modeling Workflow



Present day faults interpreted with calculated SGR from discrete facies



Fault geometries backstripped to specific defined time periods with calculated SGR ratio for that specific time period

	Age from [Ma]	Age to [Ma]	SGR [unitless(0-1)]
Fault interpretation 32	30.00	0.00	SGR (VShale)
Fault interpretation 8	30.00	0.00	SGR (VShale)
Fault interpretation 1	30.00	0.00	SGR (VShale)
Fault interpretation 14	30.00	0.00	SGR (VShale)
Fault interpretation 20	30.00	0.00	SGR (VShale)
Fault interpretation 32	45.00	30.00	SGR (VShale)
Fault interpretation 8	45.00	30.00	SGR (VShale)
Fault interpretation 1	45.00	30.00	SGR (VShale)
Fault interpretation 14	45.00	30.00	SGR (VShale)
Fault interpretation 20	45.00	30.00	SGR (VShale)

Fault geometries and associated SGR ratio used to defined fault history in Petroleum systems model

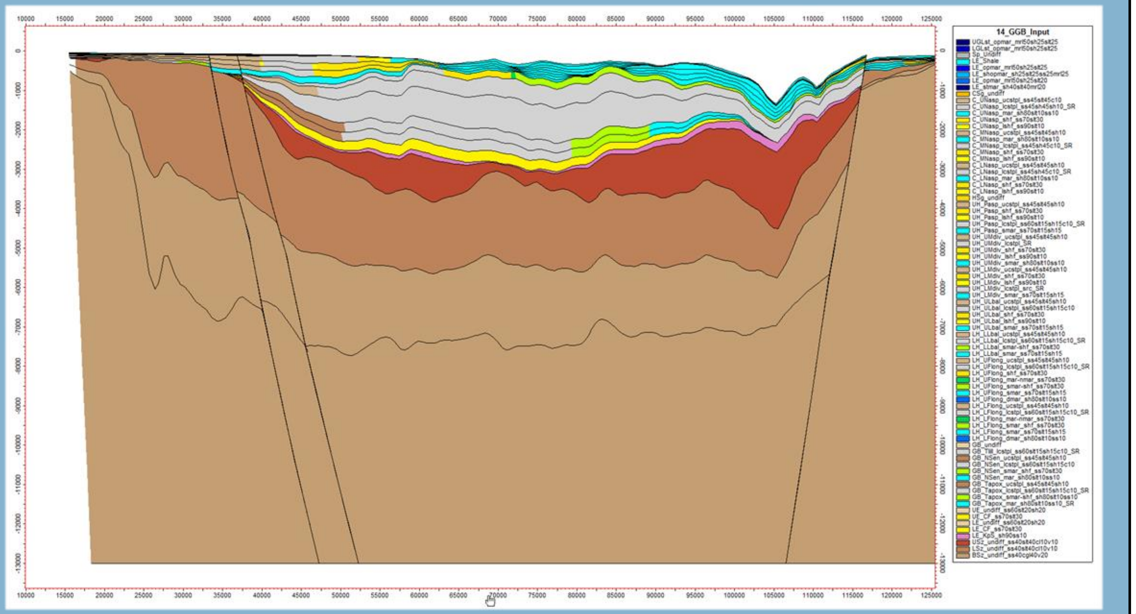
In the results in the following slides it is assumed that the fault geometries do not significantly change throughout time

Method: Calculating the vShale Property

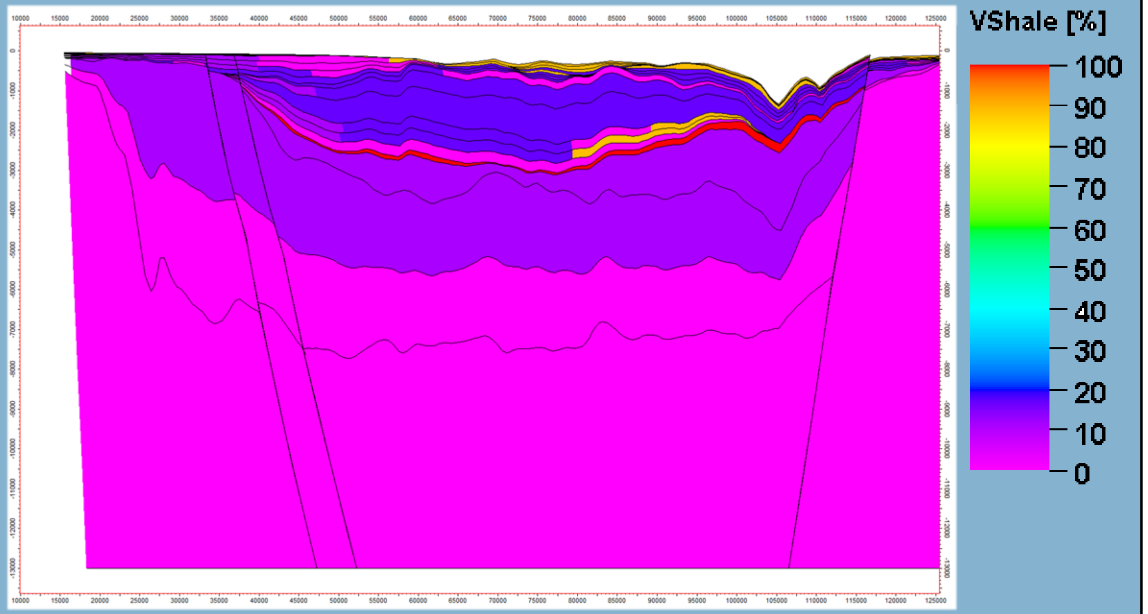
Conversion of the Petroleum Systems definition facies property into vShale property:

- If the facies mixture is 100Sh assign ---> 100% Vsh
- If the facies mixture is 50Sh50Sst assign ---> 50% Vsh
- If facies mixture is 100Sst assign ---> 0% Vsh

Cross section of Facies

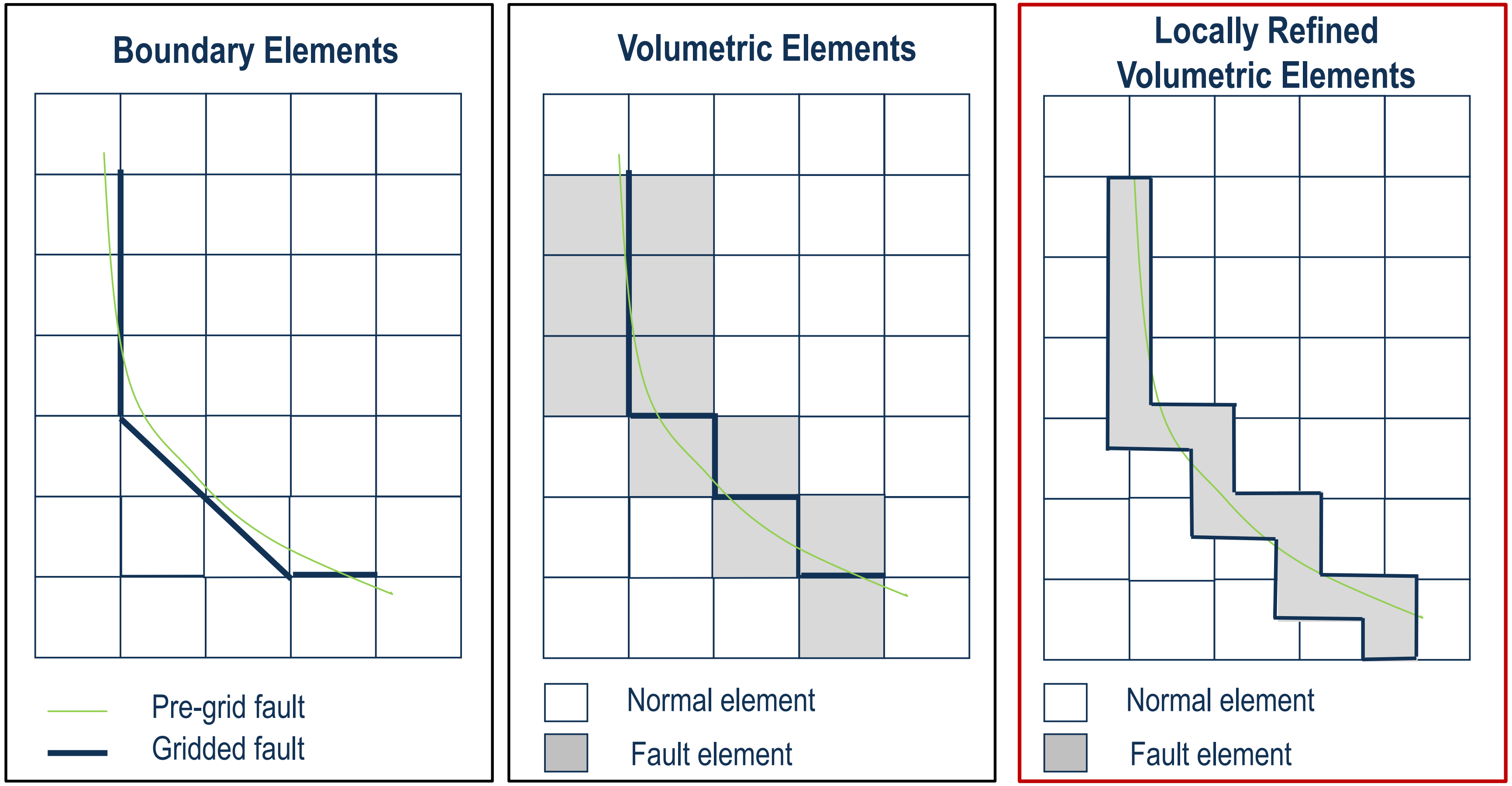


Cross section of vShale



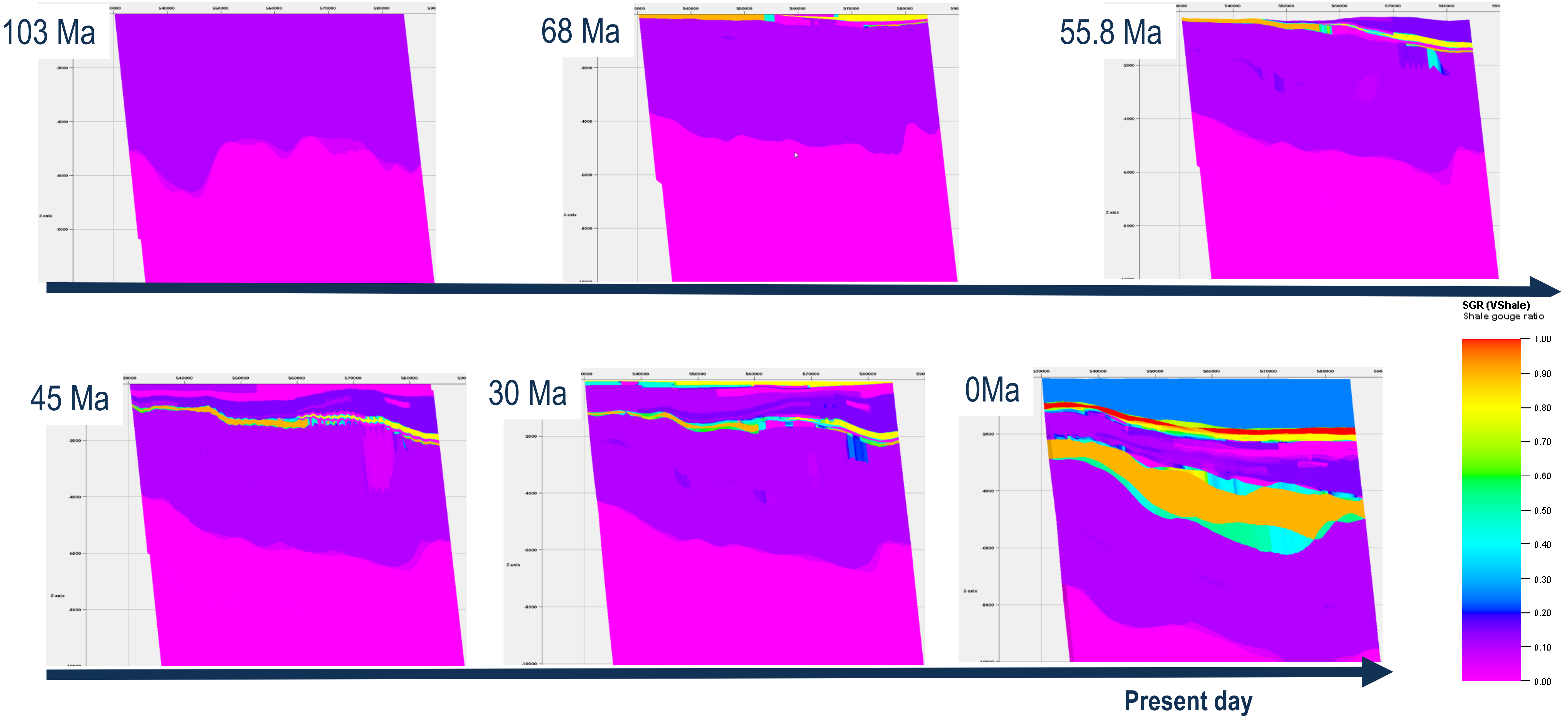
Method: Fault Migration Method

- Incorporate the fault by locally refining the grid to create small fault elements (fault width about 10m).
- This allows for detailed modelling of pressure distribution around faults.



Boundary Elements	Volumetric Elements	Locally Refined Volumetric Elements
No influence on pressure (water flow) only on HC migration.	*Modify the adjacent fault element properties to fault properties*	*Influence on pressure (water flow) and HC migration.*

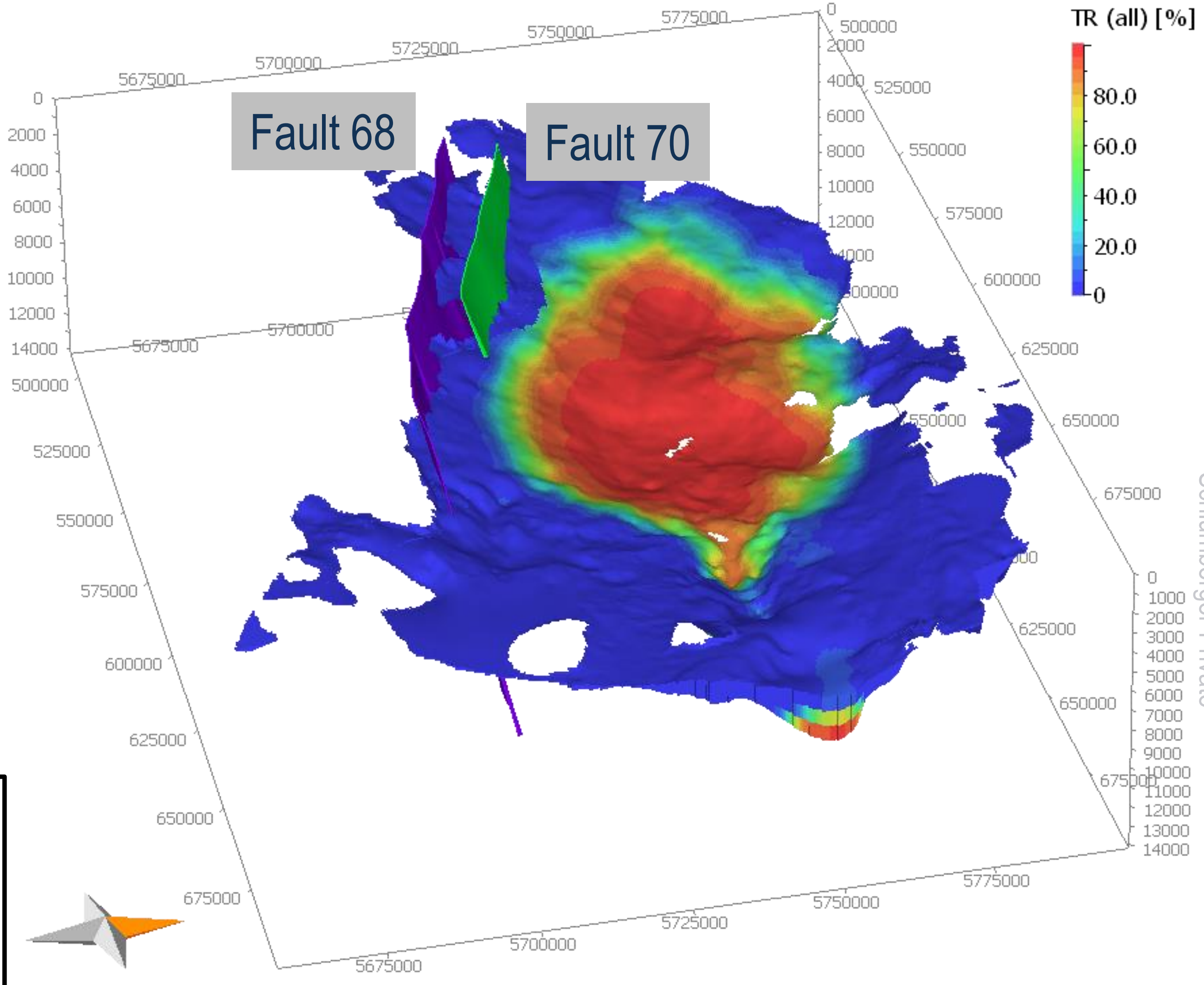
Results: Fault 68 SGR Through Time



It has been assumed that the fault geometries do not significantly change throughout time

Results: Faults of Interest

- Two faults of interest:
  - Fault 68
  - Fault 70
- Both faults connect kitchen areas of Lower Emperor, Golden Beach and Halibut with Cobia reservoirs



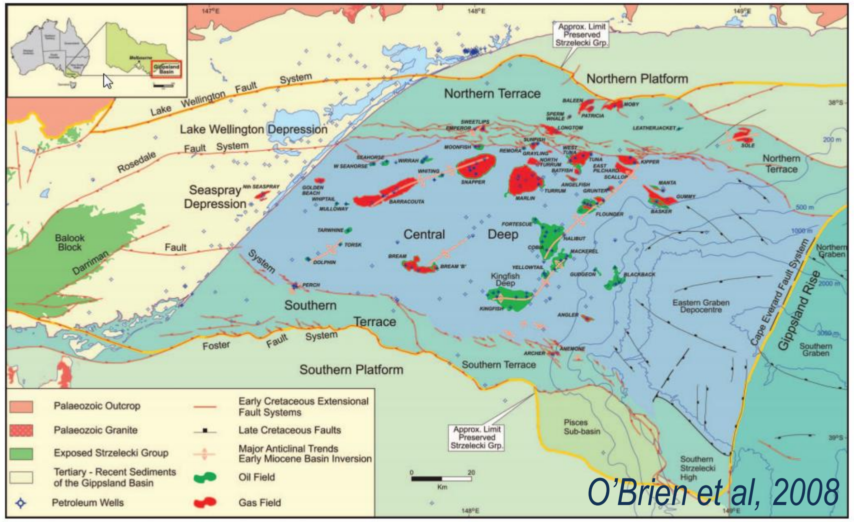
Transformation ratio present day Lower Emperor

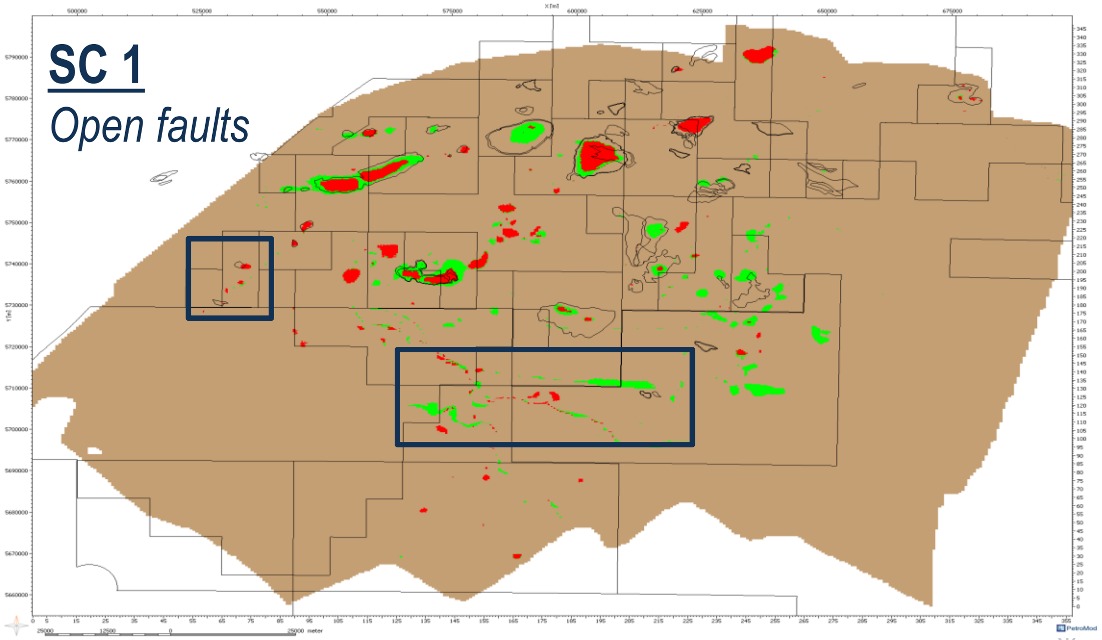
Three scenarios (SC) were run and the results are compared in the following slides:

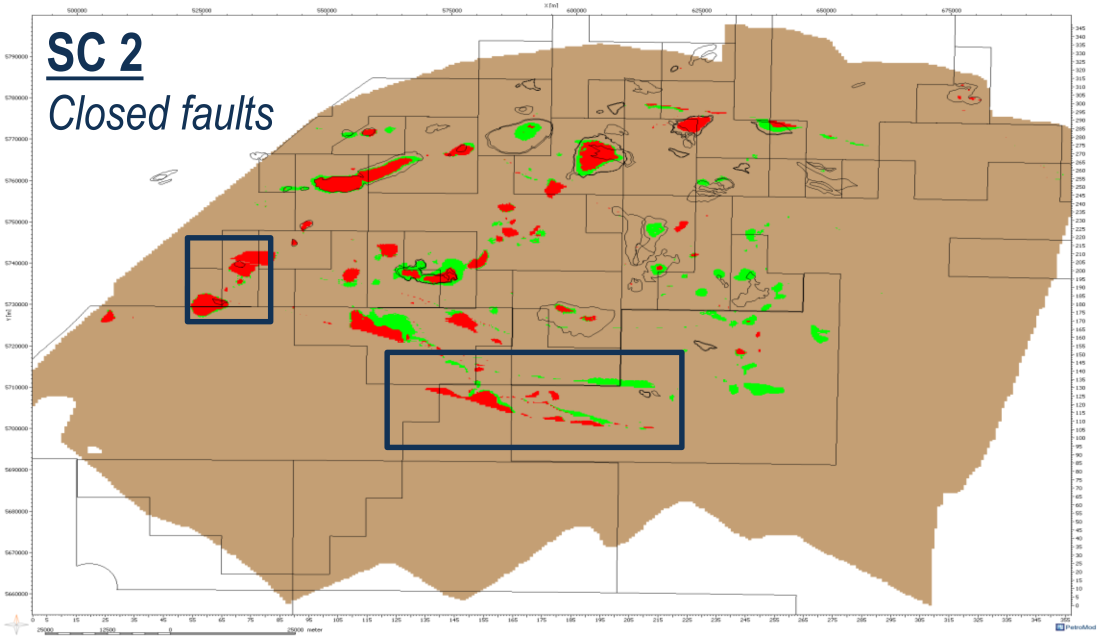
1. All open ---▸ **(SC 1)**
2. All closed ---▸ **(SC 2)**
3. SGR definition (new method) ---▸ **(SC 3)**

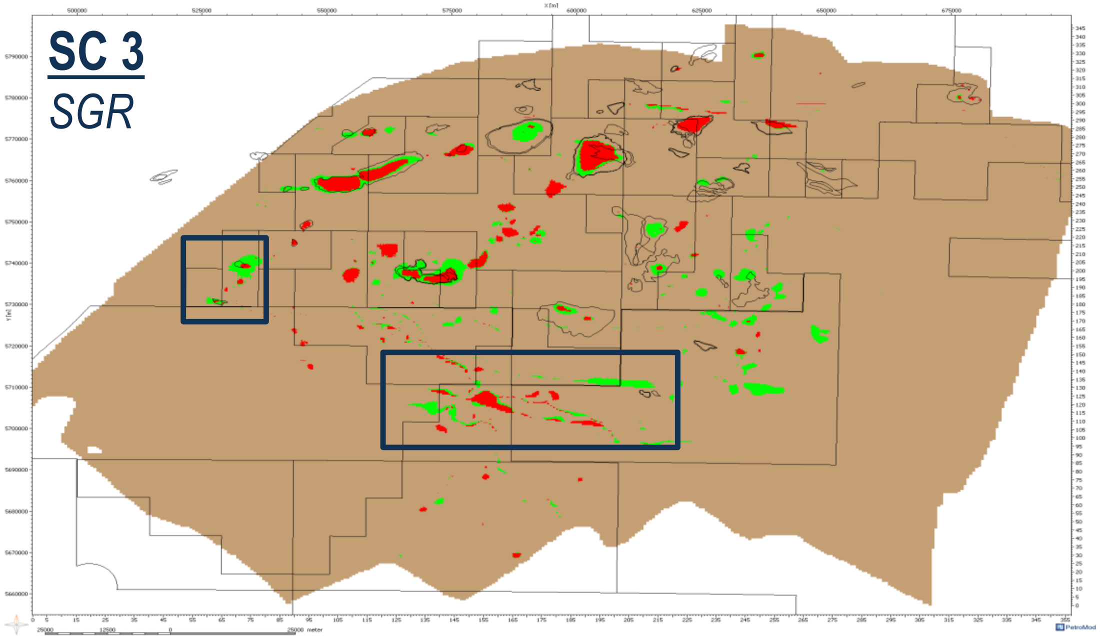
Results: Scenario Run Comparison

- Images demonstrate the simulated accumulations
- Good match to the known present day fields of the Gippsland Basin



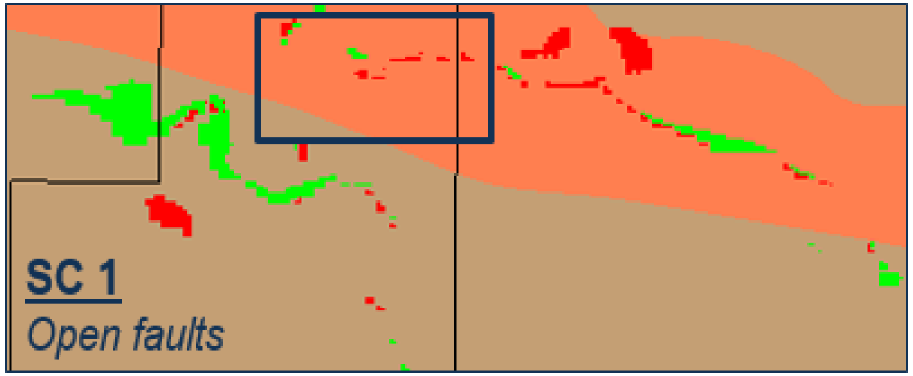


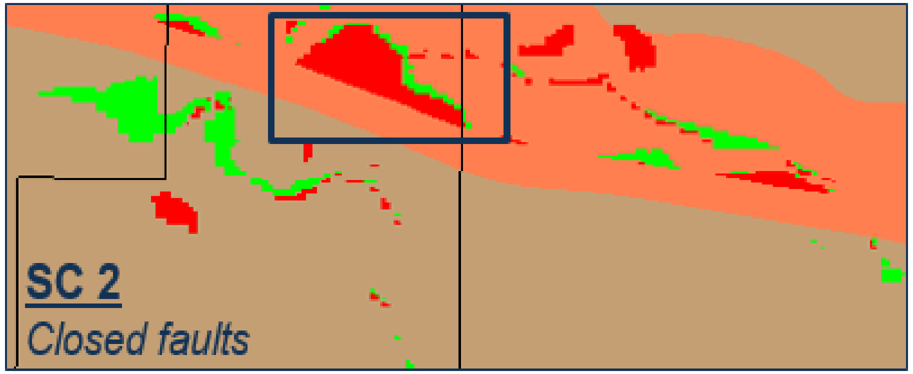


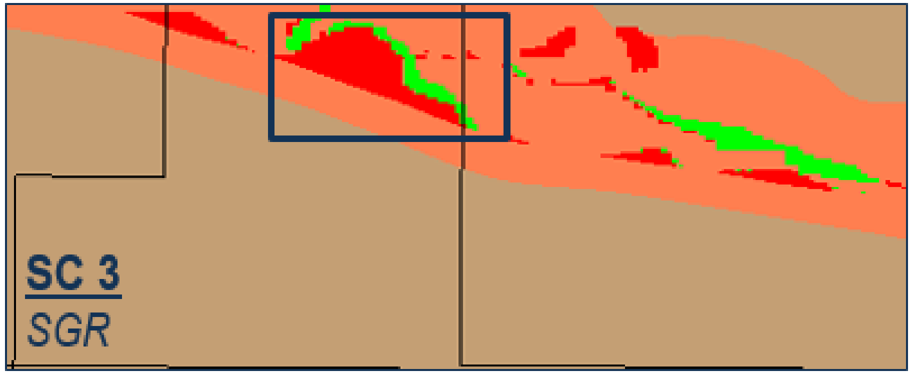


Results: Area of Interest 1

- Accumulation is influenced by Fault 68
- In **SC 1** accumulations are lost due to leakage up the fault
- **SC 2** and **SC 3** are similar with accumulations trapped along the fault

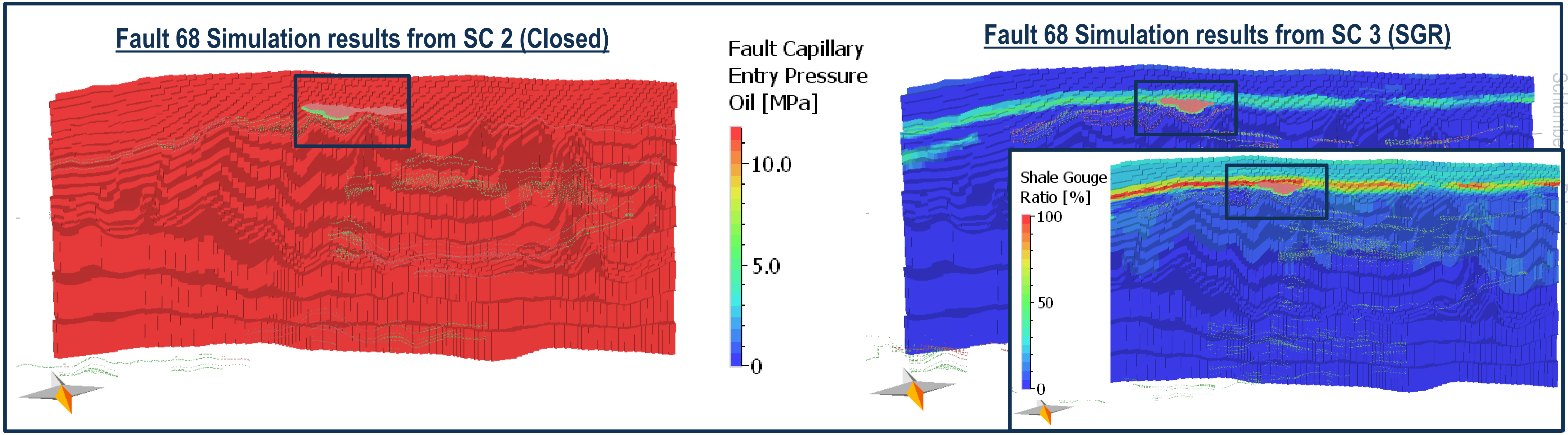






Results: Area of Interest 1

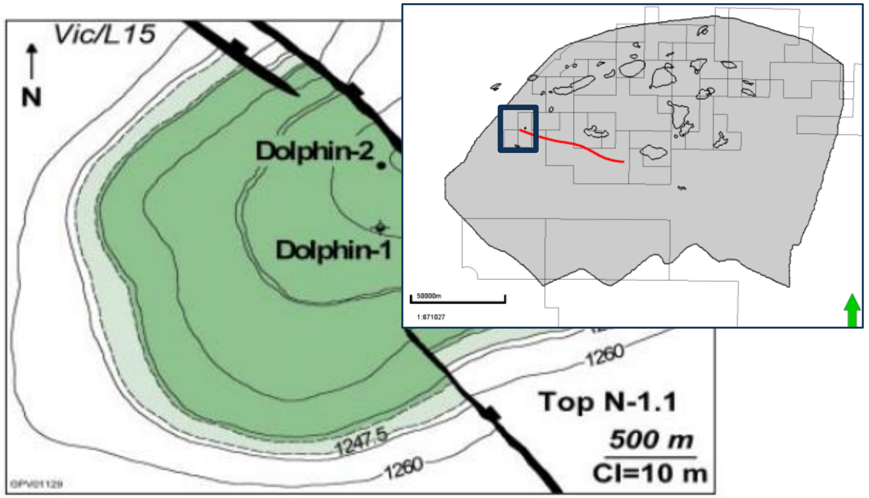
- **SC 2** and **SC 3** are similar with accumulations trapped along the fault
  - **SC 3** has a different shape due to a lateral variation in SGR and this causes capillary pressures to vary laterally as well



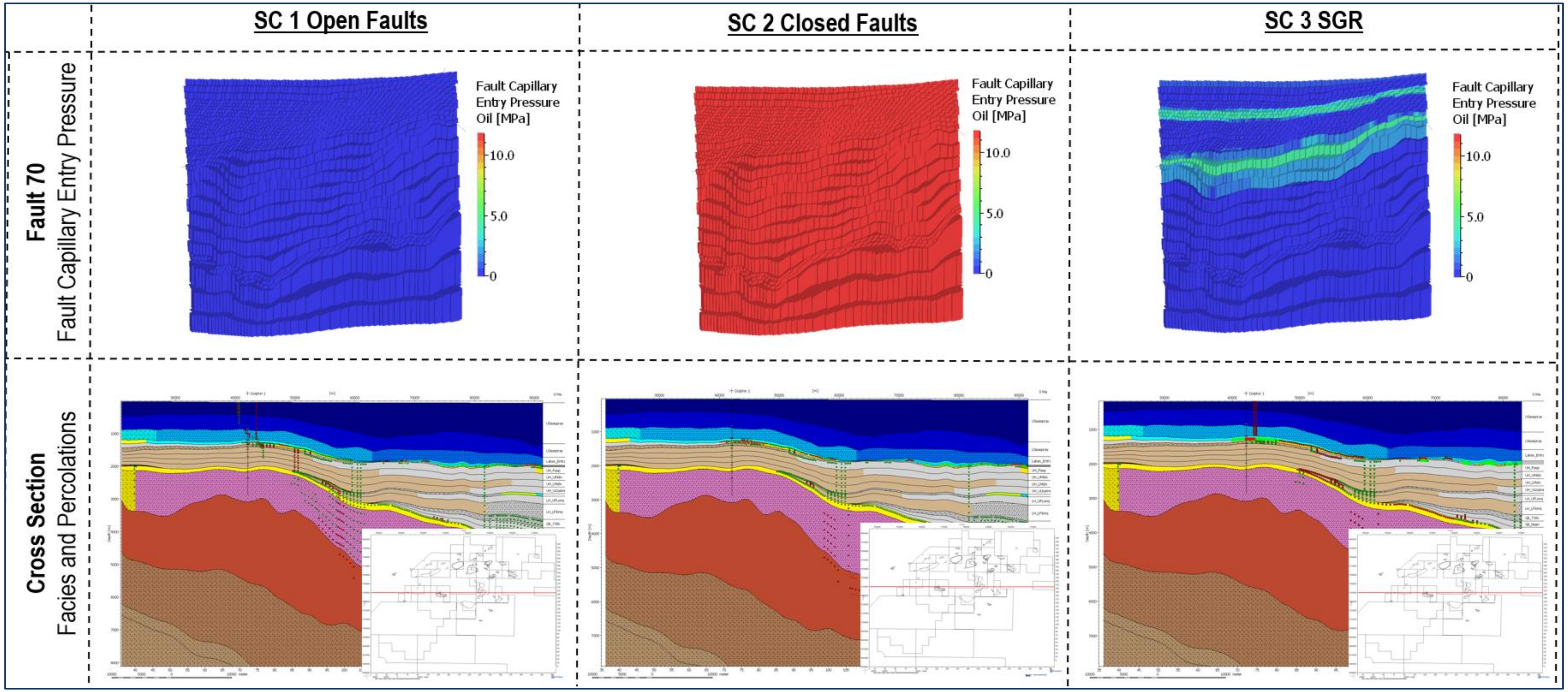
Results: Area of Interest 2

Dolphin Field and Fault 70

- Present Day oil accumulation, first discovered in 1967
- SC 3 (SGR) method is the only scenario that predicts the accumulation as oil
  - The fault acts as migration pathway and also as a seal
  - Breakthrough of gas where the capillary pressure of the seal (fault) is not efficient enough to hold the hydrocarbon column height



Malek and Mehin, 1998



Results: Discussion

Original PSM model results showed expected “extreme results”

- Open & Closed scenarios do not honor the structural evolution of the basin
- Disconnection between lower source rocks and reservoirs
- Fault losses yield no accumulations in open fault scenario

New model results show higher resolution and more complex migration pattern

- More realistic connection of kitchen areas with reservoirs
- Cross fault migration handled more accurately
- Accurate representation of present day fields
- New ways for hydrocarbon flow calibration by consistent geology based modification of fault properties

Conclusions

- vShale definitions based on regional litho-facies distributions can provide a reasonable input for shale gauge ratio predictions on regional fault zones.
- Shale gauge ratios derived from structural and fault seal analysis on these regional faults allow for a more realistic fault seal scenario modeling.
- The new method of fault property definitions in petroleum systems models provide a higher time and property resolution of fault properties on basin scales.
- The new method can be used to calibrate a petroleum systems model known to be sensitive to regional fault seals to known field data more accurately and opens up more precise ways of fault migration modeling and analysis.

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