Regional migration and trapping frameworks in the frontier ceduna sub-basin: new insights from stratigraphic forward modelling and 'triangle juxtaposition' diagrams.

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SUMMARY

Despite a recent renewal in exploration, the Ceduna Sub-basin is underexplored with high uncertainty regarding lithofacies distribution. This results in limited understanding of reservoir and top seal coupling, trends for fluid migration and structural trapping for the Late Cretaceous marine and deltaic interval. In order to address these uncertainties a stratigraphic forward model was developed to recreates the development and preservation of stratigraphic successions. Over an area of interest in the centre of the sub-basin, an early investigation tool consists in a rapid screening of the stratigraphic forward model to forecast vertical and lateral stratigraphic trends which outline structural trapping opportunities.

The model shows an overall north-west to south-east net-to-gross distribution trend and stacked reservoir-seal successions predicted in both the marine and deltaic intervals. Structural trapping potential was assessed with Shale Gouge Ratio calculation and triangle diagrams. The marine-dominated Tiger and lower Hammerhead Supersequences are predicted with the higher potential for structural traps with probability of juxtaposition and membrane fault seals. A predicted sand-rich Early Campanian nearshore marine sequence is likely to act as a migration fairways.

Key words: Ceduna Sub-basin, forward stratigraphic model, fault seal.

INTRODUCTION

In the Ceduna Sub-basin oil-prone source rocks, reservoirs and seals are predicted in Late Cretaceous Turonian through Santonian (Tiger) and Campanian through Maastrichtian (Hammerhead) marine and deltaic Supersequences (Totterdell et al, 2000). Despite a recent renewal in exploration the sub-basin is underexplored with only one well (Gnarlyknots-1, Figure 1) drilled in the central >10 km thick sequence. Resulting uncertainty regarding lithofacies distribution is high, leading to limited understanding of reservoir and top seal coupling, trends for fluid migration and structural trapping.

Forward stratigraphic modelling output was used as an early investigation tool to predict the potential of marine and deltaic sequences for the purpose of broad based reservoir and seal prediction for an area of interest located in the central part of the sub-basin.

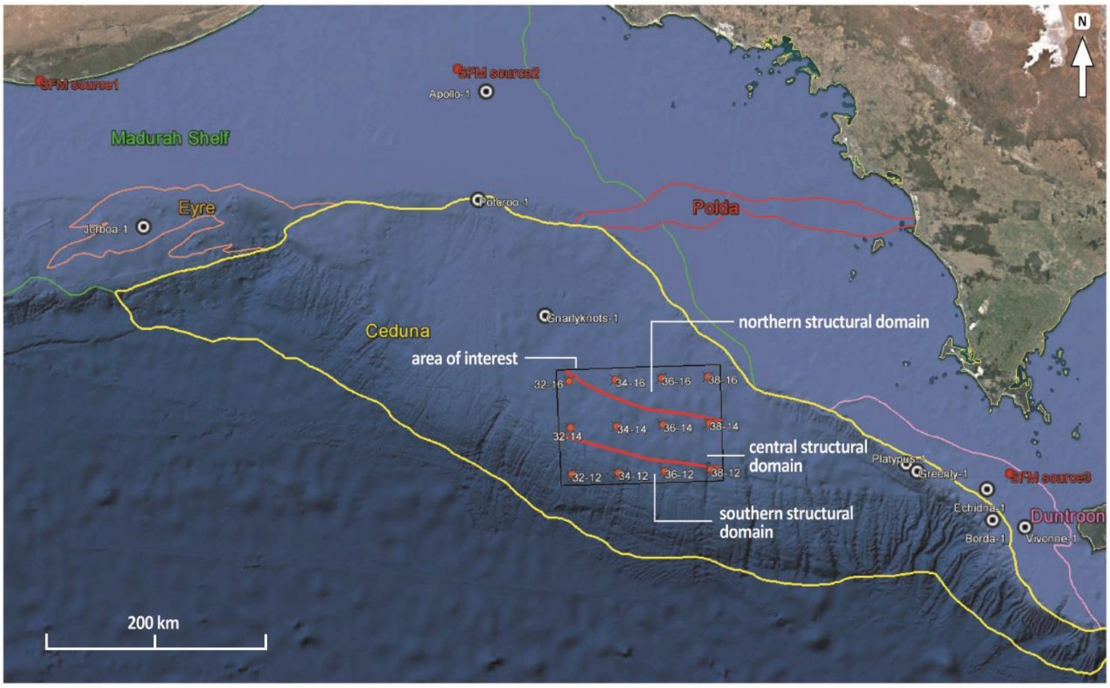

Figure 1. Ceduna Sub-basin and area of interest. The pseudo-wells are labelled 32-12 to 38-16, the stratigraphic forward model source points are displayed in red (SFM source 1 to 3) and the three structural domains are delimited by red boundaries.

STRATIGRAPHIC FORWARD MODELS

The lithofacies distribution uncertainty was reduced by using data from a Sedsim three-dimensional stratigraphic forward model (Griffiths et al., 2001) that recreates the development and preservation of stratigraphic successions. In a forward modelling approach, data are not used as the anchor points for facies interpolation or extrapolation, but to test and validate the results of the simulation. The modelling enables the prediction of facies in areas where data are sparse, unevenly distributed, or at inappropriate resolution. Sedsim is restricted to four user specified siliciclastic grain sizes (in this case medium sand, fine sand, medium silt and clay). Sedsim output is composed of a sedimentary thickness for each grain class in meters for each given time increment. The simulation grain sizes classes can be attributed to net and non-net and then converted to shale volume (Vshale). The net portion of the models are represented by the two coarser grains (medium and fine sand) and the non-net by the remaining output (medium silt and clay). Vshale value represents the non-net thickness divided by the interval thickness and the net-to-gross is 1-Vshale.

Several sets of forward models have been produced over the Ceduna Sub-basin with lateral resolution from 20 km to 2 km and with time increments (vertical resolution) from 200 ka to 40 ka.
This work purposely focuses on the modelling aspect, while the initial models were based upon 2D seismic interpretation and the output visually checked against the seismic lines, no attempt has been made to exhaustively tie the modelled results to recent 3D seismic surveys as these were not made fully available for this research.

AREA OF INTEREST

The ~10,000 km2 area of interest is located in the central part of the sub-basin (Figure 1), ~130 km south-east of Gnarlyknots-1 well and it covers three distinct structural domains observed on regional 2D seismic data with (1) basement related faulting and Cretaceous reactivation to the north, (2) Mesozoic faulting and reactivation in the centre and (3) listric faulting with upper decollement and local compression to the south.

PSEUDO WELLS

12 evenly spaced (40 km) pseudo-wells (Figure 1) were extracted from the stratigraphic model to sample, with an interval of 40 ka, the modelled lithofacies and shale volume distributions for the Tiger and Hammerhead Supersequences in the three structural domains. The Vshale values are further upscaled to predict sand (reservoir) and shale (seal) intervals using a threshold of 0.5 (sand interval = Vshale [0-0.5] and shale interval = Vshale [0.5-1]).

Stratigraphic trends
Over the area of interest the model shows an overall north-west to south-east lithological trend for the Tiger and Hammerhead Supersequences (Figure 2) reflecting the overall basin shape and the influence of the main sedimentary source points in the stratigraphic model located north of the Ceduna Sub-basin, on the Madurah Shelf (Strand et al., 2017; Figure 1). This is visible in the overall net-to-gross distribution predicted by the model for the Tiger and Hammerhead Supersequences which varies from 0.55 (55% sand

intervals) in the north-west to 0.06 (6% sand intervals) in the south-east (Figure 2); this trend is also visible in the intervals mean thickness distribution with sand intervals slightly predicted to decrease from ~40 m to the north-west to ~30 m to the south-east while the shale intervals predicted to increase from ~30 m to the north-west to up to ~400 m to the south-east (Figure 2). Although this highlights the general trend of having more likelihood of reservoir presence to the north-west and more seal presence to the south-east, the model predicts enough variability within the sequences to create a wide range of stacked reservoir-seal couplets over the entire area of interest, in all the three structural domains (Figure 3). The best sequences of reservoir-seal successions are predicted by the model in the central structural domain for the mid and upper Hammerhead Supersequences and in the northern structural domain for the Tiger and lower Hammerhead Supersequences. The model predicts thick nearshore sands, of Early Campanian age, near the top of the lower Hammerhead sequence (Figure 3).

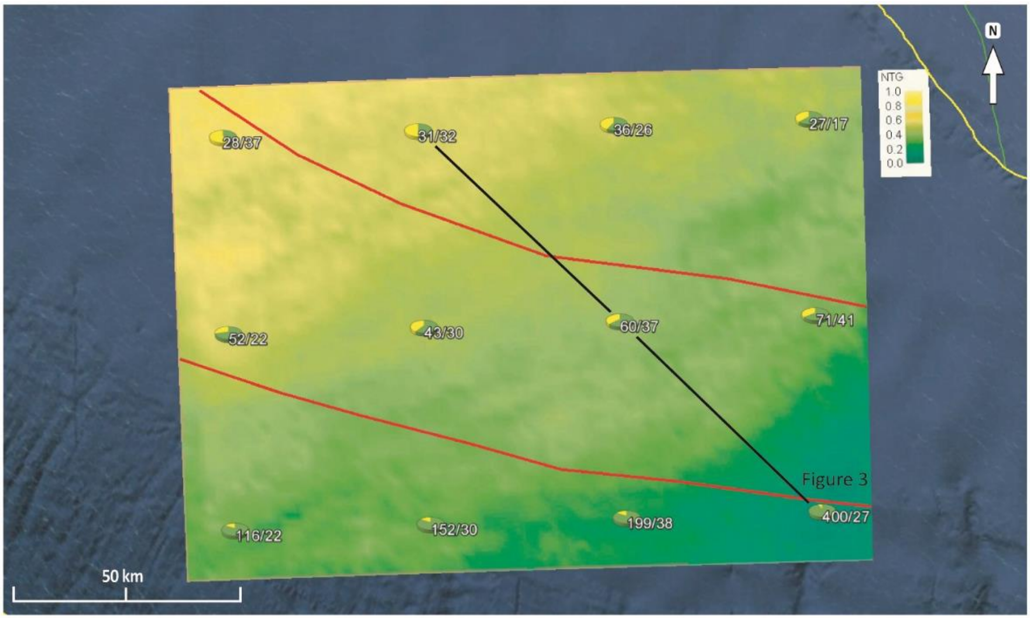

Figure 2. Stratigraphic trend for the Tiger and Hammerhead Supersequences. In the background is shown a net-to-gross map (1-Vshale) representing an average over the two Supersequence from a 2 km by 2 km stratigraphic model. For each pseudo-well the proportion of sand and shale intervals is represented as a pie chart (yellow=sand, green=shale) and the labels represent the mean thickness of sand and shale intervals in meters, respectively. The three structural domains are delimited by red boundaries.

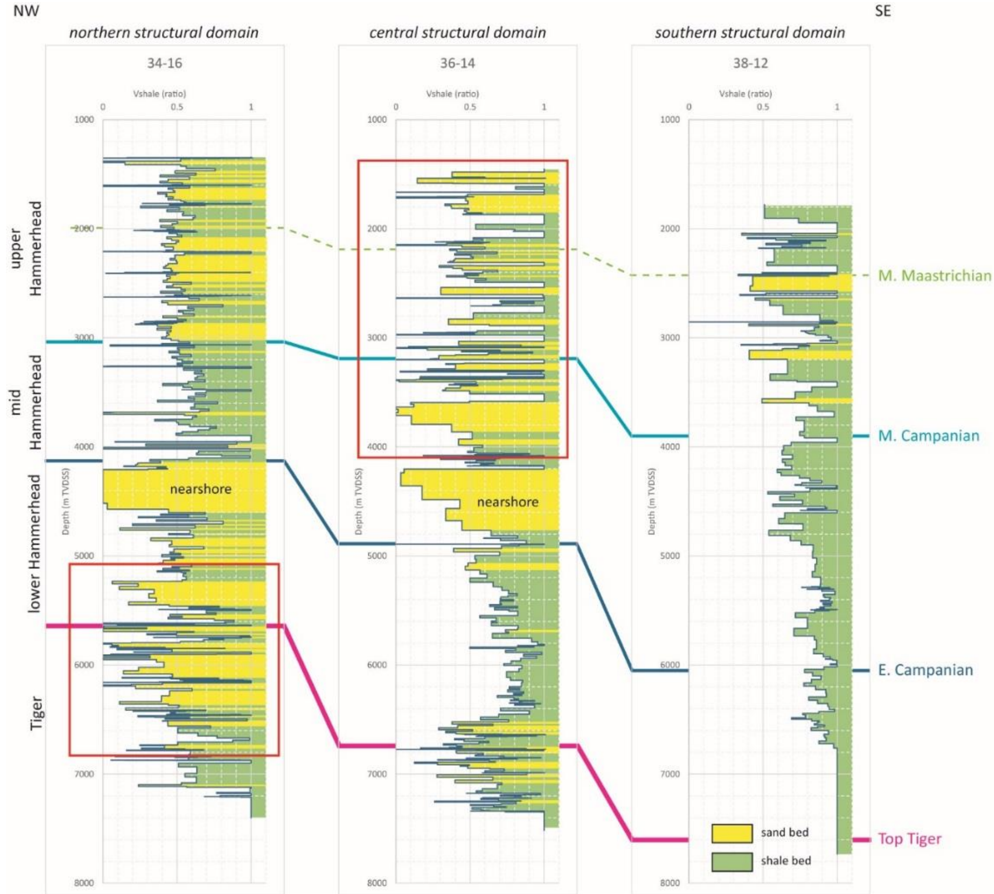

Figure 3. Pseudo wells correlation across the three structural domains. Examples of reservoir-seal successions are shown in the red boxes.

FAULT SEAL

The Vshale values from the pseudo-wells are used as inputs for triangle juxtaposition diagrams for the three structural domains. The diagrams outline the fault seal potential and associated oil column height by displaying theoretical juxtaposition seal (sand against shale intervals) and predicting membrane fault seals for sand-sand juxtaposition using Shale Gouge Ratio (SGR, Yielding et al, 1997). These diagrams allow to outline regional trapping potential and probe the sensitivity of fault throws and stratigraphic variations. The throw ranges use in the triangle diagrams are derived from regional interpretation of 2D seismic data and are estimated to represent a range of possible displacement for the Late Cretaceous sequences.

For the northern structural domain the triangle diagrams suggest favourable structural trapping potential in the upper Tiger and lower Hammerhead with series of predicted thick interbedded sand (mean thickness ~25 m; ~300 m max) and shale (mean thickness ~30 m; ~400 m max) intervals able to create juxtaposition seals and structural traps (Figure 4); for fault throw >300m membrane fault seal is predicted as average to high (SGR ≥ 0.25) due to high non-net content (40%-70%) and depth (Bretan et al, 2003). The predicted sand-rich Early Campanian nearshore marine sequence, in the lower Hammerhead, has restricted potential of forming traps against faults with large throw (≥ 400 m), however it is more likely predicted to act as a migration fairways as self-juxtaposition is unlikely to impede flow. The middle and upper Hammerhead (Mid Campanian to Maastrichian) are predicted with restricted structural trapping potential to the west with decreasing quality sand intervals (net-to-gross ~50-60%) and average fault seal capacity due to thinner shale intervals (mean thickness ~25 m) and decreasing shale content; to the east, fault sealing potential is predicted to increase with good membrane fault seal (SGR > 0.5) for fault throw ≥ 100 m but the frequency and thickness of sand-rich reservoir intervals decrease.

For the central structural domain the triangle diagrams suggest good trapping potential in the Tiger and lower Hammerhead with predicted extensive shale-rich intervals able to create juxtaposition seals and structural traps; in our models, throw > 80 m are already expected to create good membrane fault seal (SGR ≥ 0.5) for sand-sand juxtaposition (Figure 5). However the thickness and frequency of sand intervals, modelled for the Tiger and lower Hammerhead, are generally low with the exception of the north-west corner. The lower Hammerhead (Santonian and early Campanian) is mostly predicted as being shale-rich with low potential for reservoir intervals with the exception of the north-west corner where nearshore marine sand-rich sequences dominate. For this latter area the model predicts structural trapping potential associated with shale-rich intervals creating juxtaposition seals and average to good membrane fault seal for fault throw as low as 100m. The structural trapping potential for the middle and upper Hammerhead (Mid Campanian to Maastrichian) is predicted to generally grade from good in the Mid Campanian to moderate and poor upwards (Figure 5); this grading mostly reflects the reducing thickness of sand- and shale-rich intervals and decreasing burial depth. Structural trapping associated with juxtaposition seals and membrane fault seal for faults throw ≥ 200 m is still locally predicted in the upper Hammerhead (Figure 5).

For the southern domain characterised by listric faults in the Hammerhead and Tiger, the triangle diagrams suggest very low trapping potential in the Tiger and lower Hammerhead due to the high non-net content (99-100%). Interbedded sand-rich and shale-rich intervals in the mid and upper Hammerhead (Mid Campanian to Maastrichian) are predicted to be able to create juxtaposition seals and structural traps; in our models, fault throw > 100 m is expected to generate effective membrane fault seal (SGR ≥ 0.4).

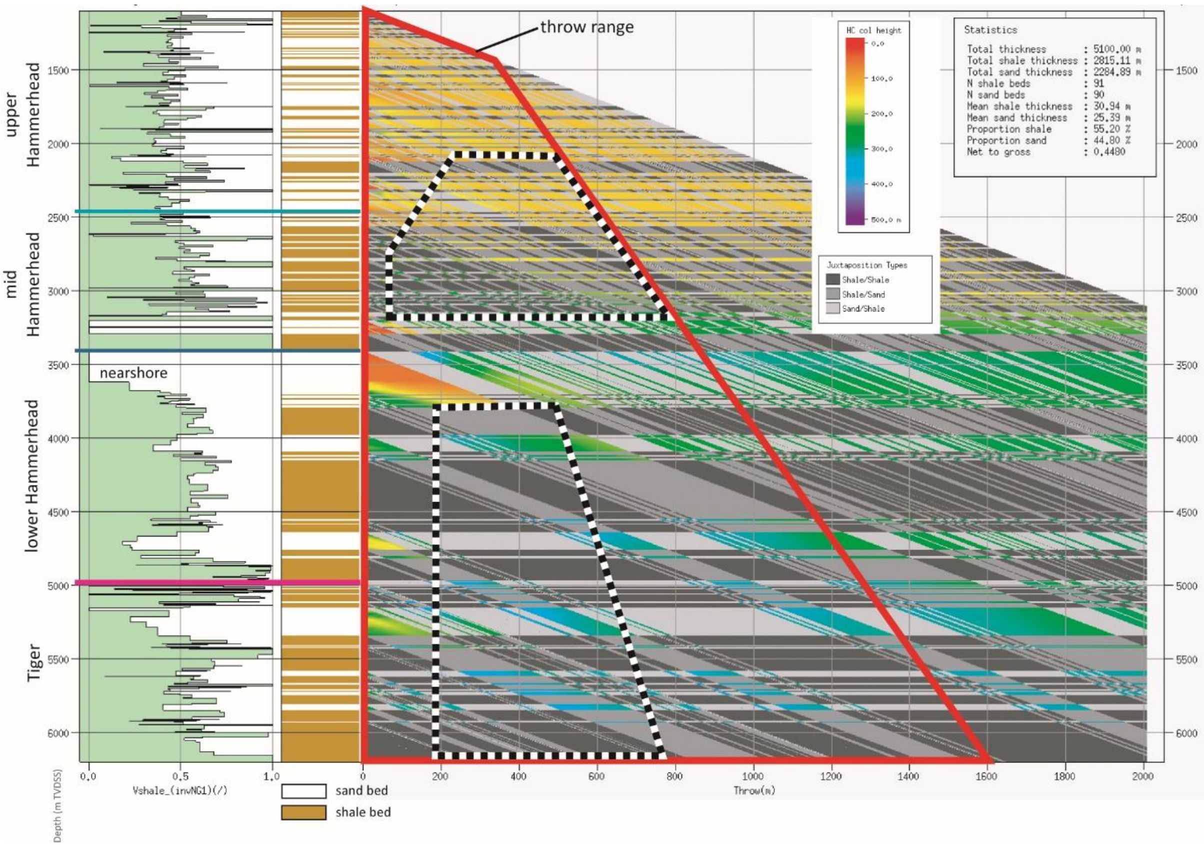

Figure 4

Triangle diagram for pseudo-well 36-16 in the northern structural domain. The theoretical juxtaposition are shown for all possible throws and the oil column supported by membrane fault seal for sand-sand juxtaposition is displayed in the background. The red polygon represents the local range of expected throws; the dotted line polygons represent combinations of stratigraphy and throw to create structural traps in the Tiger-lower Hammerhead and the mid-upper Hammerhead Supersequences.

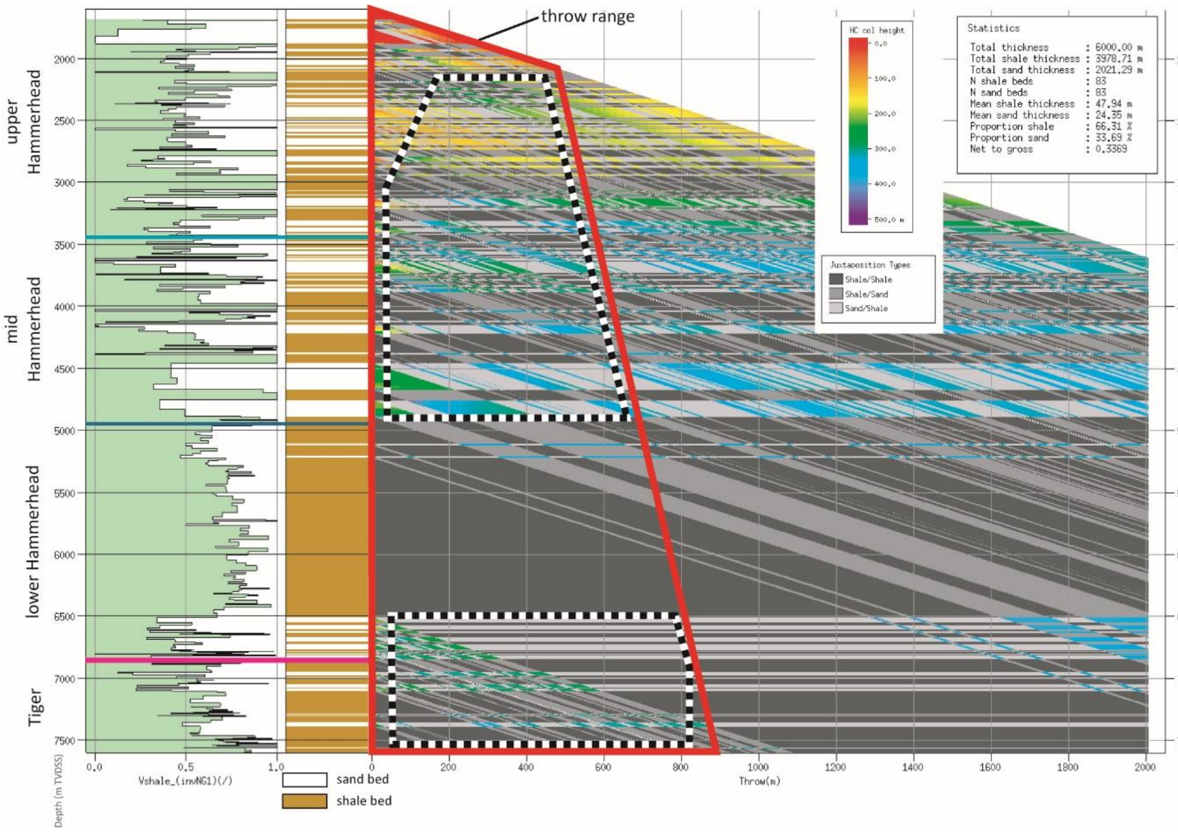

Figure 5

Triangle diagram for pseudo-well 34-14 in the central structural domain. The theoretical juxtaposition are shown for all possible throws and the oil column supported by membrane fault seal for sand-sand juxtaposition is displayed in the background. The red polygon represents the local range of expected throws; the dotted line polygons represent combinations of stratigraphy and throw to create structural traps in the Tiger and the mid-upper Hammerhead Supersequences.

CONCLUSIONS

With an area of interest located ~130 km from the nearest exploration well the forward stratigraphic model permits simulation of facies development and preservation. This work focuses on a rapid analysis of the stratigraphic model results and provides an early investigation tool to forecast vertical and lateral stratigraphic trends which outline structural trapping opportunities in the central Ceduna Sub-basin. Adequate reservoir-seal couplets are predicted in the two sedimentary sequences and the three structural domains over the area of interest. The Tiger and lower Hammerhead sequences in the northern structural domain are predicted with the best combination of throw and facies for structural trapping; the mid and upper Hammerhead in the central and southern domains are predicted with the good combination of throw and facies for structural trapping.

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REFERENCES

Bretan, P., Yielding, G. and Jones, H. 2003, Using calibrated shale gouge ratio to estimate hydrocarbon column heights. AAPG Bulletin, 87, 397–413.

Griffiths, C., Dyt, C., Paraschivoiu, E., Liu, K., 2001, Sedsim in hydrocarbon exploration. In: Merriam, D., Davis, J. (Eds.), Geologic Modelling and Simulation. Kluwer Academic, New York, 71-97.

Totterdell, J.M., Blevin, J.E., Struckmeyer, H.I.M., Bradshaw, B.E., Colwell, J.B. and Kennard, J.M., 2000, A new sequence framework for the Great Australian Bight: starting with a new slate. APPEA J. 40, 95-117.