Hidden in Plain Sight: The Bamaga Basin

Wolfgang Fischer
Gulf Energy Pty Ltd
PO Box 215 Paddington NSW 2021 Australia
wolfgang@gulfenergy.com.au

SUMMARY

The Gulf of Carpentaria was extensively explored in the 1970s and 1980s targeting the Carpentaria (Jurassic-Cretaceous) and Karumba (Tertiary) sag basins, the sediments of which show little or no structuring. This activity failed to recognise the presence of the deeper and older Bamaga Basin and in 1984 Duyken-1, the only well so far in the Gulf of Carpentaria, tested the Carpentaria and Karumba sediments without success, but missed the unrecognised Bamaga Basin 120 km to the northeast.

Poor quality seismic data and preconceived ideas 'masked' the Bamaga Basin and it was only in 2012 that modern 2D regional seismic data followed by an infill seismic survey in 2014, revealed the presence of a sedimentary succession in the Bamaga, probably of early-middle/late Paleozoic age. The carefully processed new seismic data uncovers an intriguing, complex structural history, and large potential petroleum traps.

Basin modelling in the centre of the Bamaga Basin where the sedimentary section is deepest shows that the sediments are mature for petroleum generation with the hydrocarbon phase being either oil or gas, although gas is more likely, especially below 2,000m.

Analysis of the available data indicates that in the oil generation zone there are many targets each of which has the potential to hold Prospective Resources of more than 250 MMstb of oil, the largest of which could hold 660 MMstb oil. In the gas generation zone, there are also numerous targets, each with the potential to hold Prospective Resources of 1 Tcf or more gas, the largest of which could hold as much as 2.5 Tcf gas.

The water depth (60m), closeness to shore (150km) and reasonable target depths means exploring the Bamaga Basin is operationally and commercially attractive.

Key words: Bamaga Basin, gas, Gulf of Carpentaria, Paleozoic, petroleum generation.

INTRODUCTION

Petroleum Exploration Permit Q/23P covers an area of approximately 7,500 sq km with water depths of 60-70 m, in the Gulf of Carpentaria approximately 150 km offshore from the town of Weipa (Figure 1). The block lies within the frontier, undrilled Bamaga Basin, the presence of which was postulated by Passmore et al (1992).

Q/23P is underlain by three sedimentary Basins: Bamaga (Pre-Jurassic), Carpentaria (Jurassic-Cretaceous) and Karumba (Tertiary). The closest exploration well to Q/23P is Duyken-1, approximately 120 km to the southwest, which drilled the Carpentaria and Karumba successions before encountering basement but did not penetrate the Bamaga Basin.

A technical analysis of the petroleum systems of Q/23P and of the prospective petroleum resources of targets identified by Gulf Energy Limited (GULF), who hold 100% of petroleum exploration permit, was conducted based on interpretation of modern seismic data recorded by GULF in 2012 and 2014 as well as other regional data.

Basin modelling was undertaken to estimate the potential for oil and gas generation or expulsion from any potential source rocks in Q/23P. Volumetric estimates and chance of success were assessed for eleven of the targets identified by GULF.

EXPLORATION HISTORY

Early Exploration

Before GULF's involvement, exploration of the Gulf of Carpentaria was focussed on the shallower Jurassic - Cretaceous Carpentaria Basin sediments with Duyken-1 providing most of the present knowledge of the offshore Carpentaria Basin stratigraphy. The presence of the Bamaga Basin was only confirmed recently by GULF's its undrilled stratigraphy must be inferred from local and regional analogues.

More than 20 wells and stratigraphic boreholes have been drilled onshore to the south and east of the Carpentaria Basin (Table 1) with Duyken-1 being the only well offshore. Most wells are shallow and encountered basement beneath the Carpentaria sequence. Hydrocarbon shows were seen in several wells but to date no discoveries have been made. In general, the lack of success has been attributed to drilling off structure.

Duyken-1 failed to find the Jurassic sands and pre-Jurassic carbonates which were the target reservoirs, but penetrated shale dominated Jurassic-Cretaceous section with no shows and terminated in basement (Blake et al, 1984).

The main phase of petroleum exploration in the Gulf of Carpentaria occurred during the 1970s to early 1990s and at its height in the 1980s the offshore was covered by ten permits held by several companies including Shell. During this time twelve 2D seismic surveys were conducted recording a total of more than 19,000 km of seismic data focussed on the Carpentaria Basin section.

The surveys created a sparse patchwork of poor quality 2D seismic data with most of the seismic, geographic, recording and processing records for the surveys over and around Q/23P being unusable. This meant GULF had to acquire new, modern seismic data across the area.

Most Recent Exploration

Initially GULF compiled previous work and interpreted the open file gravity and magnetic data available over and around Q/23P. The interpretation suggested the basin is a failed intra-cratonic rift system containing several large horst blocks and intrusions that could control formation of hydrocarbon traps (Gunn, 2002). The Bamaga Basin was interpreted to be an elongate, segmented, normal-faulted, north-south trending graben about 200 km long and 80 km wide and almost entirely contained within the Q/23P permit. Possible transfer or relay zones, cross cutting the basin, possibly related to underlying basement type, block configuration of inherent zones of weakness were also identified, which may be associated with wrench structures. More than 3,000 m of sedimentary section was predicted to occur in the basin. The concurrence of magnetic anomalies with some of the previously recognised, poorly defined features on the legacy seismic data led Gunn to conclude that they could correspond to very large structures.

GULF's first, regional, 2D seismic survey in 2012 was designed to delineate the structural features identified by the gravity-magnetic interpretation. It confirmed the presence of a sedimentary succession in the Bamaga section and identified several leads (Carty, 2013). However, the data quality at depth was only fair because of residual multiple contamination which made detailed mapping of the complex structures within the basin difficult. Infill 2D seismic data acquired in 2014 underwent improved de-multiple and broadband processing. These data show greatly improved image quality at depth, more clearly defining structures, and increasing the prospectivity of the basin (Carty, 2015). Figure 2 shows the regional seismic data coverage of Q/23P, including the 2012 and 2014 seismic surveys.

Because of the lack of well control to tie seismic events within the deeper, Bamaga sequence, a series of marker horizons were selected in the thickest part of the section and propagated from there as far as they could be interpreted. Surfaces below the base Mesozoic unconformity, which marks the boundary between the Carpentaria and Bamaga Basins, are either truncated at the unconformity or laterally at the basin margins. In total sixteen horizons were mapped within the Bamaga Basin succession and the maps of these horizons are the basis for estimates of Prospective in-place and recoverable volumes.

Gunn's interpretation of the structural form of the basin from gravity and magnetic data is consistent with the data mapped from GULF's two seismic surveys.

THE BASIN

Geological Setting

The Bamaga Basin is separated from the overlying Carpentaria (Jurassic-Cretaceous) and Karumba (Tertiary) Basins by an unconformity. The Karumba and Carpentaria Basins are broad, shallow intra-cratonic sag basins that underlie most of the Gulf of Carpentaria and extend onshore to the south and east. Several small pre-Jurassic basins, including the Bamaga Basin, lie beneath the Carpentaria Basin. Figure 3 shows a map of the basins in the Gulf of Carpentaria with a schematic cross-section of the basins in Figure 4 and a seismic section across Q/23P in Figure 5.

Basin Formation

The Gulf of Carpentaria is bordered by several Mesozoic, Palaeozoic and Proterozoic basins (Figure 1). To the west is the mainly offshore Palaeozoic Arafura Basin with the overlying Mesozoic Money Shoals Basin, while onshore are the Proterozoic McArthur and Palaeozoic Georgina Basins. Most of the onshore area to the east and south of Q/23P is covered by the extensions of the Carpentaria and overlying Karumba Basins. Non-sedimentary basement rocks also occur onshore and likely underlie the Carpentaria Basin sediments in much of the Gulf of Carpentaria. The stacked nature of the Carpentaria Basin and its underlying infrabasins are thought to be analogous to Queensland's Eromanga Basin and the basins which underlie it.

The Karumba Basin is a saucer shaped feature which was formed by uplift of its margins. Maximum sediment thickness is approximately 300 m, and the sediments are not considered prospective for petroleum exploration. The Carpentaria Basin is a broad north trending oval depression separated from surrounding basins by several basement highs and filled with up to 1,800 m of sediment, thickening from the highs into the basin centre. Structures in the basin are very subtle, either fault related or drape structures over basement highs.

The Bamaga Basin's formation was far more active than the overlying basins and it is far less understood, there being limited literature on the subject. The basin trends north-south and is structurally complex, formed by intra-cratonic rifting or pre-Mesozoic crustal thinning. It has a central trough, broken up by saddles and ridges, with structured margins and has undergone compression evidenced by a large, four-way dip closed structure just to the south of the central trough (Prospect 3195) with two thrust faults, one of which shows significant displacement. The compression appears to have resulted in the uplift of sediments and a large section has been removed by erosion at the base Mesozoic unconformity. There are compressional structural features in the sediments abutting high angle, bounding reverse faults along the Bamaga Basin's eastern margin.

The nearest depocentre to provide an analogue for the Bamaga Basin sediments is the Goulburn Graben of the Arafura Basin, located northwest of the Gulf of Carpentaria. The Arafura Basin is a Neoproterozoic-Palaeozoic Basin, overlain by the Money Shoal Basin, a Mesozoic-Cainozoic Basin, with the Goulburn Graben being an infrabasin within the Arafura Basin. No seismic data is available providing a direct seismic tie between the Bamaga Basin and Goulburn Graben, however similar seismic data character suggests that the Goulburn Graben sediments are a feasible analogue.

The Arafura Basin underwent a complex subsidence and uplift history, with several phases of basin development. The subsidence history of the Arafura Basin, along with evidence shown by the seismic data in the Bamaga Basin, has been used as an analogue in reconstructing the basin history of the Bamaga Basin.

Stratigraphy

The possible stratigraphy of Q/23P is based on a review of public domain information, particularly the three-volume report by Passmore et al (1992), which provides the most comprehensive review of the geology of all the sedimentary basins of the Gulf of Carpentaria and surrounds.

The Bamaga Basin has not been penetrated by any wells and its stratiraphy can only be inferred from other intra Carpentaria Basins in the region which have been penetrated. In the Burketown Depression to the south Burketown-1 drilled through 180 m of possible glacial deposits and 137 m of dolomite above quartzite basement. Beamesbrook- l to the northwest of the Burketown depression intersected 34 m of redbeds and 823 m of siltstone, mudstone and fine-grained red sandstone of potentially Triassic age below the Carpentaria Basin succession. In the Canobie depression fluvial sandstones of Middle Triassic age which were interbedded with siltstone were drilled by the Dobbyn-1 well.

In the Olive River Basin, to the east of the Bamaga Basin, the earliest deposits drilled are Late Devonian to Early Cretaceous rhyolites and welded tuffs. Lacustrine and fluvial Pascoe River beds were deposited in isolated pockets contemporaneously with volcanism. The sequence was faulted, folded and partly eroded before deposition of fluvial, fine grained clastic sediments and coal stringers in the Late Devonian. Exploration drilling for coal in the Olive River Basin penetrated thickly interbedded clean quartzose sandstone and dark carbonaceous shales of unreported age, but probably Upper Permian.

Basement rocks in the Gulf of Carpentaria are Precambrian or Palaeozoic in age with wells intersecting quartzite, granite, schist and volcanics. Duyken-1 drilled to a total depth of 1,117 m, where it encountered rhyodacite dated at 1,750 MM years (Blake et al, 1984).

The Arafura Basin is the closest analogue, based on comparable character of the seismic data. Three distinct sedimentary successions occur within the Palaeozoic section of the Arafura Basin; the Late Cambrian-Ordovician Goulburn Group, the Devonian Arafura Group and the Carboniferous Kulshill Group. The Goulburn Group represents a prolonged deposition in a shallow marine shelf formed by thermal subsidence. The lithology consists of carbonates and shales with dolomite at the base, and shales, siltstone and limestones at the top. The Arafura Group consists of shallow marine to non-marine interbedded mudstone, siltstone, sandstone and minor carbonates. The Kulshill group consists of non-marine to marginal marine interbedded sandstone, siltstone and claystone, with minor coal and dolomitic rocks.

PETROLEUM POTENTIAL

Potential Petroleum Systems

The sparsity of data makes it inherently difficult to accurately predict likely petroleum systems in the Bamaga Basin. Information on possible Bamaga Basin petroleum systems can be inferred from data obtained from other infrabasins of the Carpentaria Basin and analogue basins. Data for these infrabasins is sparse but the Goulburn Graben in the offshore Australia portion of the Arafura Basin is a possible analogue.

In July 2008, an offshore seep detection study was undertaken using analysis of high-resolution satellite data. The study identified a large cluster and additional scattered slicks over Q/23P including four possible seepage-slicks (Fugro NPA Limited, 2008). Fugro NPA concluded that it is possible slicks in the southwest of Q/23P are indirectly associated with diffuse gas leakage.

Reservoir Rocks

Potential reservoirs in the infrabasins believed to be equivalent to the Bamaga Basin are poorly understood. The Dobbyn-1 well intersected Triassic redbeds in the Canobie Depression with core samples showing visible porosity. In the Burketown Depression glacial deposits found in Burketown-1 have moderate reservoir potential. The underlying dolomite shows some secondary fracture porosity and similar dolomites intersected in the MacArthur and Georgina Basins contain hydrocarbon shows.

Beamesbrooke-1 intersected 850 m of pre-Jurassic sediments which included low porosity Triassic sandstones. Reservoir potential of the pre-Carpentaria sequences in the Burketown area is generally only fair with most prospective reservoirs likely to be the Lower Palaeozoic or Precambrian dolomites encountered in Burketown-1.

In the Olive River Basin none of the exploration wells have penetrated the basement. The upper Permian age coal bearing sequence has been reported to contain interbedded clean sandstones with some reservoir potential.

In the McArthur Basin, the MacArthur and Nathan Groups contain fair to good reservoirs in vuggy and porous clastics, but deposits are highly variable with areal extents which are hard to predict. In the Stretton Sandstone of the McArthur Group core analysis revealed porosity of 5-16% and permeabilities of 1-1200 mD.

In the offshore Australia portion of the Arafura Basin, the Goulburn Graben contains over 10 km of Palaeozoic strata. Reservoir properties of formations drilled to date are generally poor with primary porosity in many sandstones destroyed by silica overgrowth. In the Upper Cretaceous and Permian sections from one well show minor porosities of 3-4% with stratigraphically lower zones of fair to good porosities (3-19%) and permeabilities up to 10 mD being reported from Devonian clastics in two wells. The Ordovician-Cambrian section is generally non-porous except for some vugular porosity and permeability in Ordovician dolomites.

Source Rocks

The source rock potential of the Bamaga Basin can be inferred from the potential of other infrabasins within the area. In the Canobie Depression, the Middle Triassic section in Dobbyn-1 contained interbedded siltstones and mudstones, analysis of these show moderate to high proportions of lipid rich detritus indicating potential to source both liquids and gas.

In Beamesbrook-1 source rock studies on the lower pre-Devonian section show organic richness of >2.0% TOC implying good source potential. Hydrocarbon Index (HI) analysis however suggests organic matter is virtually devoid of oil-prone components which may suggest that the source was oil prone and has already been generated as vitrinite reflectance values indicate over maturity.

In the Olive River Basin, coal bearing Permian rocks are considered a potential source for hydrocarbon generation, however depth of burial in that basin is too shallow for them to be mature.

In the McArthur Basin, Precambrian source rocks have been identified in both lacustrine and marine sequences. Migration of hydrocarbons out of source rock intervals has been demonstrated by oil shows in low quality reservoirs.

The potential source rock units within the offshore Australia portion of the Arafura Basin, which can be used as analogue for the source rock in the Bamaga Basin, are as follows (Gaffney, Cline & Associates, 2015):

1) the basal formation of the Goulburn Group, which has type I/Il algal bacterial type of kerogen with TOC of up to 5% and initial HI of 600 mgHC/gTOC;
2) the basal and top part of the Arafura Group, which has type II kerogen with TOC of 1.5-2% and initial HI of 400-600 mgHC/gTOC; and
3) the Kulshill Group that has type Il/Ill kerogen with TOC of up to 5% and initial HI of 200-450 mgHC/gTOC.

Oil shows in wells in the offshore Goulburn Graben indicate hydrocarbons have been generated within that basin.

Seals

The lack of well data from the Bamaga Basin means likely seals can only be inferred. The character of the seismic signal varies both laterally and vertically which may be indicative of different sedimentary lithologies. The base of Mesozoic unconformity is overlain by a thick section of sediment with little in the way of internal reflectivity which could indicate a thick regional seal over the unconformity surface.

The seismic data character that could indicate repeated, stacked reservoir-seal pairs through the upper half of the Bamaga Basin sedimentary sequence. The alternating seismic signals become less in the lower sedimentary section suggesting a tendency to increased lithological homogeneity, such as might occur with carbonate sediments.

The faults along the eastern margin of the Bamaga Basin are high angle reverse suggesting significant compressional forces occurring during their creation. On some seismic lines this is further evidenced by structural rollover on the downside of the fault. Given the nature of the eastern margin faults they may provide fault plane seals for petroleum traps.

Traps

The 2D seismic data set shows that the Bamaga Basin is highly structured with evidence of both extensional and compressional regimes having affected the basin sediments over time. This results in the possibility of numerous structural trapping mechanisms including four-way dip closed structures, and both hanging and footwall related fault traps. There is potential for traps along the Bamaga Basin’s eastern margin created in part by high angle reverse faults.

Structures in northern part of the basin are more complex, with a style that appears to be different to potential structural traps in the south of the basin. The reasons for this are not yet fully understood.

Potential Plays

Data limitations mean that it is too early to define specific plays within the Bamaga Basin however, drawing on the Goulburn Graben of the Arafura Basin as an analogue, the shallower horizons in the upper to middle section of Bamaga Basin sedimentary sequence could possibly be equivalent to sediments of the Kulshill (Permo-Carboniferous), Arafura (Devonian) Groups, with reservoirs more likely to be clastic.

Continuing the analogy, the deeper horizons in the Bamaga Basin could be equivalent to the Goulburn Group (Cambro-Ordovician), where carbonate reservoirs may be more likely.

Basin Modelling

To better understand the petroleum potential of the Bamaga Basin, 1D basin modelling was undertaken at a Pseudowell location in the southern part of the Bamaga Basin (Figure 6), where the sediment succession is thickest, and encompassing the Karumba, Carpentaria and Bamaga Basin successions (Gaffney, Cline & Associates, 2015).

Given the Bamaga Basin is undrilled, there is very limited data available to constrain maturation modelling. Information from Duyken-1, located approximately 170 km south west of the Pseudowell location, was used as one of the control points.

Vitrinite reflectance data from Duyken-1 shows that most of the sediments encountered in the well are immature. Only at the base (Mid-Early Albian) are the sediments marginally mature for initial oil generation. Geochemical and source rock analysis data from Duyken-1 also shows that the shallower/younger sediments are organically lean. Moderate quality source rock was encountered at the bottom of the interval (Albian). The vitrinite reflectance data was used to constrain the 1D basin model at Duyken-1 location. This turns out to be difficult because to match the vitrinite reflectance (Ro) value from Duyken-1's Albian interval relatively high heat flow is required, this is in contrast with the bottomhole temperature data. It is unclear why the Ro data at the Albian interval is high. It may indicate an age problem (i.e., the sample should be older), or if the sample age is correct and the Ro is accurate then it could indicate a larger unconformity between the Tertiary and the Cretaceous. The approach taken during the modelling was to set aside the Ro data from the Albian interval, and use the temperature data from the well instead as input for the thermal gradient and heat flow. Matching the high Ro value from the Albian section would push the whole Bamaga sediment section further into the gas window.

The Duyken-1 ID basin modelling shows that the well is immature for hydrocarbon generation. There is only very small amount of hydrocarbon generation, and it only entered the initial phase very recently.

In conducting 1D basin modelling for the Pseudowell location, data from Duyken-1 was used as input and constrained to the upper Karumba and Carpentaria intervals of the model. Duyken-1's subsidence history, heat flow, thermal gradient and source rock were adapted to fit into the Pseudowell 1D basin model.

For the Bamaga Basin interval an analogue approach was used. Comparison between the sediment fill of the Bamaga Basin was made with the sediment fill of the neighbouring Goulburn Graben in the Arafura Basin to determine horizon ages for the Bamaga Basin interval. The subsidence and tectonic history of the Goulburn Graben were used as a direct analogue. Accordingly, the sediments at the Bamaga Basin were divided into Kulshill Group (Carboniferous), Arafura Group (Devonian) and Goulburn Group (Ordovician) equivalents. Hiatuses and the amount of erosion were estimated, based on Arafura Basin data.

The Pseudowell 1D modelling results show that the maturity profile of the sediment within the Bamaga Basin jumps to mature for oil generation immediately below the base Mesozoic unconformity. However, the maturity profile rapidly passes into gas generation at approximately 2,000 m with dry gas forming at approximately 3,000 m.

Gas and oil generation happened in two peaks. Depending on the depth in the section of the prospects and leads, the hydrocarbon phase could be either oil or gas, although gas is more likely.

EXPLORATION TARGETS

Resources Estimates

Eight prospects and leads have been identified within Q/23P, some of which have multiple target intervals. The prospects and leads are named after the graticular blocks they are in (Figure 7) and have generally been identified using the 2014 seismic data set which shows much greater detail of the structures within the basin. All identified prospects and leads are structural targets and range in structural form from four-way dip closed features to horst blocks almost entirely reliant on fault seal.

Monte Carlo simulation was conducted to estimate the in-place and Prospective Resources for each of the prospects and leads. The geological chance of success (GCoS) was also estimated based on the chance of finding the estimated hydrocarbon volumes which can flow to surface. The calculation of the GCoS considered the following five factors:

- Trap and Seal
- Reservoir presence and quality
- Hydrocarbon source (presence, quality, maturity and migration)
- Geological timing
- Play factor

Hydrocarbon Phase

Estimates for both oil and gas cases were made for each prospect and lead, where applicable. Although oil accumulations may be possible, as suggested by the basin modelling, the likely age of the Bamaga Basin sediments and their time of burial suggests that gas is more likely, especially in the middle and bottom part of the Bamaga Basin section.

Gross Rock Volumes

Estimates of gross rock volumes (GRV) for each of the prospects and leads was based on depth maps and these were inputs to the Monte Carlo simulations. The structure top depth map was used for each prospect and lead to which were applied varying hydrocarbon column heights to build a possible range of GRVs.

In general, the lowest closing contour (LCC) was used for the P5 case and a hydrocarbon column height of 100 m as the P90 case. Each structure was reviewed individually and, in some cases, where the structure's closure height was considerable, the LCC was felt to be too optimistic to include in the range of GRVs. In these cases, a higher contour was used for the P5 case. Similarly, where it was felt a 100 m column height was too conservative as a P90 case, for example where gridding between seismic lines created a contouring artefact in the grid, a deeper contour has used to estimate the P90 GRV. For some targets, horizontal seismic reflections not in alignment with the prevailing structural dips are present, which could be interpreted as a potential flatspots. In such circumstances the P90 closure was based on this. The P90 and P5 GRV estimates were used as reference points for a lognormal distribution to estimate the P50 GRV.

Reservoir Parameters and Formation Volume Factors

Reservoir parameters for the estimation of in-place hydrocarbon volumes of the shallower reservoir intervals were guided by those recorded for sediments penetrated in the Arufura-1 well. For the deeper reservoir interval parameters recorded for sediments penetrated by the Goulburn-1 well were used as a guide.

Arufura-1 penetrated 1,700 m of terrigenous rock overlying a carbonate section of Devonian-Carboniferous age. Two separate hydrocarbon bearing zones, both overlain by potential cap rocks were encountered at 1,409 m in the upper terrigenous unit and at 1,835 m in the lower carbonate unit. Porosity and permeability values were low in both reservoir units. The section is dominated by the largely clastic Devonian-Carboniferous section and modest porosities averaging 9.5% were recorded with low permeability of 8 mD.

Goulburn-1 was drilled to a total depth of 1,300 m and encountered a sedimentary section of Mesozoic - Cambrian/Ordovician age. The upper section consisted of 700 m of terrigenous rocks while the lower section comprised carbonates. The older Cambrian-Ordovician marine carbonates are generally tight with 2% porosity, but there are sections with 8% porosity. Drilling data indicates probable secondary porosity with washouts and lost circulation zones being present in the well.

The reservoir parameters were chosen assuming that the shallow reservoirs probably a clastic section with the deeper reservoir more likely being a carbonate section.

Formation volume factor ranges were estimated based on predicted reservoir pressure ranges for individual lead depths and generic fluid composition for both oil and gas.

Prospect 3195

Prospect 3195 is the largest and most obvious structure mapped in the area, lying near the basin centre, over the deepest sediments. It is defined by fourteen 2D seismic lines and is a four-way dip closure, divided into several fault blocks by a series of thrust faults. This, with the possibility of reservoir-seal pairs (as suggested by the seismic data character), results in numerous, stacked potential traps being present. The structure has closure at four mapped horizons.

Horizontal features on the seismic data which are in contrast to the prevailing structure could be interpreted as 'flatspots', but these require further evaluation.

Prospect 3195 has been chosen as the target for the first exploration well to be drilled into the Bamaga Basin. Figure 8 shows the depth structure map mapped at Marker-05 level, the location of exploration well 3195-1 and two orthogonal seismic lines through Prospect 3195.

Volumes have been calculated for each of the potential reservoir intervals independently and each has been assigned a GCoS. Estimates of in-place oil, in-place gas and GCoS for each potential reservoir interval are shown in Table 2.

CONCLUSIONS

The Bamaga Basin offers an attractive, unique, exploration opportunity with potential for a working petroleum system and the presence of large structures within it which could hold substantial volumes of petroleum.

Prospect 3195, a relatively straightforward 200 sq km, faulted, four-way dip closure with multiple target horizons, is considered the most prospective target for the first exploration well in the Bamaga Basin. Current plans are for this prospect to be drilled by the 3195-1 well in mid-2022.

ACKNOWLEDGMENTS

The author wishes to acknowledge the work by Virginia Passmore and her colleagues at the Bureau of Mineral Resources (now Geoscience Australia) for their work which led to them to speculate the Bamaga Basin exists. It was their work that led to GULF launching its grass roots exploration project in Q/23P.

Thanks to the distinguished international, independent consulting firm GaffneyCline for their evaluation of GULF's exploration work, their helpful insight into the Bamaga Basin's undiscovered petroleum potential, and for their permission to include the results of their work in this paper. I also wish to acknowledge Dr Peter Gunn for his work during the initial exploration of the Bamaga Basin and Mr Chris Carty for his interpretation of the seismic data acquired and reprocessed by GULF. Thanks to the DownUnder GeoSolutions through whose excellent work processing GULF's seismic data has contributed significantly to understanding the character of the whole Bamaga Basin.

REFERENCES

Blake et al (1984). Duyken-1 Well Completion Report, Permit NT/P30, Carpentaria Basin, Northern Territory, Australia. Norther Territory Geological Survey, Open File Report PR85/31 B. Volumes 1-3.

Carty, C.J. (2013). Interpretation Report, 2012 Bamaga 2D Marine Seismic Survey, Permit Q/23P Offshore Queensland, Gulf Energy Limited. Gulf Energy, Sydney.

Carty, C.J. (2015). Interpretation Report, 2014 Bamaga 2D Marine Seismic Survey (GE-B14-MSS), Permit Q/23P, Gulf of Carpentaria, Offshore Queensland. Gulf Energy, Sydney.

Fugro NPA Limited (2008). Offshore Basin Screening, Gulf of Carpentaria, Block Q/23P Seep Detection Study for Gulf Energy Limited. Gulf Energy, Sydney.

Gaffney, Cline & Associates (2015). Petroleum System Analysis and Prospective Resource Estimate for Leads in Block Q/23P in the Gulf of Carpentaria prepared for Gulf Energy Limited. Gulf Energy, Sydney.

Gunn, P (2002). Interpretation of Aeromagnetic and Gravity Data in the Context of Petroleum Prospectivity: Q/23P, Bamaga Basin, Gulf of Carpentaria, Queensland. Gulf Energy, Sydney.

Passmore et al (1992). Gulf of Carpentaria Petroleum Prospectivity Study, Bureau of Mineral Resources, Geology and Geophysics, Australia, Record 1992/20. Open File Report. Volumes1-3.

Table 1: Exploration well results in the Carpentaria Region

Well	Year	Total Depth (m)	Results
FBH-1 (Wyabba)	1957	860	Gilbert River Formation on greenstone
ZCL-1 (Weipa)	1957	989	Garraway Sandstone on metamorphics
AAO-8 (Karumba)	1958	721	Gilbert river Formation (brown oil stain and yellow fluorescence) on granitised quartzite
Mornington Island-1	1961	842	Gilbert River Formation on granite
Mornington Island-2	1961	914	Gilbert River Formation (dead oil stain) on quartzite
Normanton Scout-1	1963	243	Wallumbillah Formation
Normanton Scout-2	1963/4	464	Wallumbillah Formation on quartzite
Burke Town -1	1964	1,013	Permian tillite on Palaeozic-Pre-Cambrian dolomite on metamorphics. Dead oil in Toolebuc Formation
Duyken-1	1984	1,103	Wallumbilla Formation on igneous basement
Armraynald-1	1988	638	Eulo Queen Group on quartzite
Beamesbrook-1	1988	1,393	Gilbert River Formation on Triassic redbeds and pre-Devonian siltstone
Jackin Creek-1	1988	812	Garraway sandstone on quartzite
Silverleaf-1	1988	681	Gilbert River Formation on gneiss
Jackin Creek-2	1991	802	Gilbert River Formation on gneiss
Pennefather-1	1991	720	Gilbert River Formation on gneiss
Rum Bottle-1	1991	635	Gilbert River Formation on gneiss

Table 2: Estimates of In-Place Volumes and GCoS for Prospect 3195

Prospect 3195					
Hydrocarbon Phase	**Reservoir**	**P_{90}**	**P_{50}**	**P_{10}**	**GCoS**
Oil (MMBbl)	Marker-04	99	531	2,142	0.11
	Marker-04a	45	375	2,782	0.11
	Marker-05	57	456	3,319	0.12
	Marker-06b	35	166	806	0.16
Gas (Bscf)	Marker-04	100	516	2,105	0.11
	Marker-04a	49	427	3,361	0.11
	Marker-05	71	552	3,886	0.12
	Marker-06b	36	239	1,336	0.16

Figure1: Q23/P location map

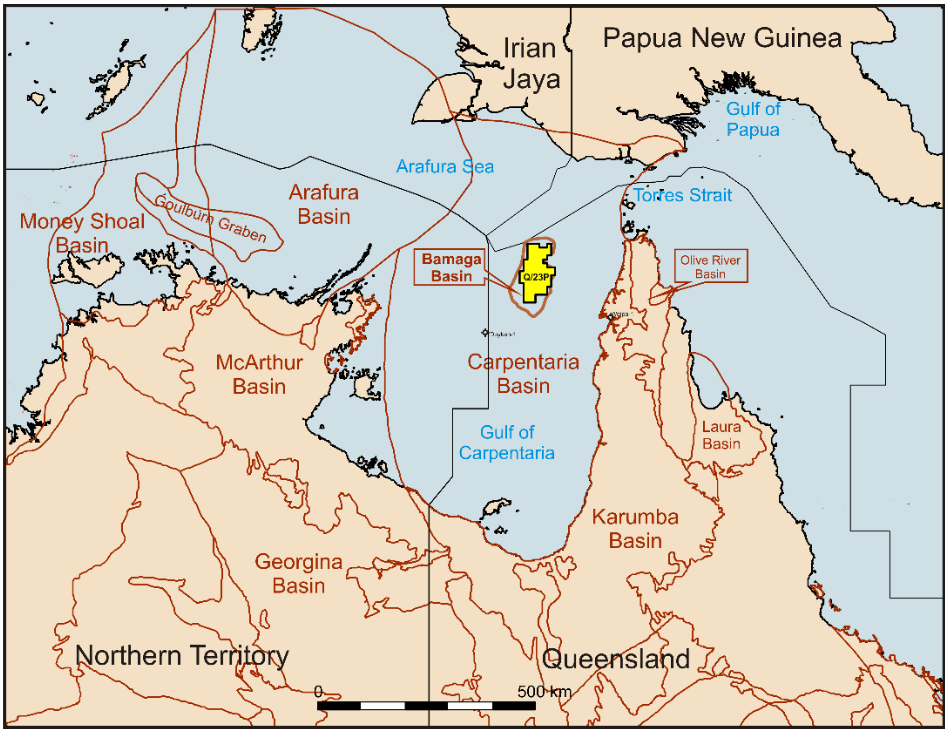


Figure 2: Regional seismic data coverage over and around Q/23P

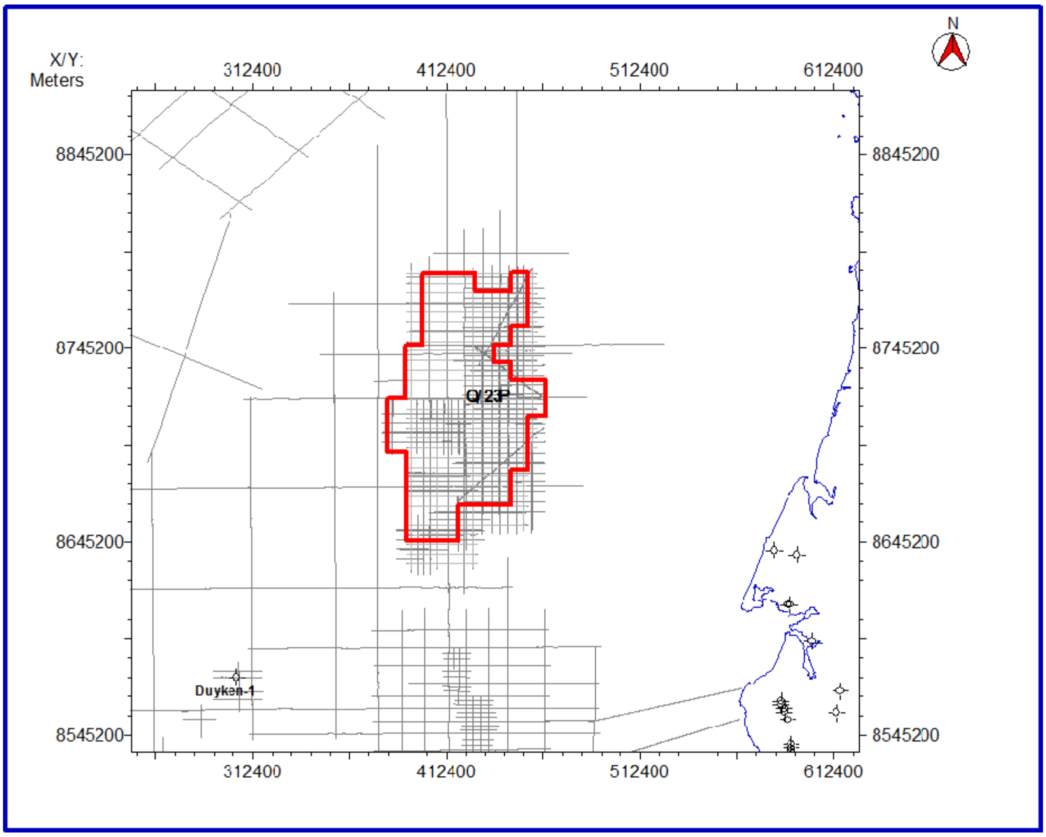


Figure 3: Basins in the Gulf of Carpentaria region with line of section A-B-C-D through Q/23P

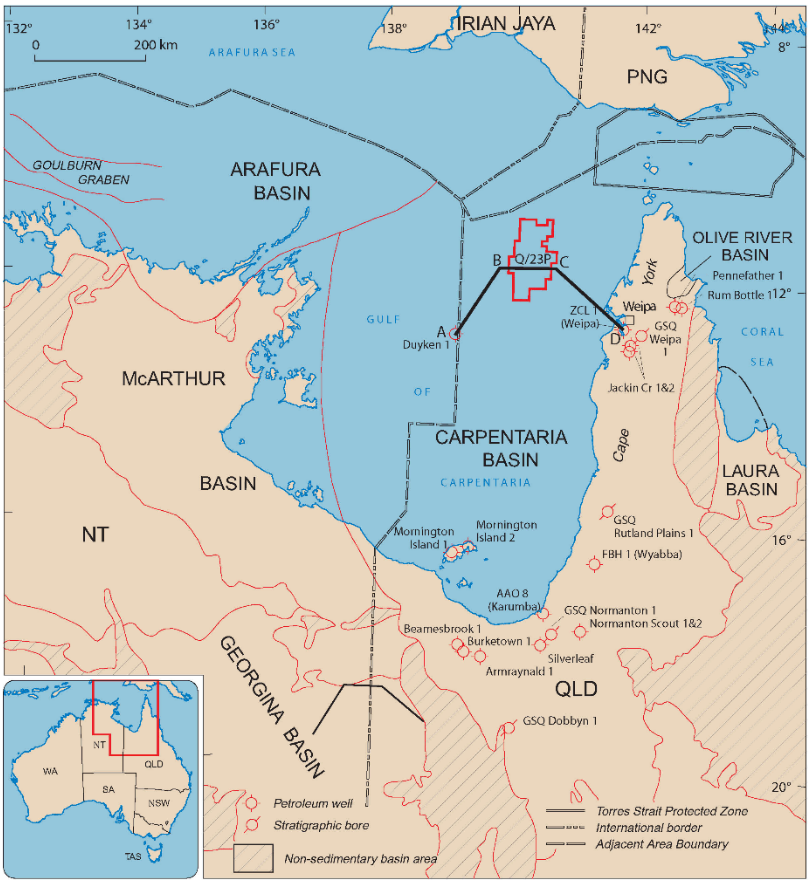


Figure 4: Schematic cross-section A-B-C-D of the basins beneath Q/23P

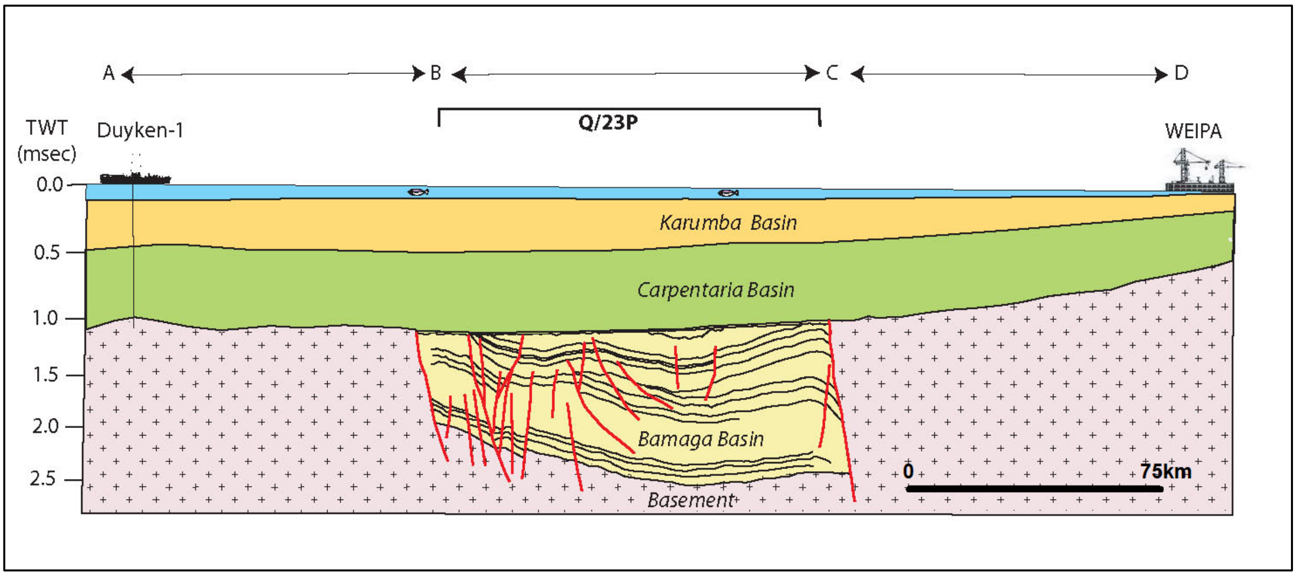


Figure 5: Seismic section across Q/23P showing Bamaga Basin succession

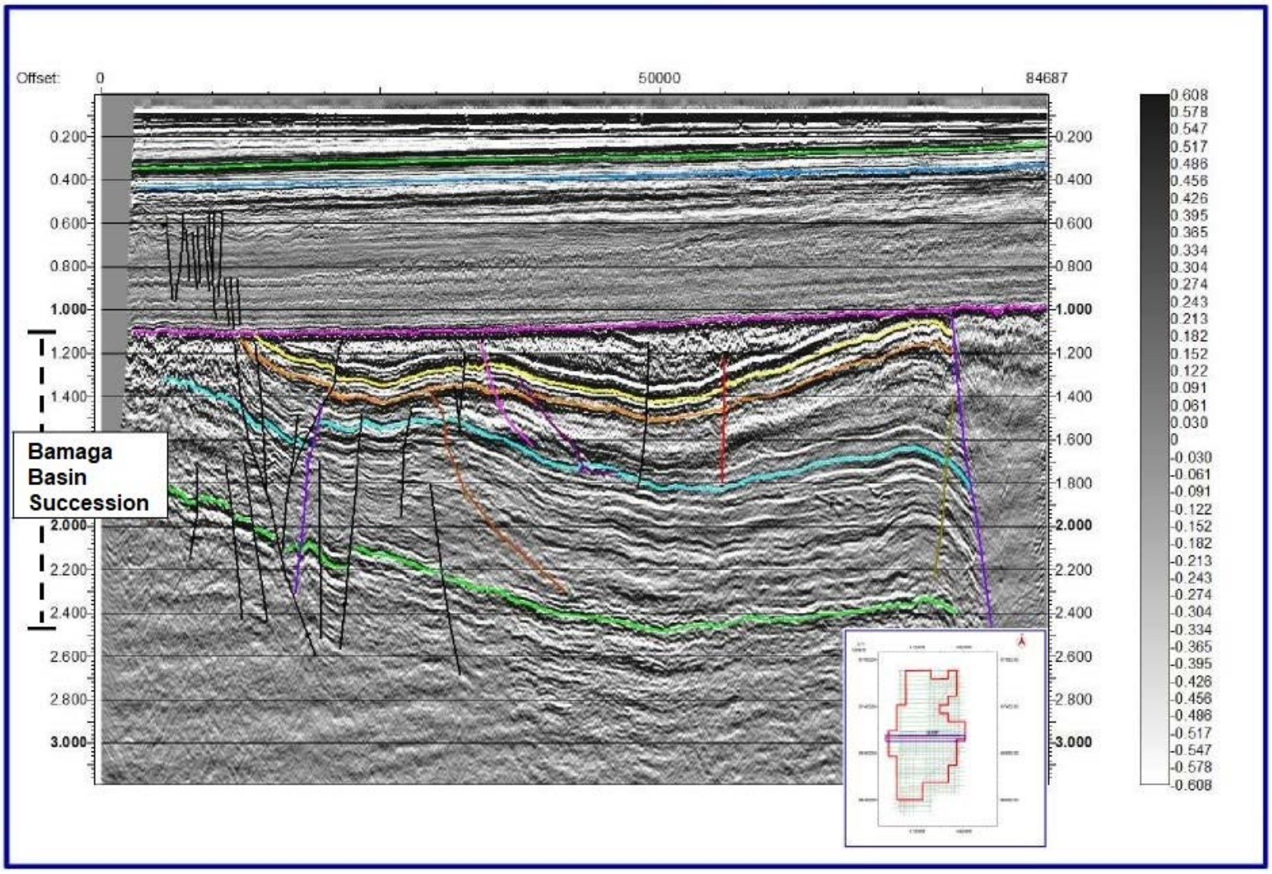


Figure 6: Location of Pseudowell on 'Near Basement' depth map

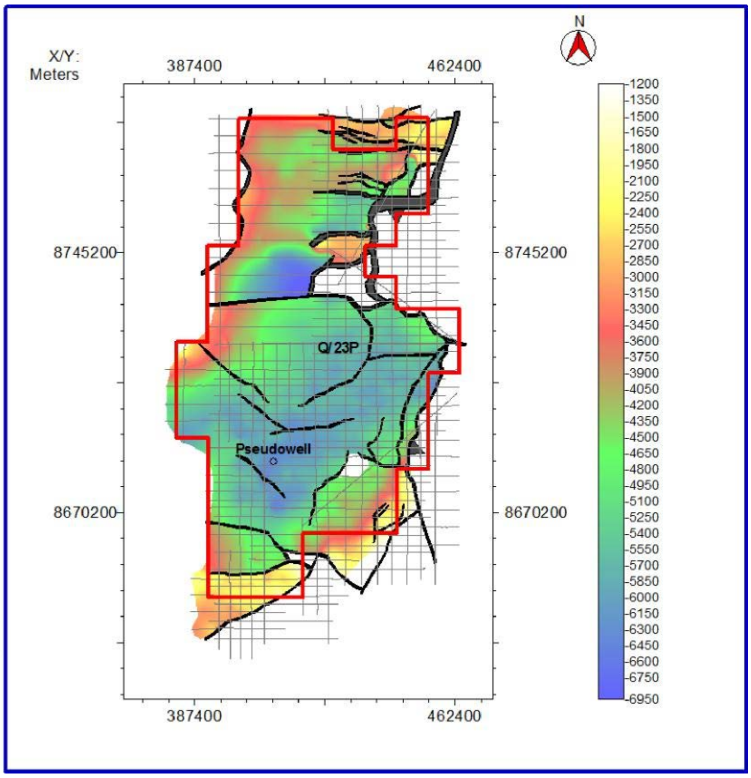


Figure 7: Prospects and leads location map

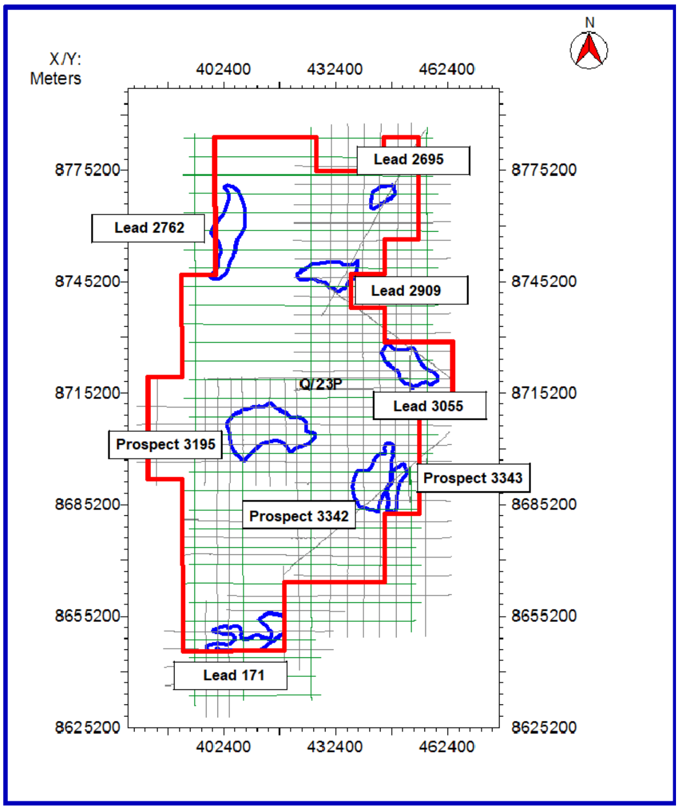
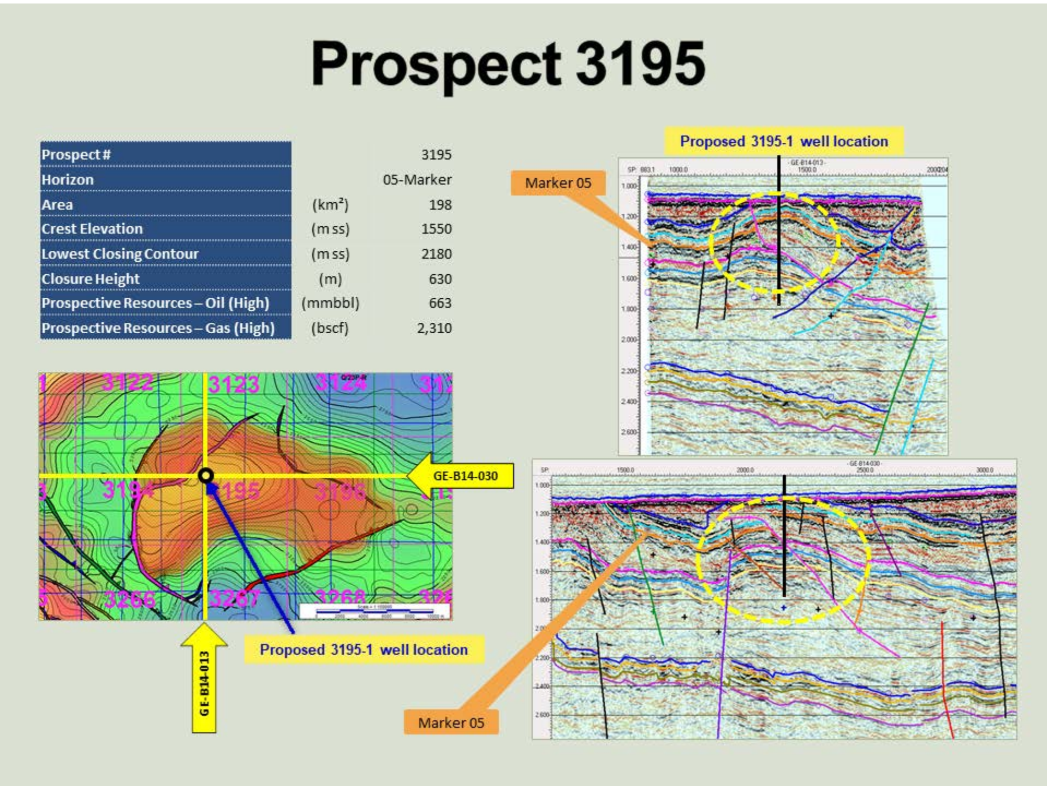


Figure 8: Prospect 3195 depth structure map and seismic lines



Prospect #		3195
Horizon		05-Marker
Area	(km²)	198
Crest Elevation	(mss)	1550
Lowest Closing Contour	(mss)	2180
Closure Height	(m)	630
Prospective Resources – Oil (High)	(mmbbl)	663
Prospective Resources – Gas (High)	(bscf)	2,310