The interpretation and integration of old seismic with new gravity data – an example from the northern Perth Basin

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ABSTRACT

The recent discoveries of Hovea (2001), Red Back (2009), Red Gully (2010), Senecio/Waitsia (2014) in the northern Perth Basin encourage explorers that opportunities still exist in this mature basin. Challenging conditions exist here in the forms of difficult land access, structural complexity of the geology and both low quality and limited coverage of the seismic data. This may explain the patchy exploration success within a relatively small basin with well-developed infrastructure for exploration and production.

The recently acquired regional ground gravity data by Geological Survey of WA (GSWA) which was released in 2016 over the northern Perth Basin provides additional geophysical information that can be used for petroleum exploration by integrating it with the existing seismic data. This paper discusses an example of interpretation and integration of existing seismic and new gravity data over a limited part of the basin.

Interpretation of the geological structures from the new gravity data coincides with structures interpreted from seismic data and provides encouragement that gravity surveys may be a useful exploration tool in areas with no or limited coverage and/or poor quality seismic data.

Regional faults are recognised by linear gravity gradients. Low intensity gravity anomalies are interpreted to be related to low relief anticlines and high intensity anomalies to tilted fault blocks. These fault blocks are likely the result of Late Jurassic-Early Cretaceous strike-slip tectonics and are not easily mapped by seismic.

Low cost gravity surveys can identify leads and assist in planning new seismic surveys and also help in the interpretation of the seismic data all of which can therefore make exploration more economically effective.

KEY WORDS: ***Australia, northern Perth Basin, seismic and gravity data interpretation and integration.***

INTRODUCTION

The seismic method has been thriving for the past decades. Technological progress in acquisition, processing and interpretation have made it practically the only method used for petroleum exploration.

At the same time gravity as one of these two pioneering methods was completely forgotten for petroleum exploration, particularly in Australia. Most of the gravity data in the country were collected in 1960s and 1970s. Only government agencies and very few exploration companies conducted gravity surveys in the petroleum basins since that time (Shevchenko and lasky, 2004). It is worth mentioning, that two major Australian gravity contractors Daishsat Geodetic Surveyors and Haines Surveys had a revenue less than 5% from the petroleum industry in the last twenty years (Personal communications).

Generally, vehicle-borne gravity is 100-200 times cheaper than seismic per line kilometre. It is friendly to the environment during acquisition and takes a short time to acquire and process data. Of course, the gravity method can mostly be used as a supplement to seismic. But this addition can be very valuable, especially for conditions of poor quality and limited seismic coverage like in the northern Perth Basin. It also can help in planning seismic surveys more effectively; placing seismic lines over more prospective structures defined by gravity rather than acquiring new surveys with no guarantee of defining new leads.

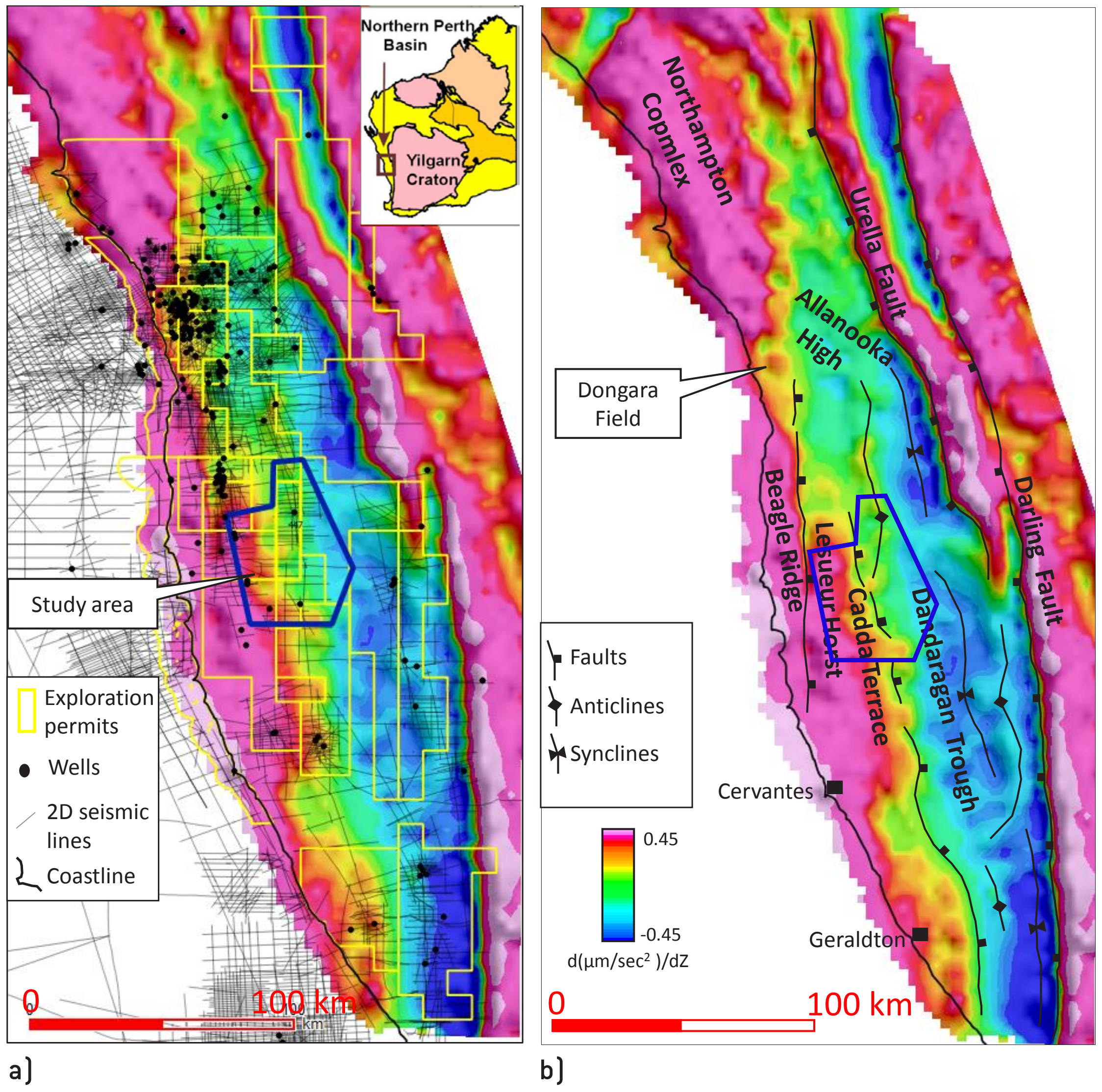


Figure 1: *First Vertical Derivative image of the South-West Yilgarn regional gravity survey over the northern Perth Basin. On a), Exploration permits, 2D seismic lines and petroleum wells are shown. On b), Major structural elements are shown.*

The reasons why gravity is used so poorly in Australia would be enough material for another paper. The purpose of this publication is to show how these methods can supplement each other with a simple example in the northern Perth Basin. In this area numerous national parks and reserves, thick near coastal vegetation and farmlands make the approval and planning process for acquiring seismic expensive and difficult particularly for the small operators with limited funds.

The study area is in the proximity of the Ocean Hill-1 gas well area. It covers EP495, partially EP454, EP488 and EP455 exploration permits in the southern part of the northern Perth Basin (Fig. 1a). Author used only publicly available 2D seismic, well and gravity data.

The petroleum industry is currently in a downturn and companies are trying hard to make exploration more economically effective. And this is exactly what this paper is about: how to get better results for less money.

GRAVITY DATA

In 2015 GSWA conducted the South-West Yilgarn regional vehicle born gravity survey. The purpose of the project was to cover the area mainly used for mineral exploration in the South-Western part of Yilgarn Craton. The survey also covered the onshore northern Perth Basin, over the area of active petroleum exploration acreage (Fig. 1a).

The Atlas Geophysics conducted the survey along the roads with gravity station spacing 2 km and with distance between the roads of 4-10 km. The survey is high vertical 0.05 m and gravity 0.30 $\mu m/s^2$ accuracy and therefore can be infilled by more detailed gravity surveys in the future. Previously, most of this area was surveyed by 11x11 km helicopter gravity grid. The new data were released to public in 2016. The author would like to stress that the new data is still regional. For comparison this irregular coverage would be equivalent to approximately 3x3 km as a regular grid gravity survey. The GSWA also processed gravity data and provided images of the whole survey to the public, although the specification for processing these images is more suitable for Yilgarn Craton geological terrains.

SIS Exploration reprocessed the gravity data with parameters applicable to the

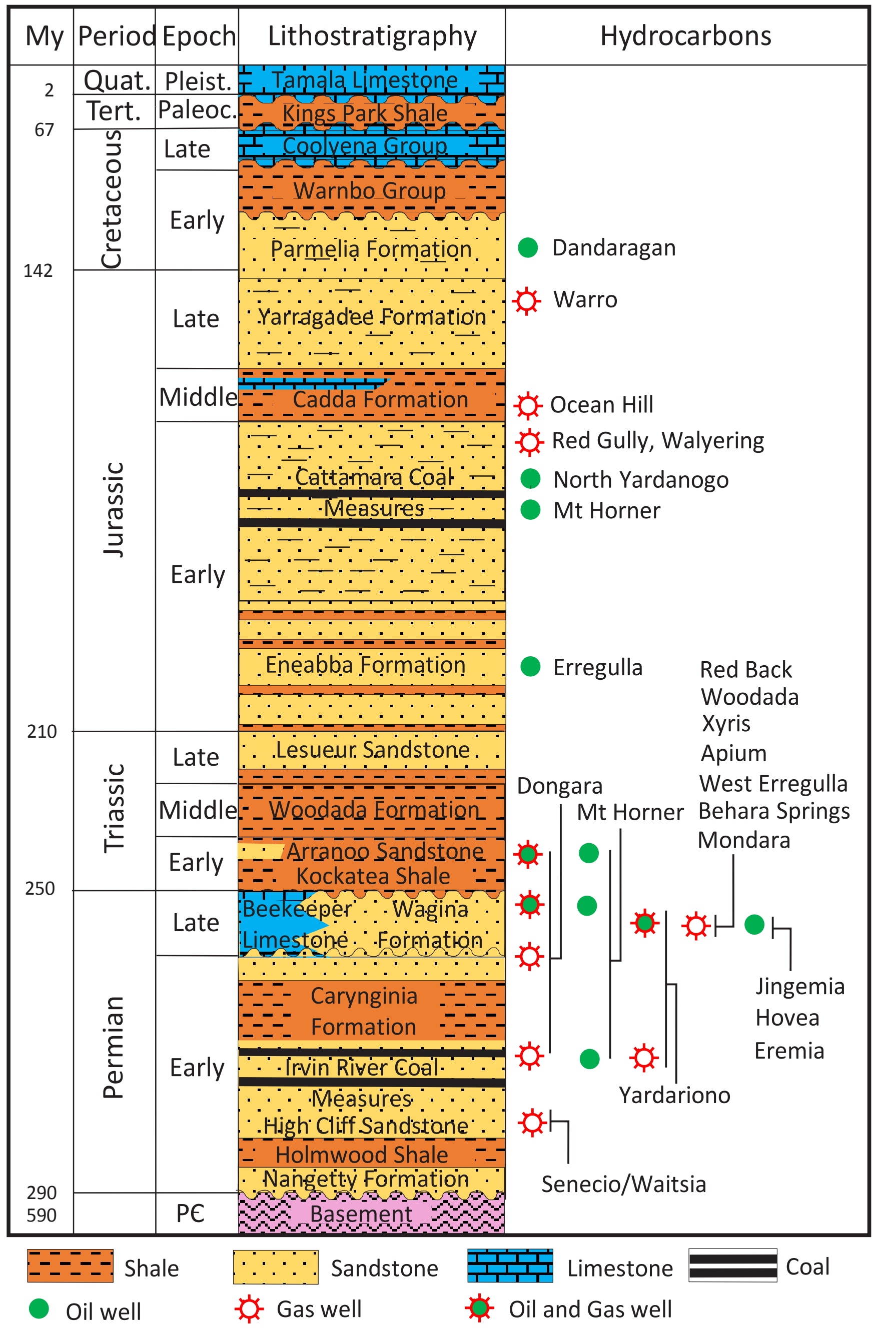


Figure 2: *The northern Perth Basin Stratigraphy.*

sedimentary geological terrains of the northern Perth Basin. The First Vertical Derivative of Bouguer Gravity (Fig. 1b) delineates the regional geological structures; while Residual Bouguer Gravity (Fig. 3a) was used in the study area to outline more detailed geology.

SEISMIC DATA

Nine seismic surveys from 1972 to 1995 vintages were obtained from Department of Mines and Petroleum public domain and were used for seismic interpretation (Fig. 3b). Not all the seismic data that exist for this area was available from the public domain. The quality of the data varies from very poor to fair but is better in the Jurassic section than the deeper Permian section. Typical fair quality seismic lines are shown on figure 4a and 4b. The majority of the seismic lines are oriented in the east-west direction with the few the north-east direction as the tie lines.

GEOLOGICAL SETTINGS AND INTERPRETATION.

The onshore northern Perth Basin bounded by the Yilgarn Craton to the east and coast line to the west in Western Australia (Fig. 1). It contains a thick Lower Permian to Lower Cretaceous sedimentary succession overlaid by thin flat-lying Cretaceous and Cenozoic strata (Fig. 2). Tectonically the basin went through three main stages. Initially, in the Late Carboniferous–Early Permian it was an extensional rift basin. In the Late Permian to Middle Jurassic there was a sagging stage basin development. Finally, it is associated with the most active structuring in the Late Jurassic – Early Cretaceous rifting that related to the break-up of Greater India from Australia (Norvick, 2004). Importantly, the basin-wide uplift occurred during the break-up and resulted in basin inversion and erosion of up to thousands of metres of the sedimentary succession. Folding by dextral strike-slip motion along the Darling-Urella fault system also inverted the pre-break-up sequences in major onshore depocentres (Song and Cawood, 2000).

The hydrocarbons are produced from nearly all formations that have reservoirs in the stratigraphic sequence from Early Permian to Early Cretaceous (Fig. 2). The most active exploration area is in the proximity of the Dongara Field in the north of the basin where good reservoir with regional seals are developed in the Permo-Triassic (Fig. 1a). This area has the densest coverage of 2D and 3D seismic surveys and the most wells drilled. Most of the commercial oil and gas discoveries have been found to date in this region. They are mainly related to structural highs: horsts and anticlines and therefore have gravity signature (Figs. 5a and 5b). Some of the fields have been mapped as leads using gravity prior to drilling: Eremia, Evandra and Tarantula (Shevchenko and lasky, 2003).

The area of the current study is located in the southern part of the northern Perth Basin in an area with relatively poor seismic coverage and few drilled wells. The area is outlined in figure 1b by the blue polygon and lies within the Dandaragan Trough and the Cadda Terrace structural domains. In this region, particularly in the Dandaragan Trough, Jurassic-Cretaceous reservoirs are the main objectives.

Two seismic horizons Near Top Cadda Formation and Near Top Intra-Cattamarra Coal Measures (Coaly Units) were mapped and tied to Ocean Hill-1 (SAGASCO, 1991), Comallo-1 (Young et al., 1974), Woolmulla-1 (Pudovskis, 1963) and Donkey Creek-1 (Cooper et al., 1966) wells. Only major faults have been mapped due to objectives of the project and only structural aspects for the leads were considered.

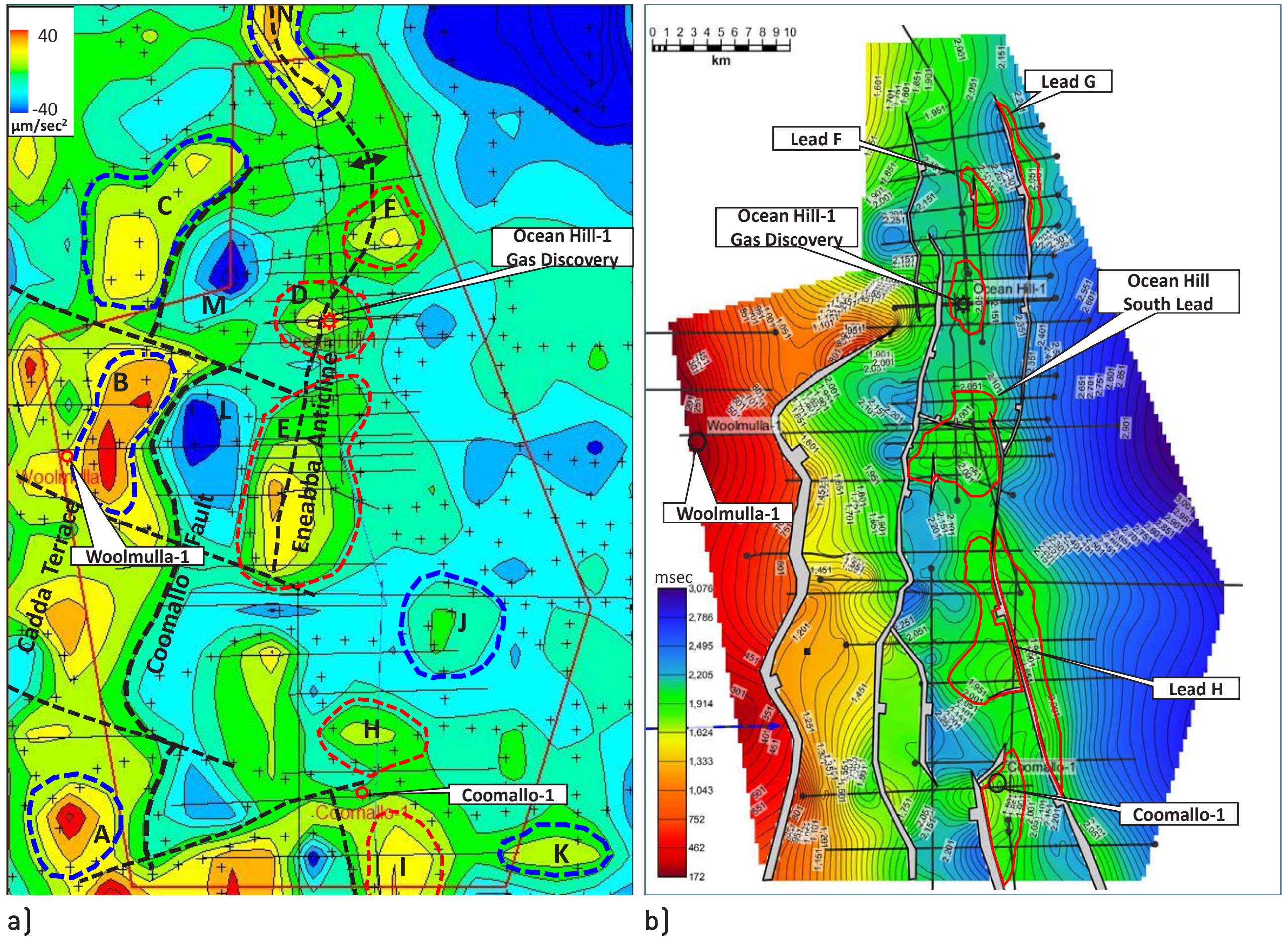


Figure 3: *a) Residual Bouguer Gravity map. Contour interval 10 $\mu m/sec^2$. Black crosses are gravity stations. Blue dash polygons are leads interpreted from gravity only. Red dash polygons are leads interpreted from the gravity that correspond to leads interpreted from seismic. Red polygon is the area of seismic interpretation. Black lines are the seismic lines. b) Near Top Intra-Cattamarra Coal Measures Two-way time structural map the same scale as the gravity map. Red polygons are the leads and prospects interpreted from seismic.*

Interpretation of the Near Top Intra-Cattamarra Coal Measures horizon is shown on figure 3b with the Residual Bouguer Gravity on figure 3a shown at the same scale for the comparison. It is worth mentioning that the seismic interpretation is robust only in the northern part of the area where there is reasonably good quality and coverage of the seismic. The challenging area for interpretation is in the western part with limited seismic and no available north-south tie lines.

Several regional structures are prominent and interpreted on both seismic and gravity. Strong gravity high from the uplifted Cadda Terrace is limited by strong linear gravity gradient generated by Coomallo Fault from the east (Figs. 3a and 3b). The Coomallo Fault from gravity has a zigzag shape. This may be related to rotated fault blocks formed along the fault plain caused by strike slip tectonics during the rifting. There are several strong gravity anomalies on the terrace A, B, C on figure 3a that are interpreted as fault block leads. Interestingly, the Woolmulla-1 dry well was drilled off the high of gravity anomaly indicating that it may not be positioned at the crest of the structure. The quality of the seismic line going through the structure and the well is very poor and it is difficult to interpret the crest of the structure from this seismic line.

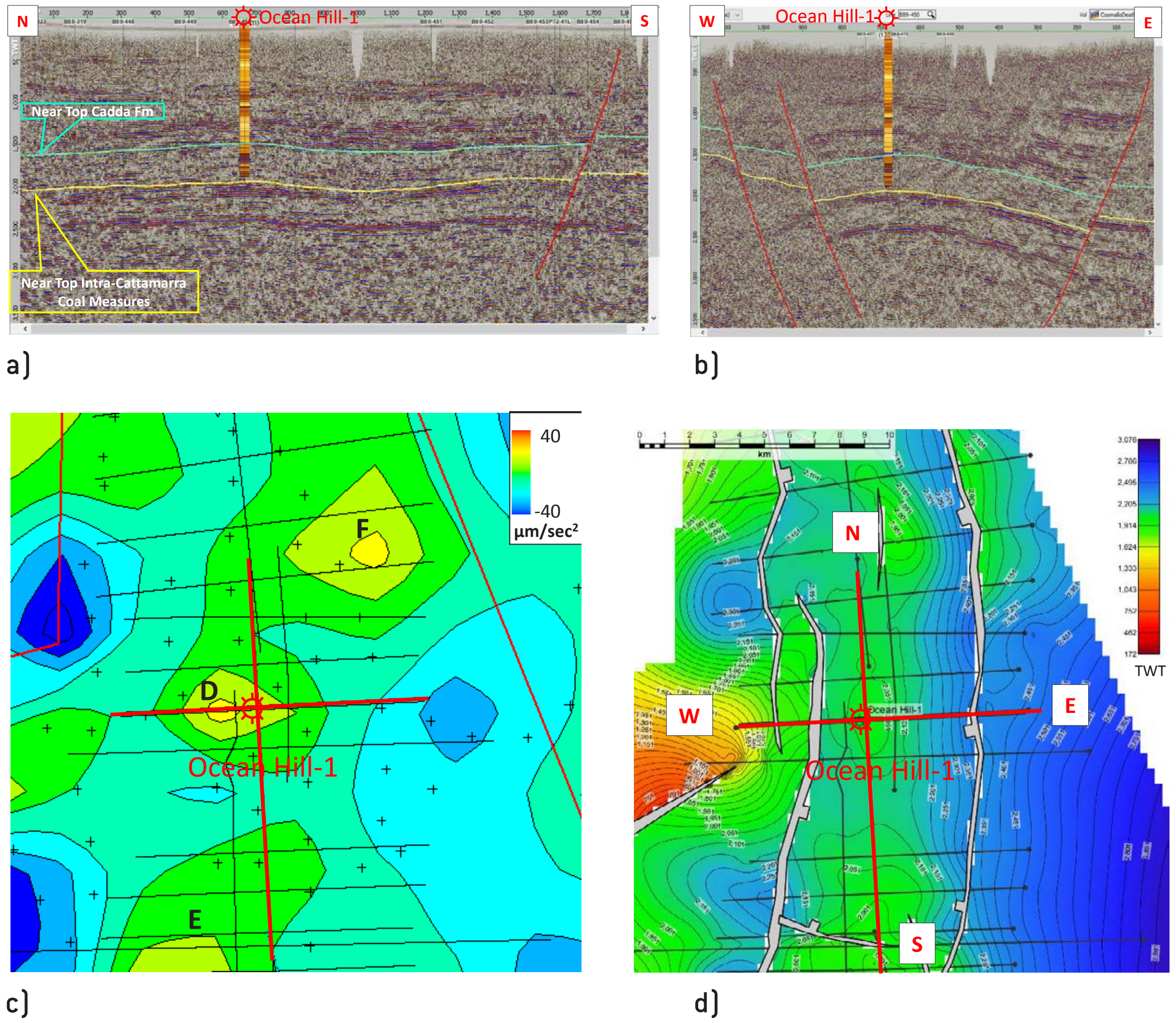
The limited number of the north-south seismic lines and the nature of mainly horizontal shear movement makes interpretation of these blocks from seismic difficult. The shape of the Coomallo Fault on the seismic map has been amended from the gravity interpretation.

Another regional structure delineated from the gravity is the Eneabba Anticline. This anticline corresponds very well with seismic interpretation and several interpreted leads within the structure on both seismic and gravity maps.

The Ocean Hill gas discovery is a classic example of a four-way dip closure that perfectly coincides with 20 $\mu m/sec^2$ positive gravity anomaly D over the structure (Fig. 4).

The Ocean Hill South lead (Stefani, 2017) is another four-way dip closure that coincides with 40 $\mu m/sec^2$ anomaly E (Figs. 3a and 3b, 4c and 4d). The gravity anomaly extends further south-west indicating that the structure may extend further into an area where there is no seismic coverage.

North of the Ocean Hill-1, the positive gravity anomaly F likely relates to the seismically mapped lead F as the 3-way dip closure bounded by the north-south fault. The reason that this gravity anomaly is bigger is because of the false gridding effect as there is not enough gravity stations coverage over the lead.



a) b) c) d)

Figure 4: *a) Seismic cross-section line B89-415 across the Ocean Hill-1 discovery. b) Cross-section line B89-450. c) Residual Bouguer gravity over the area of the Ocean Hill structure. Red lines are seismic cross-sections a) and b). d) Near Top Intra-Cattamarra Coal Measures Two-way time structural map the same scale as the gravity map.*

The stations are shown as the crosses on the image for the reference.

Another gravity anomaly H relates to seismically mapped lead H north of the Coomallo-1 well. Gravity here does not exactly image the seismically mapped elongated shape of the faulted anticlinal structure, likely due to lack of gravity stations coverage.

The Coomallo-1 dry well is located on a tilted fault block interpreted from the seismic. The structure generates a high intensity $30\,\mu m/sec^2$ positive gravity anomaly I. The well was drilled off the top of the seismically mapped structure and off the high of the gravity anomaly.

Two weak gravity anomalies J and K further to the east into Dandaragan Trough are interpreted as leads which are likely to be low relief anticlines or 3-way dip closures. Here in the Dandaragan Trough the gravity field has subtle features. The gravity anomalies are weak indicating much less structural complexity than at Cadda Terrace and Eneabba Anticline structures. Seismically mapped lead G is a 3-way dip closure bounded by the north-south Eneabba fault (Fig. 3b) and has no gravity signature, because there are no gravity stations over this lead (Fig. 3a).

There are still some questions to be resolved. One of them is the nature of the East Eneabba Fault. Initially a normal fault, it seems that during reactivation it has become inverted in some parts according to the gravity data. This is supported by steep gradient east of the gravity anomaly E and strong negative anomaly L and possibly M indicating the downthrown geometry of the structure. More detailed gravity and modelling would help to answer this question. The quality of the existing seismic over this area is not sufficient to confidently map these structures.

Higher density gravity stations would be required to map these structurally complex leads more confidently. The figures 5a and 5b show an example of the South-West Yilgarn regional survey and detailed GSWA gravity survey acquired at 1000m x 300m stations grid for comparison (Shevchenko and lasky, 2004). The difference is striking and shows how much information can be obtained from detailed gravity survey. Red cycles outline gravity anomalies related to oil and gas field structures.

CONCLUSIONS AND RECOMMENDATIONS

Geological structures like faults, synclines and anticlines can be interpreted from the new regional ground gravity data and coincide with leads mapped from seismic interpretation. Some leads were interpreted from gravity only where there is no or limited seismic coverage. Features like rotated fault blocks caused by strike-slip tectonic movement are difficult to interpret from seismic but can be interpreted from the gravity.

The gravity data used in this project are still based on an insufficient number of stations to obtain a full advantage of the method. Additional gravity stations can be infilled into this regional data using high density network roads and tracks in the northern Perth Basin to get more detailed structural interpretations.

Interpretation and integration of gravity and existing seismic data should be done before acquiring any new seismic.

The northern Perth Basin is an ideal area and a good example where integration of 2D seismic with low cost gravity surveys can be applied and would give an economical benefit to petroleum exploration.

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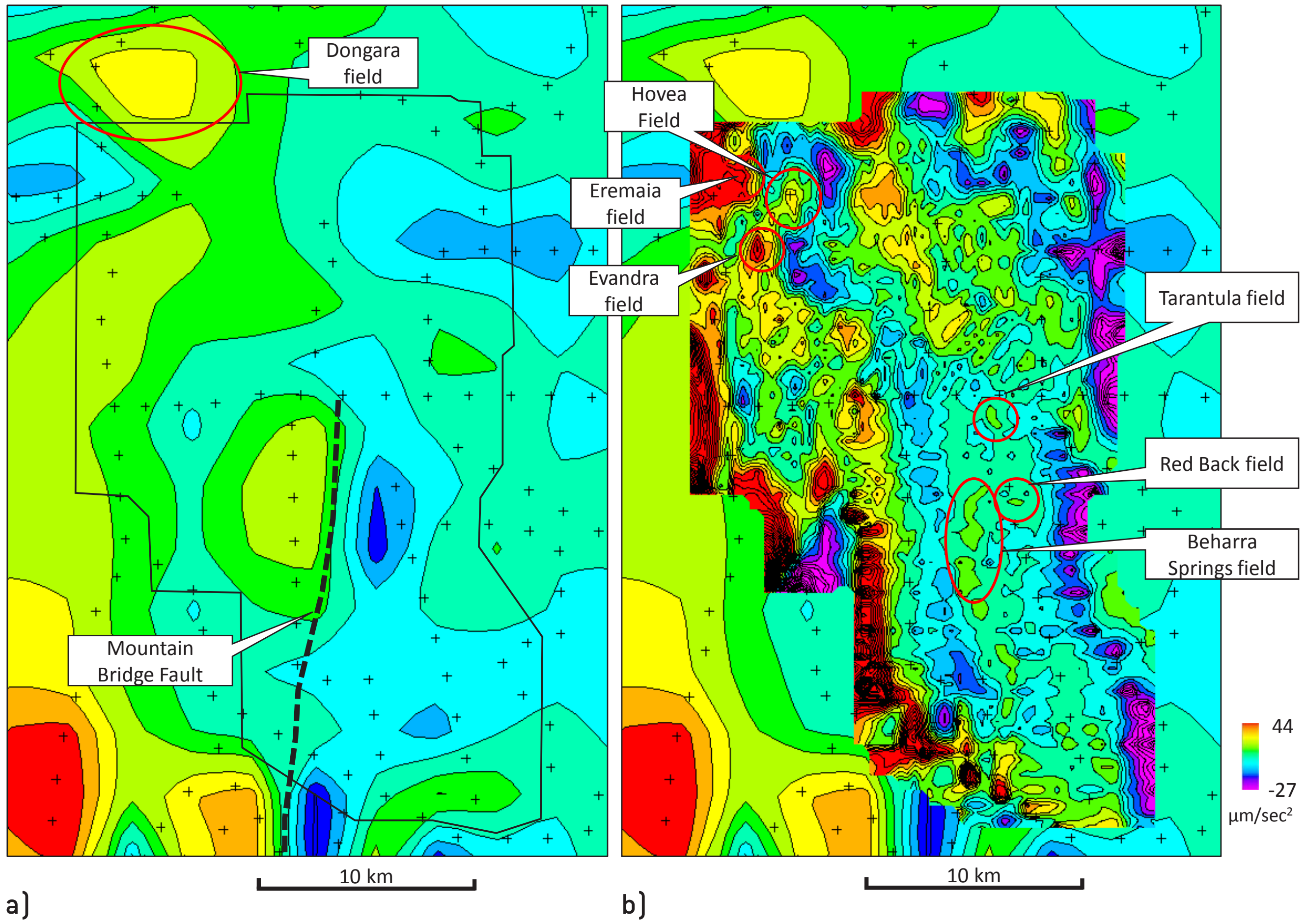

a) b)

Figure 5: *a) Residual Bouguer Gravity map of the South-West Yilgarn regional gravity survey in the south of the Dongara field area. Black crosses are the gravity stations. Contour interval is $10\,\mu m/sec^2$. b) Residual Bouguer Gravity map of the detailed gravity survey 1000mx300m gravity stations grid as the insert into the regional survey. Contour interval of the detailed survey is 1.5 $\mu m/sec^2$. Red circles show gravity anomalies caused by the oil and gas field structures.*

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