AUSGEO news
ISSUE 105 Mar 2012

Reducing exploration risk in the offshore northern Perth Basin

Trap integrity study addresses a key exploration risk

Chris Nicholson[1], Laurent Langhi[2], Yanhua Zhang[2], Nadege Rollet[1], George Bernardel[1], Richard Kempton[2], John Kennard[1]

Geoscience Australia is currently reassessing the petroleum prospectivity of the offshore northern Perth Basin (see *AusGeo News* 103 and 104). Part of the reassessment was a trap integrity study, led by CSIRO in partnership with Geoscience Australia, which evaluated the potential of fault reactivation as a critical exploration risk for hydrocarbon preservation in the Abrolhos Sub-basin. This reassessment was initiated under the Australian Government's Offshore Energy Security Program, as part of Geoscience Australia's continuing efforts to identify a new offshore petroleum province.

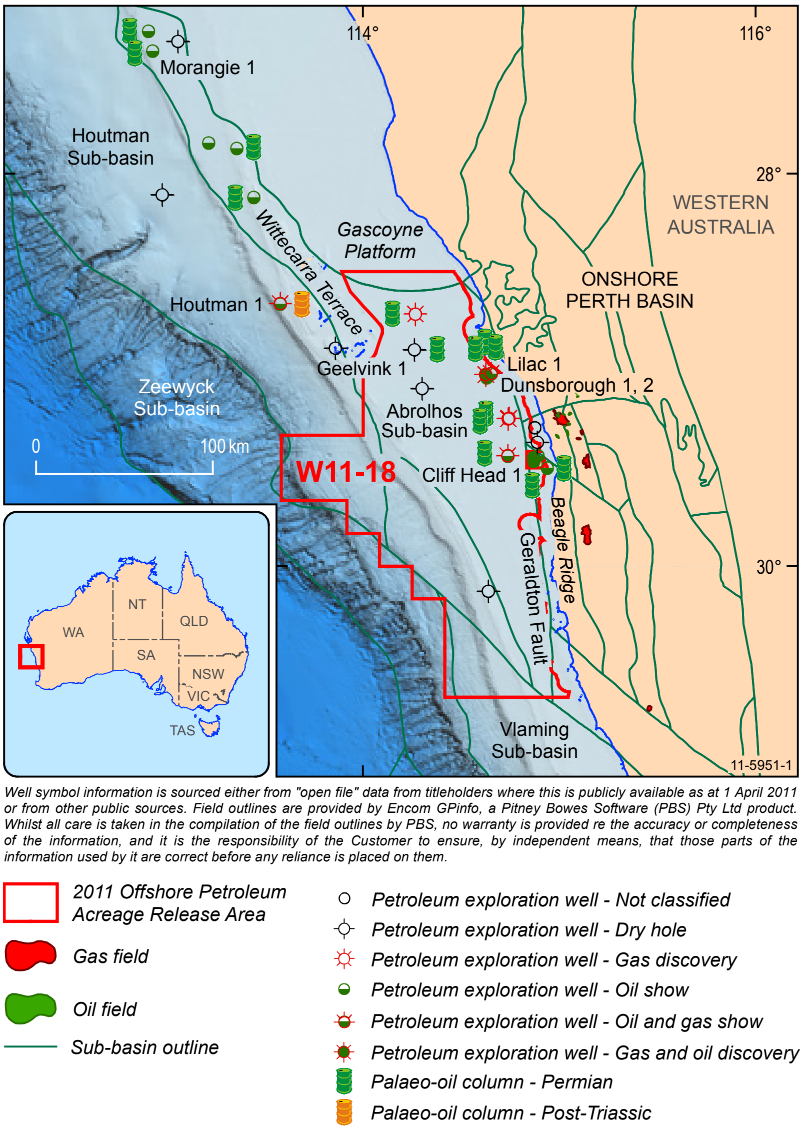


Figure 1. Location map showing palaeo-oil column distribution in the offshore northern Perth Basin (modified from Kempton et al 2011). The red outline shows 2011 Acreage Release Area W11-18.

Regional trap integrity study

A major exploration risk in the offshore northern Perth Basin is trap breach, where trapped oil or gas has been lost due to fault movements (Kempton et al 2011; Jones et al 2011a & 2011b). Evidence of lost oil accumulations, referred to as palaeo-oil columns, were detected in Permian reservoir sandstones below the Triassic Kockatea Shale regional seal in 14 of the 18 wells analysed from the Abrolhos Sub-basin (Kempton et al 2011, Kempton et al 2011b). Further outboard, a palaeo-oil column in Houtman 1 demonstrates an effective oil-charge system in Jurassic strata in the Houtman

1 Geoscience Australia, Canberra, ACT
2 CSIRO Earth Science & Resource Engineering, Kensington, Western Australia

Sub-basin. Oil charge from the Hovea Member of the Kockatea Shale west of the Beagle Ridge has been modelled as having occurred in the Late Jurassic to Early Cretaceous, and breach of many palaeo-accumulations could be attributed to structural processes after this time. These include:

- fault reactivation and structuring associated with Jurassic–Early Cretaceous extension and continental breakup in the Valanginian
- tilting and thermal subsidence of the margin post-breakup
- inversion of faults associated with collision of the Australian and Eurasian plates during the Miocene.

This study focused on several drilled prospects which are covered by three-dimensional (3D) seismic data and contain both breached and preserved oil columns all sourced and sealed by the Triassic Kockatea Shale (figure 1). 3D deformation and fluid-flow numerical modelling has been applied to these prospects to simulate the response of trap-bounding faults to Jurassic–Early Cretaceous NW–SE extensional reactivation and, therefore, to investigate hydrocarbon preservation risk in the Abrolhos Sub-basin during this time. The detailed results of this regional trap integrity study will be made available as a CSIRO open file report (Langhi et al 2012) which can be downloaded from either the CSIRO or Geoscience Australia websites, as well as the Western Australian Department of Mines and Petroleum WAPIMS database.

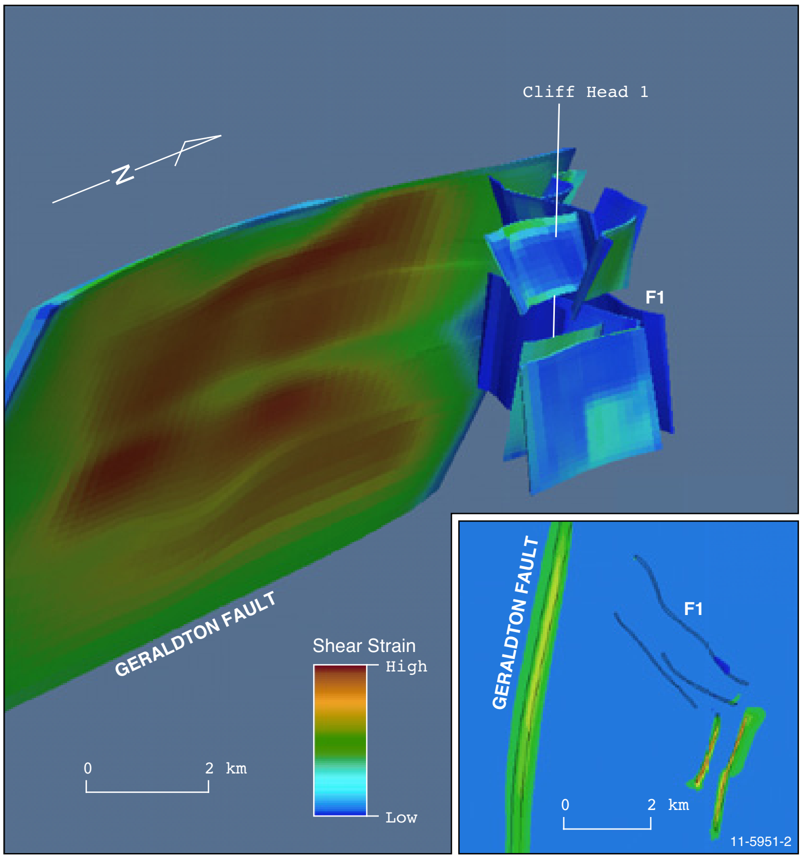


Figure 2. 3D and 2D strain distribution showing the shielding effect of the Geraldton Fault, for NW-SE extension, on the Cliff Head field. Cliff Head trap bounding fault is labelled F1. Inset shows Cliff Head-1 trajectory into structure. Note the low strain modelled on NW striking trap bounding faults.

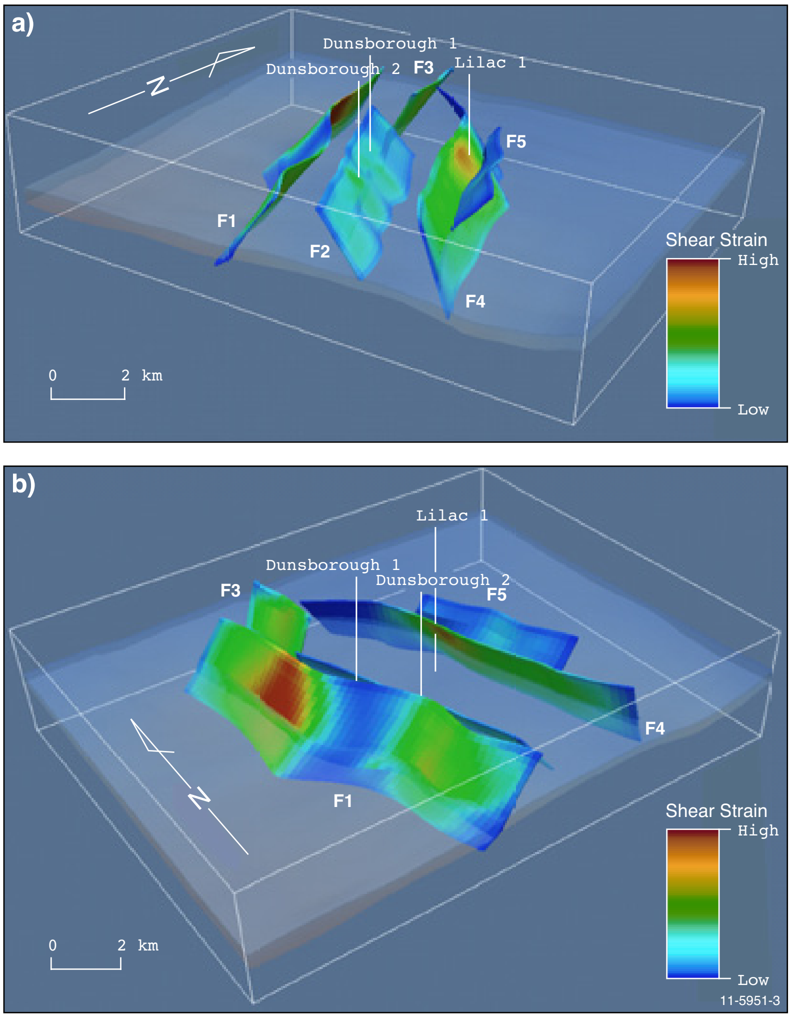
Geomechanical models

Geomechanical models, which describe the stresses and mechanical properties of a rock mass, were produced for the: (i) Cliff Head oilfield; (ii) Diana 3D survey covering the Dunsborough oil/gas discovery and the Lilac prospect; (iii) Macallan 3D survey, including the Morangie prospect. The 3D datasets were used to interpret major faults and key horizons (such as top reservoir and top seal) around these prospects, which were then used as modelling inputs. The 3D geomechanical models assist in understanding the first order factors controlling the distribution of reactivation stresses and strains, as well as the likelihood of shear failure occurring along fault planes and triggering up-fault leakage through the regional seal. The stress data were also used to compute increases in pore fluid pressure required to bring fault segments to a state of instability and, therefore, to a high risk of reactivation.

Preservation risk in the Abrolhos Sub-basin

Cliff Head oil field

The Cliff Head oil field (figures 1 and 2) was discovered in 2001 on the Beagle Ridge in a large faulted anticline to the east of the Geraldton Fault. The oil accumulation in the Cliff Head field is trapped within Permian Irwin River Coal Measures in a NW-trending main horst. The Permian fault F1 (figure 2) is the most critical structure as it bounds the crest of the horst closure to the north-east. Modelling results show that this fault, and other similar NW-oriented faults around the structure, are consistently associated with low risk of reactivation. Their strike orientations are sub-parallel to the modelled NW–SE extension direction, which is probably the main factor preventing the reactivation of the trap bounding faults. It is likely that this has prevented the trap bounding faults from breaching the regional seal and allowing hydrocarbon leakage. The geomechanical deformation models also show that the large north-striking Geraldton Fault to the west was optimally oriented to accommodate reactivation strain, which helped to shield the Cliff Head horst structure from fault reactivation.



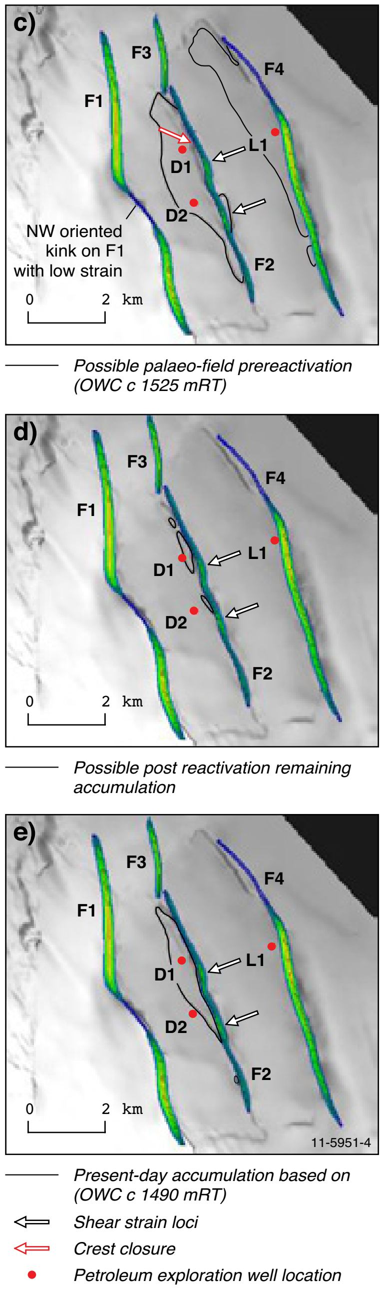


Figure 3. Relationship between strain distribution and charge history for the Dunsborough and Lilac traps: A) 3D shear strain distribution south-east view; B) 3D shear strain distribution south-west view showing the lateral variation in shear strain distribution for fault F1; C) Limit of possible palaeo-oil column at Dunsborough and Lilac prior to fault reactivation; D) Extent of remaining accumulation if high shear strain loci acted as fluid pathways at Dunsborough and Lilac; E) Probable extent of present-day oil column for Dunsborough trap. Abbreviations: F1-4 show main fault trends; D1-2 indicates Dunsborough-1 and -2 wells; L1 indicates Lilac-1 well.

Dunsborough oil/gas discovery and Lilac breached trap

Dunsborough-1 (figures 1 and 3) was drilled in 2007 to test a N–S oriented, rotated fault block trap within Permian Dongara Sandstone and Irwin River Coal Measures, and was a successful oil and gas discovery. Dunsborough-2 was then drilled approximately 1.7 kilometres to the south to test the extent of this discovery, but failed to find hydrocarbons. Palaeo-oil columns were identified in both wells below the Kockatea Shale regional seal (Kempton et al 2011). Lilac-1 (figure 3) was then drilled 2.7 kilometres to the east of Dunsborough-1 in 2008 to test an equivalent fault block trap. This well failed to find hydrocarbons, but subsequent studies detected a palaeo-oil column in the same Permian Dongara Sandstone and Irwin River Coal Measures (Kempton et al 2011).

As with Cliff Head, the modelling results show that fault segments trending more to the north show higher levels of strain and, therefore, are more likely to reactivate than the segments trending to the northwest under the Jurassic–Early Cretaceous NW–SE stress field (figure 3). In the Dunsborough prospect this resulted in strain partitioning between the main trap forming faults F1 and F2. The concentration of strain on F2 (shear strain loci, figure 3), for example, may be related to the northwest kink on F1 to the west. The increased strain at these loci may have been sufficient to force the Permian faults up through the overlying Kockatea Shale, which would promote the development of high permeability zones and, therefore, fluid leakage. This is shown in figure 3D, which models the extent of the hydrocarbon accumulation remaining after up-fault leakage and indicates that both Dunsborough-1 and -2 would be dry. However, the present day oil-water contact shown on figure 3E suggests that these leaking fault segments closed up at some later point and allowed subsequent hydrocarbon charge to accumulate around Dunsborough-1 on the trap crest.

At Lilac-1 shear strain distribution and modelled deformation on the trap bounding fault F4 was significantly greater than at the Dunsborough prospect, and was sufficient to allow migration pathways to develop through the Kockatea Shale seal (figure 3F) resulting in the total loss of hydrocarbon accumulation.

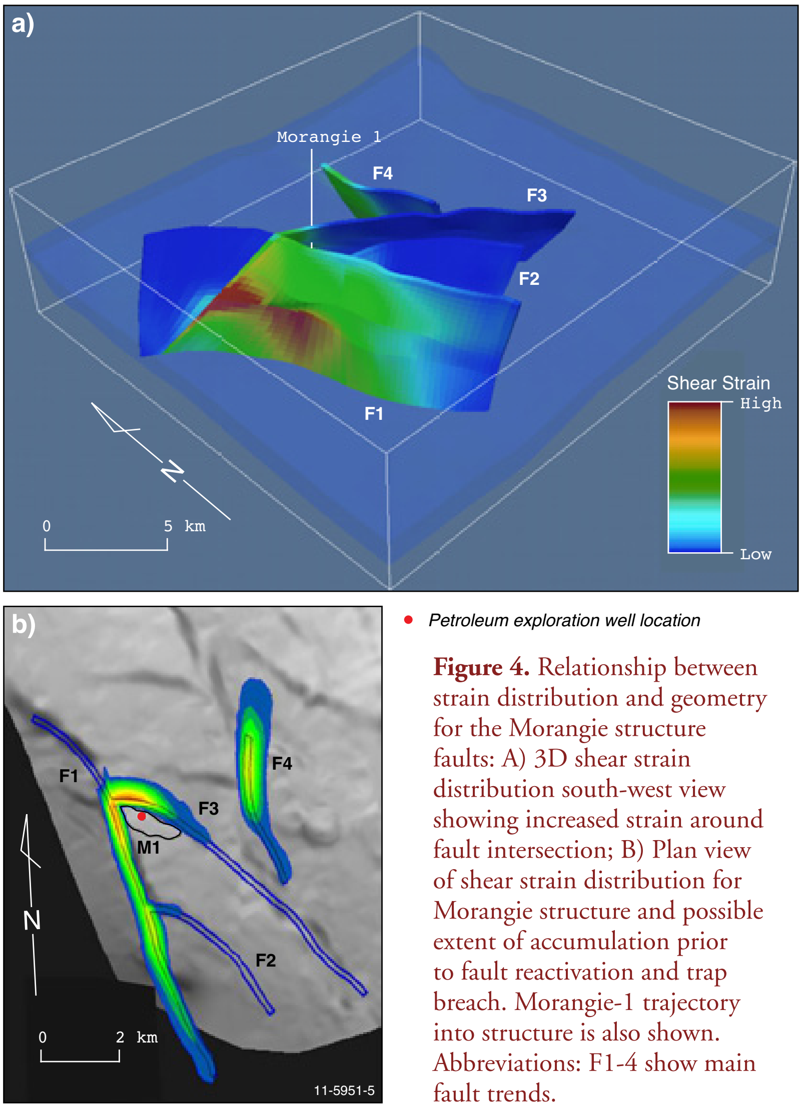


Figure 4. Relationship between strain distribution and geometry for the Morangie structure faults: A) 3D shear strain distribution south-west view showing increased strain around fault intersection; B) Plan view of shear strain distribution for Morangie structure and possible extent of accumulation prior to fault reactivation and trap breach. Morangie-1 trajectory into structure is also shown. Abbreviations: F1-4 show main fault trends.

Morangie breached trap

Morangie-1 was drilled in 2002 on the Wittecarra Terrace in the Abrolhos Sub-basin (figures 1 and 4). The well tested a tilted horst trap within Permian Dongara Sandstone that had dip closure to the south and was fault bounded in all other directions. However, despite good oil shows the well failed to find recoverable hydrocarbons. Subsequent palaeo-charge studies identified a minimum 52 metre palaeo-oil column (Kempton et al 2011) indicating that the trap had once been filled, but was subsequently breached.

A schematic palaeo-field reconstruction indicates that while the crest of the trap is fault-bound to the east by fault F3 (figure 4B) the palaeo-oil column would have also been partially fault bound to the west by fault F1. Modelling results show an increase in strain at the triple junction between these two faults. It is likely that this would result in the development of a high permeability zone, which may explain the total loss of hydrocarbons from the Morangie structure.

Reducing exploration risk

This study addresses a key exploration risk in the offshore northern Perth Basin–hydrocarbon leakage caused by trap breach. Despite the general lack of exploration success offshore, apart from the Cliff Head oil field, the identification of palaeo-oil columns in many offshore wells indicates that an active petroleum system has been widespread in this part of the Perth Basin. Trap integrity modelling provides the opportunity to investigate the likely cause of trap breach and develop a framework for assessing the risk of leakage for individual structural trap styles.

3D geomechanical modelling simulated the response of trap-bounding faults and fluid flow to Jurassic–Early Cretaceous NW–SE extension. Calibration of the modelling results with current and palaeo oil columns demonstrates that fluid flow along faults correlate with areas of local high shear and volumetric strains. The concentration of this deformation leads to: (i) an increase in structural permeability promoting fluid flow; (ii) the development of hard-linkage between reactivated Permian reservoir faults and Jurassic faults producing top seal bypass. The modelling found that several key structural factors controlled the distribution of these permeable fault segments during reactivation: (i) faults oriented between NNW and ESE were found to be at high risk of failure during the extension; (ii) fault intersections were also found to generate high permeability zones prone to leakage. In addition, large faults optimally oriented for reactivation preferentially accommodate strain and help shield nearby structures, as is the case with the Geraldton Fault immediately to the west of the Cliff Head field.

Results from this work are a step towards the development of a regional predictive approach for assessing trap integrity in the offshore northern Perth Basin. The predictive approach of this technique could be applied to newly identified, and yet to be drilled, prospects to help reduce risk for future exploration. The technique could equally be applied using modern day stress fields in the assessment of areas suitable for carbon capture and storage on other parts of the Australian Margin.

References

Jones A, Jorgensen D, Hackney R & Nicholson C. 2011b. Hydrocarbon potential of the offshore northern Perth Basin. *AusGeo News* 103.

Jones AT, Kennard JM, Nicholson CJ, Bernardel G, Mantle D, Grosjean E, Boreham C, Jorgensen DC & Robertson D. 2011a. New exploration opportunities in the offshore northern Perth Basin. The APPEA Journal 51.

Kempton R, Gong S, Kennard J, Volk H, Mills D, Eadington P & Liu K. 2011. Detection of Palaeo-Oil Columns in the offshore northern Perth Basin: Extension of the effective Permo-Triassic Charge System. The APPEA Journal 51.

Kempton R, Mills D, Bourdet J, & Liu K. 2011b. Multi-well investigation of palaeo-hydrocarbon charge & migration in the northern offshore Perth Basin, Australia. CSIRO Earth Science & Resource Engineering, Open File Report EP113734, June 2011 [unpublished].

Langhi L, Zhang Y, Gartrell A, Underschultz J & Dewhurst D. 2010. Evaluating hydrocarbon trap integrity during fault reactivation using geomechanical three-dimensional modeling: An example from the Timor Sea, Australia. AAPG Bulletin 94:4.

Langhi L, Zhang Y, Nicholson C, Bernardel G, Rollet N, Schaubs P, Kempton R & Kennard J. 2012. Geomechanical modelling of trap integrity in the northern offshore Perth Basin. CSIRO Earth Science & Resource Engineering. Open File Report EP12425, [unpublished].

For more information

email ausgeomail@ga.gov.au

Related articles/websites

Full details and results of the trap integrity study (CSIRO Open File Report EP12425) are available through:
www.csiro.au (keywords: Perth Basin, trap integrity)

Geoscience Australia
www.ga.gov.au

Western Australian Department of Mines and Petroleum WAPIMS database
https://wapims.doir.wa.gov.au/dp/index.jsp