[PS]An Enigmatic Transverse Structural Domain of the Northwest Passive Margin of Australia*

Peng Chen[1] and Chris Elders[1]

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Abstract

Rift-related structural deformation, e.g., faulting and folding, is typically perpendicular to the rift direction. The rift-related structures of most passive margins are strictly aligned with the elongate shape of the margins, which reflect the dispersal direction of the two related continents. The North West Shelf of Australia is a NE-SW trending passive continental margin and most of the faults identified across the entire North West Shelf are NE-SW oriented and attributed to the NW-SE directed Late Jurassic-Early Cretaceous breakup of the Indian Ocean. However, the detailed structural interpretation of the recently released 3D seismic surveys, together with the 2D surveys has identified a large population NW-SE trending Late Jurassic-Early Jurassic faults extending up to 30 kilometers in length and indicate a NW-SE trending structural domain in the Roebuck Basin (central North West Shelf). In the adjacent parts of the Northern Carnarvon Basin, structural trends also show irregularities. The outer board Exmouth Plateau presents both NE-SW and N-S trending Late Jurassic-Early Cretaceous faults, cutting the faulted strata into rhombic-shape compartments. The inboard Beagle Sub-basin is dominated by N-S trending faults. Our study suggests that the development of the NW-SE to N-S structural domain in the central North West Shelf was initiated during the Late Triassic-Early Jurassic deformation and is controlled by the zones of weakness in the basement. The development of this structural domain has exerted a strong influence on the sedimentary architecture in the area. The Triassic sediments show distinct thinning towards the central area, contrasting with the Jurassic sequences that are thickening. The transition of the central area from a basin high to a major depocenter was simultaneous with the initiation of the NW-SE to N-S structural domain in the Late Triassic-Early Jurassic, which support the thermal uplifting-cooling-rifting process. We propose the NW-SE to N-S structural domain we identified could represent an abandoned arm of a Late Jurassic-Early Cretaceous trilete rift system. The results of this study will lead to a better understanding of the rifting process which shaped the structural developments of the North West Shelf. Also, given the fact that there were limited significant petroleum discoveries in the central North West Shelf, the recognition of the transverse structural domain is of crucial importance for the exploration in the area.

An Enigmatic Transverse Structural Domain of the Northwest Passive Margin of Australia

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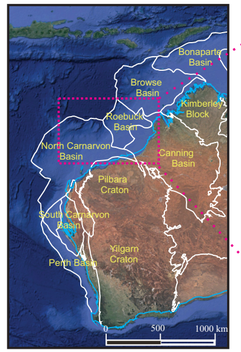
Introduction

Rift-related structural deformation, e.g., faulting and folding, is typically perpendicular to the rift direction. The rift-related structures of most passive margins are strictly aligned with the elongate shape of the margins, which reflects the dispersal direction of the two related continents.

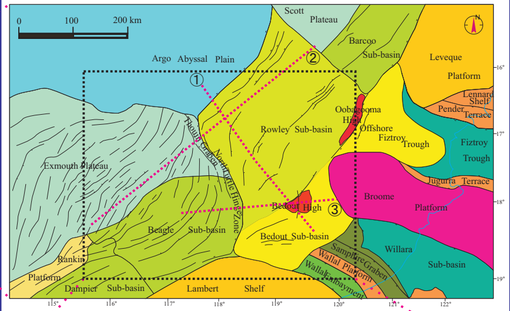
The North West Shelf of Australia is a NE-SW trending passive continental margin and most of the faults identified across the entire North West Shelf are NE-SW oriented and attributed to the NW-SE directed Jurassic-Early Cretaceous breakup of the Gondwana. However, detailed structural interpretation of recently released 3D seismic surveys, together with 2D surveys has identified a NW-SE to N-S trending structural domain in the central area of the North West Shelf.

This presentation summarises the tectonostratigraphic background, basin subdivision and framework, key evolutionary stages (Paleozoic, Triassic, Early Jurassic, Late Jurassic-Early Cretaceous) and fault linkages, segmentation, inheritance and reactivation, which help understanding of the development of the NW-SE to N-S structural domain.

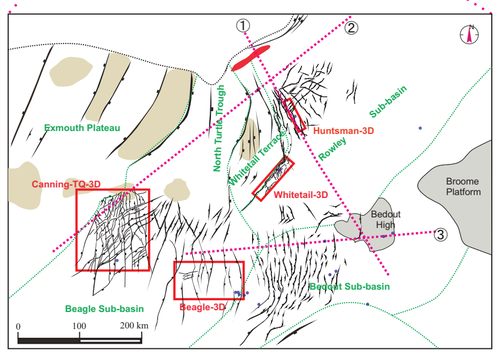
Location



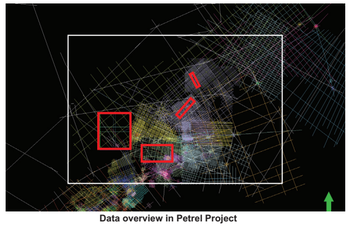
Structural Elements



Structural subdivision of the Roebuck Basin and the adjacent parts of the North Carnarvon Basin, Browse Basin and Canning Basin (Modified from AGSO Group, 1994; Hocking, 1994; Smith et al., 1999 and Stagg et al., 1999). It shows the previous understanding of the structural geology of the area.

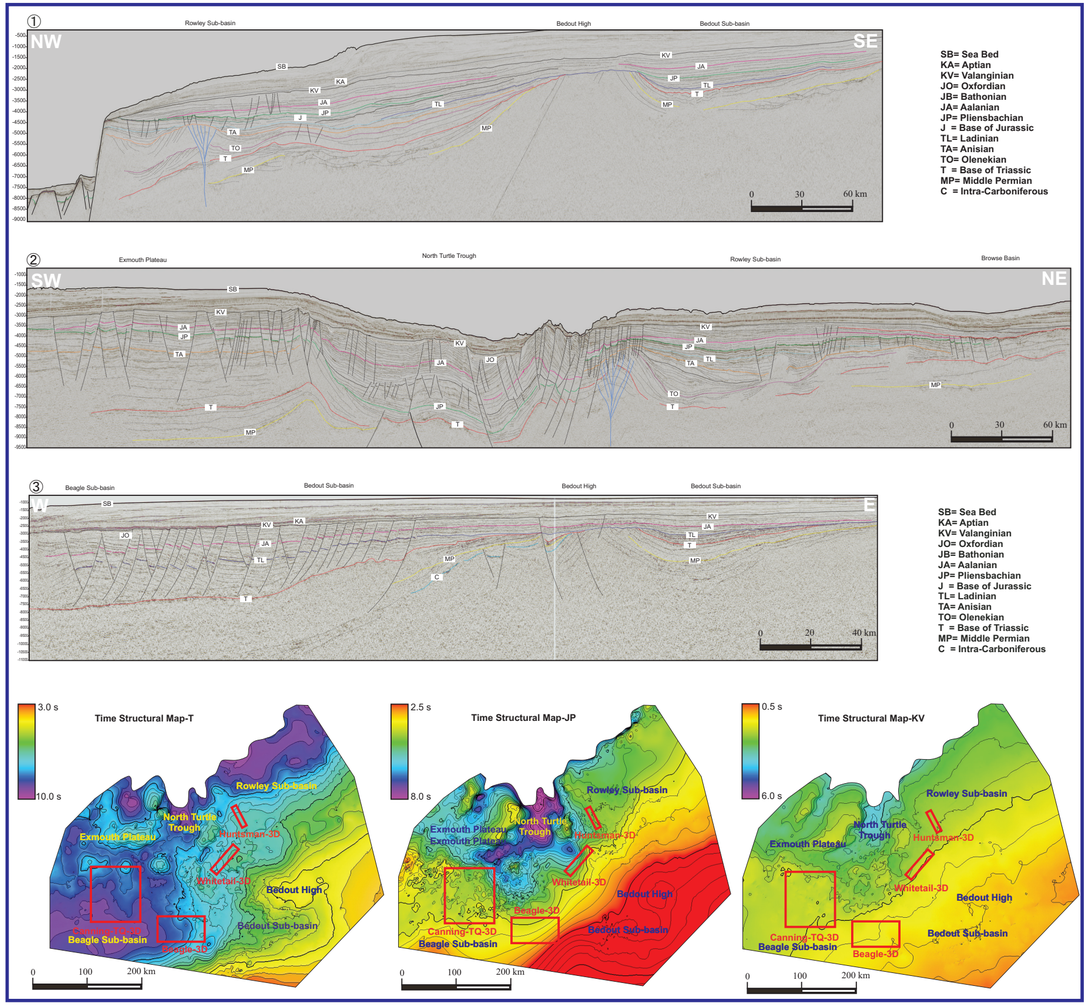


Structural elements of the study area, constructed from 3D and 2D seismic interpretation. Fault polygons are created based on the construction of the middle Jurassic horizon (JA) in the outboard area and Early Triassic horizon (TL) in the inboard area. The blank areas are a result of, 1) no data coverage; 2) poor data quality; 3) low density of 2D lines.



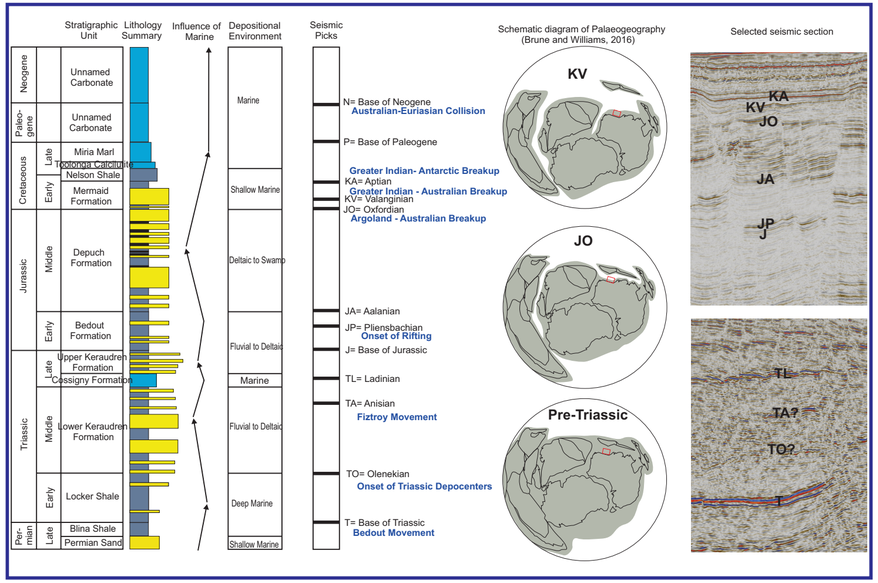
Data overview in Petrel Project

Basin Framework



SB= Sea Bed
KA= Aptian
KV= Valanginian
JO= Oxfordian
JB= Bathonian
JA= Aalanian
JP= Pliensbachian
J = Base of Jurassic
TL= Ladinian
TA= Anisian
TO= Olenekian
T = Base of Triassic
MP= Middle Permian
C = Intra-Carboniferous

Tectonostratigraphic Settings



Schematic diagram of Palaeogeography (Brune and Williams, 2016)

Selected seismic section

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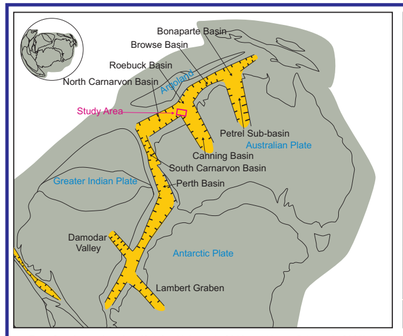
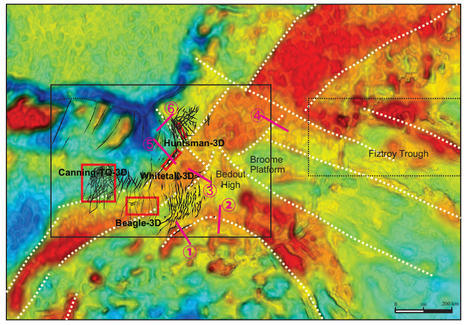
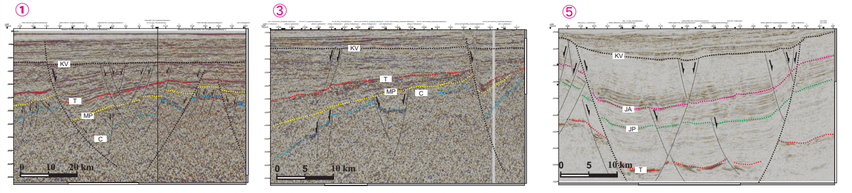
Carboniferous-Permian Rift

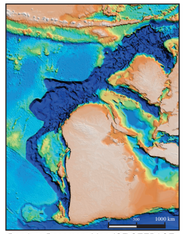


East Gondwana interior rift (after Haig et al., 2016 and Harrowfield et al., 2005)



Gravity Anomaly Map, note that linear gravity anomalies are interpreted to be Palaeozoic and older structures





Depth to Basement Map (OZ SEEBASE study, Frogtech)

Paleozoic deformation in the area is poorly known due to deep burial beneath Mesozoic and Cenozoic cover. Several sections in uplifted areas reveal evidence of Paleozoic faults.

Section 1 and 2 are on the edge of Pilbara Craton. The major faults exhibit evident Paleozoic growth (C-MP) and have been reactivated in Mesozoic extensional events. The large faults on Section 1 are NE-SW trending. Large faults on Section 2 are generally E-W trending.

Section 3 is on the Bedout High. Several large faults display Carboniferous-Permian movement, and only one was reactivated in subsequent extension. Seismic correlation and gravity anomalies both indicate they are NE-SW trending.

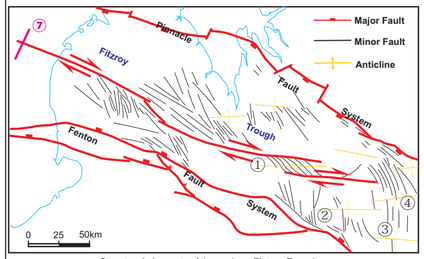
Section 4 is in the shallow offshore Fiztroy Trough. A fault bounded trough was observed at Paleozoic level. Fault age is unknown due to erosion of the upper Paleozoic section. It overlaps a NE-SW trending linear gravity anomaly.

Section 5 and 6 are in deep sub-basins. Paleozoic successions are poorly imaged on the seismic section in the deeper parts of the basins area. Given that most Mesozoic faults detach into the Lower Triassic Locker Shale, a few large faults on section 5 and 6 that offset the Upper Permian sequence, could suggest they are reactivated Paleozoic faults. These faults also overlap gravity anomaly lineations.

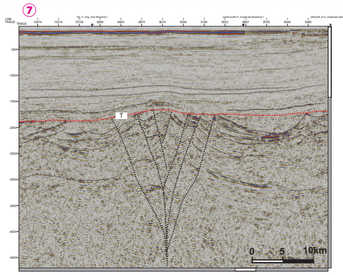
We have interpreted both NE-SW and NW-SE Paleozoic faults, representing the Paleozoic rift of the North West Shelf and onshore Canning Basin, respectively. Were they developed simultaneously (as implied by Haig's (2016) model of axial and marginal rifts to explain their orthogonal relationship)? Or, were they formed one before another?

Triassic Fiztroy Movement and Slope Tectonics

Fiztroy Movement

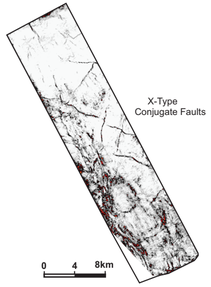


Structural elements of the onshore **Fiztroy Trough**
after Rattigan (1967); Smith (1968); Zhan and Mory (2013)

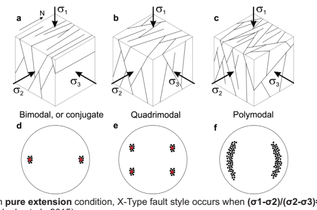


Flower Structure in the offshore Fiztroy Trough

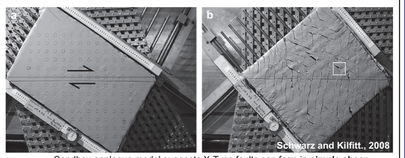
Variance-TA-Huntsman-3D



Formation Mechanism



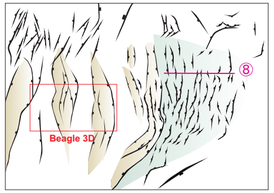
In **pure extension** condition, X-Type fault style occurs when **(σ1-σ2)/(σ2-σ3)=1**
(Healy et al., 2015)



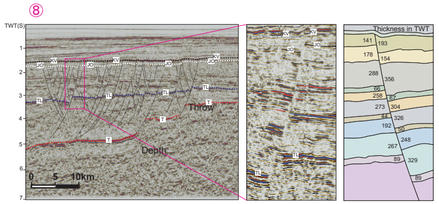
Sandbox analogue model suggests X-Type faults can form in **simple shear**

The transpressional Fiztroy Movement is not well understood. Three observations are interpreted to be the results of Fiztroy Movement. They are (1) **flower structures** in the offshore Fiztroy Trough; (2) **X-Type conjugate faults** in the Rowley Sub-basin; (3) **contractional folds** in the Rowley Sub-basin (see regional sections in Basin Framework).

Slope Tectonics

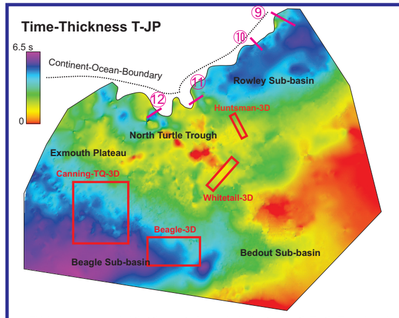


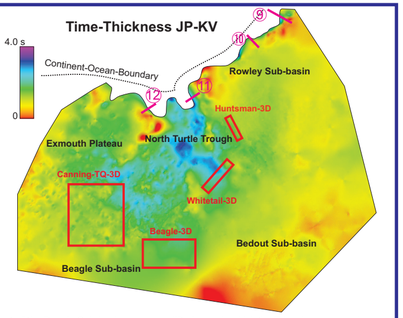
Faults in the Bedout Sub-basin **detach** into the Lower Triassic **Locker Shale**. They show **listric geometry** both in map view and on the section, and mostly **dip to the west**.



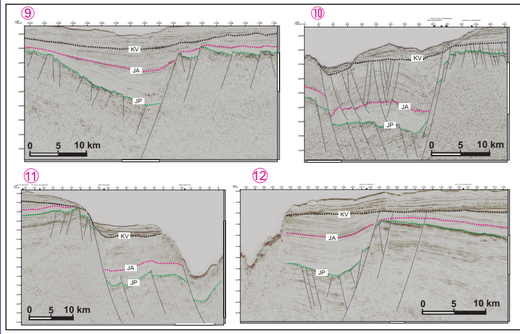
A section showing the fault architecture in the Bedout Sub-basin; Note that thickness of the Lower-Triassic sequence (T-TL) changes considerably across faults; One fault is selected and thickness of each seismic stratigraphic unit are measured on both footwall and hanging wall. It shows this fault has **constant slip** from **TL to KV**.

Early Jurassic Extension





Thickness map revealed that the **central area**, including the **North Turtle Trough** and **part of the Beagle Sub-basin**, was an **uplifted area**, in which the **Triassic sequence** is considerably **thinner** than in the Beagle and Rowley Sub-basin. However, this area was transformed into a **major depocenter** in the **Jurassic**, which received thicker Jurassic sediments than the surrounding area. This **transition from an uplift to a depocenter** of the central area was simultaneous with the **development** of the **Early Jurassic faults.**



Early Jurassic faults are easier to recognize in the outboard (close to the continent-ocean-boundary), because their magnitude decreases inboard.

Section 9 and 10 displays Early Jurassic faults that could trend **NE-SW or N-S**.

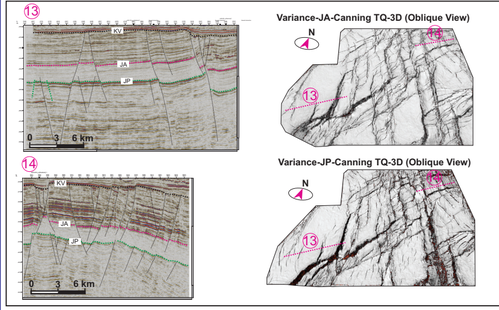
Section 10 and 11 exhibits **NW-SE to NNW-SSE** trending Early Jurassic faults.

Early Jurassic faults can be divided into two categories:

1) Early Jurassic faults with Late Jurassic-Early Cretacous **Reactivation**, e.g., faults on the footwalls of the major faults

2) Early Jurassic faults **without subsequent reactivation** e.g., faults in section 9, faults in the grabens in section 10, 11 and 12.

For Early Jurassic faults, the kinematics is unknown, and formation mechanism is enigmatic. Given that JP records a basin-wide downlapping (onlapping originally), Early Jurassic could be **initiation stage of Indian Ocean rifting**.

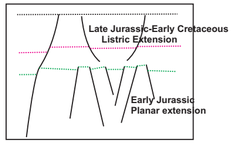


The **Early Jurassic faults** in the **inboard** have **less intensity** than in the outboard.

Comparing JP and JA, a large population of **minor faults** are only present at the **Pliensbachian** level (JP).

On section 13 and 14, these fault terminate upward in the Early Jurassic sequence (JP-JA)

The geometry of the major faults show **listric upper segments** and **planar lower segments**



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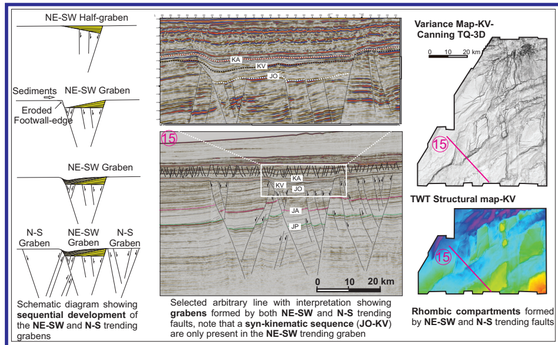
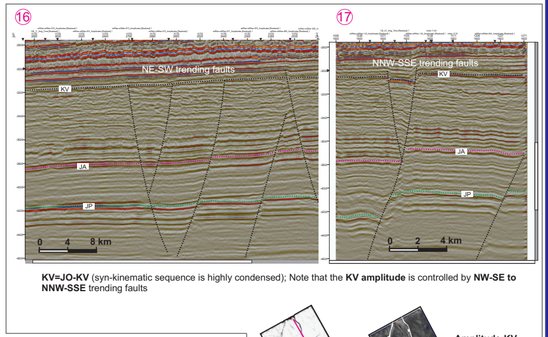
Late Jurassic-Early Cretaceous Indian Ocean Breakup



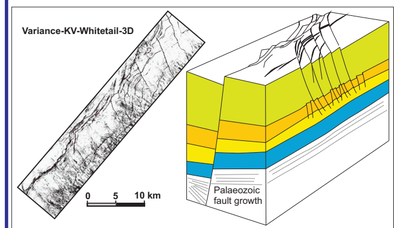
Schematic diagram showing **sequential development** of the **NE-SW** and **N-S** trending grabens

Selected arbitrary line with interpretation showing **grabens** formed by both **NE-SW** and **N-S** trending faults, note that a **syn-kinematic sequence** (**JO-KV**) are only present in the **NE-SW** trending graben

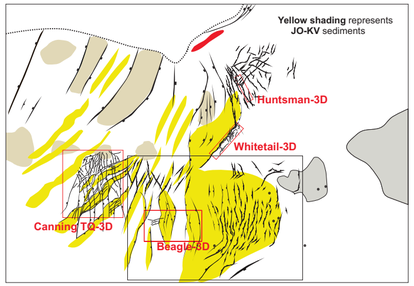
Rhombic compartments formed by **NE-SW** and **N-S** trending faults

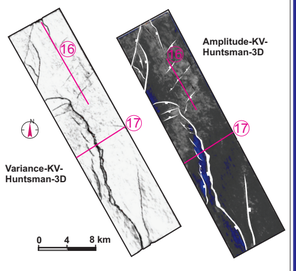


KV=JO-KV (syn-kinematic sequence is highly condensed); Note that the **KV amplitude** is controlled by **NW-SE to NNW-SSE** trending faults

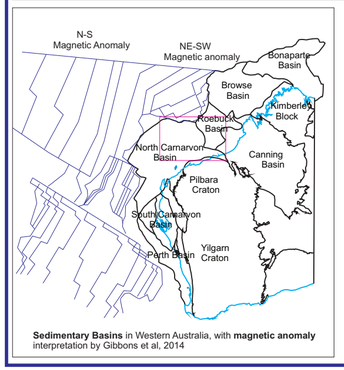


Whitetail-3D survey is generally poor in quality below the KV. The variance of **KV** has revealed a **NE-SW** trending **principal fault damage zone**, which overlaps the **Palaeozoic structural fabric** on the **gravity map** (see Carboniferous-Permian section). Several **NW-SE** trending **faults** terminate at the principal damage zone.





NE-SW trending faults show simple fault geometry. **NW-SE to NNW-SSE** trending faults are sinuous and show **en-echelon subsidiary faults**



Sedimentary Basins in Western Australia, with **magnetic anomaly** interpretation by Gibbons et al, 2014

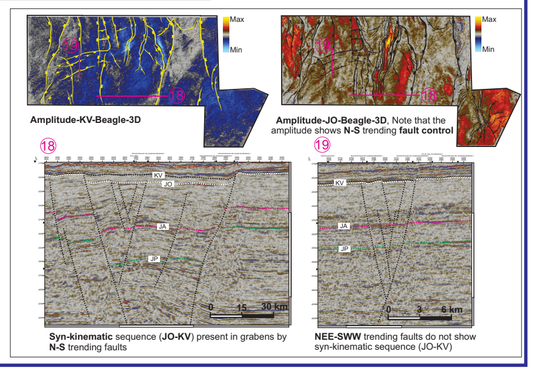
NE-SW faults (JO-KV)
..... **Argoland NW-SE breakup**

N-S faults (KV)
..... **Greater India E-W breakup**

N-S faults (JO-KV)
..... **Resurgent slope tectonics (induced by Argoland breakup)**

NW-SE to NNW-SSE faults (JO-KV)
..... **Controlled by underlying older structures**

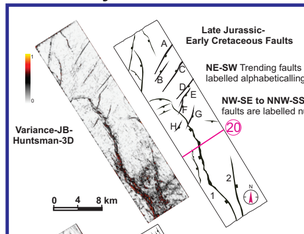
Syn-rift sediments (JO-KV) are controlled by **fault intensity, activity duration** and **sediment provenance**

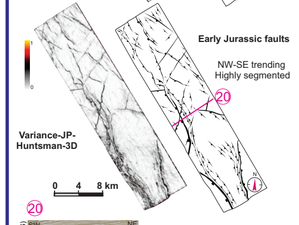


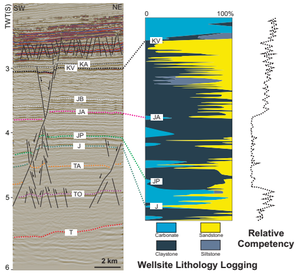
Syn-kinematic sequence (**JO-KV**) present in grabens by **N-S** trending faults

NEE-SWW trending faults do not show syn-kinematic sequence (JO-KV)

Fault Analysis

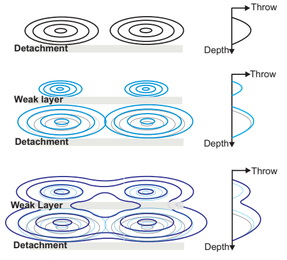




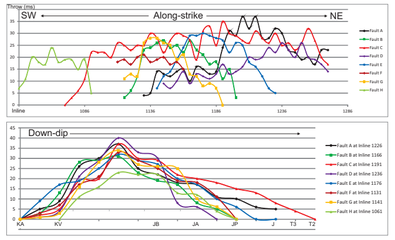


Wellsite Lithology Logging

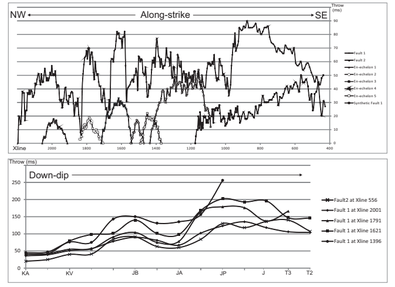
Relative Competency



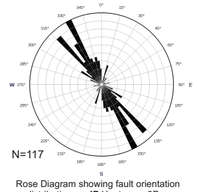
Model of fault reactivation in multi-phase extension



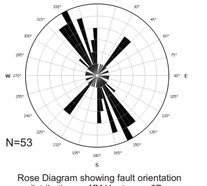
Along-Strike and Down-dip displacement profile of NE-SW trending Late Jurassic-Early Cretaceous faults (Labelled alphabetically on JB fault map)



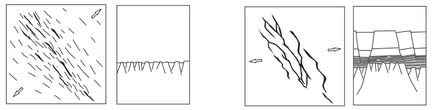
Along-Strike and Down-dip displacement profile of NW-SE to NNW-SSE trending Late Jurassic-Early Cretaceous faults (Labelled numerically on JB fault map)



Rose Diagram showing fault orientation distribution on **JP** Huntsman-3D

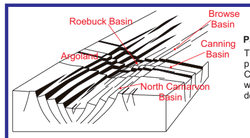


Rose Diagram showing fault orientation distribution on **KV** Huntsman-3D



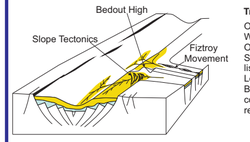
Schematic diagrams show the **NW-SE to NNW-SSE Late Jurassic-Early Cretaceous faults** are a result of **east-west directed reactivation** of the highly segmented **NW-SE Early-Jurassic faults**

Conclusions



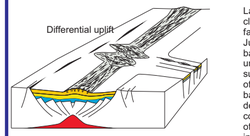
Paleozoic

The Paleozoic tectonic history of the study area is still enigmatic. Our interpretation revealed that both NE-SW and NW-SE trending Carboniferous-Permian faults have developed in our study area. But whether or not these two orthogonal Paleozoic structural domains were developed simultaneously is still a question.



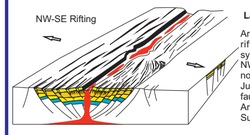
Triassic

On North West Shelf, Triassic faults are not widely reported. The North West Shelf is usually interpreted to be an intracratonic sag in the Triassic. Our interpretation has suggested that the listric faults in the Bedout Sub-basin were constantly active in the Triassic. The Triassic slip of the listric faults can be attributed to slope tectonics. The thick Lower Triassic Locker Shale, the rapidly deposited deltaic sediments, and the uplift of the Bedout High could have facilitated the slope instability. X-Type Triassic conjugate faults are observed in the Rowley Sub-basin, which could be a result of the Fitzroy Movement.



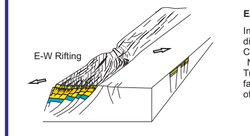
Early Jurassic

Large-displacement Early Jurassic faults are observed in the outboard area close to the continent-ocean-boundary. In the inboard area, Early Jurassic faults form a large population of highly segmented faults. Early Jurassic faults trend NE-SW, NW-SE, N-S in different part of the basin. The formation mechanism of the Early Jurassic extension is poorly understood. The basin-wide downlapping (originally onlapping) on the JP suggests the outboard area was uplifted at this time. The transition of the central area, the North Turtle Trough and part of the Beagle Sub-basin, from a basin high to a major depocenter was simultaneous with the development of Early Jurassic faults, which support the thermal uplifting-cooling-rifting process. The Early Jurassic is interpreted to be the initiation of NW-SE rifting that resulted in the separation of the Argo continental block in the Middle-Late Jurassic and E-W rifting that resulted in the separation of Greater India-Australia in the Early Cretaceous.



Late Jurassic

Argoland breakup in the Oxfordian was a result of the NW-SE directed rifting. However, the NE-SW trending faults are associated with syn-kinematic sequence (JO-KV), which suggests that the influence of the NW-SE directed Argoland Rifting lasted until the Valanginian (KV). There is no evidence that NE-SW faults have reactivated and linked with the Early Jurassic faults. However, they are controlled by large scale Paleozoic faults when overlapping the underlying Paleozoic fabrics. The Oxfordian Argoland Breakup also reactivated the gravitational faults in the Bedout Sub-basin.



Early Cretaceous

In Valanginian, Greater India started to separate (approximately E-W directed relative to North West Shelf). The N-S trending faults in the North Carnarvon Basin are a result of E-W directed Greater Indian Rifting. The NW-SE to NNW-SSE trending faults in the Rowly Sub-basin and North Turtle Trough suggest a strong control of the underlying NW-SE Paleozoic faults. Both the N-S and NW-SE to NNW-SSE faults are formed as a result of a reactivation of the highly segmented Early Jurassic fault system.

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Schlumberger

Geo conferences

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