A Geological Pressure Model for the Browse Basin and the southern Vulcan Sub-Basin, NWS Australia

Jakob Heller
Ikon Science
Kuala Lumpur, Malaysia
jheller@ikonscience.com

Toh Shi-Yuan
Ikon Science
Kuala Lumpur, Malaysia
tsyuan@ikonscience.com

Alex Edwards
Ikon Science
London, UK
aedwards@ikonscience.com

Summary

The results presented in this paper draws on a regional pressure analysis of the offshore areas of the Browse Basin and the southern Vulcan Sub-Basin.

The presented study focuses on Late Permian to Recent stratigraphy and a new stratigraphic scheme consisting of 11 main sequences has been developed as part of the study.

Vp-Rho cross plot analysis conducted for wells in the study area, indicates that undercompaction (disequilibrium compaction) is the main overpressure generating mechanism present. Although no clear deviation from a normal compaction/disequilibrium compaction trend is evident in the analysed wells, densities can be very high at depth with densities up to 2.65 g/cm^3 and above. This indicates that some cementation and possible clay mineral transformations have taken place in the deeper (and older) shales posing a challenge to conventional porosity/effective stress related pore pressure prediction.

For the purpose of this study, a model describing (shale) overpressures due to “primary” and “secondary” disequilibrium has been developed. The developed geological pressure model shows an overall good match with shale pressure predictions and/or forms the upper bound of the observed shale pressure/drilling data for the majority of the analysed wells across the study area. The model is particularly useful when planning to drill in areas with few offset wells for calibration and may also form a supplement to pore pressure predictions from seismic velocities away from well control and thereby significantly reduces the risk of encountering un-expected high pressures.

Key words: Browse; Vp-Rho cross plot; Geological Pressure Model.

Introduction

The Browse Basin contains overpressured Cretaceous, Jurassic and Triassic strata, but also shows large variations of overpressure magnitudes (from normal pressure to highly overpressured) in strata of similar age and/or depth of burial. The uncertainty in understanding the geopressure regime in the region forms a significant exploration risk.

Ikon Science recently undertook a regional pressure analysis of the offshore areas of the Browse Basin and the southern Vulcan Sub-Basin. The study, which included data from a total of 54 wells (73 wellbores including side-tracks), aimed to offer a comprehensive analysis of the pressures in the region in order to provide enhanced confidence in the understanding of drilling risks and aid exploration in the Browse Basin and the southern Vulcan Sub-basin (Figure 1).

Stratigraphic Scheme

The presented study focuses on Late Permian to Recent stratigraphy and a new stratigraphic scheme consisting of 11 main sequences has been developed as part of the study (Table 1 below). The 11 key sequences were delineated to assist with analysis and interpretation of the well data and are based on accepted major events/formation boundaries on the North West Shelf (NWS) with particular reference to the major sequence boundaries based on criteria outlined by Marshall and Lang (2013) and the regional play intervals used by Longley et al. (2002). The presented scheme is therefore, in principle, applicable to other areas/basins along the NWS allowing for comparison of overpressure distribution and pressure events between Sub-basins across the entire Shelf.

Overpressure in the Browse Basin and the southern Vulcan Sub-Basin

Velocity plotted against bulk density can be used to demonstrate that shale mudrocks are on their normal compaction curve, and if overpressured remain in balance with the effective stress, or alternatively, whether they are affected by secondary mechanisms; unloading (gas generation or uplift), cementation and/or clay-mineral transformations.

The Vp-Rho cross plot analysis conducted for wells in the study area, indicates that undercompaction (disequilibrium compaction) is the main overpressure generating mechanism present (Figure 2). However, although no clear deviation from a normal compaction/disequilibrium compaction trend is evident in the analysed wells, densities can be very high at depth with densities up to 2.65 g/cm^3 and above. This indicates that some cementation and possible clay mineral transformations have taken place in the deeper (and older) shales posing a challenge to conventional porosity/effective stress related pore pressure prediction methodology (Eaton, Equivalent Depth Method). Several wells display a trend of rapid increasing velocities with almost constant (high) density in Sequence 9 and older formations. This can be attributed to presence of ultralow porosity in the shales as bulk density approaches rock matrix values (and a minimum porosity). Within this range of densities (approaching 2.65 g/cm^3) there is no clear discrimination of process (e.g. unloading, load transfer etc.).

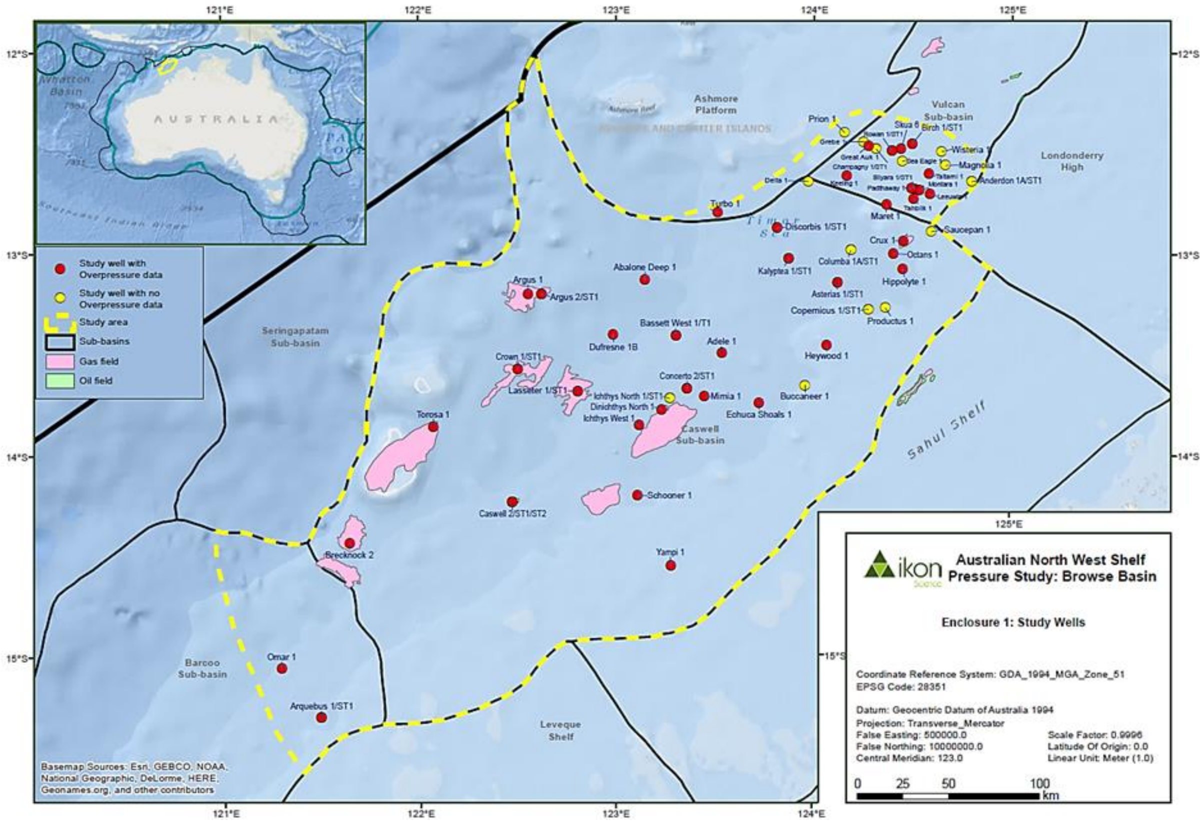

Figure 1 The yellow polygon outlines the study area for Ikon's recent regional pressure analysis in the Browse Basin and southern part of the Vulcan Sub-basin.

Key Event	Ikon Sequence	Age Ma	Sequence boundaries	Included regional play interval (Longley et al., 2002)	Key formations within interval
Water bottom		0			
	1			T40, T30	Barracouta Shoals Fm, Oliver Fm, Cartier Fm, Woodbine Gp,
Intra Oligocene		30.0	T30 SB		
	2			T20, T10	Woodbine Gp, Bassett Fm, Johnson Fm
Base Tertiary		66.0	T10 SB		
	3			K60, K50	Puffin Fm, Fenelon Fm, Gibson Fm, Woolaston Fm
Near Base Turonian		95.0	K50 SB		
	4			K40	Heywood Fm, Upper and Lower Jamieson Fm, Caswell Mbr
Near Base Aptian		123.3	K40 SB		
	5			K30, K20	Echuca Shoals Fm
Near Base Valanginian		137.7	K20 SB		
	6			K10	Upper Vulcan Fm, Upper Swan Group, Brewster Mbr
Base Cretaceous		144.2	K10.2 MFS		
	7			J50, J40, J30	Lower Vulcan Fm, Mid and Lower Swan Gp, Montara Fm
Near Base Callovian		165.6	J30.1 TS		
	8			J20, J10	Ichthys Fm, Plover Fm, Ashmore Volcanics
Top Triassic		201	J10 SB		
	9			TR30, TR20, Upper TR 10	Nome Fm, Challis Fm, Pollard Fm, Osprey Fm
Near Top Early Triassic		247.1	TR14 SB		
	10			TR10	Kinmore Gp, Mt Goodwin
Top Permian		252.2	TR10.0 SB		
	11			P50. P40, P30	Hyland Bay, Fossil Head Fm
Intra Sakmarian		293	P30.0 SB		

Table 1 Ikon stratigraphic framework for the Browse Basin and southern Vulcan Sub-Basin regional pressure analysis.

This regional pressure analysis highlights that little overpressure is present at the inner parts of Sub-basins and in the southern part of the Vulcan Sub-Basin in general. The exception to this being the older shale-dominated sections of Sequence 10 and 11 if penetrated (e.g. Echuca Shoals-1). Minor/some overpressures may be present in Sequence 4 and Sequence 5 shales where these are thick and reasonably deeply buried as for instance in Buccaneer-1 and Heywood-1. High overpressures in the study area are mainly observed in the central part of the Barcoo Sub-Basin (Omar-1), central/outer parts of the Caswell Sub-Basin and on the boundary between the Caswell Sub-Basin and the Ashmore Platform (Turbo-1).

Where overpressure is present, this generally starts to build up at the top of Sequence 4 and continues through Sequence 5, in which kicks have been encountered in several wells (e.g. Ichthys West-1 and Bassett West-1 ST1). In some wells located furthest outboard in the Caswell Sub-Basin (e.g. Argus-1), overpressure may begin to develop at the base of Sequence 2 or in Sequence 3 if shales/marls are present. The highest recorded overpressure across the study area was observed in Argus-2 ST1 where overpressure reaches 4900 psi in Sequence 7.

Significant pressure ‘reversals’ from high overpressures in Sequence 4 and Sequence 5 – overpressure up to 3900 psi (Dufresne-1 B) and mud weights up to 1.7 g/cm^3 (Caswell-2 ST2 and Ichthys West-1) - into lower (often normally pressured) zones in Sequence 6 and/or Sequence 8 below have been observed in several wells both in the central Barcoo Sub-Basin and the central Caswell Sub-Basin (Figure 3). This implies that fluids (overpressure) in places are able to drain-off along lateral continuous reservoirs or fault networks.

Geological Pressure Model for the Browse Basin and the southern Vulcan Sub-basin

The first geological model that was applied to wells in the study area is a simple model where Fluid Retention Depth (FRD) can be related to sedimentation rate (e.g. Swarbrick et al., 2002). The method assumes that overpressure is generated entirely by compaction disequilibrium and the overpressure builds-up along a near overburden parallel gradient below the FRD.

However, this relatively simple model, describing porosity/effective stress evolution due to “primary” disequilibrium compaction, fails to capture the shale pressure in most of the study wells. For the purpose of this study, this

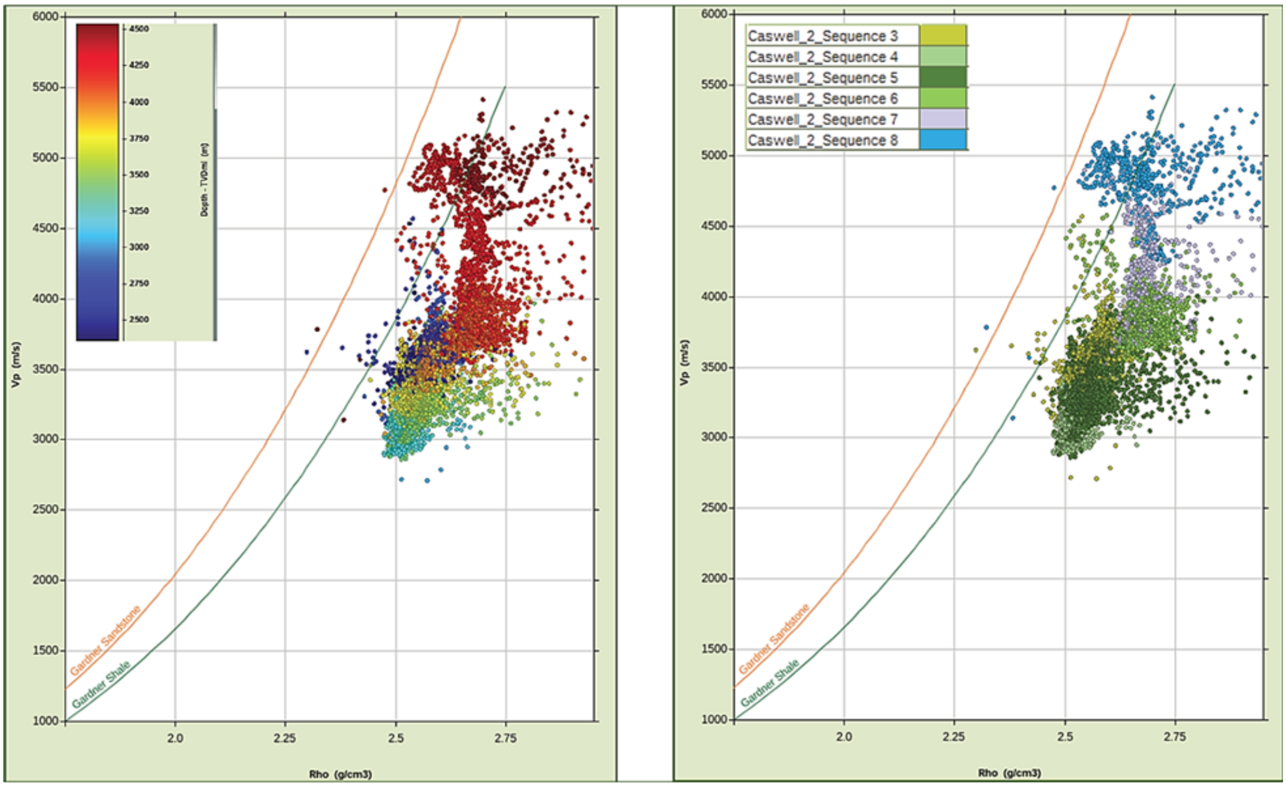

Figure 2 Vp-Rho cross-plot displays of data from Caswell-2 ST2. In the left-hand diagram, the data are coloured by depth below mud line. In the right-hand diagram data are coloured by geological sequence as defined in Table 1. Light blue and yellow coloured data (Sequence 4 and Sequence 5 data) are on top of data from shallow intervals (dark blue – Sequence 3), which is a sign of presence of undercompaction. Deeper data show increasing Vp and Rho with depth likely reflecting a return to normal compaction/pressure (see also Figure 3).

relatively simplistic model can be further split into "primary" and "secondary" disequilibrium compaction where primary disequilibrium compaction relates to overpressure generated in rocks for the first time, whereas secondary disequilibrium compaction applies to rocks where overpressure has been previously generated, but, due to depositional hiatus or unconformity, the overpressure has dissipated, leading to low porosity/permeability rocks which are prone to overpressuring as soon as burial begins again (Heller et al, 2015 and Emery, 2016).

A typical (shale) pressure profile when applying the principles of "primary" and "secondary" disequilibrium compaction in wells within the study area, can be described as shown in the diagram below (Figure 4) and is also illustrated in the Pressure-Depth plot in Figure 3. This combined geological pressure model has been found to show an overall good match with shale pressure predictions and/or forms the upper bound of the observed shale pressure/drilling data for the majority of the analysed wells across the study area.

Conclusions

A new stratigraphic scheme consisting of 11 main sequences have been provided for the Browse Basin and the southern part of the Vulcan Sub-Basin .The presented scheme, which is based on criteria outlined by Marshall and Lang (2013) and the regional play intervals used by Longley et al. (2002), allows for comparison of overpressure distribution and pressure events between Sub-basins across the entire NWS Australia.

Based on the presented regional pressure analysis for the Browse Basin and the southern part of the Vulcan Sub-Basin, a geological pressure model was developed for the study area. The presented geological pressure model describes maximum undrained shale pressure due to disequilibrium compaction. Any (potential) additional overpressure contributed from either clay mineral transformations or hydrocarbon generation has to be modelled separately and has to be added to the model. In wells, or part of wells with a high net to gross, the model forms an upper bound to the pressures that can possibly be encountered at a planned well location (less secondary mechanisms).

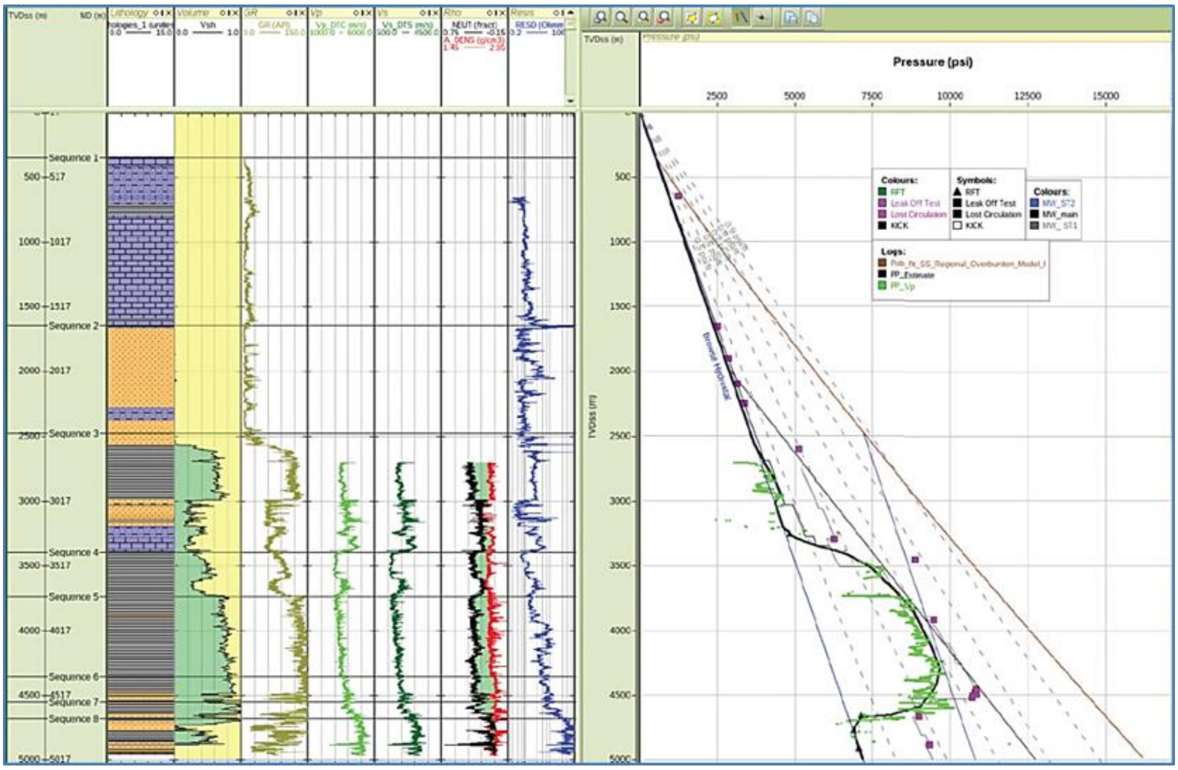

Figure 3 Pressure-Depth plot for Caswell-2 ST 2. The pressure profile for the well reflects the observations made in the Vp-Rho cross plot in Figure 2. Sequence 3 is normally pressured and overpressure is building up in Sequence 4 through 5. A pressure reversal commences near top of Sequence 6 and the reservoirs in Sequence 8 are normally pressured. The FRD profile (black Overburden parallel line) is calculated using top of Sequence 3 (thickness and age). The FRD profile captures shales (and their pressures) which have undergone primary disequilibrium compaction, while the post-unconformity loading model (blue profile) drawn from where top of Sequence 3 intersects the Overburden pressure profile captures the shales which have undergone secondary disequilibrium compaction. The green curve is the log-based shale pressure prediction from the sonic/Vp log.

In areas with lateral drainage and/or high net to gross, the modelled pore pressure will be higher than the actual observed pore pressure.

The developed geological pressure model shows an overall good match with shale pressure predictions and/or forms the upper bound of the observed shale pressure/ drilling data for the majority of the analysed wells across the study area.

The model is particularly useful when planning to drill in areas with few offset wells for calibration and may also form a supplement to – as well as a "sense check" of – pore pressure predictions from seismic velocities away from well control and thereby significantly reduces the risk of encountering un-expected high pressures.

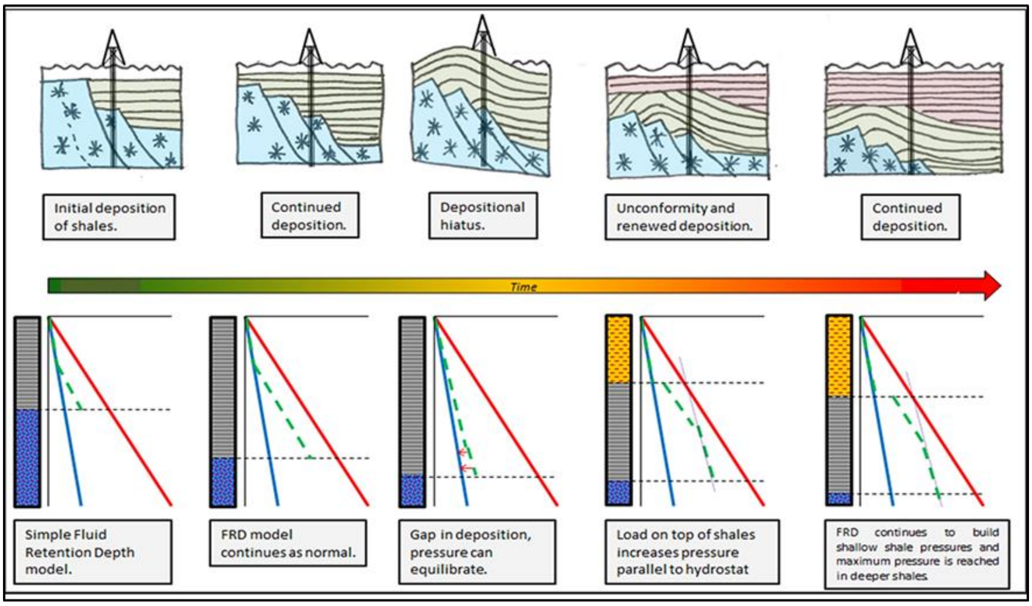

Figure 4 Geological Pressure Model for the Browse Basin and the Vulcan Sub-Basin. If a shale builds overpressure by disequilibrium compaction during deposition, but then there is depositional hiatus, it allows the shale to slowly equilibrate overpressure back to normal pressure. Depending on the length of the depositional hiatus and unconformity, the permeability of the shale and the thickness of the shale, the shale pressure may equilibrate completely, allowing the pressure to return to normal (diagrams 1 – 3 from the left). Now the shale is normally pressured and it has a hydrostatic-parallel profile. The shale has a very low permeability due to compaction, and if deposition were to recommence, the shale would not be able to compact any further. Hence, when the shale is deposited on top of, the pressure of the fluid will become overpressured immediately again. The overpressure is no longer building on an overburden-parallel trend, but builds out at a constant value of overpressure (diagrams 4-5 from the left).

Acknowledgement

KRX Energy Pte Ltd (Kim Morrison) are thanked for their contribution to the Geology of the Browse Basin Chapter and for suggesting the stratigraphic framework applied in this study. Inpex and Shell are thanked for providing funds and various discussions during the study.

References

Emery, A., 2016, Palaeopressure reconstruction to explain observed natural hydraulic fractures in the Cleveland Basin. Marine and Petroleum Geology, 77 (2016), 535-552.

Heller, J., O'Connor, S., Emery, A., Hoskin, E., Lee, J. and Ward, C., 2015, The effect of unconformities and subsequent loading on pore pressure profiles. *Proceedings, Indonesian Petroleum Association, Thirty-Ninth Annual Convention & Exhibition May 2015*.

Longley, I.M., Buessenschuett, C., Clydsdale, L., Cubitt, C. J., Davis, R.C., Johnson, M.K., Marshall, N.M., Murray, A.P., Somerville, R., Spry, T.B. and Thompson, N.B. , 2002. The North West Shelf of Australia – A Woodside Perspective, in Keep, M. & Moss, S.J., (Eds), in The Sedimentary Basin of Western Australia 3: Proceedings of the Petroleum Exploration Society of Australia Symposium, Perth, WA, 2002 pp 27-88.

Marshalle N.G and Lang S, 2013, A New Sequence Stratigraphic Framework for the North West Shelf, Australia. Proceeding of the 2013 Western Australia Basin Symposium, 1-31.

Swarbrick, R.E., Osborne, M.J. and Yardley, G.S., 2002, Comparison of overpressure magnitude resulting from the main generating mechanisms, In: Huffman, A.R. and Bowers, G.L. (eds.), Pressure regimes in sedimentary basins and their prediction, AAPG Memoir 76, 1-12.