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Insights into the Petroleum Potential of the Australian North West Shelf and Arafura Sea Revealed by Regional 2D Seismic Data

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Abstract

This contribution discusses the interpretation of over 40,000 km of 2D seismic data acquired since 2007 and covering the Northwest Australian continental shelf. This includes the Carnarvon, Roebuck, Browse and Bonaparte basins and the Arafura Sea as far as Irian Jaya, an area of about 1.5 million km^2. This data is mostly recorded to 10-12 s with an 8 km dual sensor streamer. It is of better quality than vintage seismic, providing increased resolution and improved penetration, particularly in the deeper part of the section. The new data provides continuous coverage across the Australia / Indonesia boundary allowing seismic interpretation studies to include the whole of the Australian continental margin. Individual lines are up to 600 km long and composites can be made which are up to 1,500 km long.

The interpreter can now see relationships amongst basins on a regional scale. Horizons below the top Triassic, including top Permian and often basement are mappable consistently over the whole of the Northwest Shelf, leading to a better understanding of the evolution of the continental margin. In the Exmouth Plateau area of thinned crust, the seismic has imaged reflectors possibly down to the Moho. Modelling of gravity data acquired with the seismic has helped with interpretation of the deeper horizons.

Better imaging at depth now permits the Australian continental margin sequence to be followed under the accretionary wedge in both Seram and West Timor, demonstrating that Mesozoic source and reservoir rocks may be present under the wedges, improving the prospectivity of both areas and perhaps of the poorly explored Outer Banda Arc in general.

The poster is illustrated with examples of seismic sections taken from a range of structural settings and geographical locations covering the whole Australian shelf from the Carnarvon Basin to Seram.

Introduction

Across offshore north and northwest Australia (essentially the North West Shelf) and adjoining parts of Indonesia, more than a dozen basins have been described which conservatively cover approximately 1.6 million km^2. Much of the hydrocarbon exploration efforts to date have been focussed mainly on the inboard areas of the North West Shelf (abbreviated to NWS hereafter), resulting in multiple province scale oil or gas discoveries. The relatively high density of exploration drilling along the inboard part of the NWS implies that little potential exists for any new major oil or gas discoveries in this area. However, the under-explored deepwater part of the NWS is huge and entire untested basins are present along the Australian northern continental margin in the vast Timor and Arafura Seas including the eastern part of the Indonesian archipelago. In this region are basins covering hundreds of square kilometres, with as much as 10 km of sediments and evidence of active petroleum systems (that are part of the Westralian petroleum supersystem). PGS's seismic coverage in this area demonstrates the potential for multiple large drilling targets. The primary geological risks in these frontier areas are a combination of reservoir presence, source and seal effectiveness. It is clear that the thrust of future exploration will be in the untapped outboard frontier areas, as demonstrated by the recent multi-tcf Abadi gas discovery. Planned infrastructure such as floating liquefied natural gas technology will also spur more exploration activity in these relatively high-cost remote areas.

In frontier basins good quality regional seismic lines comprise the essential data for modelling petroleum systems and play given that wells are often sparse or absent. The subject of this paper is the interpretation of PGS's recent non-exclusive 2D surveys totalling about 40,000 km which provide a regional grid of modern high quality seismic data linking prolific oil and gas provinces to largely untested frontier basins that straddle more than 3,000 km of the Australian northern continental margin. These 2D surveys, acquired in 2007 -2010 across the political boundary between the northern continental margin of Australia and Indonesia, would bridge the gap in understanding of a common geological history aiding future exploration in the region. The data was acquired using a long offset (8,000 m) and 12 s record length with overall reduced noise and a broader frequency spectrum than vintage data. This has provided more detailed imaging particularly of the deep basin architecture and its sedimentary fill. Long continuous regional lines tie key wells and discoveries enabling a greatly increased understanding of prevailing petroleum systems and play fairways along the entire NWS, across northern Australia to the Timor Trough and on into the Aru and Semai Troughs in eastern Indonesia.

Geological Setting

The NWS lies predominantly within Australian territorial waters and is a Mesozoic intracratonic basin which evolved into an Atlantic style rift/drift margin after the Late Jurassic (Purcell & Purcell, 1988, 1994, 1998). The NWS is approximately 2400 km long by 400 km wide and forms one contiguous "Westralian Super-basin" (Bradshaw et al. 1988). It has been arbitrarily divided into different segments from south to north, namely the Carnarvon, Offshore Canning, Roebuck, Browse and Bonaparte Basins (Figure 1). These basins are primarily filled with pre-rift Permo-Triassic intracratonic sediments, overlain by Jurassic to Cenozoic syn- and post-rift successions (Longley et al. 2002).

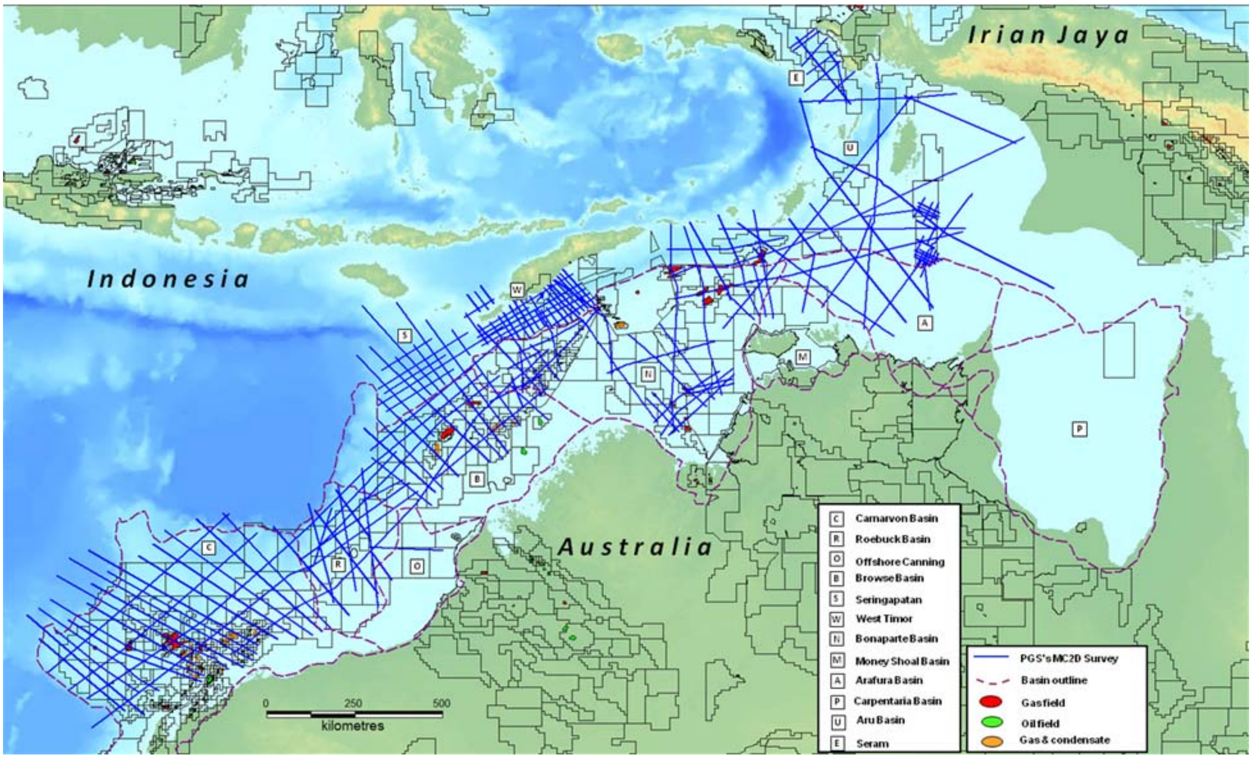

Figure 1: East I ndonesia and th e northern Australian continental margin basin o utlines and key oil and gas field locations w ith 2D seismic coverage.

The northern margin of Australia has undergone a complex tectonic evolution since Palaeozoic time, resulting in the development of several depocenters and elevated platform highs. Key regional structural elements are shown schematically in Figure 2. The overall age of the sedimentary succession extends from Cambrian to present day, reflecting poly-phase extension episodes during the Palaeozoic and Mesozoic, followed by Neogene collision between the Australian and Eurasian plates. The key tectonostratigraphic events (summarised from Longley et al. 2002) that shaped the region can be broadly classified as follows:

- Earliest rifting episodes form the building blocks during Proterozoic and Palaeozoic times including a NNW-SSE trend seen in the Goulburn Graben and Petrel Sub-basin.

- Significant tectonism, uplift and erosion take place along the edges of the craton during Late Triassic, known as the “Fitzroy Movement” (Foreman and Wales, 1981).
- Jurassic to Early Cretaceous rifting and seafloor spreading overprints the older Palaeozoic grain with a NE-SW structural trend. Regional unconformities associated with the continent-separation episodes, especially the ‘Main Break-up Unconformity” occur as major events throughout the NWS.
- Onset of thermal subsidence in the Late Cretaceous, a thick wedge of carbonate dominated sediments progrades across the entire region and continued up to Palaeogene time.
- Neogene collision of Australia with the Banda arc system gives rise to the curvilinear Timor-Tanimbar Trough and associated accretionary prism (Keep at al. 2002).

The complex tectonic history of Australian northern margin’s strongly influenced the hydrocarbon potential.

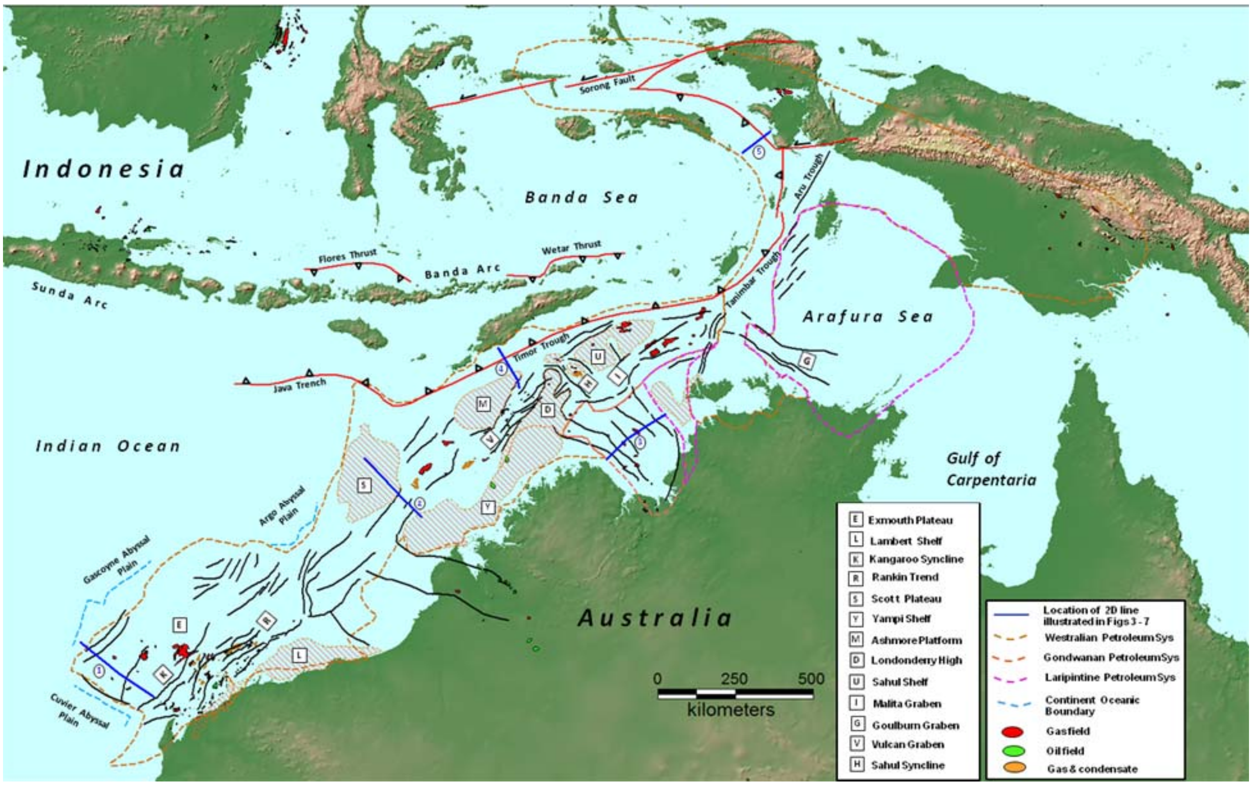

Figure 2: Simplified regional tectonic elements together with outline of recognized petroleum systems and key oil and gas locations.

Petroleum Systems

While the most successful play in the region has been hydrocarbons sourced and reservoired in Mesozoic age sediments, it is believed that both younger and older source rock successions may have potential for commercial accumulation of oil and gas. To summarise the prospectivity of the region, the petroleum supersystem model proposed by Bradshaw et al. 1994 is invoked here.

The oldest petroleum supersystem recognised in the region is the Larapintine, active in the Money Shoal and Arafura Basins (Figure 2), which is characterised by lower Palaeozoic primarily marine algal rich facies. Numerous oil, bitumen and gas shows have been attributed to this petroleum supersystem especially from wells drilled in the Goulburn Graben e.g. Arafura-1, Goulburn-1, Kulka-1 (Earl, 2006). The majority of the Arafura Shelf area covered by the Larapintine supersystem is thinly explored.

The Late Carboniferous to Early Triassic Gondwanan petroleum supersystem is proven in the Petrel Sub-basin (e.g. Petrel and Tern gas discoveries), and may also be active in parts of the Sahul Shelf (e.g. Kelp Deep-1) and northern Bonaparte Basin (Figure 2). The proven source tends to be gas prone, terrestrial organic facies. The true potential of this petroleum system over most of northern Bonaparte and adjoining Timor Trough and Sahul Shelf still remains untested.

The Mesozoic age Westralian is the most productive and widespread supersystem as it includes the numerous multi-tcf oil and gas accumulations of the Carnarvon, Browse and Bonaparte Basins. This super system links together the basins, from the Exmouth Plateau in the south to the Papuan Basin in the northeast (Fig. 2). All the basins share a common history of extension and eventual break-up in the Jurassic to Early Cretaceous. The majority of the oil and gas attributed to the Westralian Supersytem is sourced from fluvio-deltaic to shallow marine facies, Cretaceous regional seal and a thermal blanket of overlying Cenozoic carbonates. A vast area covered by the Westralian petroleum supersytem remains to be tested.

Deep crustal structures in the Exmouth Plateau

Line 1 (Figure 3) covers approximately 310 km across the southern extent of the Exmouth Plateau bounded by the ocean-continent transition (Gascoyne Abyssal Plain) to the northwest and the Kangaroo Syncline to the southeast. The Exmouth Plateau is an elongated submerged continental platform established by continental rifting and breakup of Australia and Greater India during Early Mesozoic rifting (Veevers, 1984; Barber, 1988). The most prominent features imaged on this line are the deep events possibly within the crust, including a high amplitude stratified interval (~8-9.5 s) interpreted as magmatic underplating (Milz, 2010). The relatively weak amplitude event at ~10.8-11.5 s is possibly a good candidate for the Moho. Also well imaged is an extensive network of igneous sills within the intra-cratonic Permo-Triassic section which is most likely to have been emplaced during the late Jurassic continental break-up. Imaging of these crustal-scale features would help in developing a better understanding of the palaeo-thermal history and its effect on the petroleum systems in the region.

The line displays excellent imaging of regional unconformities associated with Mesozoic rifting and continental separation episodes, especially the Callovian ‘Main’ break-up unconformity. Also well imaged are extremely large Late Triassic (Mugaroo Formation) rotated fault blocks (the prime play in the Exmouth Plateau) and prograding delta front sequences of the Neocomian Barrow Group.

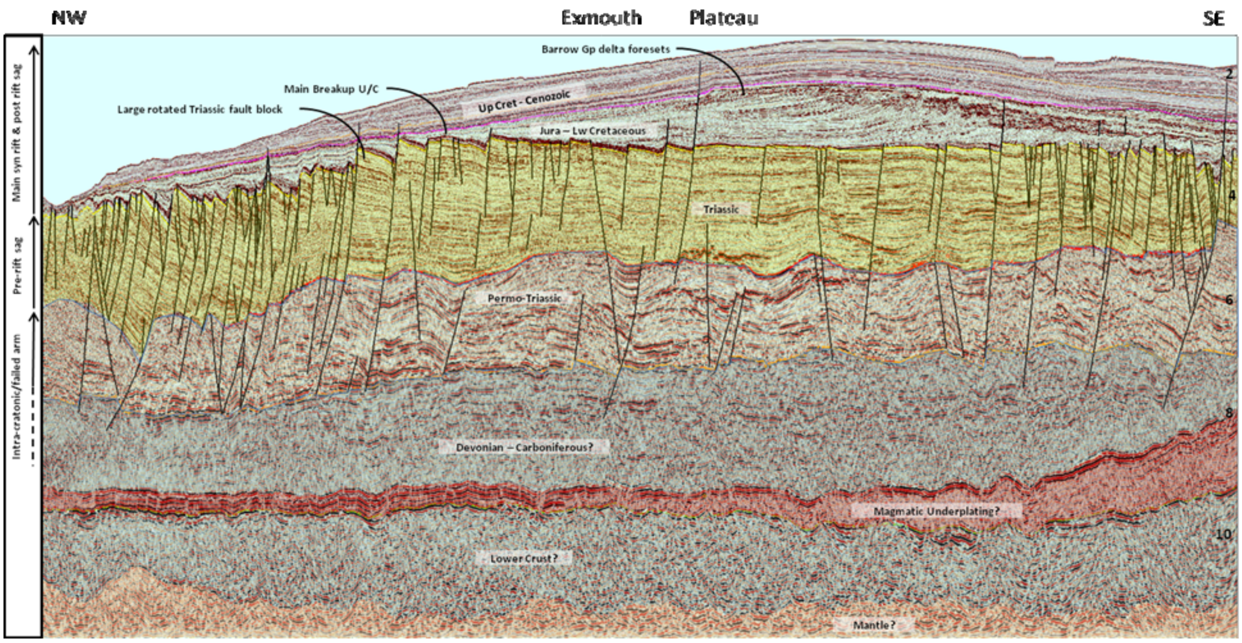

Figure 3: Interpreted seismic line-1 (line location in Figure 2) across the Exmouth Plateau, Carnarvon Basin.

Volcaniclastics in outer Browse Basin

Line 2 (Figure 4) covers approximately 260 km across the Browse Basin which is one the several major NE-SW trending Mesozoic depocentres on the NWS. It is bounded to the west by the Scott Plateau and to the east by the Yampi Shelf (Figure 2). The most prominent feature imaged on this line is the Callovian break-up associated volcaniclastics extending from Scott Plateau into the central Browse Basin where several wells have intersected thick volcanic section. Well Maginnis-1 located approximately 130 km to the NE intersected about 480 m of volcaniclastic interspersed with altered basalt (BHP, 2003). The ability to image the extent of the volcaniclastics is important as it is considered a high potential risk to reservoir quality in the target mid Jurassic Plover Formation play in the outer Browse Basin. Also well imaged is the thick Triassic succession beneath the Plover Formation. Presence of volcanics and shallow carbonates generally obscures the imaging of deeper Triassic and Permian events over much of the outer Browse Basin. Triassic plays are secondary exploration targets and the Triassic is also a potential source for oil and gas generation.

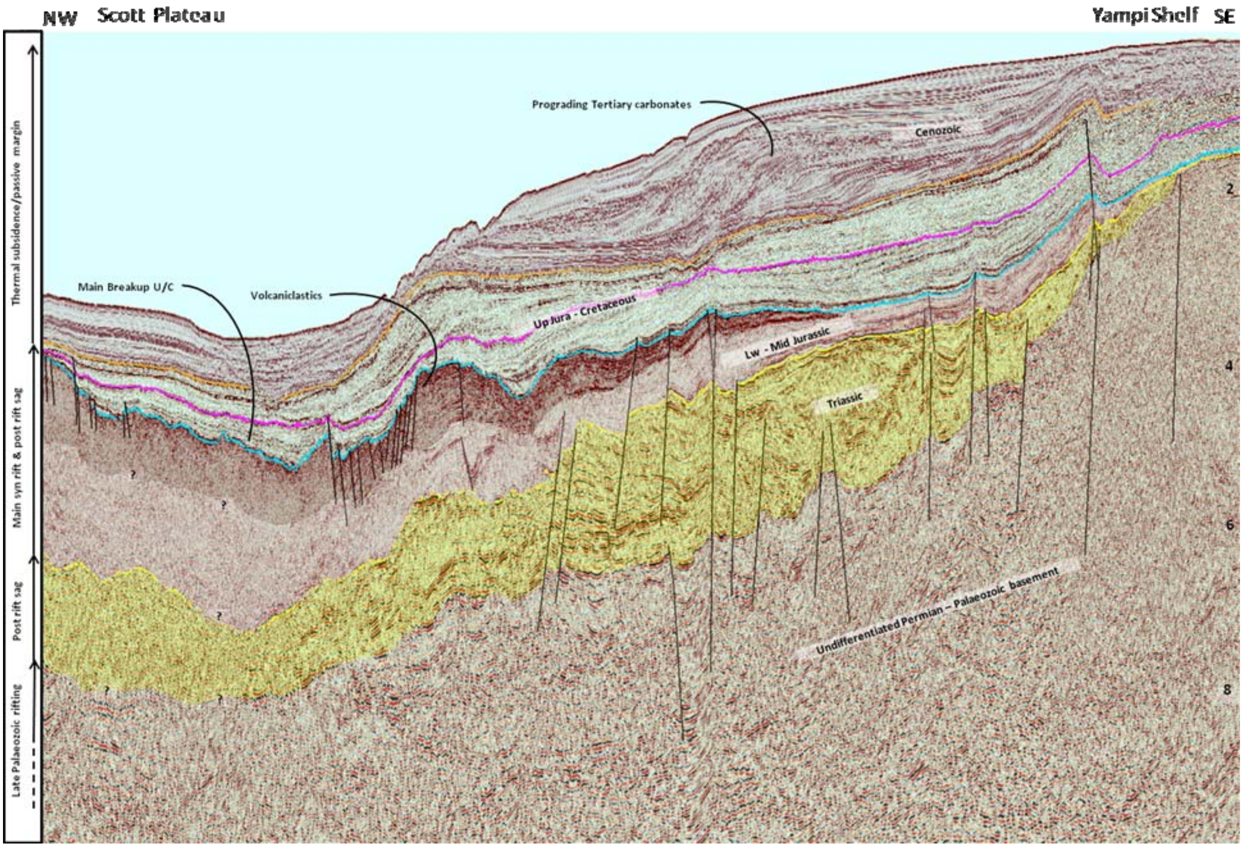

Figure 4: Line 2 (line location in Fig 2) NW-SE seismic section across the Browse Basin.

Salt mobilization associated structure in the Petrel Sub-basin

Line 3 (Figure 5) covers approximately 250 km across the Petrel Sub-basin, a NW-SE trending Palaeozoic rift basin located in the southern part of the Bonaparte Basin (Fig. 1). The Petrel Sub-basin is bounded by the Plover Shelf to the southwest and the Darwin Shelf to the northeast. The illustrated line exhibits superb imaging of deep rift-associated Palaeozoic sequences including a prominent salt diapir. Thick evaporitic sediments were deposited possibly during Silurian to Early Devonian time, which has later mobilised and formed salt-cored structures (Mory, 1988). The interpretation on this displayed line suggests that the salt movement was continuous until the Late Cretaceous. These salt movement associated structures are an important control on the occurrence of petroleum in the Petrel Sub-basin such as in the Petrel and Tern gas discoveries. Many petroleum plays associated with salt mobilisation remain untested in the Petrel Sub-basin.

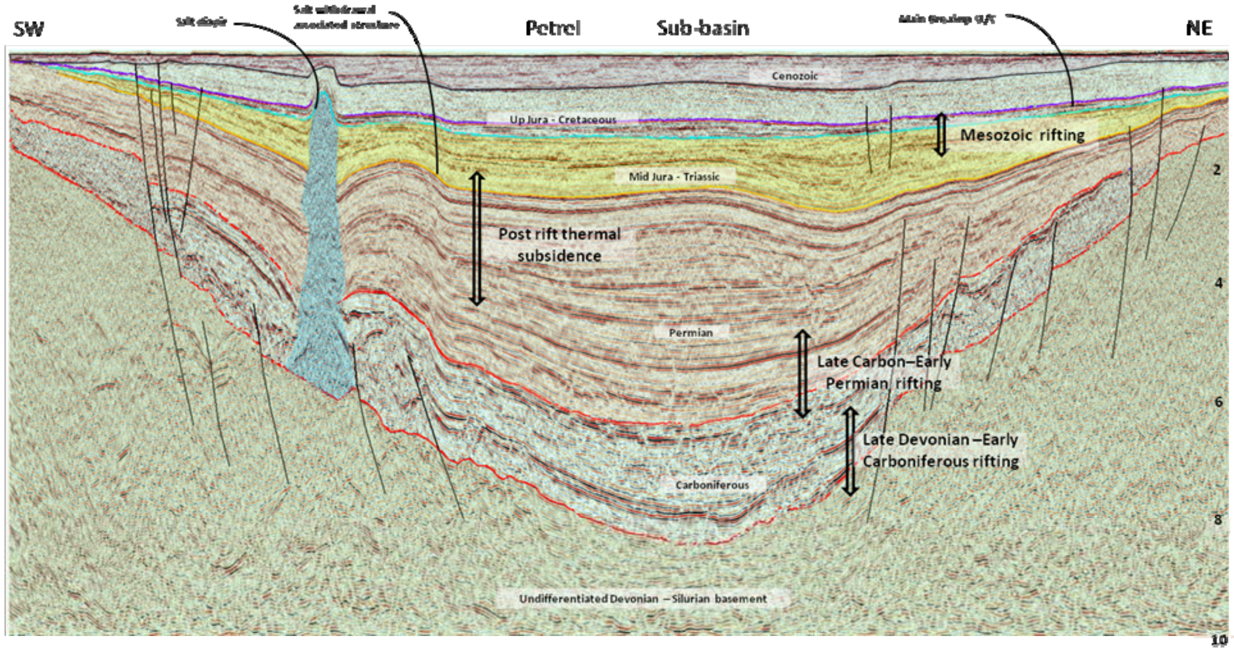

Figure 5: Line 3 (line location in Fig 2) NE-SW seismic section across the Petrel Sub-basin.

West Timor accretionary wedge

Figure 6 shows a seismic line off the south coast of West Timor which has been processed with beam migration. The deep water at 3 s marks the bottom of the Timor Trough, which is continous with the Java Trench to the west and the Taninbar Trough to the east. The southeast side of the Timor Trough shows a geological section typical of the Bonaparte basin to the south in Australian waters. The Permian here is largely a mudstone succession but its top is marked by a limestone which forms a prominent easily mapped reflector at 2-3 s. Above this the Triassic succession is generally sandier and also contains limestone horizons. The Permo-Triassic section is strongly affected by normal faulting which has produced a horst and graben structure. The top of the Triassic is truncated by an unconformity but the faulting continues upward with reduced offsets. Overlying the unconformity is a thin layer of onlapping and draping Jurassic and Cretaceous strata followed by a thick prograding limestone succession.

NW SE

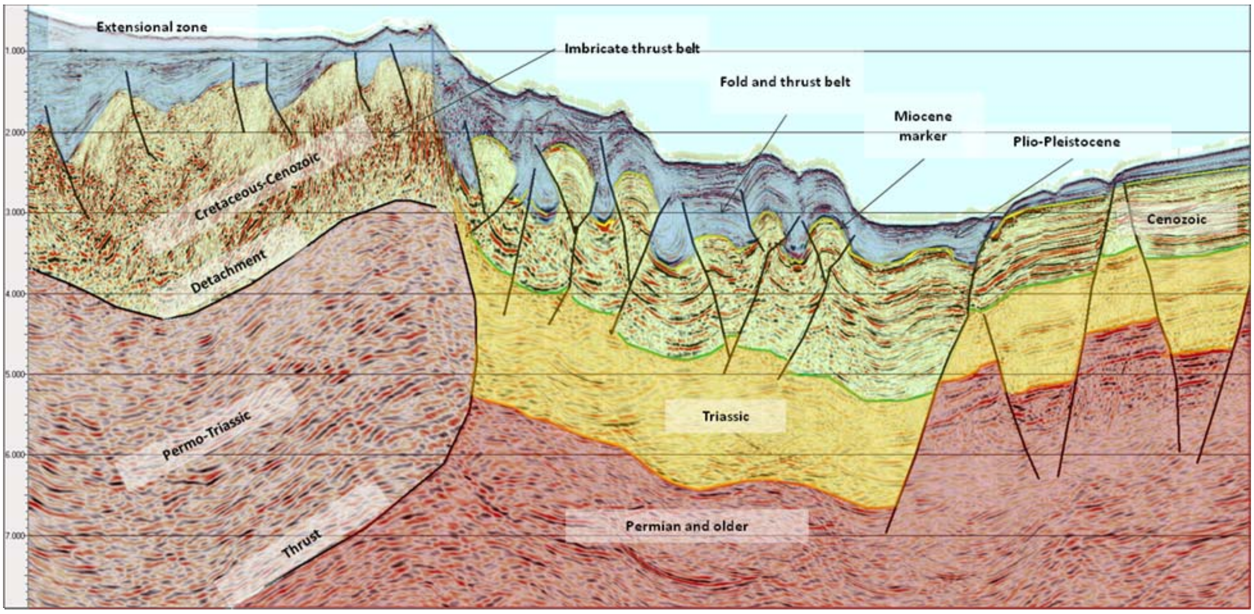

Figure 6: A section on the south side of West Timor showing subdivisions of the accretionary prism and a major underlying thrust (line 4 in Figure 2).

The northwest side of the trough is quite different in appearance. The first new feature encountered on passing to the northwest from the trough is a series of anticlines which affect the Cenozoic carbonates and sometimes affect the sea floor. This is a fold and thrust belt and marks the beginning of compressional tectonics. The anticlines are nested between southeast-verging thrust faults and northwest-verging antithetic thrusts. They can be regarded as fault tip folds. Complementary synclines occupy the footwall zones. This structure is well displayed by a strong marker horizon of probable intra-Miocene age. The pre-Cenozoic part of the section can be roughly followed beneath the anticlines as a relatively quiet zone marking the Triassic and a more reflective zone showing the continuation of the Permian.

The anticlines of the fold and thrust belt are elongated along the thrust front and may form significant traps.The fold and thrust belt ends at a culmination in the sea floor where it gives way to an imbricate thrust belt. This consists of a zone 1.5 – 2 s (3 – 4 km?) thick showing strong reflectors with steep dips to the northwest. It has a well defined lower boundary where the steep reflections become more horizontal. This is interpreted as a zone of stacked thrust slices which have slumped off the front of the growing mass of Timor Island. The lower surface is a detachment along which the thrusts slices have moved, probably along an incompetent layer. The top surface of the imbricate thrust belt is cut by a series of listric faults which define sediment filled half grabens. The half grabens become larger towards the northwest which is towards the source of the slumping and may represent proximal extension to balance the distal compression.

The detachment rises to a crest below the culmination at the distal end of the imbricate thrust belt, as though rising over an underlying obstruction. In fact in this location there is a zone of NW dipping reflections below the detachment. This probably represents a southeast verging thrust, perhaps the most distal of the slices of Australian continental crust which are believed to make up the backbone of Timor. It may consist of Permo-Triassic sediments and could be a petroleum prospect. It is significant that a well, Banli-1, on the south coast of West Timor, penetrated an imbricate thrust belt detached along a zone of overpressured Jurassic shale (Charlton 2006). If the detachment surface is generally sealing then closures in this surface would be a potential play.

Seram Accretionary wedge

Figure 7 shows a southwest-northeast oriented line between Seram and Irian Jaya. It is 120 km long and goes from the accretionary prism in the southwest to the shelf in the northeast. The reflections can be followed for 30 km below the accretionary wedge where they disappear quite suddenly.

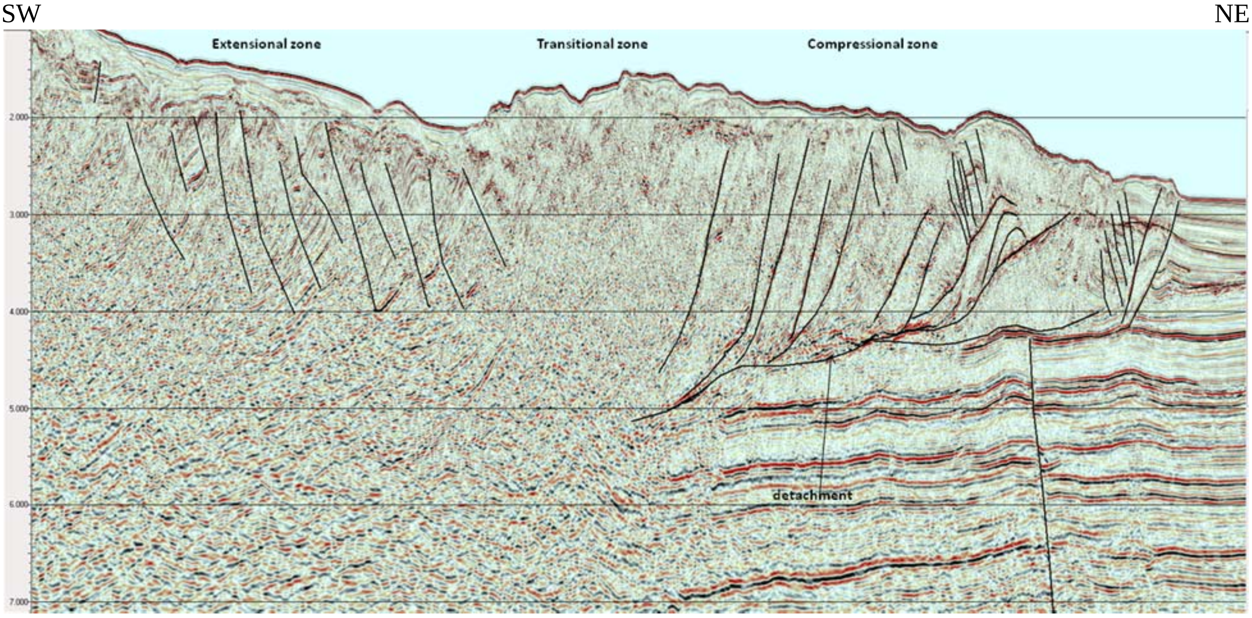

Figure 7: A SW-NE section between Irian Jaya and Seram. Reflections are visible well underneath the accretionary prism (line 5 in Figure 2).

The detachment at the base of the outer half of the accretionary wedge is clearly defined and rises by a series of ramps and flats to the northeast. It divides into a lower and upper thrust near the margin. The wedge itself consists of a series of northeasterly verging thrusts with subsidiary back thrusts. Bedding, where visible, dips either way but dominantly to the northeast.

The character of the structures in the inner half of the wedge is quite different. Here the fault planes dip and downthrow towards the northeast. These are normal, extensional faults. There is a transitional zone between the exensional and compressional zone in which structures are difficult to see. Above this zone the sea floor is offset so that the surface of the outer zone is higher than the surface of the inner zone. The reflections in the deeper section below the wedge disappear under the transitional zone.

The division of the accretionary wedge into an inner extensional zone and an outer compressional zone is reminiscent of the West Timor situation. However no underlying major thrust can be seen in the data below the transitional zone.

The continuation of the reflections below the accretionary wedge demonstrates that these probable Mesozoic rocks with their included source and reservoir rocks are accessible to drilling. The thickness of the wedge at 2-3 seconds corresponds to maybe 3-5 km. Emplacement of the accretionary wedge in Neogene times could have pushed source rocks into the oil and gas window comparatively recently.

Conclusion

A suite of good quality very long 2D lines has helped in elucidating the structure of the northern margin of Australia and adjacent parts of Indonesia. Individual basins are set in a regional context, allowing detailed comparisons between them. The use of dual sensor acquisition on these long lines has improved the resolution of the data and notably enhanced the deeper part of the section. In areas of steep dips, notably over accretionary wedges, considerable improvements have been brought about by the application of Beam migration.

On the Exmouth Plateau the better visibility of the deeper section has led to clearer images of sills in the Permo-Triassic section and a clearly defined zone deep in the crystalline crust which may result from magmatic underplating. Better imaging of the deep structure is helping to improve understanding the development of the NW Shelf. In the Browse Basin the Callovian volcaniclastic rocks are more clearly defined than before which is important because they are a major risk to the Plover Formation reservoir sands. Imaging of salt induced structures in the Petrel Basin, the principal play in this region, has greatly improved. Structures within the accretionary prisms in both the Timor and Semai Troughs are imaged with unprecedented clarity and a deep underlying thrust has been revealed in the Timor Trough. This could lead to more confident exploration within the accretionary prisms.

In summary the dual sensor 2D seismic is aiding better understanding of the basins on the Australian margin, particularly in more frontier areas.

References

Barber, P.M., 1988, The Exmouth Plateau Deep water Frontier: A Case History, Proceeding North West Shelf Symposium, Perth, 1988.

BHP Billiton, 2003, Maginnis-1, -1A, -1A/ST2 Well completion report, unpublished open file, petroleum report, Geoscience Australia.

Bradshaw, M.T., Bradshaw, J., Murray, A.P., Needham, D.J., Spencer, L., Summons, R.E., Wilmot, J., And Winn, S, 1994, Petroleum systems in west Australian basins, in PURCELL, P.G., and PURCELL, R.R., (Eds), The Sedimentary Basins of Western Australia: Proceedings of the Petroleum Exploration Society of Australia, Perth, 1994, 93-118.

Charlton, T. R., 2006.The petroleum potential of West Timor. In: Proceedings, Indonesian Petroleum Association, Twenty Eighth Annual Convention & Exhibition 2001, 301-317.

Earl, K.L., An Audit of wells in the Arafura Basin, Geoscience Australia Record 2006/02, 1 – 86.

Forman, D.J., And Wales, D.W., 1981, Geological evolution of the Canning Basin, Western Australia, Bureau of Mineral Resources, Geology and Geophysics Bulletin, 210, 91p.

Keep, M., Clough, M. And Langhi, L., 2002. Neogene tectonic and structural evolution of the Timor Sea region, NW Australia. In: Keep, M. and Moss, S. J. (Ed) The Sedimentary Basins of Western Australia 3, 341-353.

Longley, I.M., Buessenschuett, C., Clydsdale, L., Cubitt, C.J., Davis, R.C., Johnson, M.K., Marshall, N.M., Murray, A.Ap., Somerville, R., Spry, T.B. and Thompson, N.B., 2002. The North West Shelf of Australia – a Woodside perspective. In: Keep, M. and Moss, S., (Eds) Sedimentary Basins of Western Australia Volume 3: Proceedings of the Petroleum Exploration Society of Australia, Perth, 2002, p. 27 -88.

Miltz, M., Thermo-Tectonic history of the Carnarvon Basin, 2010, Unpublished thesis, Macquarie University, Sydney.

Mory, A.J., 1988, Regional geology of the offshore Bonaparte Basin, in Purcell, P.G., and Purcell, R.R., (Eds), The North West Shelf, Australia: Proceedings of the Petroleum Exploration Society of Australia, Perth, 1988, 287-309.

Purcell, P.G., and Purcell, R.R, 1988a, The North West Shelf, Australia - An Introduction, in Purcell, P.G., and Purcell, R.R., (Eds), The North West Shelf, Australia: Proceedings of the Petroleum Exploration Society of Australia, Perth, 1988, 3-15

Purcell, P.G., and Purcell, R.R., (Eds), 1994, The Sedimentary Basins of Western Australia: Proceedings of the Petroleum Exploration Society of Australia, Perth, 1994, 1 - 15.

Purcell, P.G., and Purcell, R.R., (Eds), 1998, The Sedimentary Basins of Western Australia 2: Proceedings of The Petroleum Exploration Society of Australia, Perth, 1998.

Veevers, J.J., 1984, Phanerozoic earth history of Australia, Claredon Press, Oxford.