Australian Government

Department of Industry
Tourism and Resources

2007 RELEASE OF AUSTRALIAN OFFSHORE PETROLEUM EXPLORATION AREAS

AREAS W07-18, W07-19, W07-20 and W07-21
BEAGLE SUB-BASIN
CARNARVON BASIN, WESTERN AUSTRALIA

SECTIONS

Australian Government
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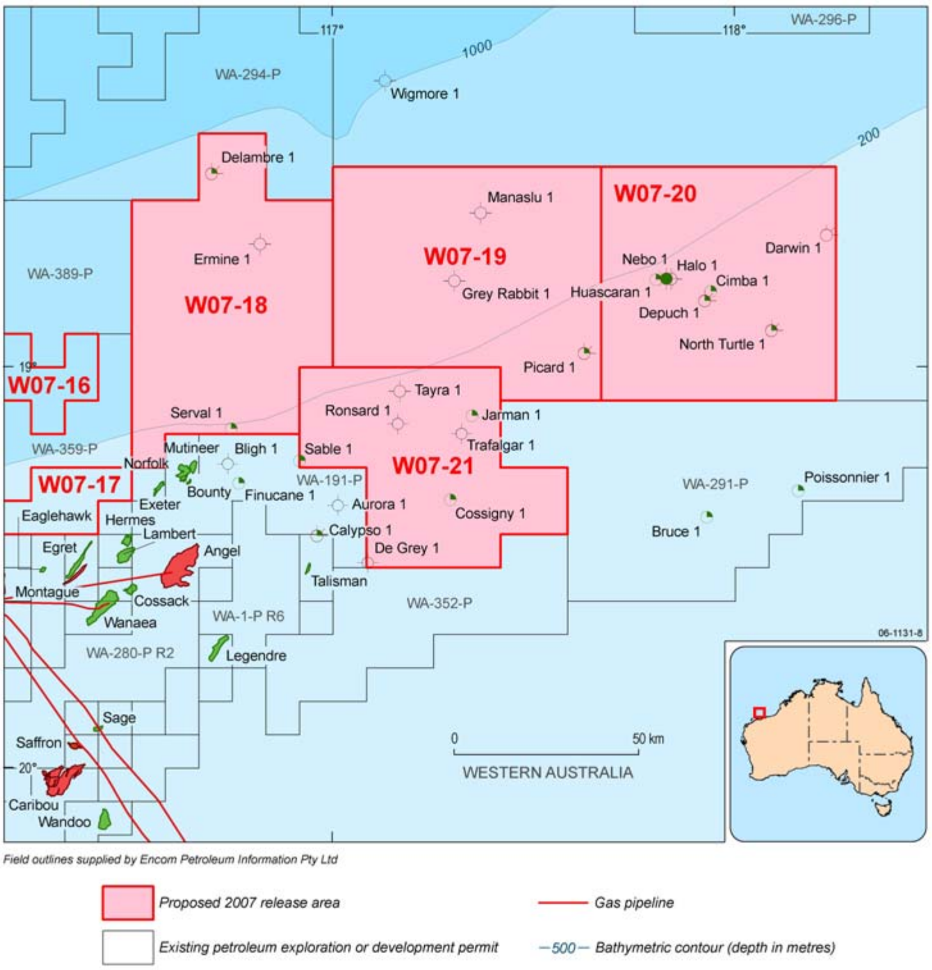
2007 RELEASE OF AUSTRALIAN OFFSHORE PETROLEUM EXPLORATION AREAS

SUMMARY

AREAS W07-18, W07-19, W07-20 AND W07-21
BEAGLE SUB-BASIN, CARNARVON BASIN
WESTERN AUSTRALIA

BIDS CLOSE 17th APRIL 2008

- Active petroleum system confirmed by Nebo 1 oil discovery.
- Abundant Jurassic–Triassic horsts and intervening wrench-controlled troughs.
- Basin-margin Permo-Carboniferous terraces and horsts.
- Triassic–Jurassic fluvio-deltaic and Late Jurassic marine fan reservoirs.
- Regional Early Cretaceous and Middle Triassic seals.
- Proven local Early Jurassic source pod, but regional source distribution/quality risk.
- Special Notices apply, refer to Guidance Notes.



Field outlines supplied by Encom Petroleum Information Pty Ltd

CARNARVON BASIN GEOLOGY

REGIONAL GEOLOGY

The Carnarvon Basin is the southernmost component of the Late Palaeozoic to Cenozoic Westralian Super-basin that underlies the northwestern continental margin of Australia from North West Cape in the south to the Arafura Sea in the north. The basin contains a series of major Mesozoic depocentres, most of which lie offshore (**Figure 1**). The southern part of the basin consists of Palaeozoic depocentres, with Palaeozoic strata out cropping onshore.

The northern, offshore part of the Carnarvon Basin evolved from a pre-rift, broadly sag basin in the Late Palaeozoic, through tectonically active syn-rift sub-basins in the Jurassic, to a passive margin carbonate shelf in the Cenozoic (**Figure 2**). The geological evolution of the basin has been discussed in detail by many authors, and the summary presented below is derived from the work of Kopsen and McGann (1985), Boote and Kirk (1989), Hocking (1990), Jablonski (1997), Westphal and Aigner (1997), Tindale et al (1998), Bussell et al (2001), Norvick (2002), and Longley et al (2002).

The offshore part of the Carnarvon Basin comprises the Exmouth, Barrow, Dampier and Beagle sub-basins, the Exmouth Plateau (including the Investigator Sub-basin) and the Rankin Platform (**Figure 1**). The tectonic elements of the region are dominated by a northeasterly trend that developed as a result of rift tectonism initiated in the Early Jurassic and continuing until the Late Jurassic. Inboard basin-bounding faults are similarly oriented, and subsequent tectonic movements have variably inherited this structural alignment. The last major rift-related tectonism occurred in the Valanginian, preceding the final continental separation of Greater India from Australia.

As a result of the Jurassic and Early Cretaceous rift tectonism, the Barrow and Dampier sub-basins form a northeast-trending graben, bounded on the outboard side by the buried fault escarpment of the Rankin Platform and the Exmouth Plateau. The outboard side of the Exmouth Sub-basin and Exmouth Plateau is bounded by oceanic crust.

The Palaeozoic evolution and stratigraphy of the northern offshore part of the Carnarvon Basin is poorly known, but it is relatively unimportant for petroleum geology. The Mesozoic and Cenozoic successions are divided into several megasequences, variably influenced by tectonic phases associated with major rifting and sea-floor spreading. A generalised stratigraphy of the basin is shown in **Figure 2** and comprises the following megasequences:

- Pre-rift active margin megasequence (Triassic to mid-Pliensbachian).
- Early syn-rift megasequence (mid-Pliensbachian to mid-Callovian).
- Main syn-rift megasequence (mid-Callovian to latest Tithonian).
- Late syn-rift Barrow Delta megasequence (latest Tithonian to mid-Valanginian).
- Post-rift active margin megasequence (mid-Valanginian to mid-Santonian).
- Passive margin megasequence (mid-Santonian to Miocene).

Depositional environments and hydrocarbon generation, migration and entrapment are strongly controlled by rift-related tectonics in the basin. During the pre-rift active margin phase, marine and fluvio-deltaic sediments were deposited in an extensive basin. This basin subsequently fragmented into smaller depocentres in which marine and deltaic sediments were deposited during the early syn-rift phase, with restricted marine sediments being deposited during the main syn-rift phase. During the late syn-rift phase, various marine sediments were deposited within the framework of the large-scale Barrow Delta system. In the post-rift active phase, transgressive shaly marine deposition prevailed. During the subsequent passive margin phase, a variety of marine carbonate sediments were deposited in open marine shelfal environments.

Clastic sediments were sourced from the southeastern cratonic flank throughout the Mesozoic and Cenozoic evolution of the basin (Longley et al, 2002). In addition, tectonic uplift in the Jurassic and syn-depositional inversions in the Cretaceous provided depocentres with reworked sediments from highstanding areas within the basin.

Pre-rift active margin

A regional marine transgression, as a result of post-rift sagging of the previous Palaeozoic rift cycle, commenced at the beginning of the Triassic, depositing the Locker Shale unconformably over Permian sediments (**Figure 2**). The Locker Shale was deposited in broad, relatively unfaulted downwarps and it grades upwards into the fluvio-deltaic Mungaroo Formation, which is composed of thick sequences of sandstones and claystones with some coals. The fluvio-deltaic system prograded to the northwest, to cover much of the offshore part of the Carnarvon Basin. The Mungaroo Formation sediments were deposited in a broad, low relief, rapidly subsiding coastal plain, which included an extensive swamp system cross-cut by multiple rivers. The Mungaroo Formation also contains limestone units.

The fluvial sandstones of the Mungaroo Formation form the principal reservoir rocks of the giant gas accumulations on the Rankin Platform. The uppermost, marine part of the Mungaroo Formation consists of shoreline sandstones and claystones. The uppermost part of the Mungaroo Formation is absent in the well explored eastern part (around the North Rankin gas field) of the Rankin Platform. In contrast, this part of the formation is well preserved on the western outboard portion of the Rankin Platform where it is one of the major reservoirs in the Gorgon, Geryon, Maenad and Orthrus gas accumulations (**Figure 3**).

Throughout much of the Triassic, the onshore portions of the Carnarvon Basin and the onshore Pilbara Block were undergoing active uplift and erosion, providing sediment sources for the Locker Shale and Mungaroo Formation. However, this abundant supply was disrupted by the end of the Triassic (Hocking, 1990).
Marking rapid subsidence at the onset of the Early Jurassic, the transgressive Brigadier Formation and Murat Siltstone were deposited in a marine shelf environment and comprise thinly bedded marine siltstones, claystones and marls. The Brigadier Formation is well preserved below a widespread Late Jurassic unconformity in the outer part of the Carnarvon Basin, and the top of the formation represents the maximum flooding surface of the Early Jurassic marine transgression.

Within the Kangaroo Syncline in the southern Exmouth Plateau, the preserved Early to Middle Jurassic section, including the Brigadier Formation, is thicker than on the Rankin Platform (Bussell et al, 2001). Thin, reservoir-quality sandstones on some horst blocks along the Rankin Platform are known as the North Rankin Formation.

Early syn-rift

The pre-rift active margin to syn-rift transition is represented by the rift-onset Pliensbachian Unconformity (JP1 seismic horizon; **Figure 2**). Extensional rift faulting and warping produced northeast-trending tilted fault blocks, horsts and graben (Barber, 1988). The development of the Exmouth, Barrow and Dampier sub-basins and Rankin Platform was initiated during this early syn-rift phase, and these elements remained tectonically active throughout the Jurassic.

The early syn-rift megasequence (mid-Pliensbachian to mid-Callovian) comprises restricted marine claystones of the Athol Formation and deltaic sandstones of the Legendre Formation. The Legendre Delta developed in the early Bathonian in the Dampier Sub-basin, but sedimentation ceased by the early Callovian.

Main syn-rift

The mid-Callovian unconformity surface (JC seismic horizon; **Figure 2**) defines the boundary between the early syn-rift (mid-Pliensbachian to mid-Callovian) and main syn-rift (mid-Callovian to latest Tithonian) megasequences. This unconformity represents the onset of the continental breakup of the northwest Australian margin (Jablonski, 1997). Claystones of the transgressive Callovian Calypso Formation were deposited in the Barrow and Dampier sub-basins over the surface of the unconformity.

Major rift faults developed along the northern edge of the Exmouth Plateau in the Callovian, but through-going oceanic crust was not created until the late Oxfordian (Norvick, 2002). The basal Oxfordian Unconformity ('Breakup Unconformity'; JO seismic horizon; **Figure 3**) represents this phase of continental breakup and the onset of sea-floor spreading to form the Argo Abyssal Plain.

The term 'Main Unconformity' (MU seismic horizon; **Figure 2**) has been used widely to refer primarily to the basal Oxfordian (JO) unconformity. In practice, however, this horizon is often a composite sequence boundary, ranging in age from basal Jurassic in one part of the basin to Aptian in another (Jablonski, 1997). For instance, in some areas on the Rankin Platform, the Norian Mungaroo Formation underlies the Albian Windalia Radiolarite or Gearle Siltstone, indicating that the Main Unconformity represents a 92 million year hiatus (Newman, 1994). A large and inconsistent time break at the Main Unconformity has led to confusion regarding the nature and timing of erosion. Because of the diachronous nature of the unconformity surface, the composite Main Unconformity is also called the 'Intra-Jurassic Unconformity (IJU seismic horizon; **Figure 2**)' (Sibley et al, 1999).

Following continental breakup, active faulting continued in the Late Jurassic. This resulted in uplift and tilting of the inboard basin-bounding shelf and Rankin Platform. Reworked sediments were deposited in depocentres adjoining the uplifted areas.

Tectonic subsidence rates far exceeded sedimentation rates in regional depocentres, resulting in a thick succession of deep-water Dingo Claystone, which gradually filled the graben depocentres and progressively overlapped the flanks of high blocks (Tindale et al, 1998). This deep-water marine sedimentation was confined to the graben depocentres of the Barrow, Dampier and Exmouth sub-basins. The Oxfordian maximum flooding phase of the graben system provided a favourable depositional environment for high quality, oil-prone source rocks (Norvick, 2002).

Although marine claystones dominate the main syn-rift (mid-Callovian to latest Tithonian) megasequence, paradoxically this is also the time when reservoir-quality turbidite, submarine fan, shoreline and fluvial sandstones were deposited locally at the edge of tectonically active graben.

On the eastern portion of the Exmouth Plateau, Late Jurassic deposition of sandy shelfal facies occurred within restricted shallow basins. The Kangaroo Syncline was also tectonically active during the Late Jurassic across the southern Exmouth Plateau and northern Exmouth Sub-basin, in response to footwall uplift of the Triassic tilted fault blocks on the Rankin Platform. The uplift created a hinterland that provided a source for coarse clastic sediments eroded from the Mungaroo Formation and transported into the shallow marine environment of the syncline. By the Tithonian, the gradual subsidence and peneplanation of the provenance area limited clastic input to the syncline (Jenkins et al, 2003).

Oxfordian shallow-marine sandstone (Jansz Sandstone) is the major reservoir in a stratigraphic trap for the giant Jansz/Io gas accumulation (Jenkins et al, 2003). The Biggada Sandstone, Dupuy and Angel formations are other significant reservoir-quality sandstones deposited in this megasequence. For example, turbidite sandstones of the Angel Formation, which are the major oil- or gas-bearing reservoirs in the Dampier Sub-basin, were deposited in the Tithonian when reactivation of horsts and graben resulted in further erosion of marginal areas with reworking of quartz-rich sandstones (Hocking, 1990).

Further inshore, an Oxfordian shallow-marine sandstone (Linda Sandstone) was deposited in the eastern Barrow Sub-basin, which has traditionally been viewed as a deep-water depocentre. Late Jurassic shore-face and shallow-marine sandstones may be aligned parallel to shorelines elsewhere in the Carnarvon Basin (Moss et al, 2003).

Late syn-rift Barrow Delta

Latest Jurassic uplift and erosion marked the onset of late syn-rift (latest Tithonian to mid-Valanginian) sedimentation. The large Barrow Delta system abruptly and briefly developed in the Carnarvon Basin during this tectonically quiescent phase. The Barrow Delta was extensive, and its sediments are up to 2500 m thick. The delta prograded in two major phases, and two main delta lobes were developed. The initial depositional phase occurred over the Exmouth Sub-basin in response to a copious supply of sediments from the south. The delta then prograded rapidly to the north over a thick pile of turbidites and pro-delta shales to a maximum northward limit roughly west from Barrow Island across the Exmouth Plateau. On the Exmouth Plateau, the Barrow Group consists of turbidites, basin floor fans and fluvio-deltaic

sediments of the lower Barrow Delta lobe. A turbidite fan formed the sandstone complex at the Scarborough gas accumulation to the north of the delta front (Norvick, 2002).
While the delta resumed progradation in the late Berriasian, erosion of the lower delta lobe occurred in the inshore part of the Exmouth Sub-basin. The new depocentre of the delta retreated 250 km to the east and extended inboard beyond the eastern limit of the first phase. As a result, a back-stepped delta (upper Barrow Delta lobe) was developed in the Barrow and Dampier sub-basins. The second phase reached its northern limit around the Gorgon horst structure.

The sediments of the lower (or western) Barrow Delta lobe are collectively known as the Malouet Formation comprising bottom-set submarine fan sandstones and pro-delta claystones, and those of the upper (or eastern) lobe are known as the Flacourt Formation, comprising basinal turbidites, fore-set claystones and top-set sandstones. The boundary between the two lobes is markedly diachronous and cannot always be picked as a continuous regional seismic horizon (Baillie and Jacobson, 1997). The lower Barrow Delta lobe contains approximately 75 % of the sediments deposited by the Barrow Delta system (Ross and Vail, 1994). Barrow Group sandstones are predominantly quartzose with minor clay matrix and are weakly cemented by calcite, pyrite or siderite. The porosity and permeability of these sandstones tend to be excellent in the outer part of the Carnarvon Basin.

Sandy units within the top Barrow Group are variously named, and their nomenclature is somewhat confusing. They include; the top sandstone of the Barrow Group, top sandstone of the Flacourt Formation, Zeepaard Formation, and Flag Sandstone. The Zeepaard Formation was deposited across wide areas of the Barrow and Exmouth sub-basins, Rankin Platform and Exmouth Plateau as progradational top-set units of the Barrow Delta in front of multiple distributaries at slightly different times in the early Valanginian. In contrast, the Flag Sandstone was deposited as a submarine fan sandstone in the northeastern inboard part of the Barrow Sub-basin, in front of the last fore-set of the Barrow Delta.

The supply of sediment to the Barrow Delta system ceased due to the disruption of a major fluvial distributary system in the Valanginian, when continental breakup commenced to the southwest of the Exmouth Plateau (Hocking, 1990). The Exmouth Sub-basin and Exmouth Plateau were tectonically inverted during breakup, but subsidence and marine sedimentation continued throughout the Barrow and Dampier sub-basins.

Post-rift active margin

After tectonic uplift and faulting associated with the separation of Greater India and Australia in the Valanginian, a large portion of the Carnarvon Basin was subjected to peneplanation. This event was followed by regional post-rift sagging sedimentation in the offshore part of the basin from the mid-Valanginian to mid-Santonian.

Post-rift marine deposition commenced on the Valanginian unconformity surface (KV seismic horizon; **Figure 2**), and the Birdrong Sandstone and glauconitic Mardie Greensand were deposited in smaller deltas. This localised sedimentation cycle was followed by the basin-wide deposition of the transgressive marine Muderong Shale, Windalia Radiolarite and Gearle Siltstone. The Muderong Shale is a regional seal, but also contains economically important petroleum-bearing marine sandstones such as the *M. australis* Sandstone (also known as the Stag Sandstone) and Windalia Sandstone in the Barrow and Dampier sub-basins. These sandstones overlie the intra-Valanginian unconformity, and are characteristically glauconitic and diachronous.

The Windalia Sandstone of the Muderong Shale was historically a major exploration target in the Barrow Sub-basin. More than 90 % of the initial oil reserves of the Barrow Island oil field, which is the largest in the Carnarvon Basin, are contained within this sandstone in at least 30 identified oil- or gas-bearing reservoir units in the field (Ellis et al, 1999).

Passive margin

Siliciclastic sedimentation ceased by the mid-Santonian as a result of tectonic stability and a decreasing supply of terrigenous sediments. Shelfal carbonate sediments were deposited on the passive continental margin in the Late Cretaceous and Cenozoic, as the whole region continued to cool and subside after cessation of the rifting process. On the deep-water Exmouth Plateau, sedimentation during this period was relatively thin, as subsidence rates outstripped sediment input. Towards the end of the Cretaceous, however, the Kangaroo Syncline on the Exmouth Plateau became the major depocentre of the Carnarvon Basin.

During the Campanian, uplift of the hinterland resulted in a phase of inversion in the Exmouth Sub-basin and Exmouth Plateau, forming the Exmouth Plateau Arch. This tectonic event also marked the onset of transpressional structural growth of pre-existing rift-related structures within the Barrow and Dampier sub-basins (Longley et al, 2002).

In the Miocene, a major compressional event associated with the collision of the Australia-India and Eurasia plates affected the entire northwest Australian margin, including the Carnarvon Basin (Longley et al, 2002). This event caused tilting, inversion, renewed movement on faults, and the creation of new strike-slip or wrench faults (Malcolm et al, 1991). This is also the time when many structural traps within the Cretaceous and Cenozoic strata were formed.

HYDROCARBON HABITAT

The Carnarvon Basin is Australia's most prolific hydrocarbon-producing basin; 77.8 MMbbls or 12.4 GL of oil, 925 bcf or 26.2 BCM of gas and 37.8 MMbbls or 6.0 GL of condensate were produced in 2005 (http://www.doir.wa.gov.au/mineralsandpetroleum/Publications.asp). This represents more than half of Australia's total hydrocarbon production. During 2005 a total of 58 wells were drilled in the basin including 25 new field wildcats, 13 extensions and 20 development wells (http://www.doir.wa.gov.au/mineralsandpetroleum/0D311793CCD44D60B1C1730FB59451C9.asp).

The majority of the hydrocarbons discovered to date in the Carnarvon Basin are reservoired in top porosity beneath the Early Cretaceous Muderong Shale, which forms the regional seal. The presence of this effective regional seal is a major contributing factor to exploration success in the basin (Baillie and Jacobson, 1997). One of the notable exceptions is the Barrow Island oil field, where the oil-bearing Windalia Sandstone of the Muderong Shale is top-sealed by the Aptian Windalia Radiolarite. Another exception is the Maitland gas accumulation, in which Paleocene sandstone is the reservoir. Intra-formational seals are also an important element of hydrocarbon accumulations in the basin, resulting in stacked hydrocarbon-bearing reservoirs beneath a regional unconformity surface. Individual pools in gas accumulations on the Rankin Platform are top sealed by a combination of the regional seal and intra-formational claystones. **Figure 3** shows the major oil and gas accumulations discovered in the Carnarvon Basin.

The main trap styles in the basin are drape anticlines, horsts, fault roll-over structures and stratigraphic pinch-outs beneath the regional seal. The stratigraphic level of top porosity, ranging from the Late Triassic Mungaroo Formation to the Early Cretaceous Mardie Greensand beneath the regional seal, generally becomes progressively younger inboard.

RESERVES

Northern Carnarvon Basin Initial Reserves

Field	Liquids mmbbls	Gas tcf	Gas mmboe	Date	Source
Angel	84.28	1.85	314.52	Dec-05	DoIR
Caribou	1.76	0.03	5.82	Dec-05	DoIR
Corvus	0.50	0.12	20.53	Dec-05	DoIR
Cossack	99.79	0.00	0.42	Dec-05	DoIR
Dixon	7.55	0.15	24.79	Dec-05	DoIR
Dockrell	15.72	0.61	103.38	Dec-05	DoIR
Echo/Yodel	59.37	0.38	64.89	Dec-05	DoIR
Egret	15.72	0.03	5.58	Dec-05	DoIR
Exeter	8.30	0.00	0.00	Dec-05	DoIR
Gaea	3.14	0.12	19.57	Dec-05	DoIR
Goodwyn	363.79	5.34	908.62	Dec-05	DoIR
Hermes	74.17	0.01	1.44	Dec-05	DoIR
Keast	10.06	0.35	59.67	Dec-05	DoIR
Lambert	40.77	0.01	1.38	Dec-05	DoIR
Legendre	43.92	0.00	0.00	Dec-05	DoIR
Mutineer	44.99	0.00	0.00	Dec-05	DoIR
North Rankin	211.45	6.58	1118.92	Dec-05	DoIR
Perseus	278.59	9.14	1554.44	Dec-05	DoIR
Rankin/Sculptor	13.84	0.39	66.28	Dec-05	DoIR
Reindeer	1.70	0.37	63.46	Dec-05	DoIR
Sage	4.65	0.00	0.00	Dec-05	DoIR
Stag	59.89	0.00	0.00	Dec-05	DoIR
Talisman	7.73	0.00	0.00	Dec-05	DoIR
Tidepole	15.72	0.52	88.37	Dec-05	DoIR
Wanaea	333.45	0.13	21.97	Dec-05	DoIR
Wandoo	97.78	0.00	0.00	Dec-05	DoIR

* All reserves are P_{50}
* Conversion factor for gas (bcf to mmboe) is 0.17
* All developed field resources from DoIR have been compiled using the remaining reserves plus the cumulative production as of December 2005. All other fields are reserves as of 31st December 2005.

DoIR - Department of Industry and Resources, Western Australia.

FIGURES – CARNARVON BASIN GEOLOGY

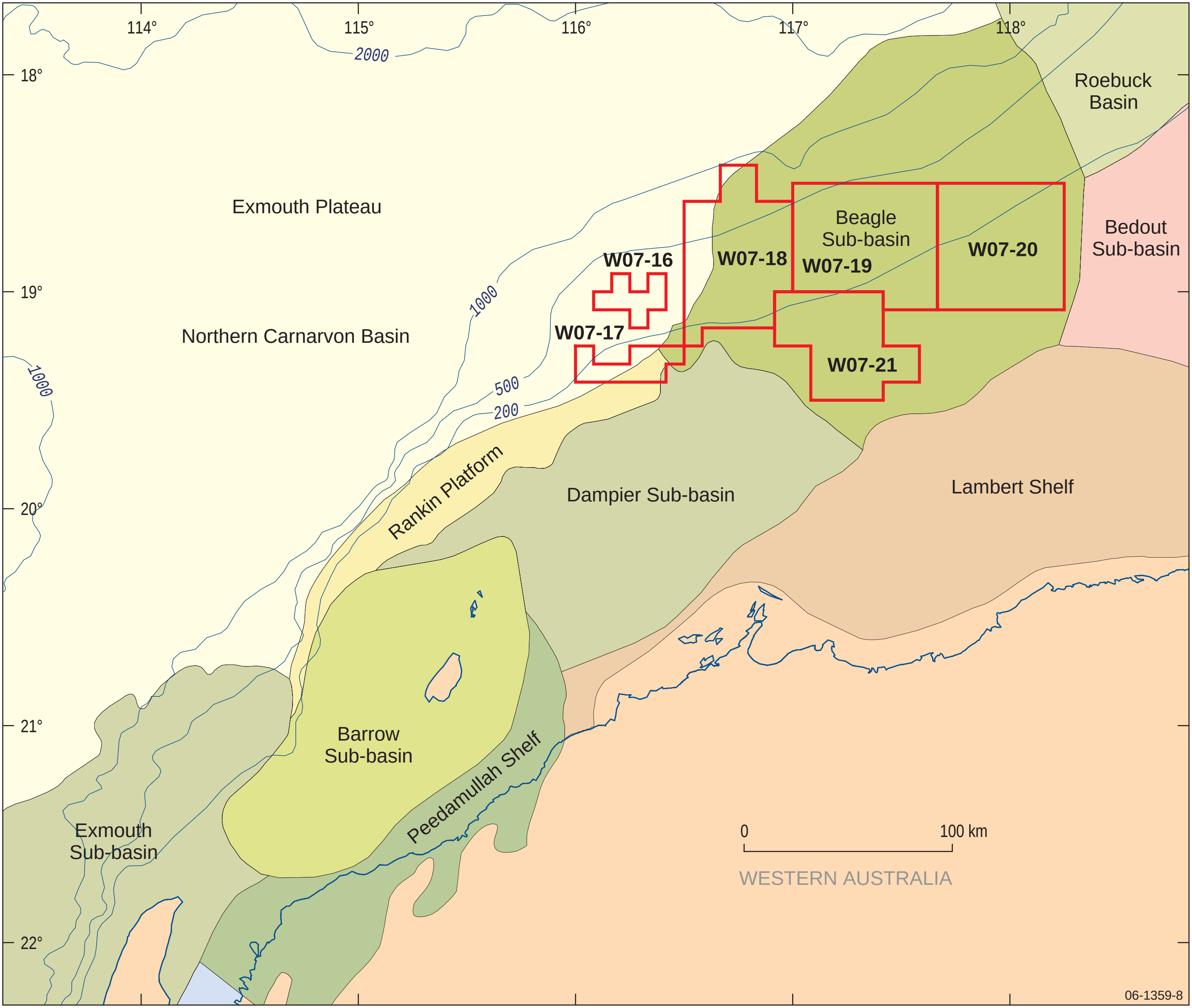


Figure 1. Structural elements of the Northern Carnarvon Basin.

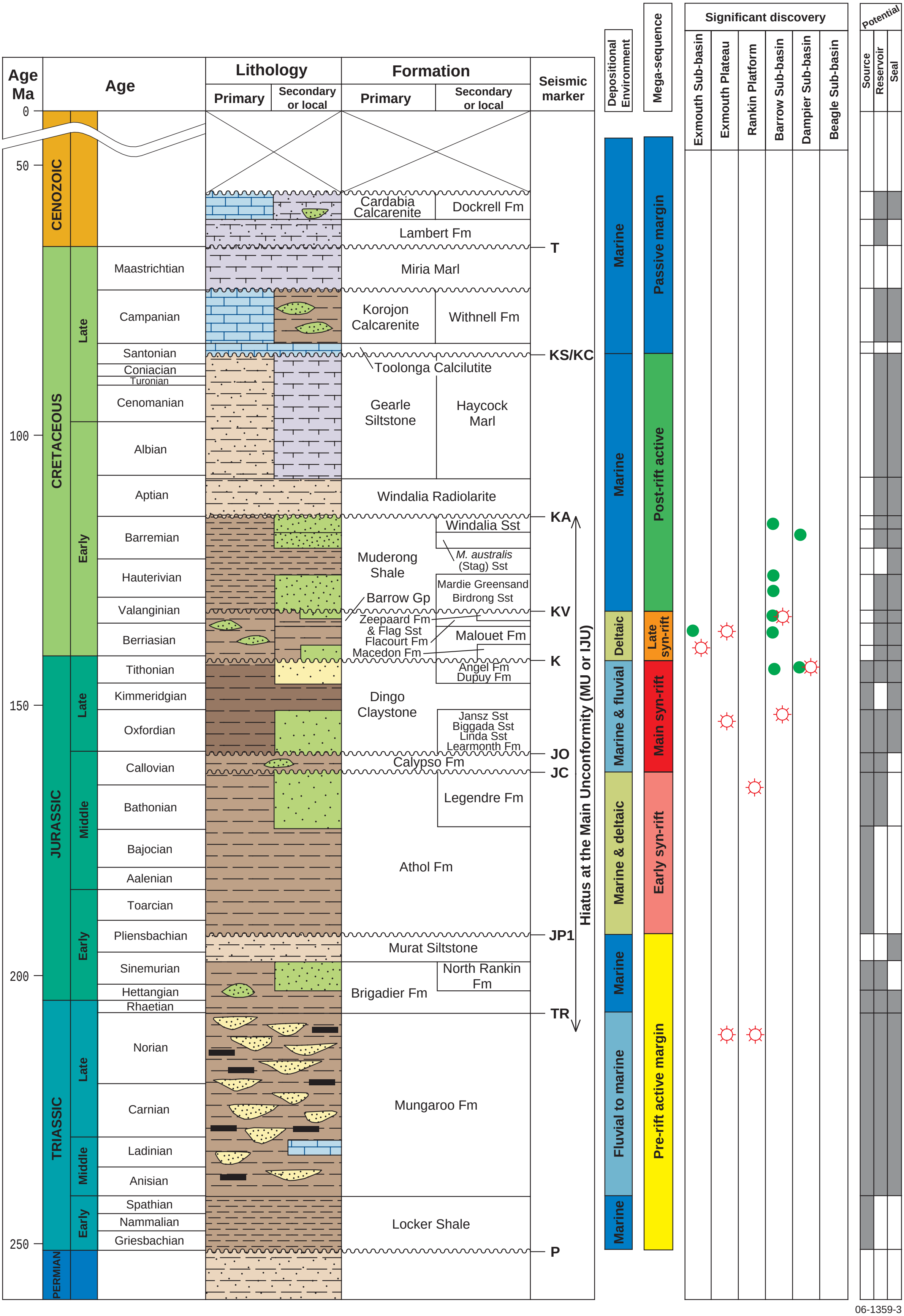
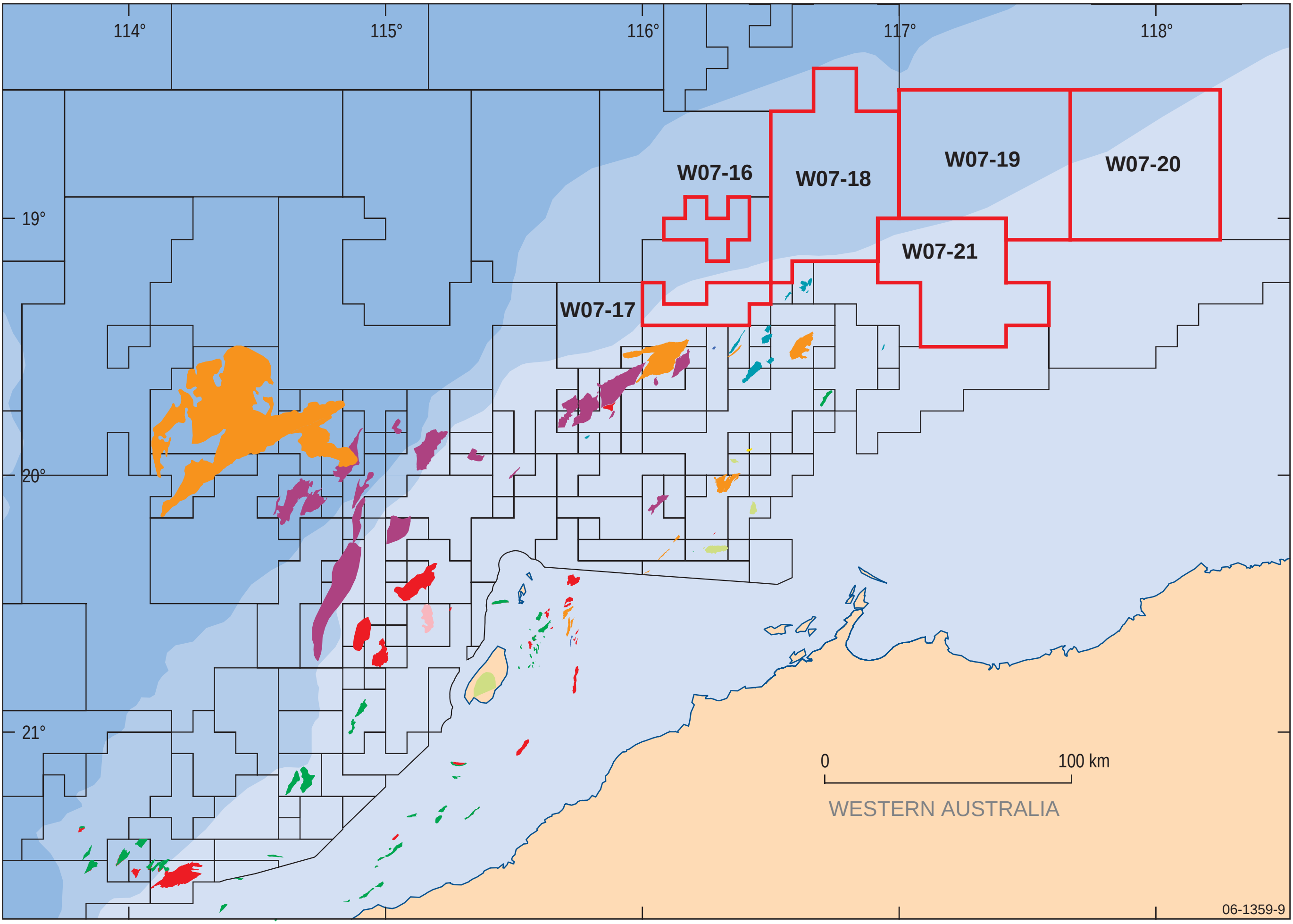


Figure 2. Regional stratigraphy of the Northern Carnarvon Basin.



Period (Formation)	Oil accumulation	Gas accumulation
Paleocene		pink
Barremian (Windalia Sandstone)	light green	yellow
Valanginian & Berriasian (Barrow Group)	green	red
Tithonian, Oxfordian and Middle Jurassic	teal	orange
Upper Triassic (Brigadier and Mungaroo Formations)	blue	purple

Figure 3. Major oil and gas accumulations in the Northern Carnarvon Basin.

AREAS W07-18, W07-19, W07-20 AND W07-21
BEAGLE SUB-BASIN, CARNARVON BASIN
WESTERN AUSTRALIA

BIDS CLOSE 17th APRIL 2008

LOCATION

Areas W07-18 to W07-21 – Beagle Sub-basin
Areas W07-18 to W07-21 lie approximately 150–250 km offshore Dampier, Western Australian, in 80–500 m water depth, increasing to 1000 m in the outer northwest portion of Area W07-18 (**Figure 1**). The release areas occur within the Beagle Sub-basin, the northern most depocentre of the Northern Carnarvon Basin. The nearest production facilities are the Mutineer/Norfolk and Exeter accumulations at the adjacent northern margin of the Dampier Sub-basin, which began production via a floating production, storage and offload facility (FPSO) in 2005. Development of the Angel gas field, also within the Dampier Sub-basin approximately 25 km south of Mutineer/Norfolk, and pipeline to the trunkline at the North Rankin platform is currently underway, and is expected to be fully operational by the end of 2008.

Area W07-18 comprises 45 graticular blocks, covers an area of 3,645 km^2 and contains 3 wells (Delambre 1, Ermine 1 and Serval 1).
Area W07-19 comprises 51 graticular blocks, covers an area of 4,130 km^2 and contains 3 wells (Grey Rabbit 1, Manaslu 1 and Picard 1).
Area W07-20 comprises 49 graticular blocks, covers an area of 3,970 km^2 and contains 7 wells (Cimba 1, Darwin 1, Depuch 1, Halo 1, Huascaran 1, Nebo 1 and North Turtle 1).
Area W07-21 comprises 34 graticular blocks, covers an area of 2,750 km^2 and contains 6 wells (Cossigny 1, De Grey 1, Jarman 1, Ronsard 1, Tayra 1 and Trafalgar 1; Sable 1 lies approximately 230 m west of this release area).

Areas W07-18 to 21 form part of previous permits WA-270-P and WA-292 to WA-295-P, which were awarded following acreage release offered in 1996 and 1998, respectively. These permits were subsequently relinquished during 2003–2005. No new acreage has been released in the Beagle Sub-basin since then, apart from one release area in 2003 (W03-8) across the De Grey Nose that included the Cossigny 1 and de Grey 1 well sites on the southern margin of the sub-basin; no bids were received for that area. The only current permits in the sub-basin are WA-191-P, WA-352-P and WA-291-P along the far southern and south-eastern margins of the sub-basin, and WA-294-P and WA-296-P, which cover a small portion of the far western and northeastern parts of the sub-basin, respectively (**Figure 1**).

GRATICULAR BLOCK LISTING AND MAP

Area W07-18
Beagle Sub-basin, Carnarvon Basin, Western Australia

Map Sheet SE 50 (Rowley Shoals)

2121	2122	2193	2194	2263	2264
2265	2266	2267	2268	2335	2336
2337	2338	2339	2340	2407	2408
2409	2410	2411	2412	2479	2480
2481	2482	2483	2484	2551	2552
2553	2554	2555	2556	2623	2624
2625	2626	2627	2695	2696	2697
2698	2699	2767			

Assessed to contain 45 full blocks

Area W07-19
Beagle Sub-basin, Carnarvon Basin, Western Australia

Map Sheet SE 50 (Rowley Shoals)

2197	2198	2199	2200	2201	2202
2203	2204	2269	2270	2271	2272
2273	2274	2275	2276	2341	2342
2343	2344	2345	2346	2347	2348
2413	2414	2415	2416	2417	2418
2419	2420	2485	2486	2487	2488
2489	2490	2491	2492	2557	2558
2559	2560	2561	2562	2563	2564
2634	2635	2636			

Assessed to contain 51 full blocks

Area W07-20
Beagle Sub-basin, Carnarvon Basin, Western Australia

Map Sheet SE 50 (Rowley Shoals)

2205	2206	2207	2208	2209	2210
2211	2277	2278	2279	2280	2281
2282	2283	2349	2350	2351	2352
2353	2354	2355	2421	2422	2423
2424	2425	2426	2427	2493	2494
2495	2496	2497	2498	2499	2565
2566	2567	2568	2569	2570	2571
2637	2638	2639	2640	2641	2642
2643					

Assessed to contain 49 full blocks

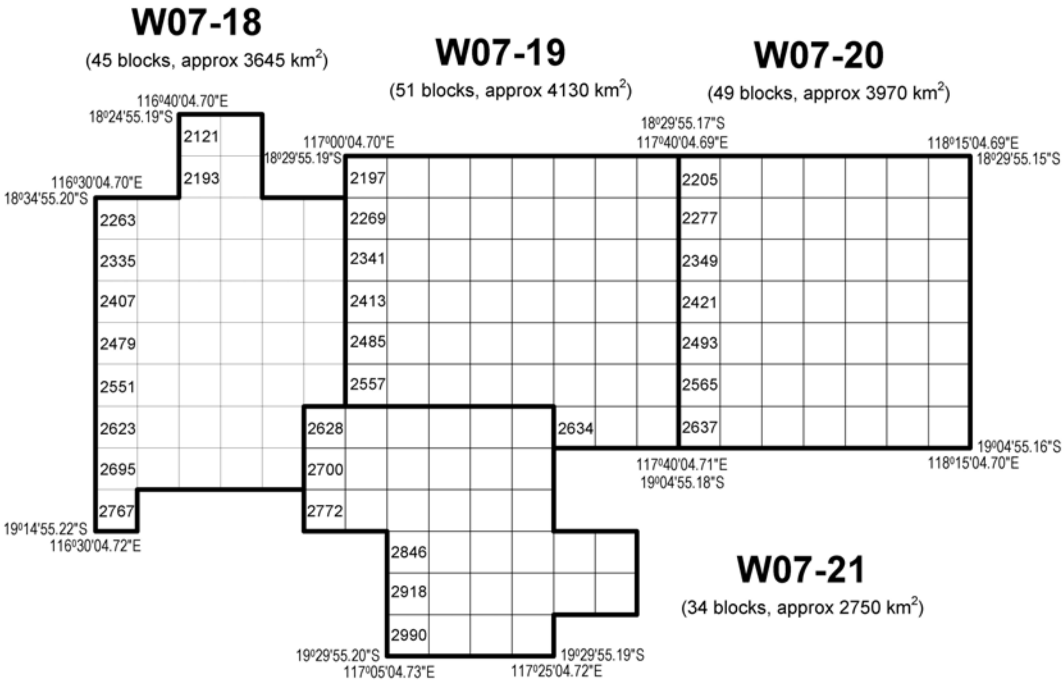
Area W07-21
Beagle Sub-basin, Carnarvon Basin, Western Australia

Map Sheet SE 50 (Rowley Shoals)

2628	2629	2630	2631	2632	2633
2700	2701	2702	2703	2704	2705
2772	2773	2774	2775	2776	2777
2846	2847	2848	2849	2850	2851
2918	2919	2920	2921	2922	2923
2990	2991	2992	2993		

Assessed to contain 34 full blocks

2007 Release Areas
Beagle Sub-basin, Carnarvon Basin
Western Australia



MAP SHEET
SE 50 (Rowley Shoals)

Grid coordinates on this map are presented with reference to the Geocentric Datum of Australia (GDA94). Permit areas are based on the same grid, Australian Geodetic Datum (AGD66), that has defined areas since the Petroleum (Submerged Lands) Act was proclaimed in 1967. However, with the adoption of GDA94, the gridlines are no longer referred to in whole multiples of 5 minutes as they were under AGD66.

ASPD 6118-12

RELEASE AREA GEOLOGY

AREAS W07-18 TO W07-21 – BEAGLE SUB-BASIN

Tectonic setting

The Beagle Sub-basin is a complex Mesozoic wrench depocentre in the northern part of the Carnarvon Basin, and is somewhat transitional between the Dampier Sub-basin to the southwest, and the Rowley and Bedout Sub-basins of the Roebuck Basin to the northeast and east. It is bounded to the east by the shallow basement areas of the Lambert Shelf, and covers an area of approximately 30,000 km^2. The sub-basin forms part of the Late Palaeozoic–Early Cretaceous rift margin of northwestern Australia, and is bordered to the southeast by the Pilbara cratonic block, and flanked to the northwest by the northern portion of Exmouth Plateau and oceanic crust of the Argo Abyssal Plain.

Sub-basin evolution and structural elements

The Beagle Sub-basin can be sub-divided into two tectonically controlled regions (Blevin et al, 1994a, 1994b; **Figure 2**):

1. An east-northeast-trending region of shallow basement in the south and east, encompassing the Lambert Shelf and flanking marginal fault blocks of the Bruce Terrace, North Turtle Terrace and De Grey Nose.
2. A Mesozoic to Cainozoic depocentre comprising the bulk of the sub-basin to the north and west of the North Turtle Fault Zone.

The structural terraces along the southeast basin margin probably formed during an early extensional phase in the Palaeozoic. The **Bruce Terrace** is a board, down-faulted, relatively shallow basement terrace adjacent to the wide shallow Precambrian basement area of the **Lambert Shelf**. The terrace is overlain by a moderately thick section of Late Palaeozoic and Triassic sediments, and a thinner section of Jurassic–Cainozoic sediments that onlap and pinchout across the Lambert Shelf.

The **North Turtle Terrace** is an arcuate north-northeast-trending zone of ?Permo-Carboniferous fault blocks that are progressively down-thrown to the northwest. The outer boundary of the terrace is defined by a narrow zone of listric northwest-dipping, growth faults (North Turtle Fault Zone). Periodic reactivation of these faults has provided a sediment source for fan systems that prograded into the main basin depocentre during the Late Jurassic to early Neocomian, and that have continued to be active into the Late Cretaceous–Early Tertiary.

The **De Grey Nose** forms the boundary between the main Beagle Sub-basin depocentre and the Dampier Sub-basin to the south. It is a Palaeozoic (?Permian) shallow basement fault block that is cut by a series of north-northwest-trending transfer faults (Blevin et al, 1994a). Late Triassic structuring virtually closed off the Beagle Sub-basin from the Dampier Sub-basin, and generated rotated fault blocks beneath the De Grey Nose. The isolation of the Lewis Trough (Dampier Sub-basin) from the Cossigny and Beagle troughs had a profound effect on subsequent depositional patterns throughout the region.

The **main basin depocentre** is characterised by a series of parallel, north-trending, Triassic–Jurassic fault blocks that are separated by intervening structural lows or troughs (**Figure 2**). The fault blocks dip gently north and appear to narrow and bifurcate to the south, whilst broadening and becoming more highly faulted to the north. Although this fault block and trough geometry resembles rift-related Jurassic extensional horsts/graben elsewhere on the North West Shelf, the principal fault movement preceding Callovian breakup was predominantly lateral in the Beagle Sub-basin with only local components of extension and compression (Blevin et al, 1994b). A major Late Triassic compressional event (Fitzroy Transpression) formed a series of topographic highs and lows, and subsequent Jurassic fault movement occurred along a series of sub-parallel, north-northeast-trending wrench zones. The Triassic–Jurassic fault blocks in the main depocentre are interpreted to have acted as relatively stable structures and wrench movement was focussed within the intervening troughs. The fault blocks are structurally high due to uplift in combination with the collapse of the surrounding wrench zones followed by a period of thermal subsidence.

During the Late Jurassic to Early Cretaceous, collapse of the wrench zones and post-breakup subsidence resulted in minor post breakup depocentres between the uplifted blocks. During this period, prograding fan systems developed down-dip of the main basin-margin fault and along the flanks of the central basin fault blocks. Subsidence continued throughout the Cretaceous and Early Tertiary and was followed by Miocene reactivation of the basin-margin fault and along the outer margin of the De Grey Nose.

Stratigraphy

The Beagle Sub-basin contains a thick sequence of Palaeozoic to Cainozoic sediments that reach an estimated maximum thickness of 10 km in the inboard Beagle and Cossigny troughs and in the outer portion of the sub-basin. Little is known of the Palaeozoic sediments in the sub-basin. In a reassessment of the Poissonier 1 well, Purcell (Ingram, 1990) identified Visean age palynomorphs in a 10 m thick porous sandstone that unconformably overlies recrystallised calcilutite and claystone, which in turn overlies sandstone and igneous basement.

The Mesozoic stratigraphy of the sub-basin is summarised in **Figure 3** (modified after Blevin et al, 1994a, 1994b and Woodside, 1999). Representative seismic transects across the sub-basin are shown in **Figures 4, 5** and **6**.

The Early Triassic section is marked by a widespread marine transgression and deposition of the Locker shale in shallow shelf and shoreline facies. The overlying Mungaroo Formation consists of numerous fining-upward cycles of thick fluvio-deltaic sandstones with minor interbeds of siltstones, shales and coals. In outboard areas (eg Delambre 1) the upper facies of the Mungaroo Formation consist of claystones and interbedded sandstones deposited in terrestrial to marginal marine environments. The Middle Triassic Cossigny Member comprises paralic to marine siltstones, claystones and limestone, and forms an important transgressive regional seismic marker throughout the sub-basin.

The Early Jurassic Brigadier and North Rankin formations are poorly documented in the Beagle Sub-basin, as they are either thin or absent along the basin margin and rarely fully intersected in the deeper basin depocentre. The Brigadier Formation comprises numerous fining- and coarsening-upward cycles of thinly bedded sandstones, siltstones and claystones deposited in low energy, marginal to shallow marine environments. The North Rankin Formation comprises thick clean sandstones deposited in a high energy shallow marine setting, and minor interbedded siltstone and claystone units.

The Early–Middle Jurassic Legendre Formation is characterised by a series of stacked coarsening-upward fluvio-deltaic cycles of sandstones, siltstones, shales and minor coals, capped by massive sandstones. The cycles are up to 60 m thick and are interpreted as sand-dominated north-to-northwest prograding delta-front deposits separated by fine-grained interdistributary and overbank deposits. The Athol Formation and Murat Siltstone represent marine facies outboard of the Legendre delta. At Picard 1, an informal member of the Athol Formation known as the Picard Shale (early Pliensbachian, approximately upper *C. torosa* zone; Partridge, 1988) comprises restricted marine shale with potential source quality.

The Callovian Calypso Formation disconformably overlies the Legendre Formation and consists of glauconitic claystone and thinly interbedded sandstones and siltstones. It represents a widespread transgressive marine unit associated with the onset of continental breakup and sea-floor spreading in the Argo Abyssal Plain to the north. The top of the unit is marked by the Oxfordian and/or amalgamated base Cretaceous unconformity.

Late Jurassic sediments are generally thin or locally absent in the Beagle Sub-basin, but thicken markedly into the Dampier Sub-basin to the southwest where they are dominated by organic-rich restricted marine claystones of the Dingo Claystone. Prograding fan sands of Tithonian age (Angel Formation), and locally more restricted fans of Oxfordian age (Eliassen Formation), occur along the flanks of horst blocks in the southern portion of the sub-basin, and down-dip of the main basin-margin fault. These sands consist of good quality reservoir sands and thin claystone interbeds.

The Berriasian to early Valanginian Forestier Claystone is a marine claystone that drapes and onlaps the horst blocks and basin margin. The claystone thickens into the troughs between the uplifted blocks, and forms a regional seal across the sub-basin, although seal quality deteriorates towards the south-eastern margin.

The Valanginian–Aptian Muderong Shale is a thick marine claystone that occurs throughout the sub-basin, and provides an important regional seal where the underlying Forestier Formation is thin or absent.

The mid-Cretaceous to Cainozoic section comprises claystones, marls and calcilutites deposited on a progradation, increasingly carbonate-dominated, open marine passive ramp margin.

EXPLORATION HISTORY

AREAS W07-18 TO W07-21 – BEAGLE SUB-BASIN

Exploration of the Beagle Sub-basin region began in 1965 with regional seismic, gravity and magnetic surveys. Subsequent exploration led to the drilling of 13 wildcat wells between 1971 and 1983. The wells tested a range of plays, including uplifted Triassic–Jurassic fault blocks, Triassic and Jurassic anticlines, and fault controlled structures down dip of the main basin-margin fault. Drilling confirmed the presence of a thick Late Palaeozoic–Cainozoic sedimentary sequence which contained prospective reservoir, source and seal units. Despite several minor shows, no significant hydrocarbon discoveries resulted.

Only two wells were drilled in the sub-basin between 1983 and 1992 (Trafalgar 1 in 1988, and Aurora 1 in 1990), together with two wells along the northern margin of the adjacent Dampier Sub-basin (Bounty 1 in 1983, and Calypso 1 in 1985). However, no hydrocarbon shows were recorded in these wells.

In the early 1990's, a third wave of exploration activity was initiated in the sub-basin. Nebo 1 (1993) encountered thin oil-bearing sands in the Callovian Calypso Formation, and was the first well to confirm the presence of an active petroleum system in the Beagle Sub-basin (Osborne, 1994). In 1994–1995 the same joint venture consortium drilled 3 unsuccessful wells (Cimba 1, Darwin 1 and Halo 1).

In 1998, Mutineer 1B discovered oil in the Late Jurassic Angel Formation at the northern tip of the Dampier Sub-basin, and this discovery helped encourage further exploration in the adjacent Beagle Sub-basin. Woodside subsequently drilled four unsuccessful wells (Serval 1, Ermine 1, Grey Rabbit 1 and Tayra 1) in the western-central sub-basin in 1999–2001, and IB Resources drilled two unsuccessful wells (Manaslu 1 and Huascaran 1) in the central sub-basin in 2001–2002. Wigmore 1, the most recent well to be drilled in the Beagle Sub-basin, was drilled by Kerr McGee in 2002–2003 in the outer, deep-water, northwest portion of the sub-basin, and was also unsuccessful.

Twenty five wells have been drilled to date in the Beagle Sub-basin (**Figure 1**). No commercial accumulations of hydrocarbons have been encountered, and Nebo 1 is the only significant discovery in the sub-basin. The following summaries are based on the relevant well completion reports, and a review presented by Blevin et al (1994a).

De Grey 1 (1971) tested stacked targets, a possible stratigraphic onlap onto the Main Unconformity, and a deeper rotated Triassic fault block, on the De Grey Nose. There were no hydrocarbon shows recorded during drilling, and the well reached a total depth (TD) of 2088 mRT in Triassic sandstone. Subsequent mapping has shown that closure is absent at the Triassic level, and that the post-breakup 'onlapping sequence' is potentially a transgressive sand sheet without closure near the well (Blevin et al, 1994a). A review of the well has revised the age of sediments at total depth to be Early–Middle Triassic (Ingram, 1990), rather than the Late Triassic age originally interpreted during post-drill analysis.

Picard 1 (1972) was the first well to test structures in the main Mesozoic depocentre of the Beagle Sub-basin. The well was an apparent crestal test of a large north-trending Middle–Early Jurassic horst block, draped by an Early Cretaceous seal. The well reached a TD of 4216 mRT, and intersected a thick section of Middle–Early Jurassic sandstone with interbedded claystones, siltstone and minor coal, including a 216 m thick predominantly claystone section (3665–3881 mRT). Analysis by Surdam and Warme (1984) and Robertson Research (1986) concluded that the Early–Middle Jurassic Athol and Legendre claystones have good to very good oil source potential. Only minor fluorescence and gas shows were recorded in thin shaly sand interbeds within the Early Jurassic section, and wireline logs indicated that all sands were water saturated. Reactivation of north-trending bounding faults during the Late Cretaceous to early Tertiary may have breeched the Picard structure (Blevin et al, 1994a).

Sable 1 (1972) tested a large northeast-trending Triassic–Jurassic fault block in the southwest Beagle Sub-basin. The well reached a TD of 3972 mRT in the Late Triassic Mungaroo Formation and penetrated a thick section of Early Jurassic to Late Triassic interbedded sandstone and claystone, overlain by Early Cretaceous claystone. Only minor fluorescence and gas shows were recorded in the Early Jurassic section, and wireline logs indicated that all sands in the section were water saturated. The Sable 1 well is regarded as a valid test of the southern Sable horst block, but more recent seismic data across the area indicates that faults bounding the Sable Block have undergone minor periods of reactivation into the Early Tertiary (Blevin et al, 1994a).

Cossigny 1 (1972) tested a large down-thrown fault block on the southern margin of the main Mesozoic depocentre of the Beagle Sub-basin, adjacent to the elevated De Grey Nose to the south and the deeper Cossigny Trough to the north. The well reached a TD of 3203 mRT, and penetrated a thick section of Middle Triassic to Early Jurassic sandstone with minor interbedded claystone, siltstone and coal, including a 65 m thick section of Middle Triassic dolomite and limestone. The Triassic–Jurassic section was unconformably overlain by mid-Cretaceous argillaceous sediments, the regionally sealing Early Cretaceous section being absent. No hydrocarbon shows were encountered during drilling, and subsequent seismic data indicates that only minor closure is present in the Miocene at Cossigny 1.

Ronsard 1 (1973) was drilled to test a fault controlled Jurassic horst block with overlying drape closure in the central southwest portion of the Beagle Sub-basin. The well reached a TD of 2848 mKB in Early Jurassic interbedded sandstone and claystone with minor coal. This Early Jurassic section is unconformably overlain by a 38 m thick section of Early Cretaceous (early Aptian–late Neocomian) claystone, which is in term unconformably overlain by 31 m of interbedded marl, claystone and calcilutite of Albian age. No hydrocarbons were recorded during drilling or post drill analysis of sidewall and conventional cores. The well is considered to be a valid test of the structure. However, Early Tertiary reactivation of the north-trending faults bounding the structure has juxtaposed the thin sealing Neocomian claystone drape against the porous Late Cretaceous Toolonga calcilutite; thus any generated hydrocarbons could have leaked across the fault (Blevin et al, 1994a).

Poissonier 1 (1973) targeted Permian–Triassic sands in a down-thrown fault block along the southeastern basin-margin fault against the Lambert Shelf. The well was intended to test the potential of pre-Locker Shale sandstones down faulted against impermeable basement. Overlying Jurassic–Triassic sandstones truncated by the basal Cretaceous unconformity represented a secondary objective. The well intersected basic igneous basement at 1947 mKB, unconformably overlain by a thick sequence of sandstones, claystones, siltstones and minor coal of Early Jurassic and Triassic age. No significant hydrocarbon shows were recorded, but minor fluorescence was observed above the objective horizons in the upper Locker Shale and overlying sandstones of the Mungaroo Formation. Remapping of the area indicates there is little or no closure at the Triassic and Middle Jurassic unconformity levels (Blevin et al, 1994a).

Sandstones intersected beneath the Locker Shale have been reassessed as Early Carboniferous (Visean) in age, rather than earliest Triassic as originally thought (Ingram, 1990). The revised age of this pre-Locker Shale sandstone does not eliminate the concept of basal Triassic transgressive sandstone plays, and also highlights that Palaeozoic sandstones could be considered targets in inboard portions of the sub-basin.

Depuch 1 (1974) tested a fault controlled Jurassic horst block draped by Early Cretaceous claystone on the eastern margin of the Thouin Graben in the central eastern portion of the Beagle Sub-basin. The well reached a TD of 4300 mKB and intersected a thick section of Early–Middle Jurassic interbedded sandstones, claystones, siltstones and minor coal (Legendre Formation), overlain by 60 m of Callovian sandstone and claystone (Calypso Formation) and 180 m of Neocomian claystone (Forestier Claystone). No significant hydrocarbon shows were recorded, but fluorescence was noted over several sections within the Calypso and Legendre formations, although this was usually associated with the occurrence of carbonaceous material.

Regional mapping indicates that the well was sited on the flanks of a Jurassic fault block and lies only marginally within closure at the top Legendre level, and outside of closure at the top Calypso level (Kufpec, 1994).

Jarman 1 (1978) tested a large anticline on the northwest flank of the Cossigny Trough in the central southern Beagle Sub-basin. Closure at the top of the Late Jurassic sandstone (primary objective) and at the Main Unconformity level (secondary objective) were originally mapped as simple rollovers without the presence of major faulting. The well reached a TD of 2906 mKB within Middle Jurassic sandstone (Legendre Formation). No significant hydrocarbons were recorded while drilling, although four sidewall cores exhibited weak to moderate white solvent fluorescence. Jarman 1 was the first well in the Beagle Sub-basin to test post-breakup sandstones (Angel Formation) as the primary objective. Remapping of the area indicates the well was drilled outside structural closure along the flanks of the much larger Jarman Anticline (Blevin et al, 1994a).

Finucane 1 (1978) tested a faulted horst anticline on the southwest margin of the Beagle Sub-basin adjacent to the Dampier Sub-basin. The objective was sandstones of probable Middle–Early Jurassic age lying beneath the Main Unconformity. The well reached a TD of 3300 mKB and penetrated 195 m section of Middle Jurassic sandstones, claystones and minor coal (Legendre Formation), overlain by 122 m of Tithonian sandstones (Angel Formation), in turn unconformably overlain and sealed by Neocomian claystone (Forestier Claystone). No significant hydrocarbon shows were encountered and potential reservoir sands were water saturated. Post-drill mapping suggests that Finucane 1 was drilled outside structural closure (Blevin et al, 1994a).

Bruce 1 (1979) tested a Middle Triassic anticline down-dip of the southeastern basin margin fault against the Lambert Shelf, approximately 15 km west-southwest of Poissonier 1. The structure is interpreted to have been initiated by Late Triassic–Middle Jurassic right lateral wrench movement along small scale antithetic faults orthogonal to the main-basin margin fault (Blevin et al, 1994a). The well reached a TD of 2168 mKB and intersected a thick succession of Late–Middle Triassic sandstones, siltstones and claystones with minor carbonates (Mungaroo Formation), gradationally overlying a Middle–Early Triassic section of claystones and minor siltstones and sandstones (Locker Shale). The Triassic section is unconformably overlain by 50 m of Early Cretaceous claystone. Sidewall cores in Middle Triassic sandstones (Mungaroo Formation) directly beneath a 54 m thick siltstones and claystone unit (Cossigny Member) showed good bright gold fluorescence, bright silver blue solvent fluorescence and visible brown oil stain.

The Bruce 1 well confirmed the existence of a regional mid-Triassic seal (Cossigny Member) which has a distinctive seismic character, and the local generation of early mature hydrocarbons. Post-drill mapping suggests the well was drilled inside closure at the mid-Triassic level, but outside closure at the level of the Early Cretaceous seal, and that faulting above the Middle Triassic Cossigny Member may have breached the seal (Blevin et al, 1994a).

Delambre 1 (1980) tested a Middle Jurassic–Triassic eroded tilted fault block on the Brigadier Trend at the outer western margin of the Beagle Sub-basin. The well had two objectives, Middle Jurassic sandstones (Legendre Formation) subcropping the Main Unconformity horizon and sealed by Early Cretaceous claystone, and Early Jurassic–Late Triassic sandstones sealed by Early Jurassic claystone. The well reached a TD of 5495 mKB and penetrated a thick section of Middle Jurassic (Bathonian to Bajocian) sandstones, siltstones and claystones beneath the Main Unconformity, grading downward to Early Jurassic (Aalenian) to Late Triassic (Carnian) marginal marine claystones, sandstones and siltstones. Minor fluorescence and gas shows were recorded within Middle Jurassic to Late Triassic sandstones and claystones. The well appears to be a valid test of dip and postulated fault closure at the Main Unconformity and base Jurassic levels; however, there is some evidence of minor late stage (post-MU) reactivation of faults bounding the structure.

North Turtle 1 (1982) tested a tilted fault block outboard of the North Turtle Fault Zone in the eastern portion of the Beagle Sub-basin. The primary targets were 1) Early Jurassic sandstones of the 'lower Depuch Formation' (Legendre Formation equivalent), 2) Early Jurassic–Late Triassic sandstones of the 'Bedout Formation' (North Rankin and Brigadier Formations equivalent), and 3) Late Triassic sandstones of the 'Upper Keraudren Formation' (Mungaroo Formation equivalent). A secondary target was Middle Jurassic sandstones of the 'upper Depuch Formation' (Legendre

Formation equivalent). The prognosed total depth of the well was 5,000 m. The well reached a TD of 4420 mKB without encountering any significant hydrocarbons, and was terminated within sandstones and minor interbedded siltstones, mudstones and coals of an unexpectedly thick ‘Depuch Formation’ because of porosity deterioration within these Early Jurassic sediments. The deeper ‘Bedout’ and ‘Upper Keraudren Formation’ targets were not reached, and there was no structural development at the intersected secondary target (‘upper Depuch Formation’) level.

Bounty 1 (1983) tested a Tithonian sandstone (Angel Formation) drape over a tilted fault block near the southwest margin of the Beagle Sub-basin where Late Jurassic sediments begin to thicken into the northernmost Dampier Sub-basin; here the Angel Formation is oil-bearing at Talisman 1. The secondary objective was westward-dipping Middle to Early Jurassic sandstones (Legendre Formation) subcropping the Main Unconformity. The well reached a TD of 3524 mKB within Tithonian sandstones without reaching the Middle Jurassic secondary objective due to operational difficulties. There were no significant hydrocarbon shows, but a ‘black, tar-like substance’ was noted on ‘1 % of sandstone grains’, together with moderate fluorescence, over the depth range 3231–3234 mKB in Tithonian sediments. Bounty 1 appeared to be a valid test of the structure, and the results suggest problems with regional migration and/or charge in this region.

Calypso 1 (1985) tested a faulted anticline at the northeastern end of the Lewis Trough in the Dampier Sub-basin, near the southern margin of the Beagle Sub-basin. The primary target was Early Cretaceous (Berriasian) to Late Jurassic (Tithonian) sandstones of the Angel Formation, which is oil-bearing in Talisman 1 8 km to the south, with a secondary target of Middle–Early Jurassic sandstones (Legendre Formation) below the Main Unconformity. Calypso 1 reached a TD of 2843 mKB within the Middle Jurassic Legendre Formation, and penetrated good quality reservoir sands of the Angel Formation. There were only minor hydrocarbon shows in the well, and the primary and secondary objectives were water wet.

Trafalgar 1 (1988) tested a composite four-way dip closed antiformal trap with faulting on its southern flank, in the central southern Beagle Sub-basin. The primary target was post-breakup Tithonian sandstones (Angel Formation) up-dip from Jarman 1. The well reached a TD of 2743 mKB within Middle Jurassic sandstones and interbedded claystones, siltstones and rare coal (Legendre Formation). The post-breakup sands predicted at Trafalgar were found to be interbedded siltstones and claystones with very poor reservoir potential, and no hydrocarbon shows were recorded in the well.

Aurora 1 (1990) was drilled near the southern margin of Beagle Sub-basin and the northeast Dampier Sub-basin, and tested a culmination on a transpressional en-echelon fault block mapped at the top Angel Formation. The primary reservoir objective was the Berriasian–Tithonian Angel Formation, which is oil bearing at Talisman 1, 18.7 km to the south-southwest. The underlying Late–Middle Jurassic sandstones of the Calypso Formation and Legendre Formation were secondary objectives. The well reached a TD of 3021.7 mRT in the Legendre Formation, unconformably overlain by sandstones of the Angel Formation and the regional Forestier Claystone seal. No hydrocarbon indications were encountered.

Nebo 1 (1993) targeted a large fault-dependent anticlinal structure (Nebo High) located in the southern Thouin Graben. The Nebo High has closure mapped in both time and depth at several levels extending from the Oxfordian Unconformity up to the Aptian Unconformity. The structure below the Oxfordian Unconformity comprises a major tilted fault block beneath the central Nebo High and separates tilt blocks beneath the flanks. The primary objective was deltaic sandstones of the Middle Jurassic Legendre Formation, sealed by claystones of the overlying Callovian Calypso Formation. Sandstones of the Tithonian Angel Formation were predicted as a possible secondary objective, but these were absent over the crest of the structure. The well reached a TD of 3132 mRT (-3110 mSS) in the Legendre Formation. Sandstones within the Legendre Formation were found to be porous (15–19 % average log porosity), but water wet. However, oil was discovered in thin sandstones within the overlying Calypso Formation. A total of 5.9 m of potential net oil pay was interpreted in 6 discrete thin sands (17–26 % average log porosity) over a gross section of 33 m, below 2663 mRT. A drill stem test perforated over the best reservoir zone in the depth range 2664.5–2668 mRT was carried out, and the well flowed 42 °API oil at a maximum flow rate of 1840 BPD on a inch choke. The lack of shows in the underlying target Legendre Formation was attributed to the poor seal quality of the overlying Calypso Formation at the Nebo location.

Cimba 1 (1994) tested a tilted horst block on the up-thrown eastern margin of the Thouin Graben, 3.1 km to the north-northeast of Depuch 1 in the eastern Beagle Sub-basin. The primary objective was deltaic sandstones of the Middle Jurassic Legendre Formation, and marine sands within the overlying Calypso Formation provided a potential secondary objective. The well reached a TD of 2603 mRT within the Legendre Formation. No hydrocarbon shows were encountered, and all potential reservoirs were interpreted to be water-bearing. The demonstrated structural relief between Cimba 1 and Depuch 1 suggests that the well tested a valid trap.

Darwin 1 (1995) tested the crest of a four-way dip closure situated along the axis of the North Turtle Graben near the eastern margin of the Beagle Sub-basin. At mapped base Cretaceous level, the structure is controlled by drape over normal faults antithetic to the main graben-bounding faults, and by regional dip. The primary objective was the Callovian Calypso Formation, with secondary targets in the Early Cretaceous Muderong Shale and Forestier Claystone, Late Jurassic Angel Formation, and the deeper Middle Jurassic Legendre Formation. The well reached a TD of 2723 mRT within the Legendre Formation. No hydrocarbon shows were encountered, and the primary target sandstones of the Calypso Formation were water wet (including two very good quality sandstones with 12–30 %, average 25 %, calculated log porosity), as were sands in the Forestier Claystone and Legendre Formation. No sands were encountered in the Muderong Shale, and the Late Jurassic Angel Formation/Dingo Claystone was absent. Post-drill depth conversion confirmed that the well was a valid structural test at the Calypso and Legendre reservoir levels, but that sandstones within the overlying Forestier Claystone are out of closure. The complete lack of hydrocarbon shows or gas in the Jurassic reservoirs indicates that there has been no hydrocarbon migration into the Darwin structure. The most likely cause for ineffective migration involve problems in the migration pathways from the Beagle Trough and North Turtle Graben kitchens, and poor migration efficiency through a very high sandstone net-to-gross section. Other potential problems involve the type, distribution and volume of mature source rocks and their expulsion efficiency in a sand-prone depositional system.

Halo 1 (1995) was drilled on the eastern flank of the Nebo High within the Thouin Graben to test prognosed Late Jurassic sands of the Angel Formation that were not encountered on the bald crest of the structure at the Nebo 1 oil discovery 1.25 km to the west. The thin oil-bearing sands of the Calypso Formation intersected in Nebo 1 were not considered an objective in Halo 1 due to its structurally lower position. The well reached a TD of 3000 mRT within a thicker than prognosed section of the Calypso Formation (a greater upper thickness of the unit preserved below the Oxfordian Unconformity). A thickened section of Early Cretaceous (Berriasian) claystones was intersected beneath the Forestier Claystone (the 'Halo Claystone'), but the targeted age-equivalent Angel Formation sandstones were not present. Beneath the Halo Claystone, a thin Kimmeridgian belemnitic limestone unit (the 'Thouin Limestone') was encountered above the Oxfordian Unconformity. No hydrocarbons were encountered, and thin potential reservoir sands within the Calypso Formation were water-bearing as anticipated (these sands occur below the level of interpreted highest-known-water in Nebo 1). Correlation with Nebo 1 suggests that the top of the Legendre Formation is likely to lie only a short distance (2–7 m) below the total depth drilled.

Serval 1 (1999) was drilled in the southwest Beagle Sub-basin and tested the Angel Formation sands in a crestal four-way dip closure. A secondary objective was to test the underlying Legendre Formation sands. The well penetrated 105 m of blocky Angel Formation sandstone (with an average porosity of 21 %) overlying interbedded sandstones and claystone of the Legendre Formation. The well reached a TD of 3210 mRT in the Legendre Formation. Both of these sands units are water wet. The intervening Calypso Formation and Dingo Claystone were absent due to truncation beneath the main unconformity, as evident on seismic. Minor fluorescence were observed in four sidewall cores, one near the top of the Angel Formation and three associated with an argillaceous section near the top of the Legendre Formation. These shows may indicate that migration into the trap was limited, or may have resulted from the contaminated, recycled, mud system. The failure of the well was considered to be due to lack of hydrocarbon charge.

Ermine 1 (1999) was drilled in the western portion of the Beagle Sub-basin to test the Legendre Formation in a near crestal dip and fault closed horst block. The overlying Angel Formation was identified as a possible secondary target. The well reached a TD of 2710 mRT in the Legendre Formation, and the Angel Formation was absent. No hydrocarbon shows were encountered in the well, and failure was considered to be due to a lack of hydrocarbon charge, although fault seal integrity was also questionable. Lack of charge may be due to inadequate source richness, insufficient maturity, or migration bypass of the faulted horst structure.

Grey Rabbit 1 (2001) tested a fault dependent closure on the northern end of the Ronsard Horst, adjacent to the eastern flank of the Ronsard Graben in the central western portion of the Beagle Sub-basin. The objective was the Legendre Formation sandstone, unconformably overlain and sealed by the Forestier Claystone and Muderong Shale. The well reached a TD of 2518 mRT and penetrated a 60 m section of the Legendre Formation that showed excellent reservoir properties, with 75 % net to gross and net sandstone average log porosity of 22.5 %. No hydrocarbon shows were encountered and the objective Legendre Formation was water wet. The failure of the well is considered to be lack of effective hydrocarbon charge from mature Early Jurassic section (Athol Formation) in the Ronsard Graben.

Tayra 1 (2001) was a crestal test of a fault dependent, hanging-wall, compressional rollover with small four-way dip closure on the eastern margin of the Ronsard Graben in the central southwest portion of the Beagle Sub-basin. The fault juxtaposes the objective Legendre Formation on the hanging wall against the Athol Formation on the foot wall. Top seal is provided by the overlying Calypso Formation and by the regionally sealing Forestier Claystone and Muderong Shale. The well reached a TD of 2907 mRT in sandstones of the Legendre Formation, and also penetrated a 6 m section of undifferentiated Late Jurassic claystone and calcilutite (Dingo Claystone equivalent) and an unexpected 29 m section of Oxfordian marine fan sandstone (interpreted as the Eliassen Formation) above the Calypso Formation. No hydrocarbon shows were encountered, and the objective Legendre Formation was water wet and poorer that prognosed reservoir quality (average log porosity 14.6 % and 68 % net/gross). Potential reservoir sandstones of the Oxfordian Eliassen Formation were also water bearing (average log porosity 16.7 % with a net/gross of 89 %). The objective Legendre Formation in Tayra 1 has direct access to the underlying mature Athol Formation potential source unit in the Ronsard Graben, so the complete lack of hydrocarbons in the small fault-independent crestal portion of the closure indicates that the generative potential of the Athol Formation is inadequate to charge the Tayra structure.

Manaslu 1 (2001) tested the Middle Jurassic Legendre Formation in a faulted anticline in the central-western portion of the Beagle Sub-basin. The well reached a TD of 2,531 mRT without any significant hydrocarbon shows. Detailed interpretative results have not been released at the time of this review.

Huascaran 1 (2002) tested the Middle Jurassic Legendre Formation in a rotated fault block in the eastern central Beagle Sub-basin, approximately 3 km west of the Nebo 1 oil discovery well. The well reached a TD of 2970 mRT without any significant hydrocarbon shows. Detailed interpretative results have not been released at the time of this review.

Mutineer/Norfolk and Exeter accumulations: The Mutineer/Norfolk structure (Petroleum in Western Australia, October 2002) is a north–south trending mid-Jurassic tilt block at the northern tip of the Dampier Sub-basin, adjacent to the southern margin of the Beagle Sub-basin. The Exeter structure is a separate culmination 9 km southwest of the Mutineer/Norfolk complex. The primary reservoir in the Mutineer/Norfolk and Exeter region is within the Late Jurassic upper Angel Formation. These sandstones are distributed as amalgamated sheet turbidites bodies that originated from the north or northeast of the basin to drape and onlap the rifted tilt block topography. The likely hydrocarbon source rock is the Late Jurassic Dingo Claystone within the Kendrew Trough of the Dampier Sub-basin to the south/southwest. The Forestier/Muderong shale provides top seal to the structures.

Exploration drilling in this area commenced with Bounty 1 (1983), followed by Pitcairn 1 (1987) and Mutineer 1B (1988). Mutineer 1B (1998) intersected an 8.2 m oil column, Norfolk 1 (March 2002) a 15 m oil column, and Norfolk 2 (March 2002) a 9 m oil column. The Mutineer 2 well (April 2002) was designed to test the northern extent of the field, but did not encounter the reservoir Angel sands. Exeter 1 (April 2002) encountered a 23 m gross oil column, and Exeter 2 (May 2002) an 11 m gross oil column. However, Bligh 1 (September 2002) was unsuccessful. Extension of the Mutineer High play fairway into the Beagle Sub-basin to the north carries a high risk of being bald of the Angel Formation reservoir sands, as is Mutineer 2 and Bligh 1.

Wigmore 1 (spudded November 2002) tested a large fault-controlled closure in a complex faulted area near the junction of the Beagle Sub-basin and the Delambre Platform. The envisaged petroleum system at Wigmore consists of a dual source from the Early Jurassic Picard Shale and Athol Formation, with reservoirs in the Early Jurassic North Rankin Formation and Middle Jurassic Legendre Formation (Petroleum in Western Australia, April 2003). Thick transgressive shales of the Muderong Shale provide the top seal, whereas at the North Rankin Formation level, the Early to Middle Jurassic Picard Shale and Athol Formation provide top and flank seal. The well reached a TD of 5394.7 mMD RT (5135.86 m TVD SS). Although detailed interpretative results have not been released, the lack of any reported hydrocarbons in Wigmore 1 (as well as in Whitetail 1, in the adjacent Rowley Sub-basin to the northeast) downgrades the prospectivity of the deeper outer portion of the Beagle Sub-basin.

Relevant Wells – W07-18 to W07-21, Beagle Sub-basin

Well	Operator	Year	Total Depth (m)	Hydrocarbons
Aurora 1	Marathon Petroleum Australia Ltd	1990	3020	No shows
Bligh 1	Santos Limited	2002	3205	No shows
Bounty 1	Marathon Petroleum Australia Ltd	1983	3524	No shows
Bounty 2	Santos Limited	2004	3811	Potential oil zone, gas indication
Bounty 2 ST1	Santos Limited	2004	3807	Potential oil zone, gas indication
Bruce 1	Stirling Petroleum NL	1979	2168	Strong oil indication
Calypso 1	Marathon Petroleum Australia Ltd	1985	2843	Oil & gas indications
Cimba 1	Kufpec Australia Pty Ltd	1994	2600	Oil indication
Cossigny 1	B.O.C. of Australia Ltd	1972	3203.4	Oil indication
Darwin 1	Apache Beagle Pty Ltd	1995	2723	No shows
De Grey 1	B.O.C of Australia Limited	1971	2087.9	No shows
Delambre 1	Woodside Petroleum Development Pty Ltd	1980	5495	Oil & gas indications
Depuch 1	B.O.C. of Australia Ltd	1974	4300	Oil & gas indications
Ermine 1	Woodside Energy Ltd	1999	2710	No shows
Exeter 1	Santos Limited	2002	3212	Strong oil indication
Exeter 2	Santos Limited	2002	3245	Proven oil zone, gas indication
Finucane 1	Woodside Petroleum Development Pty Ltd	1978	3300	Oil indication

Grey Rabbit 1	Woodside Energy Ltd	2001	2518	No shows
Halo 1	Kufpec Australia Pty Ltd	1995	3000	No shows
Huascaran 1	IB Resources Pty Ltd	2002	2970	Oil indication
Jarman 1	Woodside Petroleum Development Pty. Ltd.	1978	2906	Oil indication
Manaslu 1	IB Resources Pty. Ltd.	2001	2531	No shows
Mutineer 1	Santos Ltd	1998	872	No shows
Mutineer 1A	Santos Ltd	1998	1690	Oil Indication
Mutineer 1B	Santos Ltd	1998	3399	Proven oil zone, gas indication
Mutineer 2	Santos Limited	2002	3250	Oil indication
Mutineer 3	Santos Limited	2002	3320	Proven oil zone
Nebo 1	Kufpec Australia Pty Ltd	1993	3132	Proven oil & gas zones
North Turtle 1	BP Petroleum Development Australia Pty Ltd	1982	4420	Oil & gas indications
Picard 1	B.O.C. of Australia Limited	1972	4216	Oil & gas indications
Poissonnier 1	B.O.C. of Australia Ltd.	1974	1962	Oil indication
Ronsard 1	B.O.C. of Australia Ltd	1973	2848	No shows
Sable 1	B O C of Australia Limited	1972	3971.5	Oil indication
Serval 1	Woodside Energy Ltd	1999	3210	Oil indication
Tayra 1	Woodside Energy Ltd	2001	2907	No shows
Trafalgar 1	Ampol Exploration Limited	1988	2743	No shows
Wigmore 1	Kerr McGee NW Shelf Energy Australia Pty. Ltd.	2003	5394.7	No shows

PETROLEUM POTENTIAL

AREAS W07-18 TO W07-21 – BEAGLE SUB-BASIN

The discovery of oil in the upper Calypso Formation sands at Nebo 1 (1993) demonstrated the presence of an active petroleum system within the southern Thouin Graben of the Beagle Sub-basin. This well also confirmed adequate top seal at the Oxfordian Unconformity, and suggested that down-dip potential exists within the Nebo Structure. However, the subsequent failure of the Halo 1 and Huascaran 1 wells to encounter hydrocarbons indicates risks associated with vertical and lateral migration, top seal between the Legendre and overlying Calypso Formation reservoirs, fault seal and fault movement/reactivation timing, or adequate source rock quality and distribution for effective regional charge.

The hydrocarbon potential of the remainder of the Beagle Sub-basin is unproven. The main Middle Jurassic (Legendre Formation) horst plays have been unsuccessfully tested by numerous wells, including many drilled after the Nebo discovery, as have down-dip hanging wall targets (Halo 1 and Tayra 1). The southern Late Jurassic Angel Formation play, which hosts the Mutineer/Exeter, Angel and Talisman accumulations in the adjacent northern portion of the Dampier Sub-basin, has also been unsuccessfully tested by several wells (Jarman 1, Finucane 1, Serval 1, Bounty 1, Calypso 1, Trafalgar 1 and Aurora 1). The deep-water northwestern potential has been unsuccessfully tested by Delambre 1 and Wigmore 1, as well as at Whitetail 1 (2003) and most recently Huntsman 1 (2006) in the adjacent Rowley Sub-basin to the north.

Source rocks

In contrast to the major rift depocentres on the northwest Australian margin, the Beagle Sub-basin succession lacks the development of thick Late Jurassic restricted marine organic-rich source rocks. Late Jurassic claystones are either thin or absent in the Beagle Sub-basin, and where present, are generally immature. Other potential source units within the sub-basin occur within the Early Triassic Locker Shale, Middle–Late Triassic Mungaroo Formation and Early–Middle Jurassic Legendre/Athol Formation, including the 'Picard Shale' **(Figure 3)**.

The Early Triassic Locker Shale generally has poor source potential and tends to be silty and immature to marginally mature where intersected along the basin margin (Poissonier 1 and Bruce 1). However, source quality may improve in more outboard areas and it is likely to be mature in the outer portion of the North Turtle Terrace. The Locker Shale can be expected to be overmature in the Beagle and Cossigny troughs, and throughout the outer parts of the sub-basin.

Claystones within the Middle–Late Triassic Mungaroo Formation where intersected at Poissonier 1 and Cossigny 1 have little or no source potential. Source quality may improve in more outboard areas, similar to the Exmouth Plateau where coaly facies of the Mungaroo Formation are thought to have sourced significant gas accumulations.

Claystones and thin coaly sediments within the Early–Middle Jurassic Legendre/Athol Formation at Cossigny 1, Depuch 1, North Turtle 1 and Picard 1 have good to very good source potential and together with its inferred maturity level, make this the prime potential source unit within the Beagle Sub-basin (Blevin et al, 1994b). If these units are sufficiently rich to expel hydrocarbons, expulsion and migration is likely to have occurred during the Late Cretaceous and Tertiary, but in more outboard areas (eg, Wigmore 1) potential charge could predate emplacement of the top Legendre seal (Muderong Shale).

The oil recovered at Nebo 1 is sourced from either oil-prone deltaic coals or lacustrine mudstones of presumed Early–Middle Jurassic age, and does not show a generic affinity with any oil from the nearby Dampier Sub-basin or greater North West Shelf (Edwards and Zumberge, 2005). A source rock extract of shale (TOC = 4.6 %) from 3840–3850 m in Picard 1 ('Picard Shale' or Murat Siltstone/Athol Formation) is reported to have a similar biomarker character to that of the Nebo 1 oil (Geotech, 1994; Scott and Hartung-Kagi, 1998).

The complete absence of significant hydrocarbon shows, including fluid inclusion analyses, in all other wells in the Beagle Sub-basin strongly suggests the lack of effective source rock quality and distribution within the sub-basin, apart from a local source pod within the southern Thouin Graben that generated the oil recovered at Nebo 1.

Reservoir
The Beagle Sub-basin has an abundance of widespread sand facies. Good quality potential reservoirs occur at several levels, including the Middle–Late Triassic Mungaroo Formation, Early Jurassic North Rankin Formation, Early–Middle Jurassic Legendre Formation and La te Jurassic Angel Formation (**Figure 3**). Secondary potential reservoirs include basal Triassic transgressive sands, the Late Triassic–Early Jurassic Brigadier Formation and the Callovian Calypso Formation.

Seal
Regional seals are provided by the Early Triassic Locker Shale, Middle Triassic Cossigny Member of the Mungaroo Formation, and the Early Cretaceous top seals of the Forestier Claystone and Muderong Shale (**Figure 3**). Potential intraformational seals occur within the Early Jurassic 'Picard Shale' unit of the Athol Formation/Murat Siltstone, and the Callovian Calypso Formation.

Fault trap breaching of seals by late-stage faulting and inadequate migration pathways have been suggested to explain several well failures (Blevin et al, 1994a, 1994b), but the general absence of significant hydrocarbon shows is probably largely a consequence of the lack of adequate source rocks resulting in a high charge risk for the sub-basin.

FIGURES

AREAS W07-18 TO W07-21 – BEAGLE SUB-BASIN

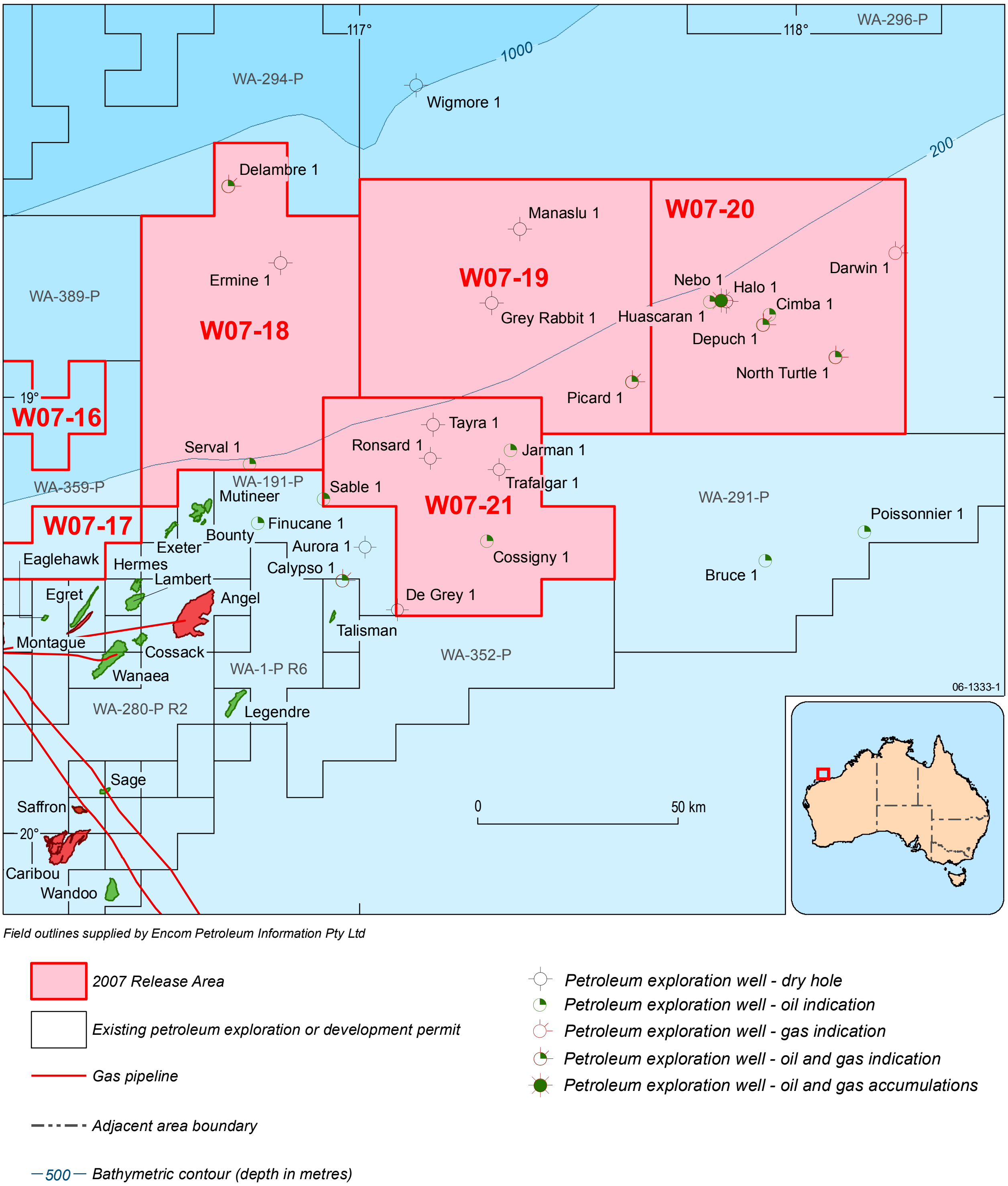


Figure 1. Location map of 2007 release areas in the Beagle Sub-basin, W07-18 to W07-21, Carnarvon Basin.

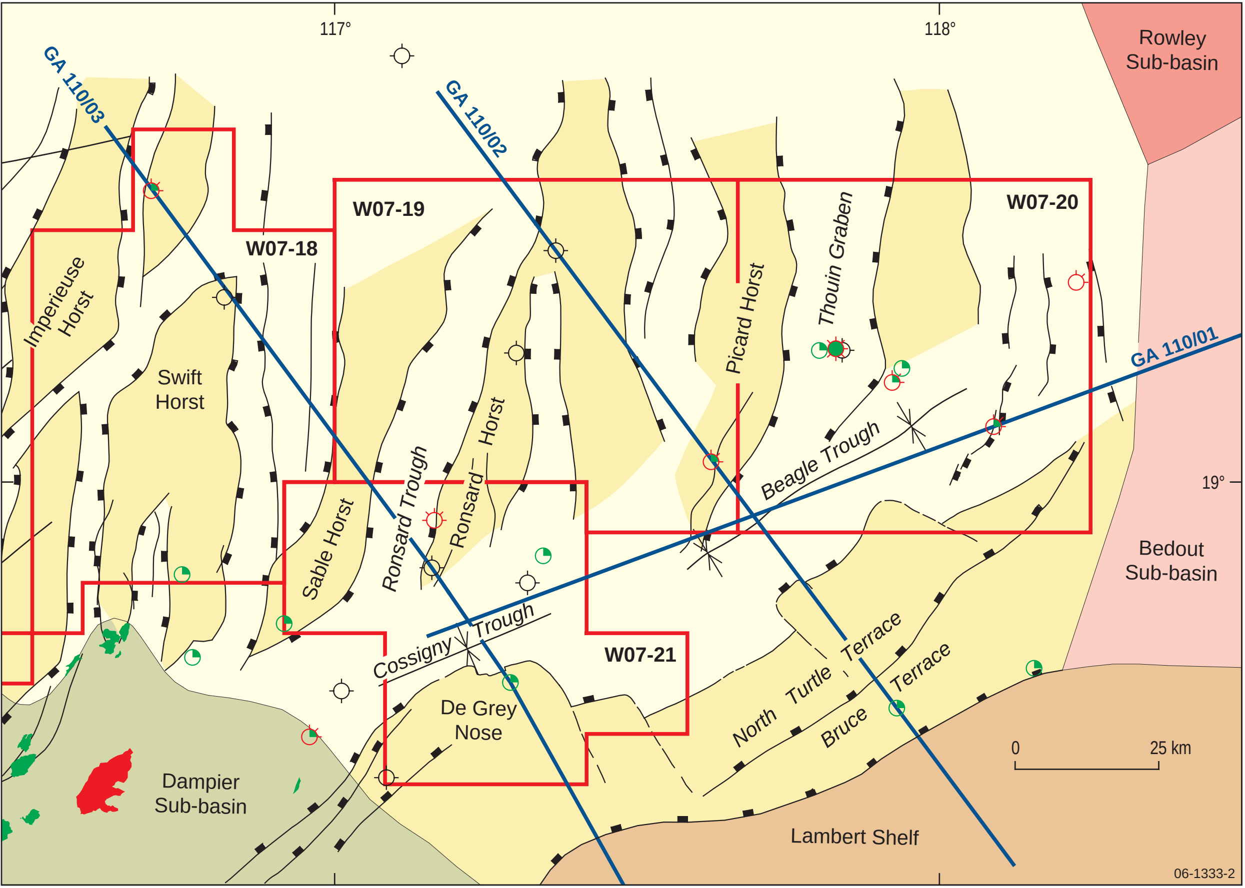


Figure 2. Structural elements of the Beagle Sub-basin (modified after Blevin et al., 1994b; Kufpec, 1995; Woodside, 1999).

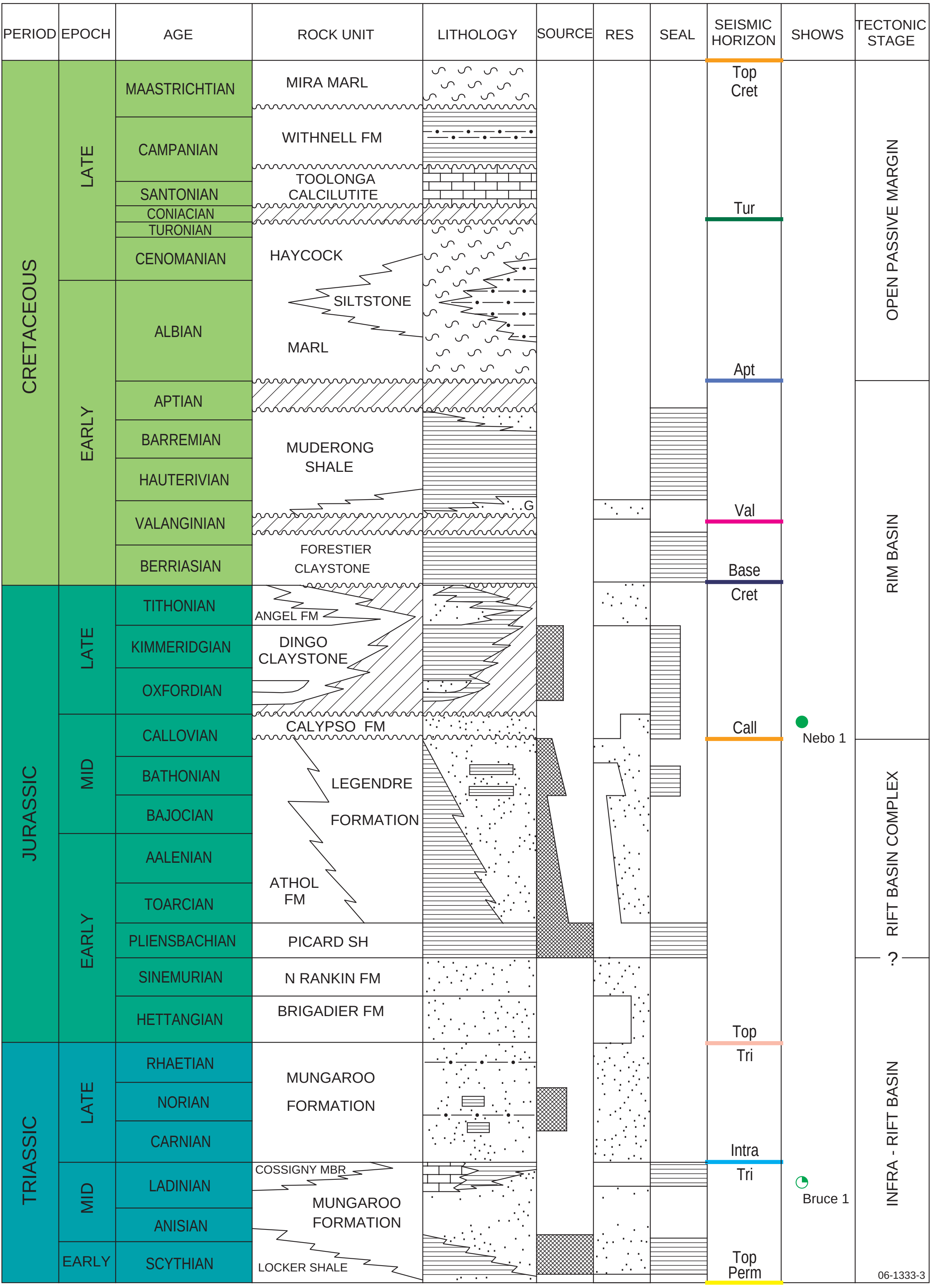


Figure 3. Stratigraphy of the Beagle Sub-basin (modified after Blevin et al., 1994b).

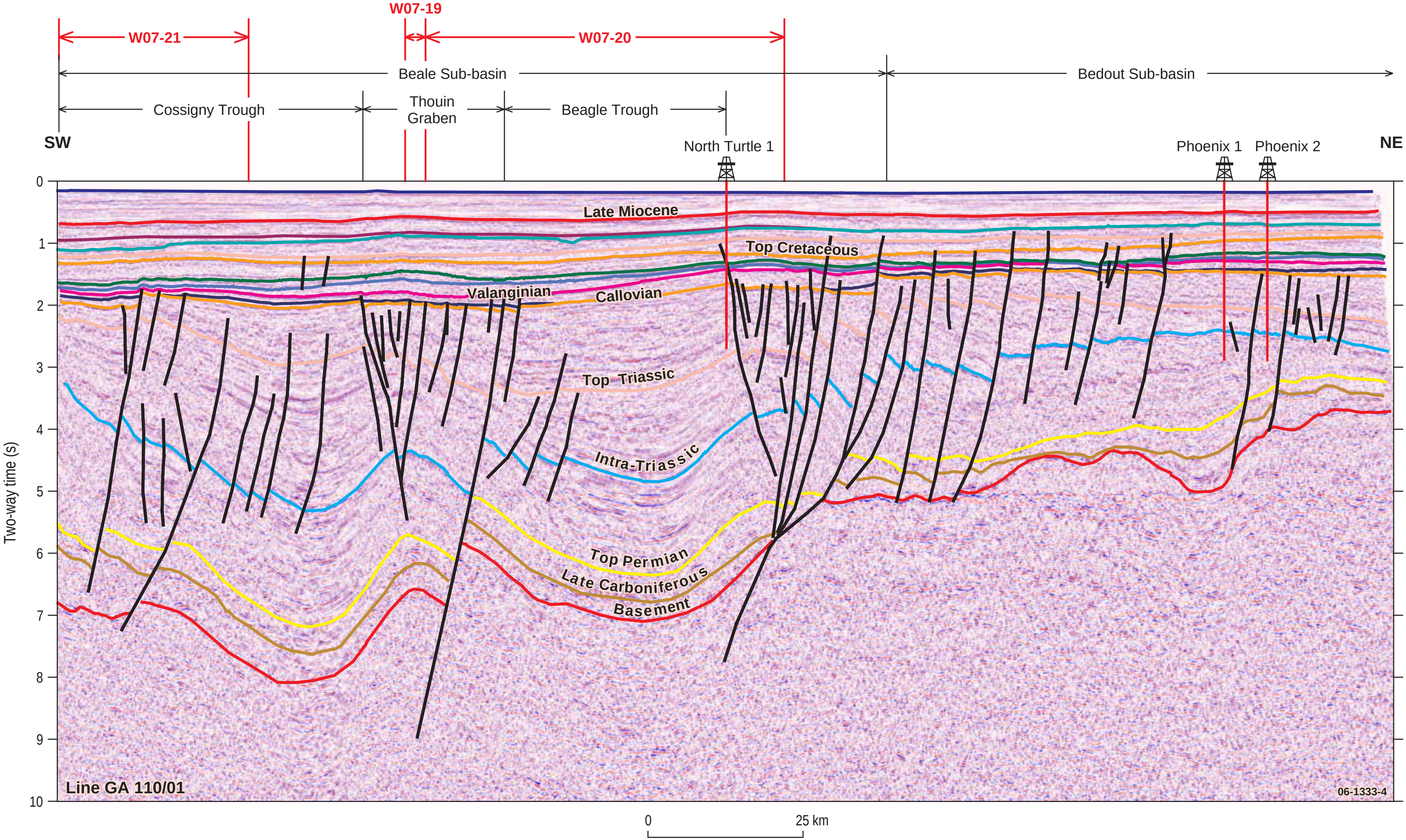


Figure 4. Seismic line 110-01 through North Turtle 1 (location of line shown in Figure 5), Beagle Sub-basin.

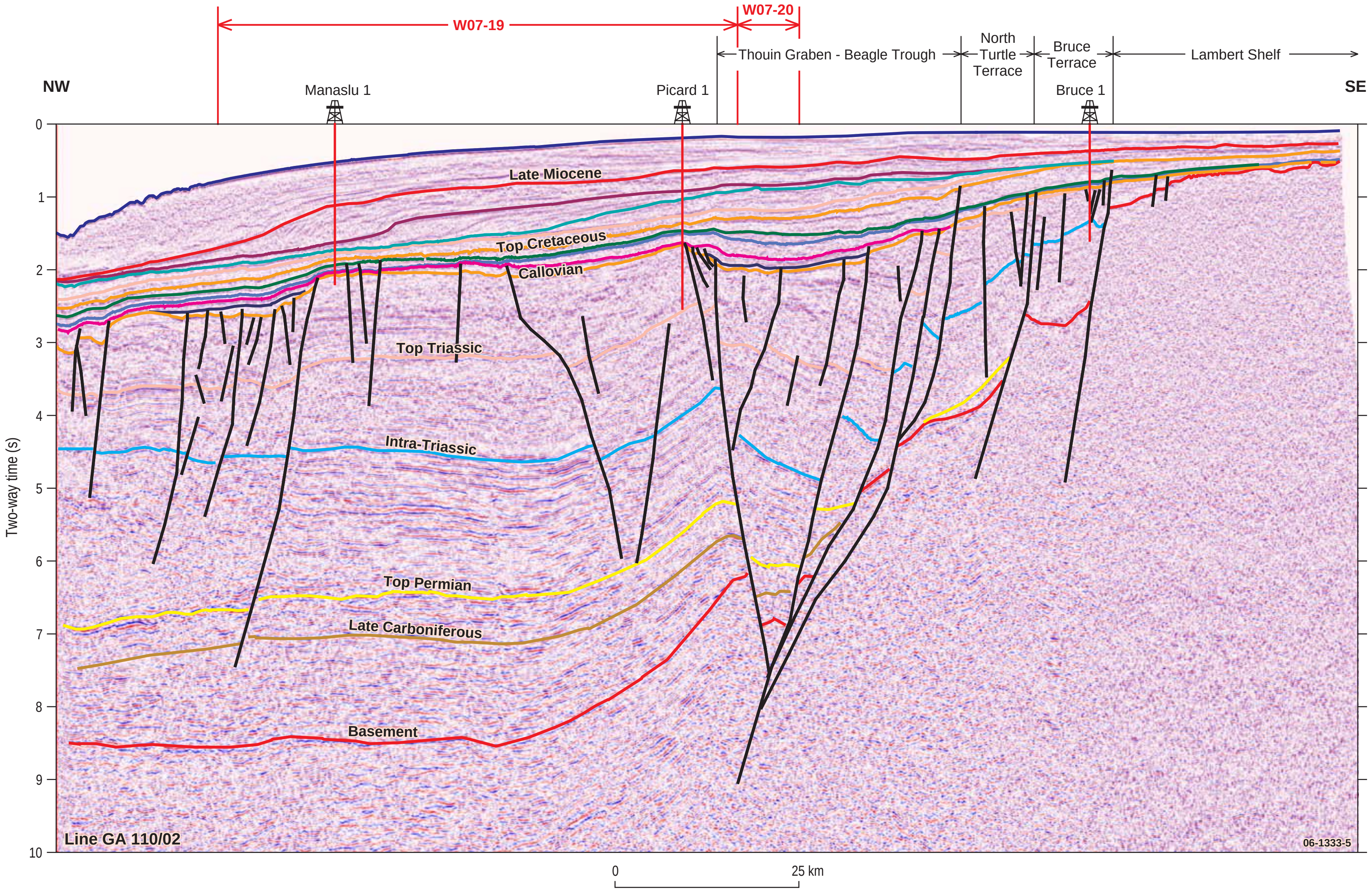


Figure 5. Seismic line 110-02 through Bruce 1, Picard 1 and Manaslu 1 (location of line shown in Figure 5), Beagle Sub-basin.