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2007 RELEASE OF AUSTRALIAN OFFSHORE PETROLEUM EXPLORATION AREAS

AREA NT07-2 MONEY SHOAL BASIN, NORTHERN TERRITORY

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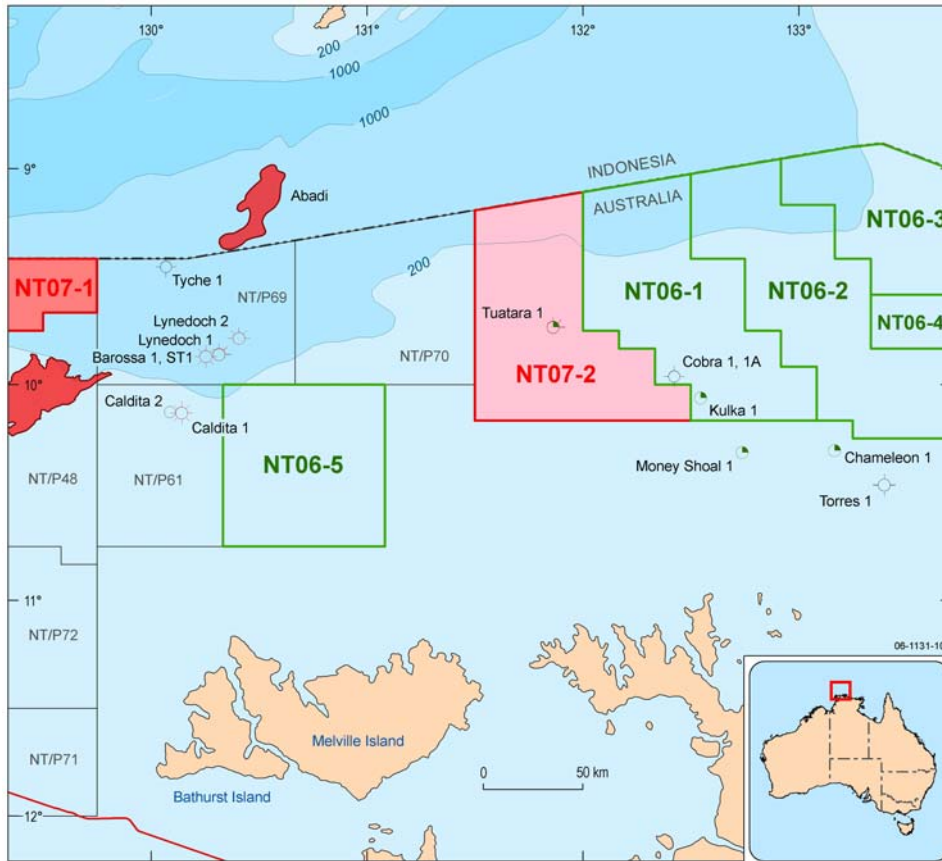
2007 RELEASE OF OFFSHORE PETROLEUM EXPLORATION AREAS

SUMMARY – MONEY SHOAL BASIN RELEASE AREA

AREA NT07-2 MONEY SHOAL BASIN NORTHERN TERRITORY

BIDS CLOSE 18th OCTOBER 2007

- Large under-explored Mesozoic basin.
- Shallow water depths (70–220 m) and shallow targets.
- Palaeozoic and Mesozoic potential source rocks.
- Numerous stratigraphic and structural plays.
- Recent studies have reduced charge risk factor.
- Hydrocarbon shows/indications in nearby wells.
- Large gas discoveries in adjacent Bonaparte Basin.
- Special Notices apply, refer to Guidance Notes.



Field outlines, with the exception of Abadi, supplied by Encom Petroleum Information Pty Ltd. The Abadi field is generalised and shown for approximate size and position only.





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AREA NT07-2 MONEY SHOAL BASIN NORTHERN TERRITORY

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LOCATION

Area NT07-2 is located about 280 km northeast of Darwin in the Arafura Sea, between Australia's Northern Territory and Indonesia. Water depths range from about 75 to 230 m (**Figure 1**). The release area overlies the Mesozoic to Cenozoic Money Shoal Basin (**Figure 2**). In the southeastern part of the release area, the Money Shoal Basin is underlain by the Goulburn Graben, which is part of the Neoproterozoic to Permian Arafura Basin. The release area is located to the east of the recent gas discoveries at Caldita 1 and Barossa 1, ST1 and the Lynedoch gas field. Tuatara 1, the only exploration well located in the release area, had oil and gas indications. Area NT07-2 comprises 99 graticular blocks (8030 km²).

GRATICULAR BLOCK LISTING AND MAP

NT07-2 Money Shoal Basin, Northern Territory

Map Sheet SC 52 (Melville Island)

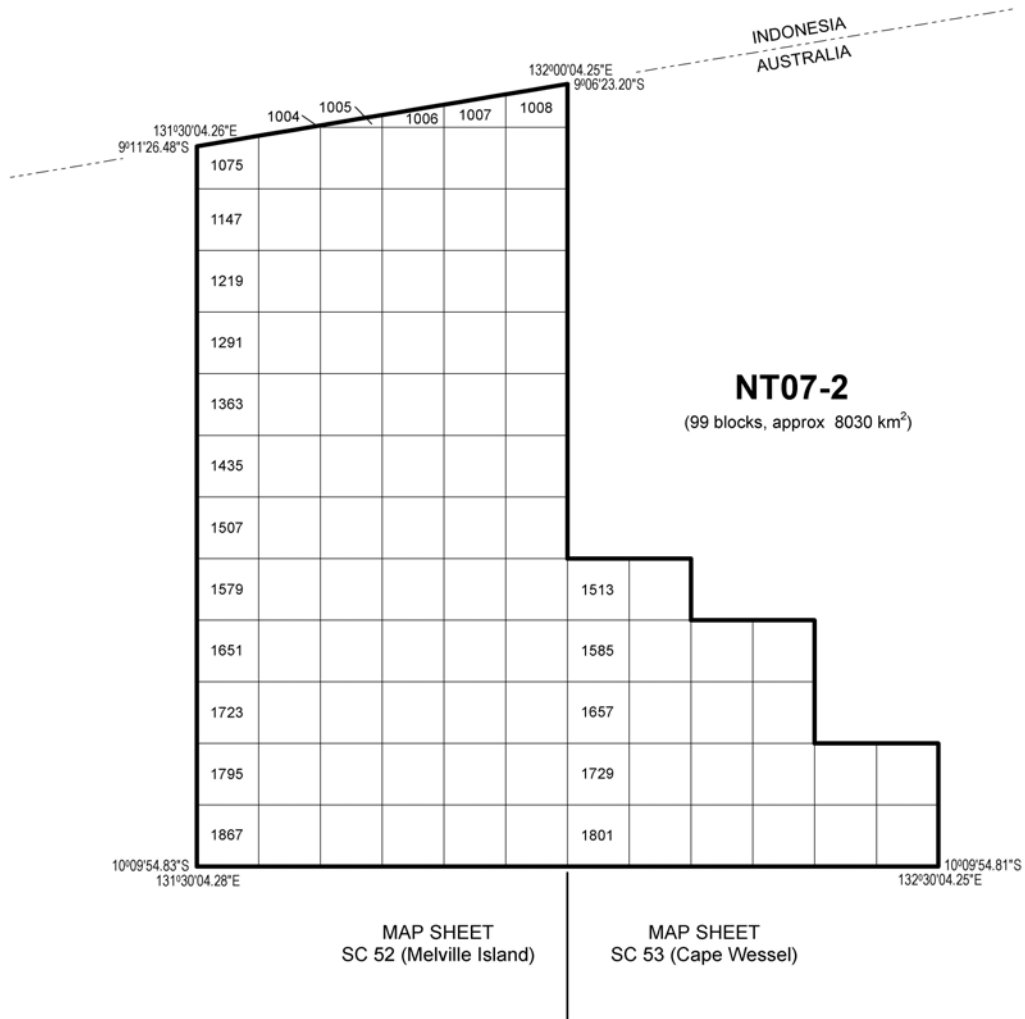
1004 part	1005 part	1006 part	1007 part	1008 part	1075 part
1076 part	1077	1078	1079	1080	1147
1148	1149	1150	1151	1152	1219
1220	1221	1222	1223	1224	1291
1292	1293	1294	1295	1296	1363
1364	1365	1366	1367	1368	1435
1436	1437	1438	1439	1440	1507
1508	1509	1510	1511	1512	1579
1580	1581	1582	1583	1584	1651
1652	1653	1654	1655	1656	1723
1724	1725	1726	1727	1728	1795
1796	1797	1798	1799	1800	1867
1868	1869	1870	1871	1872	

Map Sheet SC 53 (Cape Wessel)

1513	1514	1585	1586	1587	1588
1657	1658	1659	1660	1729	1730
1731	1732	1733	1734	1801	1802
1803	1804	1805	1806		

Assessed to contain 99 blocks (includes 92 full blocks and 7 part blocks)

2007 Release Areas Money Shoal Basin, Northern Territory



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 6118-2

MONEY SHOAL BASIN GEOLOGY

Regional tectonic setting

This summary of the regional petroleum geology draws heavily on a recently completed Geoscience Australia study of the Arafura and Money Shoal basins (Earl, 2006; Struckmeyer, 2006a, b; Totterdell, 2006). The greater part of Area NT07-2 is underlain by the Mesozoic to Cenozoic Money Shoal Basin (**Figure 2**) which directly overlies the offshore continuation of the Pine Creek Inlier, a Palaeoproterozoic orogenic province containing a range of sedimentary, metamorphic and igneous rocks (Carson et al, 1999). The Money Shoal Basin is a mainly offshore basin and is up to 4.5 km thick. In the west, the basin is bounded by the Lynedoch Fault System, which separates the Money Shoal Basin from the Calder and Malita graben of the Bonaparte Basin. In the east, a Mesozoic hinge separates the Money Shoal Basin from the Carpentaria Basin. The southern basin boundary is defined by the depositional edge of Mesozoic to Recent sediments. The northern part of the basin extends beyond the Australian–Indonesian boundary. The basin thins rapidly eastwards but, in the release area, the thickness of the Money Shoal Basin typically ranges between 2.5 and 4.5 km.

In the southeastern part of the release area, the Money Shoal Basin is underlain by the Goulburn Graben of the western Arafura Basin (**Figures 2 and 3**), a Neoproterozoic to Permian intra-cratonic basin. The Goulburn Graben is a highly deformed, obliquely inverted rift that formed during a Late Carboniferous–Permian extensional event, and underwent contractional deformation during the Triassic. It contains up to 10 km of Proterozoic–Permian sedimentary section.

Basin evolution

The subsidence history of the **Arafura Basin** has been episodic, with periods of basin-wide subsidence in the Neoproterozoic, Middle Cambrian–Early Ordovician, Late Devonian and Late Carboniferous–Early Permian, separated by long, relatively quiescent periods of non-deposition and erosion (**Figure 4**). Deposition in the Arafura Basin commenced in the Neoproterozoic during a period of upper crustal extension. Northwest–southeast oriented extension resulted in the formation of northeast–southwest-trending half graben across much of the basin (Totterdell, 2006). Subsequent periods of subsidence in the Cambro-Ordovician and Late Devonian probably were the result of regional-scale stresses, generated by plate-margin events or thermal processes. Subsidence in the Late Carboniferous–Early Permian was driven by northeast–southwest directed extension, which was localised in the Goulburn Graben. Seismic data suggest that this extensional deformation was focused along a northwest–southeast oriented highly deformed zone within the Pine Creek Province. Prior to the Triassic, the basin underwent little deformation, and the entire Neoproterozoic to Permian succession appears to be structurally conformable.

During the Triassic, the Goulburn Graben underwent contractional, probably transpressional, deformation characterised by inversion on pre-existing faults, folding, uplift and the formation of thin-skinned thrust faults. This event is considered to be equivalent to the Middle–Late Triassic Fitzroy Movement (Forman and Wales, 1981), which affected the Canning Basin and adjacent

regions, including the Bonaparte Basin (Colwell et al, 1996). Deformation was largely focused on the Goulburn Graben, but the rest of the basin was affected to a lesser extent. Erosion following the Triassic deformation eventually resulted in the development of a peneplain across the basin. During this period of erosion, the basin was affected by a minor extensional episode resulting in relatively small displacement planar normal faults in the upper part of the pre-Triassic section.

The **Money Shoal Basin** contains a sedimentary succession (**Figure 4**) equivalent to that of the Bonaparte Basin to the west (eg Mory, 1988, 1991; McLennan et al, 1990; Miyazaki and McNeil, 1998). However, the Money Shoal succession is thinner and less complete than that of the Bonaparte Basin because it consists of the proximal onlap edge of the Mesozoic to Cenozoic succession. In the release area, the thickness of the Money Shoal Basin ranges between about 2.5 and 4.5 km (1900–2800 ms two-way time, **Figure 5**). The basal sediments are Early Jurassic in age and onlap the regional angular unconformity of probable Triassic age. Although the Triassic event resulted in the formation of a peneplain across the region, it is likely that some topography remained, facilitating initial deposition of the Troughton Group equivalent. In the Bonaparte Basin, the Late Jurassic was characterised by Oxfordian to Tithonian rifting events that led to the formation of the Malita Graben, Calder Graben and Vulcan Sub-basin (eg Pattillo and Nicholls, 1990; Longley et al, 2002). In the region of the release area, this is reflected in relatively small-scale normal faulting along the boundaries of the Goulburn Graben, particularly along the southern boundary (**Figure 6**). These faults are likely to be reactivated Late Carboniferous faults, which controlled sedimentation during the Late Jurassic to Early Cretaceous. The Jurassic faults underwent further, compressional reactivation in the Neogene resulting in both small- and large-scale anticlinal features (**Figure 6**). **Figure 7** shows the distribution and thickness (in milliseconds two-way time) of the Jurassic to Early Cretaceous succession and illustrates that the depocentres align along the western Goulburn Graben and continue northwest towards the Calder Graben.

Arafura Basin (Goulburn Graben) stratigraphy

The oldest succession in the Arafura Basin is the Neoproterozoic **Wessel Group** (**Figure 4**), which outcrops onshore (Plumb and Roberts, 1992; Rawlings et al, 1997), and is present throughout the offshore extent of the basin. Offshore, the fill of the basal half graben and the overlying post-rift succession are interpreted as belonging to the Wessel Group (**Figure 3**). Onshore, the group consists mainly of shallow marine sandstone and mudstone, with lesser conglomerate and carbonate rocks (Plumb and Roberts, 1992; Rawlings et al, 1997). The age of the Wessel Group is poorly constrained, but limited radiometric data and stratigraphic constraints suggest that it is Neoproterozoic (Rawlings et al, 1997). The group reaches a maximum thickness of approximately 10 km in the central part of the basin, northeast of the Goulburn Graben, but is likely to be thinner in the graben itself.

The Wessel Group is overlain disconformably by the early Middle Cambrian–Early Ordovician **Goulburn Group** (Bradshaw et al, 1990; Nicoll et al, 1996; **Figure 4**). The Goulburn Group has a sag- to sheet-like geometry overall and reaches a maximum thickness of about 2500 m. The Goulburn Group represents prolonged deposition on a shallow marine shelf. The basal unit is the

early Middle Cambrian Jigaimara Formation (Nicoll et al, 1996), a shallow marine limestone, shale and dolomite succession. It is overlain by the largely dolomitic ?Middle Cambrian–earliest Ordovician Naningbura Formation (Nicoll et al, 1996). The Early Ordovician marine shelf mixed carbonate and clastic rocks of the Milingimbi and Moorooonga formations form the uppermost units of the Goulburn Group.

The Late Devonian **Arafura Group** (Petroconsultants, 1989; Bradshaw et al, 1990; McLennan et al, 1990) overlies the Goulburn Group (**Figure 4**). The Arafura Group has a sheet-like geometry overall and reaches a maximum thickness of approximately 1500 m. The Arafura Group consists of shallow marine to non-marine interbedded mudstone, siltstone, sandstone and minor carbonate. The basal unit is the Frasnian Djabura Formation, a dominantly shallow marine succession of interbedded clastics and minor limestone. It is overlain unconformably by the interbedded clastics of the ?Frasnian–Famennian Yabooma Formation (Bradshaw et al, 1990), which is also interpreted to represent dominantly shallow marine deposition. The overlying Famennian Darbilla Formation is a mudstone and siltstone dominated succession interpreted to have been deposited in a largely non-marine environment (Petroconsultants, 1989; Bradshaw et al, 1990).

The Arafura Group is overlain unconformably by a Late Carboniferous–Early Permian succession that is approximately equivalent in age to the **Kulshill Group** of the Bonaparte Basin (**Figure 4**). Well intersections of the Kulshill Group consist of non-marine to marginal marine interbedded sandstone, siltstone and claystone, with minor coal and dolomitic rocks. In the Goulburn Graben, where the lower part of the section comprises an extensional growth wedge, the Kulshill Group is up to 5 km thick. The upper part of the succession represents post-rift deposition.

Money Shoal Basin stratigraphy

The Money Shoal Basin unconformably overlies the Arafura Basin succession and comprises Jurassic to Cretaceous siliciclastic sediments and Cenozoic carbonates that thin rapidly towards the east (**Figure 5**). The oldest unit, the **Troughton Group**, is represented only by its youngest component, the Plover Formation, which directly overlies the Triassic regional unconformity. The oldest sediments, intersected at Tuatara 1 (**Figure 8**), are of late Early Jurassic age (*C. torosa* to *C. turbatus* spore/pollen zone). The upper boundary of the unit is defined by the regional Callovian unconformity (cal). Deposition of the Troughton Group occurred mostly in the western Goulburn Graben region where it is up to 564 m thick at Tuatara 1. It thins rapidly to the north and east and is absent in wells of the eastern Goulburn Graben.

The **Plover Formation** comprises fine- to coarse-grained sandstones with interbedded siltstones and claystones, and minor coal. A generally blocky to serrate gamma log character, the absence of marine microfossils and the presence of coal all indicate an overall fluvial depositional environment. Barber et al (2004) suggested that a series of braided river systems fed into a wide, northeast–southwest-trending marine shelf, with the Goulburn Graben the focus of one of these ‘trunk rivers’. Lowe-Young et al (2004) postulated increasing marine influence in the upper Plover Formation in the Evans Shoal area to the west of the study area. Seismically, the Plover Formation is characterised by

moderate to high amplitude, moderately continuous, parallel reflections (**Figure 6**), but the sequence geometry often is below seismic resolution.

The overlying **Flamingo Group** ranges in age from Callovian (upper *W. digitata* dinoflagellate zone) to Hauterivian (*M. testudinaria* dinoflagellate zone). The base of the Flamingo Group is defined by the Callovian unconformity (cal), which also marks the commencement of a minor extensional event. This is reflected in the clear increase in thickness of the lower Flamingo Group across a reactivated boundary fault of the Goulburn Graben (**Figure 6**). A clastic unit of Hauterivian age, equivalent in age to the Darwin Formation, is here included in the Flamingo Group rather than the Bathurst Island Group as defined by Hughes (1978) and Mory (1991), because a major Barremian to late Aptian hiatus observed in all wells of the Goulburn Graben is interpreted to represent the boundary between two major depositional cycles. In the Bonaparte Basin, the age equivalent of this unit is generally known as the Echuca Shoals Formation (eg Pattillo and Nicholls, 1990; Whittam et al, 1996).

In the Bonaparte Basin, the Flamingo Group is characterised by a condensed section of open marine strata consisting mostly of mudstones (eg Longley et al, 2002). At Tuatara 1, the unit is mudstone-rich with a strong marine influence, but it becomes increasingly sand-prone towards the east, reflecting deposition in mostly fluvio-deltaic environments. Similar to the Troughton Group, the Flamingo Group is thickest in the western Goulburn Graben region (up to 1230 m at Money Shoal 1), thins rapidly to the north and east, and is absent in wells of the eastern Goulburn Graben. A number of erosional surfaces and flooding surfaces can be identified within this unit (**Figure 6**). A major feature of the Flamingo Group is a fluvial channel system along the northern edge of the Goulburn Graben (**Figure 6**) that straddles the hanging wall of the reactivated graben-bounding fault system (Enclosure 4 of Miyazaki and McNeil, 1998). It is present along the entire length of the Goulburn Graben, but is most pronounced near Kulka 1. A distinct flooding surface (mthiflood: **Figure 4**) defines the upper limit of the channel fill and separates the fluvio-deltaic sediments of the lower Flamingo Group from the prograding marine deltaic deposits of the upper Flamingo Group.

The **Bathurst Island Group** of the eastern Money Shoal Basin is late Aptian (*D. davidii* dinoflagellate zone) to Maastrichtian in age. The base of the group is defined by a major unconformity of Aptian age (apt), which forms the base of a series of thick prograding packages. At the toe of the progrades, in the more distal parts of the basin, this unconformity merges with the overlying downlap surface. Overall, the unit consists of mostly fine-grained rocks including claystone, marl and siltstone, with locally thick interbeds predominantly comprising fine-grained sandstones. In the release area, it reaches a thickness of up to 2000 m (1400 ms two-way time; **Figure 9**), but seismic data show that it thickens further into the Calder Graben near Lynedoch 1.

The Bathurst Island Group consists of a series of stacked prograding units deposited in deltaic to open marine environments. The distribution of the group in the offshore Money Shoal Basin and the age of sediments mapped onshore (Hughes, 1978; Carson et al, 1999) suggest that the most far-reaching marine transgression occurred during the Aptian to Cenomanian. The increasing presence of planktonic foraminifera at Lynedoch 1 to the west of the release

area suggests a westwards deepening marine environment. Deeper water environments are also indicated by the presence of upward fining units suggestive of turbidites, particularly in the upper part of the Bathurst Island Group. Submarine canyons and coeval deep-water deposits, such as basinward building shingled fan systems, consisting of slope fans and basin floor sands (**Figure 10**) are present, particularly north and south of Tuatara 1.

Sediments of the **Woodbine Group** are typically Late Miocene and younger in age and are generally less than 400 m thick. West of Kulka 1, where the unit includes Middle Miocene sediments, it thickens rapidly towards the Calder Graben, reaching about 800 m at Tuatara 1, and 1300 m at Lynedoch 1 to the west of the release area. The Woodbine Group was sampled in a limited number of wells only. For example, at Cobra 1A, a lower unit of probable Lower to Middle Miocene, coarse, quartzitic sandstones with claystone interbeds and minor coal and dolomite is overlain by an upper unit of Late Miocene and ?younger calcareous claystone and marl with calcarenite interbeds (BHP Petroleum, 1993). This suggests initially localised, shallow marine to deltaic sedimentation followed by more widespread open marine environments in the Late Miocene. In the release area, the Woodbine Group is generally unstructured.

EXPLORATION HISTORY

Exploration summary

Petroleum exploration in the Arafura Sea region began in the 1920s when several boreholes were drilled on Elcho Island in response to reported bitumen strandings. In the 1960s and early 1970s, stratigraphic drilling occurred on Bathurst and Melville islands (McLennan et al, 1990). During this time Shell Development (Australia) was awarded exploration permits covering the western region of the Arafura Sea and drilled the first well in the offshore Arafura Basin, Money Shoal 1 (1971). This well was drilled primarily to test the Mesozoic Money Shoal Basin sequence. At the same time, Aquitaine was operating in the central southern region of the Arafura Sea. The two operators carried out extensive mapping based on seismic data and defined the Goulburn Graben as an important structural feature. Lynedoch 1, to the west of the release area, was drilled in 1973.

The next phase of exploration occurred in the early 1980s, with several companies operating in the region, including Diamond Shamrock, Esso, Petrofina and Sion Resources. A number of wells were drilled at this time, all of which tested the Palaeozoic Arafura Basin sequence. Petrofina drilled two wells, Arafura 1 (1983) and Goulburn 1 (1985). Arafura 1 recorded important oil shows over a 425 m depth range in the Devonian and Ordovician sections and still provides the most important Palaeozoic stratigraphic control in the basin. The company also mapped a number of large fault-related closures that remain untested (Miyazaki and McNeil, 1998). Esso drilled two wells, Tasman 1 (1983), which targeted a fault block on a domal feature originally interpreted as salt-related, and Torres 1 (1983), which targeted a prominent Palaeozoic anticline. Diamond Shamrock drilled Kulka 1 (1984), which provides important stratigraphic control for the Late Palaeozoic and Mesozoic sections.

A third phase of petroleum exploration by BHP Petroleum in the late 1980s and early 1990s targeted mostly Mesozoic plays in the Goulburn Graben. The exploration program included an extensive 17,000 km seismic survey, a regional aeromagnetic survey, and the drilling of three exploration wells, Tuatara 1 (1990), Chameleon 1 (1991) and Cobra 1A (1993). Tuatara 1 targeted a faulted anticline within Jurassic Troughton Group equivalents. During the early 1990s Geoscience Australia (then the Bureau of Mineral Resources) acquired a total of 5342 km of regional deep seismic data across the Arafura Basin (**Figure 10**).

In the past 10 years, several exploration activities have contributed to the available dataset and have high-graded the prospectivity of the region. These include, for example, non-exclusive regional 2D seismic data sets by TGS Nopec in 1998 and Veritas DGC in 2002, a 3728 km regional 2D seismic survey acquired for Nexen Petroleum Australia as part of their exploration commitment, and Synthetic Aperture Radar acquisition and interpretation across the region by Infoterra in 2003. Lynedoch 2 was drilled in 1998 and encountered a tight gas column in the Plover Formation, which had originally been suspected from the results of Lynedoch 1. Tyche 1 (2000) was unsuccessful, but the drilling of the Abadi 1, 2 and 3 wells in Indonesian waters (Yui, 2003), and of Caldita 1 in NT/P61 resulted in the discovery of large-scale gas accumulations.

Relevant Wells Listing – NT07-2, Money Shoal Basin

Well	Operator	Year	Total Depth (m)	Hydrocarbons
Arafura 1	Petrofina Explor	1983	3635	Gas flowed on test, oil shows
Chameleon 1	BHP Petroleum	1991	2179	Oil indication
Caldita 1	ConocoPhillips Exploration Australia Pty Ltd	2005	4037	Proven gas zone
Caldita 2	ConocoPhillips Exploraiton Australia Pty Ltd	2006	N/A	Drilling at time of publication
Cobra 1	BHP Petroleum Pty Ltd	1993	409	No shows
Cobra 1A	BHP Petroleum Pty Ltd	1993	2542	Oil indication
Goulburn 1	Petrofina Explor	1986	1300	Oil recovered
Lynedoch 1	Shell Development (Australia) Pty Ltd	1973	3967	Strong gas indications
Lynedoch 2	Shell Development (Australia) Pty Ltd	1998	4225	Gas flowed on test
Kulka 1	Diamond Shamrock Oil Company (Australia)	1984	3998	Oil indication
Money Shoal 1	Shell Development (Aust.) Ltd	1971	2590.1	Oil indication
Tasman 1	Esso Explor and Prod Aust Ltd	1983	2720	Oil indication
Torres 1	Esso Explor and Prod Aust Ltd	1983	2758	No shows
Tuatara 1	BHP Petroleum	1990	3875	Oil indication

PETROLEUM POTENTIAL

To date, no commercial discoveries have been made in the Money Shoal and Arafura basins, but there are numerous hydrocarbon indications in wells drilled in the Goulburn Graben (**Figure 2**). Arafura 1 and Goulburn 1 had the most promising results with oil shows, and a gas show in Arafura 1. Chameleon 1, Cobra 1A, Kulka 1, Money Shoal 1, Tasman 1 and Tuatara 1 all contain oil indications in Mesozoic and Palaeozoic reservoirs (Miyazaki and McNeil, 1998). A review of available data sets together with new data and interpretations (Earl, 2006; Struckmeyer, 2006a, b), and results from a recent survey investigating potential hydrocarbon seepage in the Arafura Basin (Logan et al, 2006) show that the region contains not only all the required essential petroleum systems elements to generate, expel and trap hydrocarbons, but also evidence that this generation and expulsion has occurred.

Source rocks

Based on RockEval total organic carbon (TOC) data (**Figure 11**), the Arafura and Money Shoal basins contain several units with potential source rocks (Boreham, 2006; Struckmeyer, 2006a, b). In the western Goulburn Graben of the Money Shoal Basin, which underlies the southeastern part of the release area, the oil window typically occurs at depths between 2400 and 2900 m. None of the three wells in or near the release area (Tuatara 1, Cobra 1 and Kulka 1) intersected sediments older than Permo-Carboniferous, but seismic data show that older Palaeozoic rocks intersected by wells in the eastern Goulburn Graben are also present in the release area (**Figure 3**). Descriptions of the source potential of these rocks are based on wells from the eastern Goulburn Graben.

Samples from the Cambro-Ordovician Goulburn Group contain up to 8.6 % TOC contents (**Figure 11**). The higher values represent migrated oil and solid bitumen (Keiraville Consultants, 1984; Sherwood et al, 2006) rather than dispersed organic matter as reported in previous publications (Bradshaw et al, 1990, Edwards et al, 1997). A recent oil-source correlation study in the Georgina Basin (Boreham and Ambrose, 2005) identified three Middle to Late Cambrian petroleum systems related to source rocks of algal/bacterial origin. One of these, the early Middle Cambrian Thornton(!) Petroleum System, has similar geochemical and isotopic characteristics to oil stains in Early Palaeozoic rocks at Arafura 1 and Goulburn 1 (Boreham and Ambrose, 2005). This suggests that the effective source rock in the Arafura Basin is likely to occur in the Jigaimara Formation, which is an age equivalent of the Thornton Limestone in the Georgina Basin. The presence of abundant interstitial bitumen in association with oil stains in Early Palaeozoic samples is indicative of a multi-charge history from a prolific source nearby (Sherwood et al, 2006). Potential source rocks may also be present within the Neoproterozoic Wessel Group; however, no data are available for this section.

A limited number of samples from the Devonian suggests a generally poor source potential for this section; however, one sample at Arafura 1 contains 0.85 % TOC which consists predominantly of lamalginite (Sherwood et al, 2006). This confirms that potentially fair source rocks are present within Devonian marine calcareous mudstones. Higher TOC values in other samples reflect the presence of bitumen (**Figure 11**). Based on well data, the Early

Palaeozoic succession is typically mature to overmature for hydrocarbon generation.

Good to very good potential source rocks are also present in the Permo-Carboniferous Kulshill Group equivalent. The typical TOC range is <0.4 to 3 % with hydrogen index (HI) values of up to 321 mg hydrocarbons/gTOC (**Figures 11 and 12**), but several samples in the central Goulburn Graben contain up to 9 % TOC, comprising land plant-derived organic matter such as vitrinite, sporinite and liptodetrinite (Sherwood et al, 2006). Based on vitrinite reflectance data at Kulka 1 (0.9–2.4 %), the Kulshill Group in the western Goulburn Graben is mature to overmature for oil generation and mature for gas generation.

The Jurassic section contains good to excellent potential source rocks and has a typical TOC range of 0.5–8 % and HI values of up to 454 mg hydrocarbons/gTOC (**Figures 11, 13 and 14**). Several coaly units with TOC values up to 60 % are also present, particularly in the Early–Middle Jurassic Troughton Group equivalent. Sediments of this age (Plover Formation) provide the source rocks for gas/condensate accumulations in the nearby Bonaparte Basin (eg Preston and Edwards, 2000). In the Arafura Basin region, the Jurassic section is mostly immature for oil generation; however, it reaches oil maturity in the westernmost Goulburn Graben (VR values of 0.6–0.79 % at Tuatara 1) and is probably mature for oil generation in the western half of the release area. Here, the lower Flamingo Group should also be marginally mature to mature for oil generation. Cretaceous potential source rocks contain up to 5 % TOC, but are immature for hydrocarbon generation.

Reservoir rocks

Potential reservoir rocks in the Arafura Basin (**Figure 15**) include shallow marine limestones and dolomites of the Cambro-Ordovician Goulburn Group, and terrestrial to fluvio-deltaic interbedded sandstones and mudstones of the Devonian Arafura Group and Permo-Carboniferous Kulshill Group equivalent. The Goulburn Group dolomite could be an important potential reservoir in the region, hosting an oil and gas show in Arafura 1 and oil indications in Goulburn 1. The unit has a maximum porosity of 7.7 %, but averages about 2 % in sections lacking significant secondary porosity (**Figure 15**). Permeability values are also generally low. As a result, reservoir quality in this unit relies on the development of secondary porosity through features such as vugs and fractures. These features are common, as evidenced by repeated mud losses, increases in drilling rates, variable caliper logs and drilling breaks (Earl, 2006). Movement of fluid into and through the unit is facilitated by these secondary features, as indicated by the numerous associated oil occurrences. A risk associated with this unit is cementation reducing secondary porosity. The cementation is probably at least partly related to Triassic contraction and uplift.

Siltstones and sandstones of the Arafura Group form another important reservoir in the region, hosting oil shows at both Arafura 1 and Goulburn 1. The unit has a maximum porosity and permeability of 19 % and 7.83 mD at Goulburn 1, but averages 9.6 % porosity with a large standard deviation (**Figure 15**). A significant proportion of the primary porosity has been destroyed by diagenetic effects, including silica overgrowths and carbonate cementation.

The Kulshill Group equivalent generally has poor reservoir quality, with porosities averaging 5.5 %. However, the upper parts of this unit generally have better porosities (**Figure 15**) with a maximum of 17.7 % at Tasman 1. Carbonate cements are sporadic throughout the unit but there is evidence of multiple fracture sets (such as at Chameleon 1), which could enhance the overall permeability and porosity.

Mesozoic reservoirs are important in the adjoining Bonaparte Basin, where they host a number of commercial hydrocarbon accumulations (Barrett et al, 2004; Cadman and Temple, 2005). The Money Shoal Basin also contains high quality reservoirs (**Figure 16**), including the Troughton Group equivalent (Jurassic), the Flamingo Group (Jurassic to Early Cretaceous) and the Bathurst Island Group (Cretaceous). Due to their distribution, Money Shoal Basin reservoirs are well positioned to receive any late hydrocarbon charge from underlying potential Palaeozoic source rocks. Sandstones of the Jurassic Troughton Group equivalent have average porosities of 8.5 % with a maximum of 27 % at Tasman 1 (**Figure 17**). Blocky fluvio-deltaic sands of the Flamingo Group have an average porosity of 18.5 %, with a maximum of 32 % at Tasman 1 and a range of 5–17 % at Tuatara 1. There is some dolomite cementation in these rocks, but the unit also contains fractures that may help facilitate fluid movement. Where it is sandstone-rich, the Darwin Formation equivalent (eg at Kulka 1) has excellent porosity, with an average of 25 %. The Bathurst Island Group also contains units with possibly excellent reservoir potential. For example, at Tuatara 1, porosities range between 13 and 33 %, although no permeability data are available. The reservoir potential of basin floor sands within this unit remains untested.

Seals

Mudstones of the mid- to Late Cretaceous Bathurst Island Formation, which provide a regional seal in the Malita Graben of the Bonaparte Basin, are also present in the release area. The unit is laterally and vertically extensive and typically overlies high quality Mesozoic reservoirs. Fault breach is unlikely due to the thickness of the unit.

Other seals in the region are less homogenous. The Jurassic to Early Cretaceous section tends to be sand-dominated, but contains extensive mudstones. These include maximum flooding surfaces and abandoned channel fill and overbank deposits that could provide good intraformational seals. There is little information about potential Palaeozoic seals; however, oil shows/indications below thick Devonian fine-grained sediments at Arafura 1 and Goulburn 1 attest to the sealing capacity of this unit (Petroconsultants, 1989). Oil indications above this seal in Arafura 1 are the result of fault migration (Labutis et al, 1992; Earl, 2006). Mudstones at the top and base of the Cambro-Ordovician Goulburn Group may also provide a seal for adjacent carbonate reservoirs, and Permo-Carboniferous dolerite sills such as that intersected in Kulka 1 could provide local seals.

Timing of generation and expulsion

Moore et al (1996) concluded that oil generation and migration from potential Palaeozoic source rocks in the Goulburn Graben, where all exploration wells are located, pre-dates the Triassic structural event and thus potential trap

formation. A recent geohistory study of all wells and several pseudo-well sites in the Arafura and Money Shoal basins by Struckmeyer (2006a, b) confirmed this conclusion, but demonstrated that some areas in the western Goulburn Graben could have experienced a late phase of generation and expulsion from potential Palaeozoic source rocks. For example, this includes the possibility of a minor phase of late expulsion of light oil from a Type I/II Cambrian source rock at Tuatara 1, where the lack of success is considered to be due to an absent or inadequate seal (Earl, 2006).

More significantly, the greater part of Late Cenozoic expulsion in the release area would have been from potential source rocks in the Devonian Arafura Group and the Permo-Carboniferous Kulshill Group (**Figure 17**), in areas where the basin experienced enough post-Triassic loading for these sediments to reach the oil window during the Late Cretaceous to Cenozoic. Modelling of wells in the western Goulburn Graben suggests that a burial depth of about 3 km is required for the upper Kulshill Group to generate and expel oil. For example, at Cobra 1A, where these conditions are met, oil generation and expulsion is modelled to have occurred during the past 10 million years (**Figure 18a**), whereas at Kulka 1, where these potential source rocks are present at a depth of 2.5–2.7 km, some generation may have occurred, but hydrocarbons are unlikely to have been expelled. Thus, modelling of these units is highly sensitive to the amount of Triassic erosion interpreted for any location. The lack of an accumulation at Cobra 1A has been attributed to a seal issue, rather than source and reservoir problems (Earl, 2006).

Potential source rocks of the Troughton Group (Plover Formation) are typically immature in all wells in the Goulburn Graben, apart from Tuatara 1. Here the unit reaches oil maturity and has probably generated some oil, but expulsion is unlikely to have occurred. However, at pseudo-well site G, to the west of Tuatara 1 (**Figure 17**), a thicker Money Shoal overburden (about 4 km) is present and modelling suggests that oil expulsion has occurred at this site during the Late Cretaceous to Recent (**Figure 18b**). Struckmeyer (2006b) concluded that a Plover Formation source rock could have expelled hydrocarbons in the undrilled western Goulburn Graben and in the western Money Shoal Basin towards the Calder Graben of the Bonaparte Basin, where hydrocarbon accumulations sourced from this unit are present. Both of these potential source kitchens occur within the release area. Expulsion from potential source rocks of the lower Flamingo Group probably also occurred in the Late Cenozoic to Recent in the region west of pseudo-well G.

Exploration plays and risks

Interpretation of available seismic data indicates that a variety of potential play types are present in the 2007 release area (Struckmeyer, 2006b). Palaeozoic plays include large faulted anticlines and fault blocks that could provide traps at several stratigraphic levels. Sub-unconformity plays below the Triassic regional unconformity are present in all release areas (**Figure 19**) within Neoproterozoic, Cambro-Ordovician, Devonian and Permo-Carboniferous strata. Diagenetic traps and other stratigraphic traps within the Cambro-Ordovician and Devonian carbonate successions are a strong possibility in this region, but are as yet untested and insufficient stratigraphic information is available to allow a detailed assessment.

The Mesozoic Money Shoal Basin section offers a variety of stratigraphic and combined structural/stratigraphic plays (**Figure 19**) for hydrocarbons sourced from underlying Early Palaeozoic sediments and from mature Late Palaeozoic and Mesozoic source kitchens. Onlap plays associated with the Triassic unconformity could provide numerous potential targets within Middle Jurassic fluvial sandstones and/or Late Jurassic to Early Cretaceous fluvio-deltaic clastics in lowstand, transgressive and highstand settings. Plays associated with these deposits also include drape closure over Triassic topography, fluvial channel plays, lowstand wedge plays and fault block plays. One of the main features of the Money Shoal Basin section is a Tithonian channel system that runs along the major bounding faults of the Goulburn Graben (BHP Petroleum, 1993; Miyazaki and McNeil, 1998; Barber et al, 2004) and thus could provide an important play type in the 2007 release area. The northern channel system was assessed by BHP Petroleum (1993) to be at least 225 km long and, on average, 10 km wide. Although the channel system has been unsuccessfully tested at several locations (such as Chameleon 1, Cobra 1A and Kulka 1), the feature still provides numerous untested stratigraphic/ structural traps within channel fills and associated erosional features.

The mid- to Late Cretaceous prograding shelf and contiguous slope and basin deposits provide numerous potential plays, particularly within lowstand wedge deposits such as slope fans, channel-levee systems and basin floor fans (**Figures 10 and 19**). Seismic data suggest that the basin floor fans are 15 to 25 km long, indicating the presence of significant prospect sizes. Tuatara 1 did not intersect fan deposits but the generally fine-grained nature of the Late Cretaceous succession suggests that good seals for any accumulations within basin floor sands exist.

A recent audit of exploration wells in the Goulburn Graben (Earl, 2006) identified timing of hydrocarbon charge, breach of structure and reservoir quality as the major reasons for the failure of wells. Thus, reservoir quality of Palaeozoic rocks and the timing of generation, expulsion and trap formation in relation to the major structuring event in the Triassic are regarded as the key risks in the southeastern release area. Risks for the younger, mostly stratigraphic plays include the presence of suitable seals.

Evidence that hydrocarbon generation and expulsion has occurred in the Money Shoal and Arafura basins is provided by oil shows/indications and gas indications in the majority of wells drilled in the region, and the presence of interstitial solid bitumens in many samples (Sherwood et al, 2006). More indirect evidence is provided by Synthetic Aperture Radar (SAR) data which revealed several anomalies across the region (Infoterra Ltd, 2003), and by the presence of a number of ALF (Airborne Laser Fluorosensor) fluors (Cowley, 2001). Seismic data show bright amplitudes at various stratigraphic levels, particularly within interpreted basin floor fans in the Bathurst Island Group (**Figures 10 and 19**), and these may indicate the presence of hydrocarbons.

The tectonostratigraphic and event history of the basin, together with modelled expulsion from both Palaeozoic and Mesozoic potential source rocks and the indirect hydrocarbon indicators described above, provide strong cumulative evidence for the presence of active petroleum systems and potential plays in the release area.

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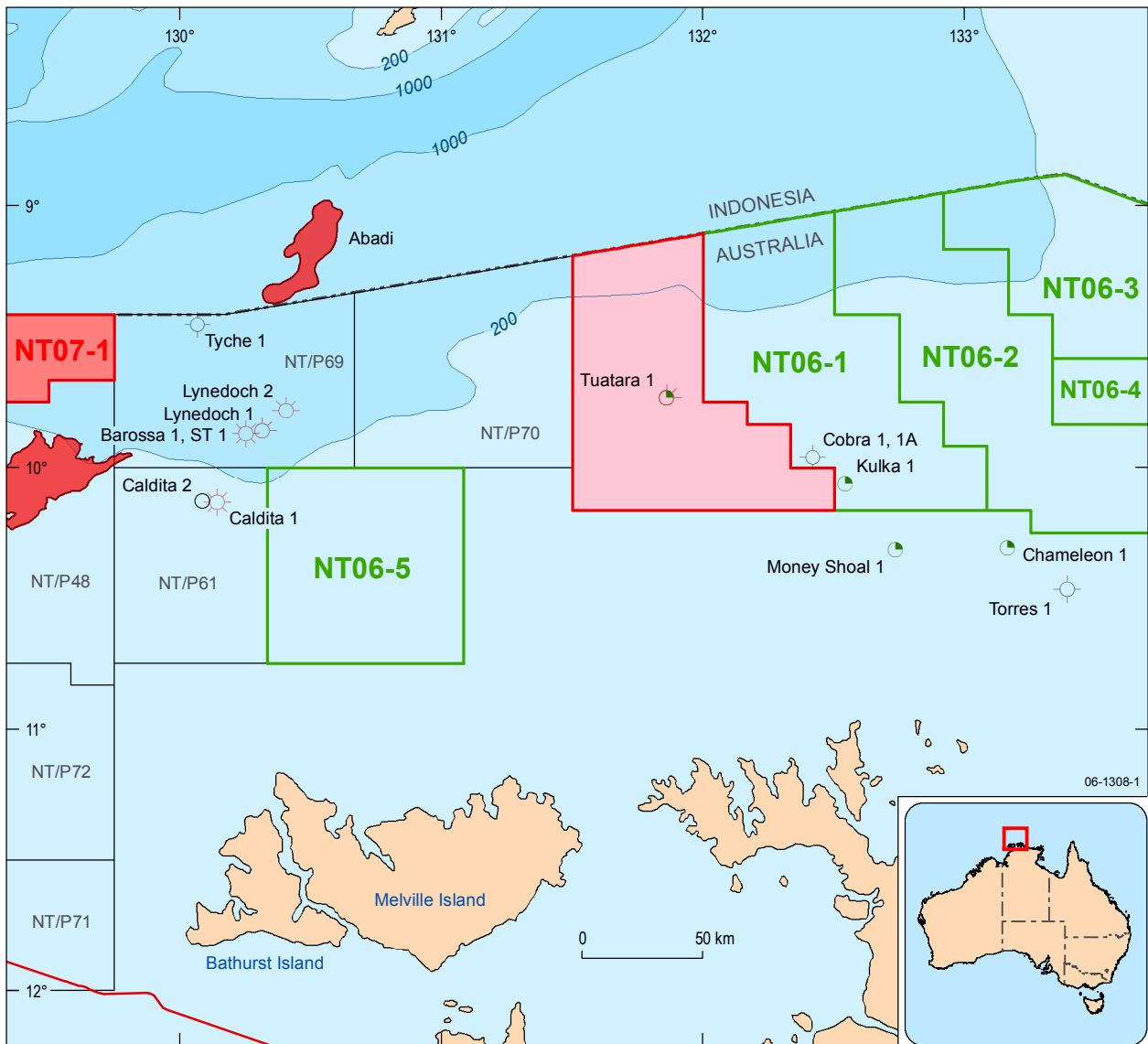
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FIGURES

- Figure 1: Location map of Area NT07-2, Money Shoal Basin.
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- Figure 4: Arafura and Money Shoal basins correlation chart, showing stratigraphy, seismic horizons, petroleum systems elements, and structural setting. Due to uncertainty in the age of the Proterozoic section, absolute ages are not shown for this part of the timescale (after Earl, 2006).
- Figure 5: Thickness (milliseconds two-way time) of the eastern Money Shoal Basin (Struckmeyer, 2006b).
- Figure 6: Seismic example (courtesy Australian Seismic Brokers) illustrating the stratigraphy of the Money Shoal Basin. TG = Troughton Group equivalent, FG = Flamingo Group equivalent; 1, 2 and 3 indicate unconformities within the Flamingo Group (Struckmeyer, 2006b).
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- Figure 8: Tuatara 1 well composite, summarising stratigraphy, predominant lithologies, hydrocarbon shows, RockEval and maturity data (Earl, 2006)
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- Figure 10: Seismic example (flattened on base Aptian seismic horizon) illustrating basinward building shingled fan systems with basin floor sands showing bright amplitudes (blue arrows) within the Bathurst Island Group. Seismic line courtesy Australian Seismic Brokers.
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- Figure 12: RockEval pyrolysis plot for samples from the Kulshill Group equivalent (Struckmeyer, 2006b).
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- Figure 15: Porosity data for samples from the Arafura Basin (Earl, 2006).
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- Figure 17: Map of the western Arafura and eastern Money Shoal basins showing interpreted areas of hydrocarbon expulsion from potential Devonian (Arafura Group), Permo-Carboniferous (Kulshill Group) and Jurassic (Troughton Group) source rocks (Struckmeyer, 2006b).
- Figure 18: Hydrocarbon generation and expulsion models for a) Kulshill Group source rocks at Cobra 1A, and b) Troughton Group (Plover Formation) source rocks at pseudo-well site G, showing rate of oil expulsion (Struckmeyer, 2006b).
- Figure 19: Seismic example illustrating potential play types in area NT07-2: sub-unconformity plays (1) below the regional Triassic unconformity within Permo-Carboniferous clastics of the Kulshill Group; stratigraphic plays (2) associated with Jurassic to Early Cretaceous fluvial channels; fault block (3) and drape (4) plays within Jurassic to Early Cretaceous (Troughton and Flamingo groups) fluvial and deltaic sediments; basin floor and slope fan plays (5) within the mid- to Late Cretaceous Bathurst Island Group.



Field outlines, with the exception of Abadi, supplied by Encom Petroleum Information Pty Ltd. The Abadi field is generalised and shown for approximate size and position only.















- | | | | |
|---|--|---|---|
|  | 2007 release area |  | Petroleum exploration well - currently drilling |
|  | 2007 designated frontier area |  | Petroleum exploration well - dry hole |
|  | 2006 release area |  | Petroleum exploration well - oil indication |
|  | Existing petroleum exploration or development permit |  | Petroleum exploration well - gas indication |
|  | Gas pipeline |  | Petroleum exploration well - gas show |
|  | Adjacent area boundary |  | Petroleum exploration well - oil and gas indication |
|  | -500- Bathymetric contour (depth in metres) |  | Petroleum exploration well - gas accumulation |

Figure 1. Location map of Area NT07-2, Money Shoal Basin.

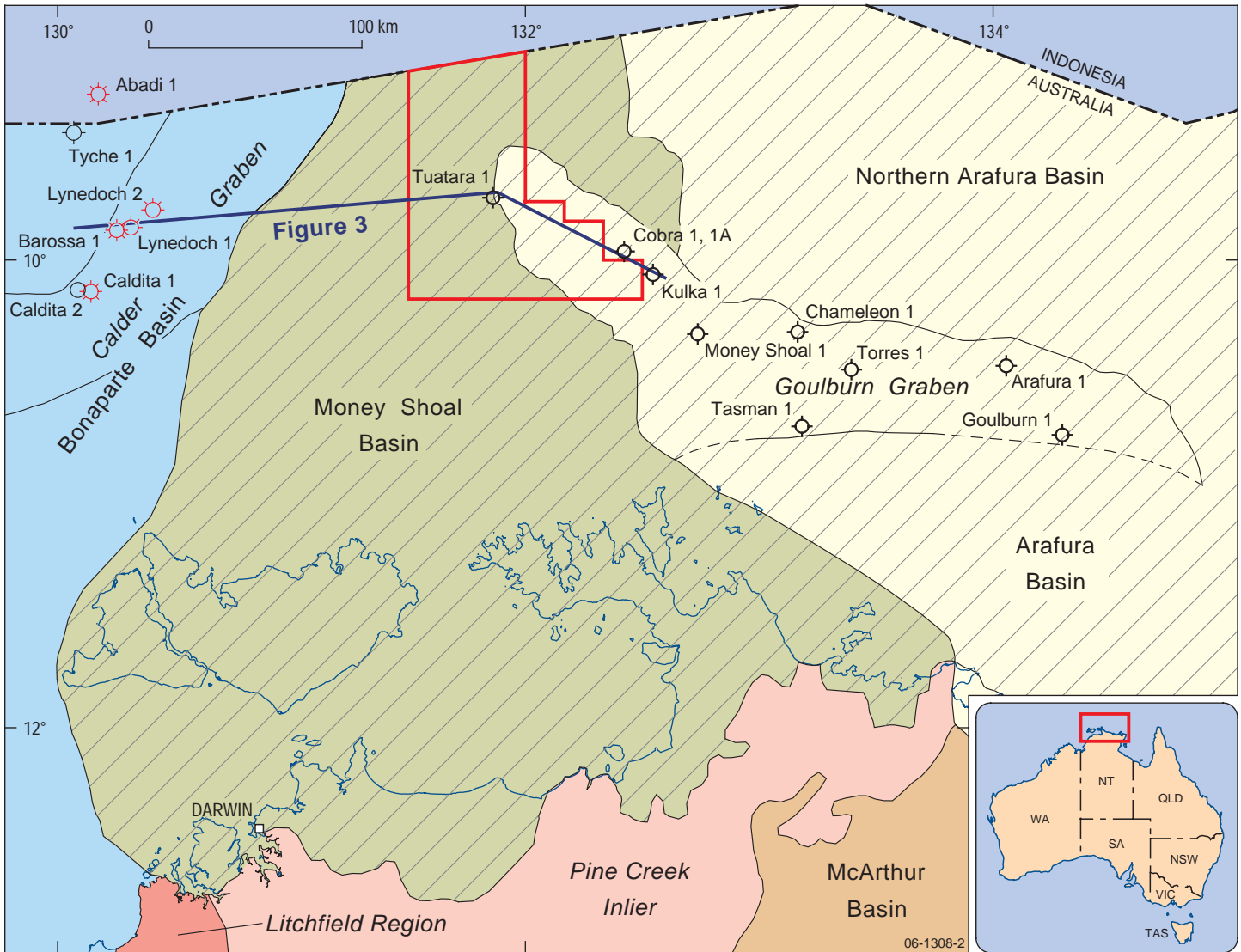


Figure 2. Regional setting of the Money Shoal Basin, also showing the location of Figure 3.

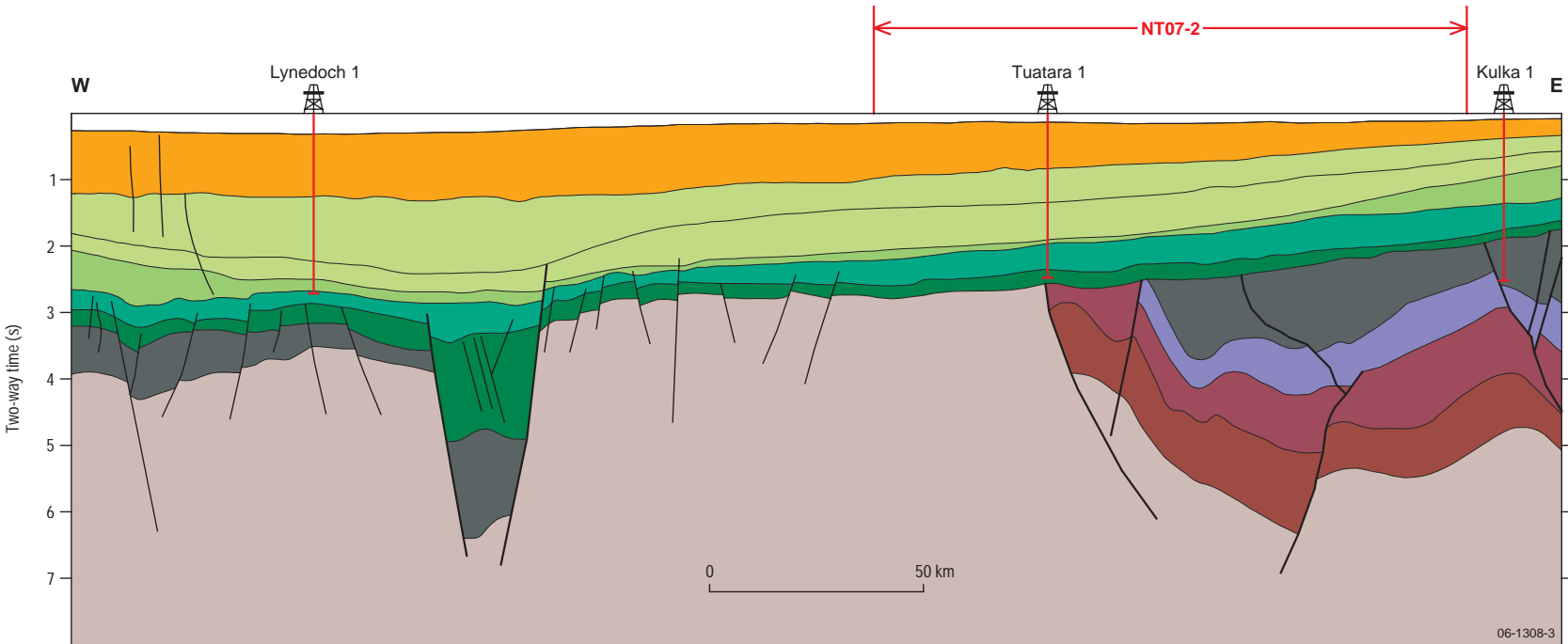


Figure 3. Geoseismic cross-section from the Calder Graben to the western Goulburn Graben of the Arafura Basin.

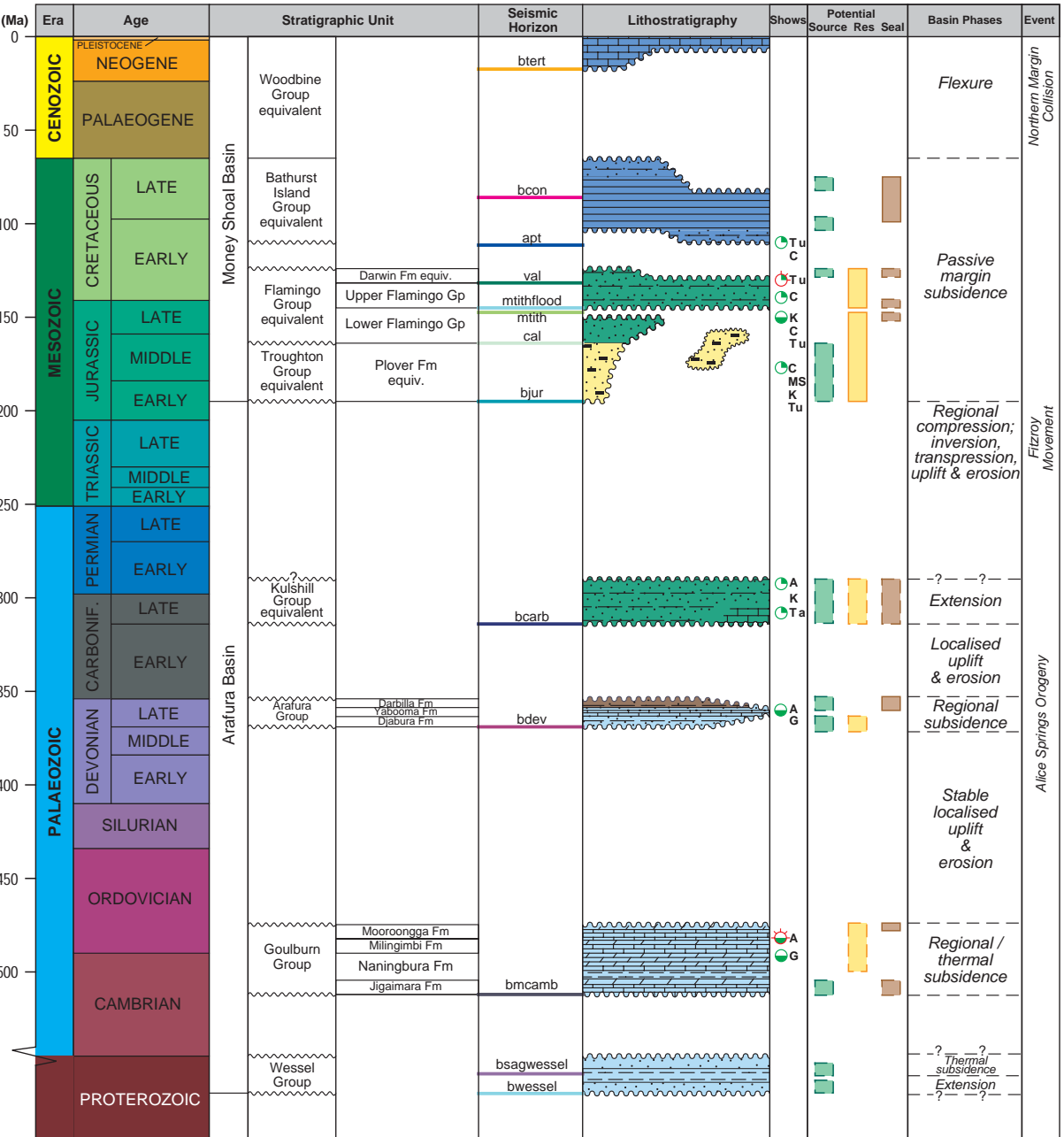


Figure 4. Arafura and Money Shoal basins correlation chart, showing stratigraphy, seismic horizons, petroleum systems elements, and structural setting. Due to uncertainty in the age of the Proterozoic section, absolute ages are not shown for this part of the timescale (after Earl, 2006).

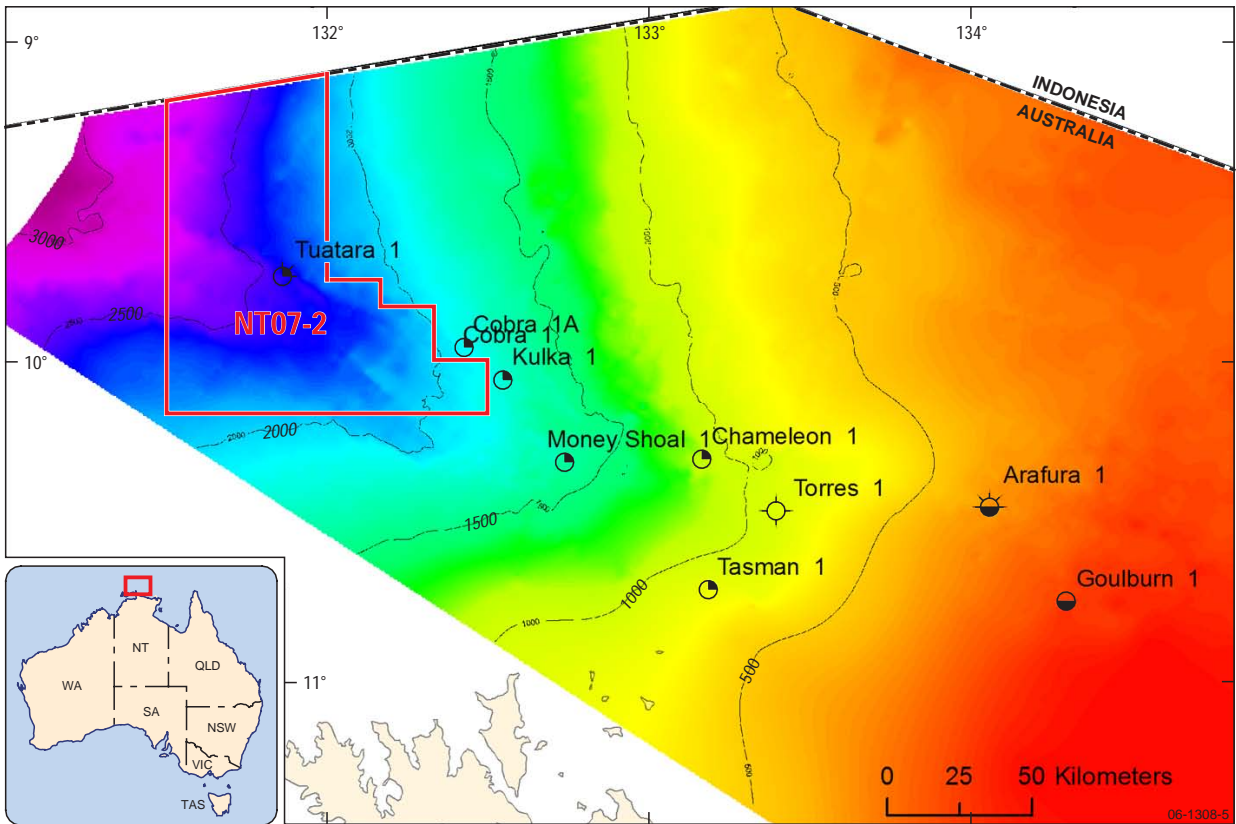


Figure 5. Thickness (milliseconds two-way time) of the eastern Money Shoal Basin (Struckmeyer, 2006b).

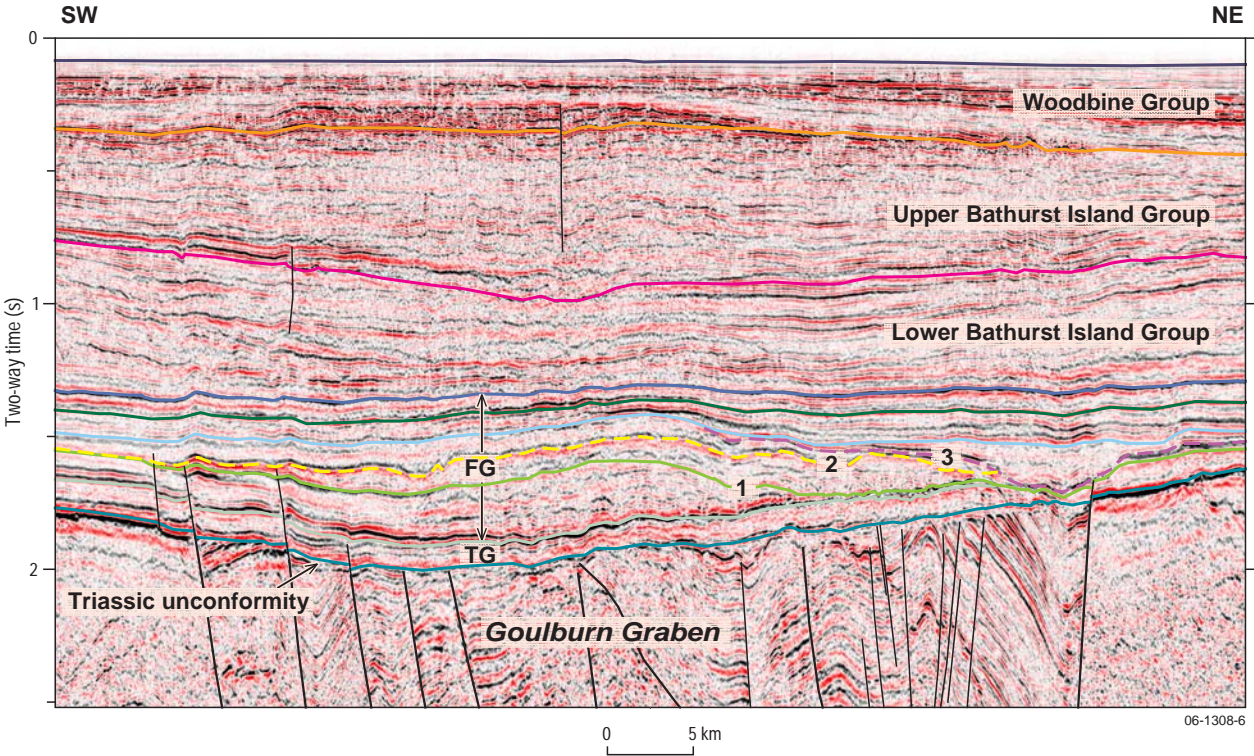


Figure 6. Seismic example (courtesy Australian Seismic Brokers) illustrating the stratigraphy of the Money Shoal Basin. TG = Troughton Group equivalent, FG = Flamingo Group equivalent; 1, 2 and 3 indicate unconformities within the Flamingo Group (Struckmeyer, 2006b).

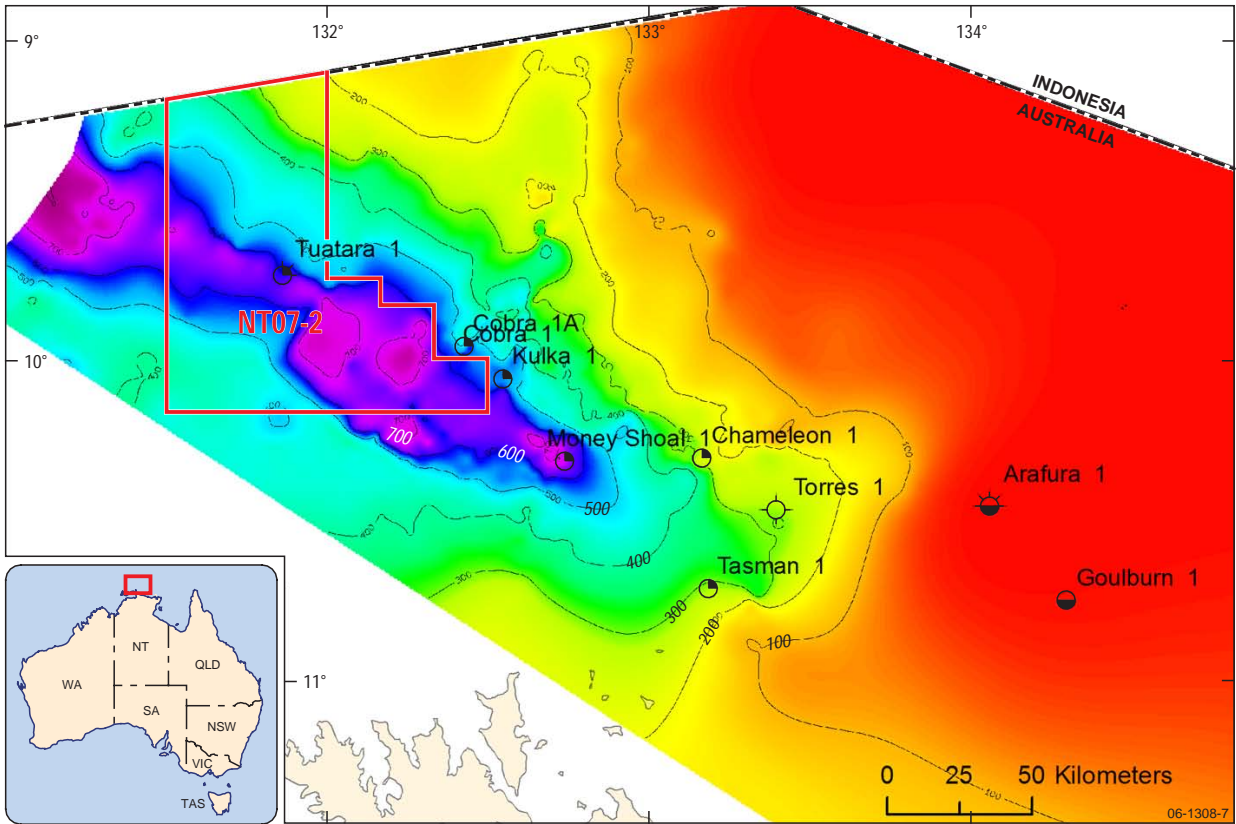


Figure 7. Thickness (milliseconds two-way time) of Jurassic to Early Cretaceous sediments (Troughton and Flamingo groups) in the Money Shoal Basin (Struckmeyer, 2006b).

