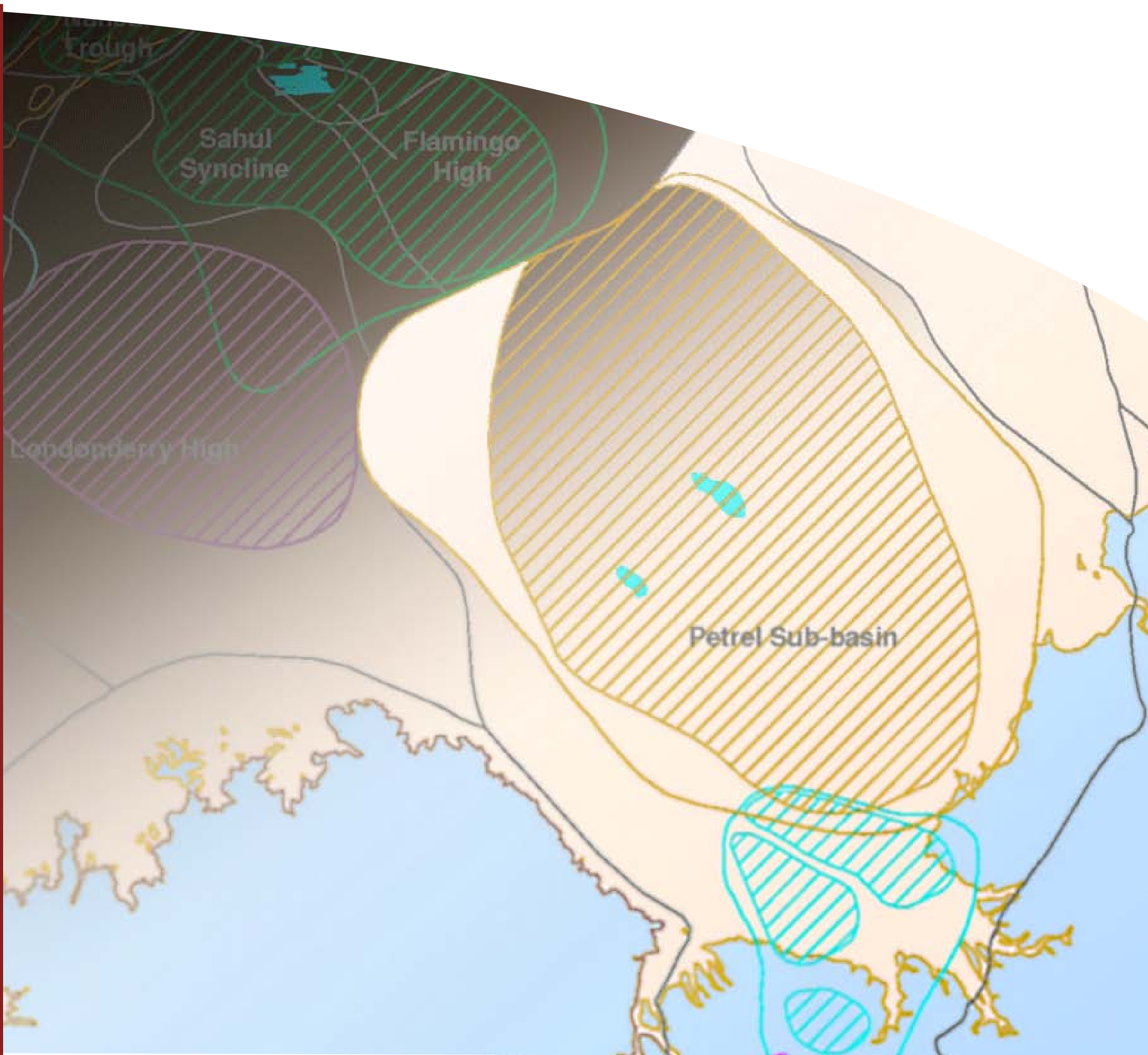
Australian Government
Geoscience Australia

The petroleum systems of the Bonaparte Basin

compiled by K.L. Earl

GEOCAT
#61365



Department of Industry, Tourism and Resources
Minister for Industry, Tourism and Resources: The Hon. Ian Macfarlane, MP
Parliamentary Secretary: The Hon. Warren Entsch, MP
Secretary: Mark Paterson

Geoscience Australia
Chief Executive Officer: Dr Neil Williams

ISSN 1448-2177

Bibliographic reference: Earl, K.L. Bonaparte Basin Petroleum Systems. Geoscience Australia, GEOCAT # 61365.

Australian Government
Geoscience Australia

Petroleum Systems of the Bonaparte Basin

Published by Geoscience Australia, Department of Industry, Tourism and Resources, Canberra, Australia. Issued under the authority of the Minister for Industry, Science and Resources.

Geocat: 61365

THE BONAPARTE BASIN

The Cambrian to Recent Bonaparte Basin is located on the NorthWest Shelf of Australia and covers 329,000 sq. km offshore and onshore (Figure 1).

The region is an established hydrocarbon province with a number of commercial discoveries. New infrastructure is being constructed within the region, such as the Bayu-Undan LNG plant, with a number of giant gas accumulations yet to be developed.

The area has remaining oil and gas potential, particularly in the Vulcan Sub-basin, Laminaria-Flamingo High and northern Sahul Platform areas, with additional discoveries likely within the next decade. The main exploration risk in the region is fault seal breach.

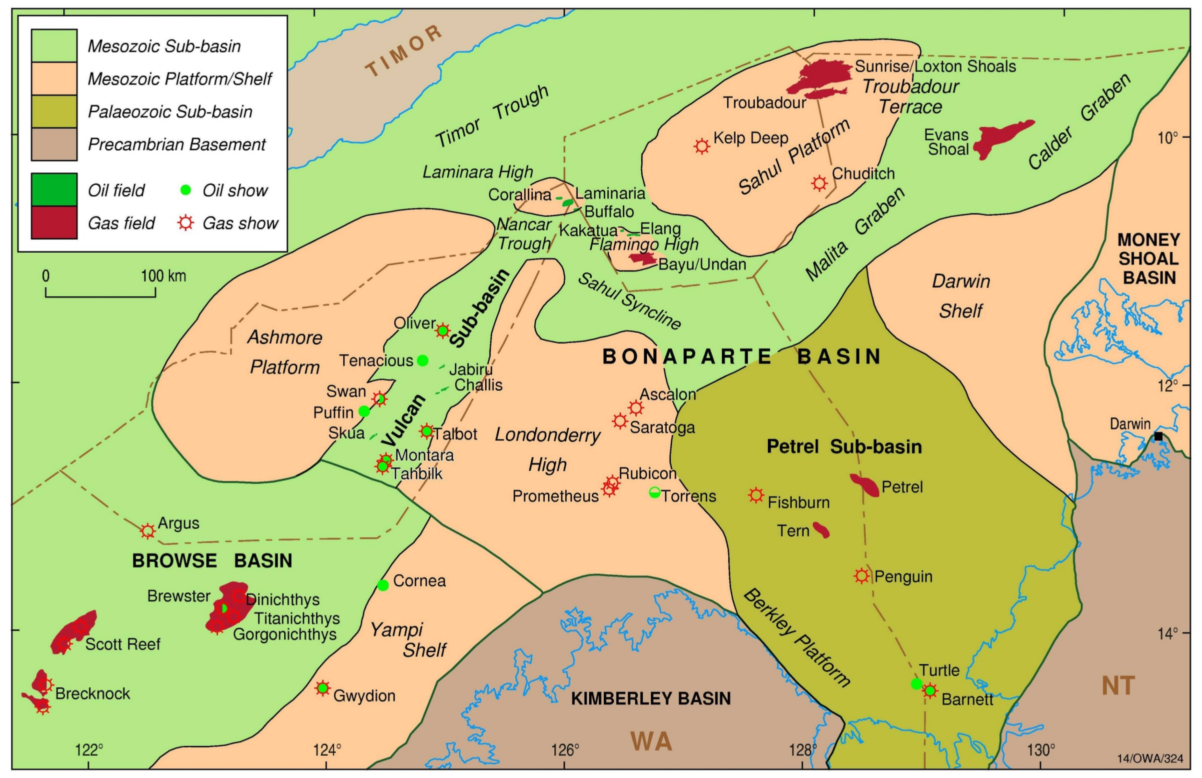


Figure 1: Palaeozoic and Mesozoic structural elements of the Bonaparte Basin.

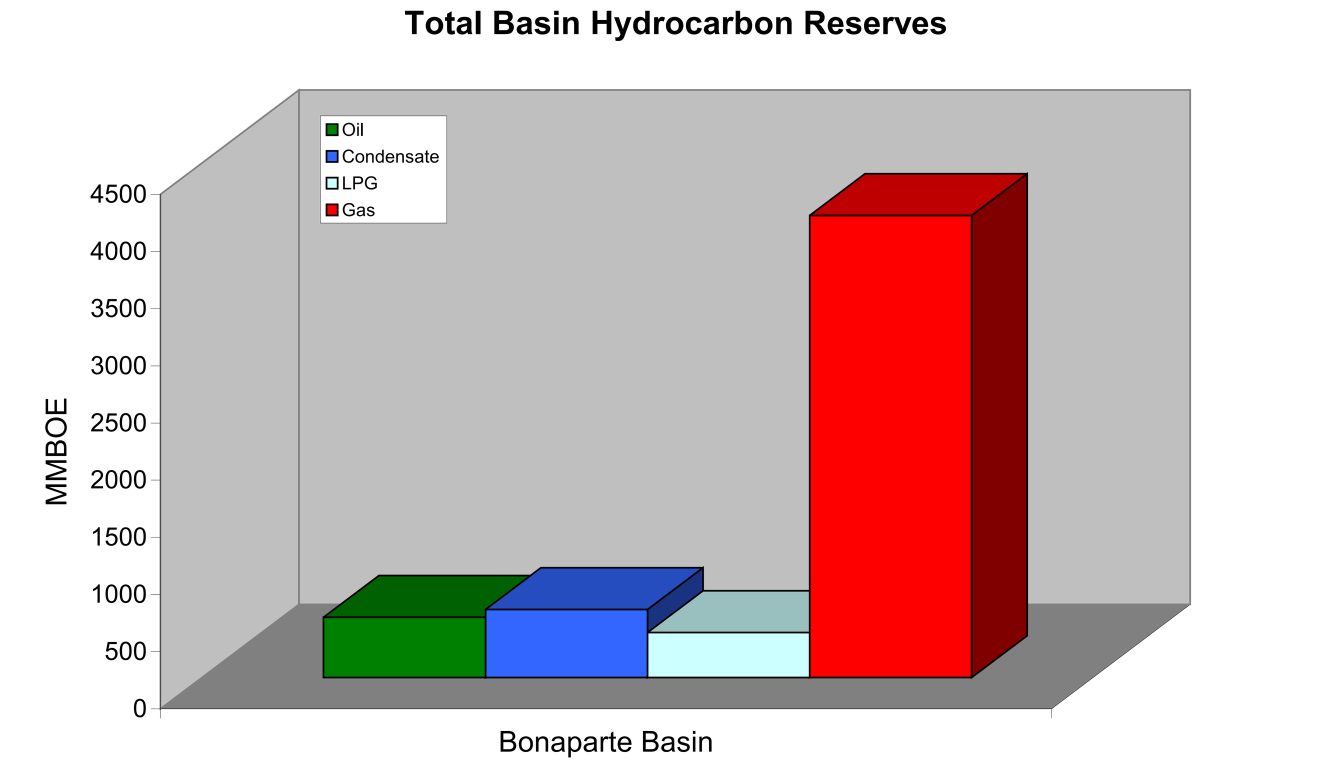


Figure 2: Total basin reserves for the Bonaparte Basin. Sourced from Oil and Gas Resources of Australia (OGRA) 2002.

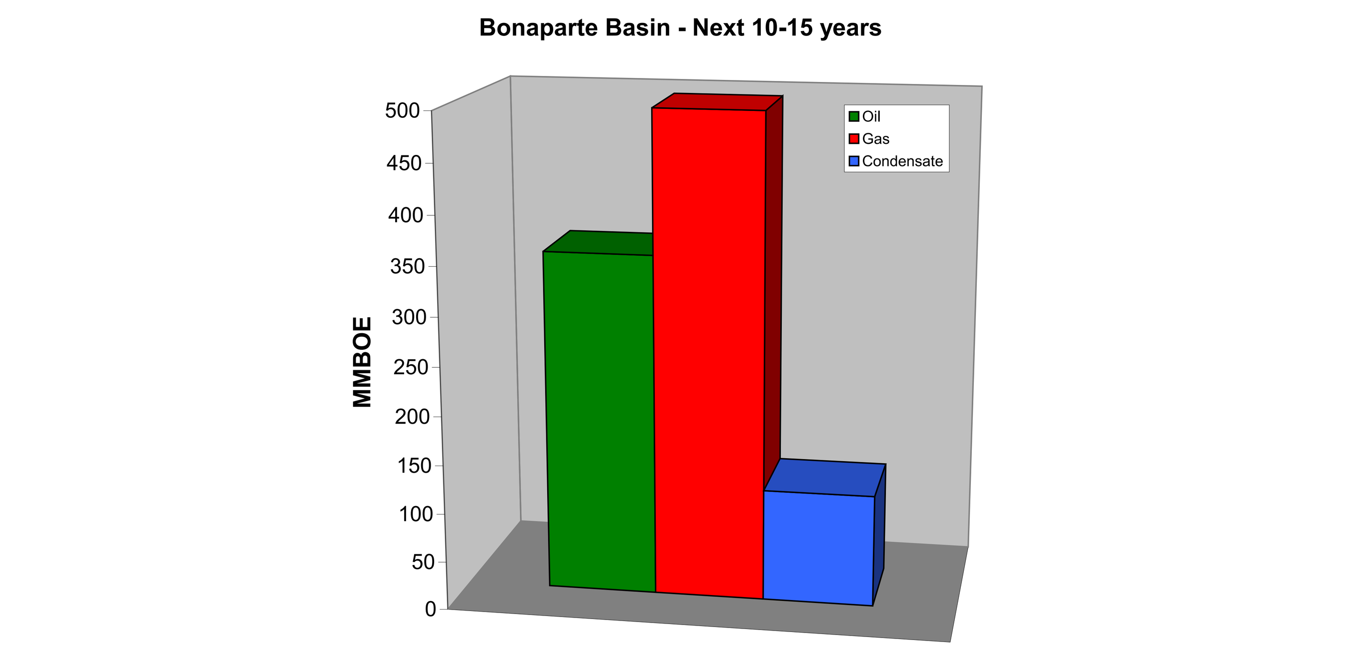


Figure 3: Geoscience Australia (Austplay) 2003 estimate of the recoverable resources to be discovered in the next 10-15 years in the Bonaparte Basin. Based on the work of Barrett et al. (2004).

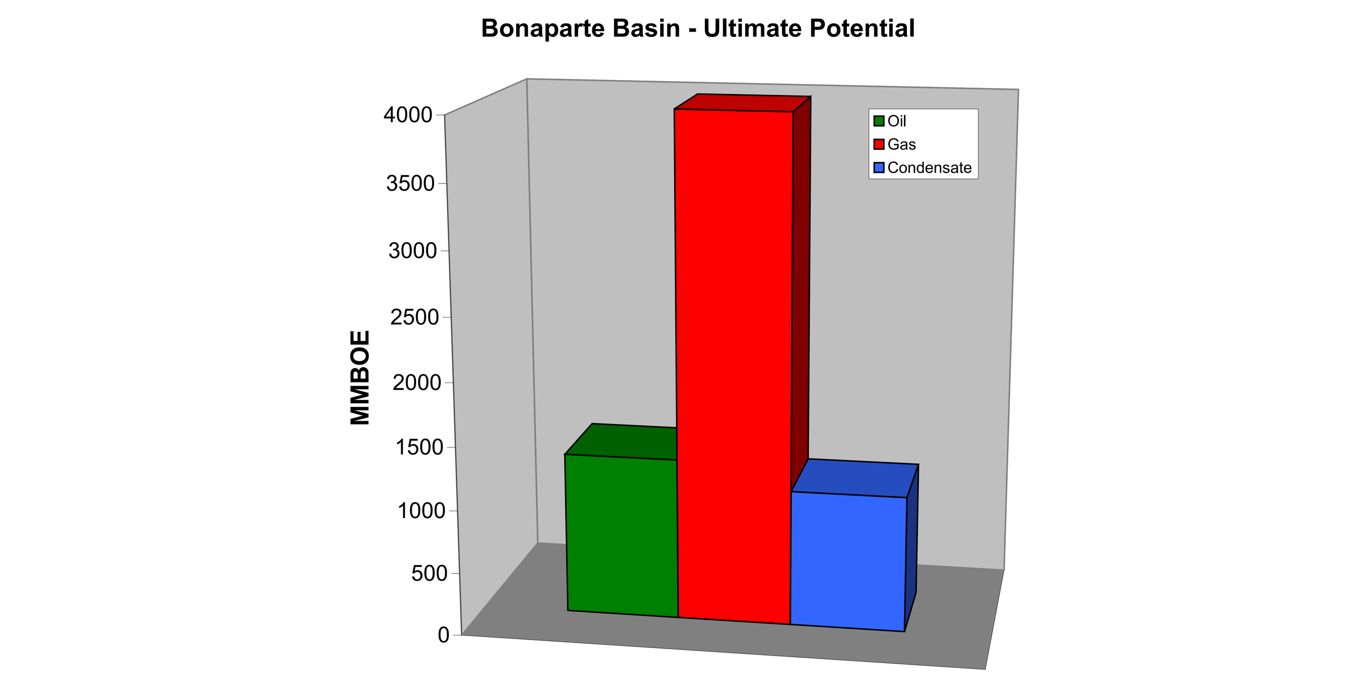


Figure 4: USGS (2000) assessment of the Bonaparte Basin. This is considered by Barrett et al. (2004) to be an assessment of the basin's ultimate potential.

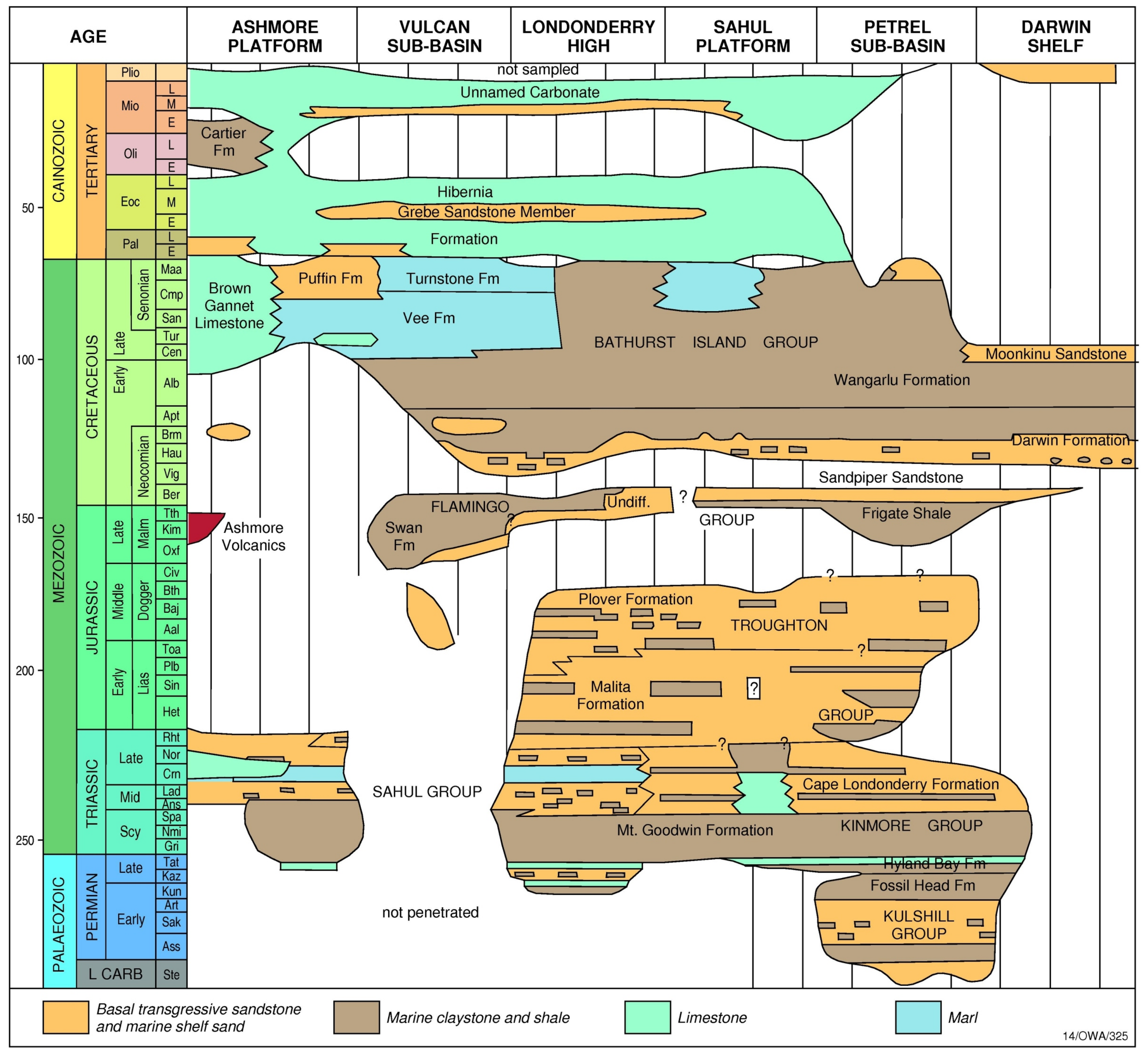


Figure 5: Stratigraphy of the Bonaparte Basin. The Bonaparte Basin contains up to 15 km of sediments, comprising the southern Palaeozoic and northern Mesozoic depocentres.

BASIN DEVELOPMENT

The Bonaparte Basin has a complex structural history, consisting of a number of Palaeozoic and Mesozoic structural features (Figure 1).

- Two phases of Palaeozoic extension:

  1) Northwest trending Late Devonian-Early Carboniferous rift system (Petrel Sub-basin).
  2) Northeast trending Late Carboniferous-Early Permian rift system (proto-Vulcan Sub-basin and proto-Malita Graben).

- Late Triassic regional north-south compression, uplift and erosion - inversion structures and anticlines.

- Late Jurassic extension - series of linked, northeast-trending (Vulcan Sub-basin, Malita and Calder Grabens) and southeast-trending (Sahul Syncline) grabens.

- Late Miocene to Pliocene convergence of the Australian and Eurasian Plates - flexural downwarp of the Timor Trough and widespread fault reactivation.

PETROLEUM SYSTEMS

The Bonaparte Basin has seven petroleum systems based on geological and geochemical information. The systems are concentrated in the Jurassic, Permian and Carboniferous (Figure 6):

Jurassic
1. Vulcan-Plover (!): Vulcan Sub-basin
2. Elang-Elang (!): Sahul Syncline, Flamingo High
3. Plover-Plover (.): Malita Graben, Sahul Platform

Permian
4. Hyland Bay-Hyland Bay (?): Kelp High
5. Permian-Hyland Bay (?): Londonderry High
6. Hyland Bay/Keyling-Hyland Bay (.): Central Petrel Sub-basin

Permo-Carboniferous
7. Milligans-Kuriyippi/Milligans (!): Southern Petrel Sub-basin

(!) Known hydrocarbon-source correlation
(.) Geochemical evidence for a hypothetical system
(?) Lack of direct evidence for a speculative system

References:
Barrett et al., 2004.
Edwards et al, 2000.

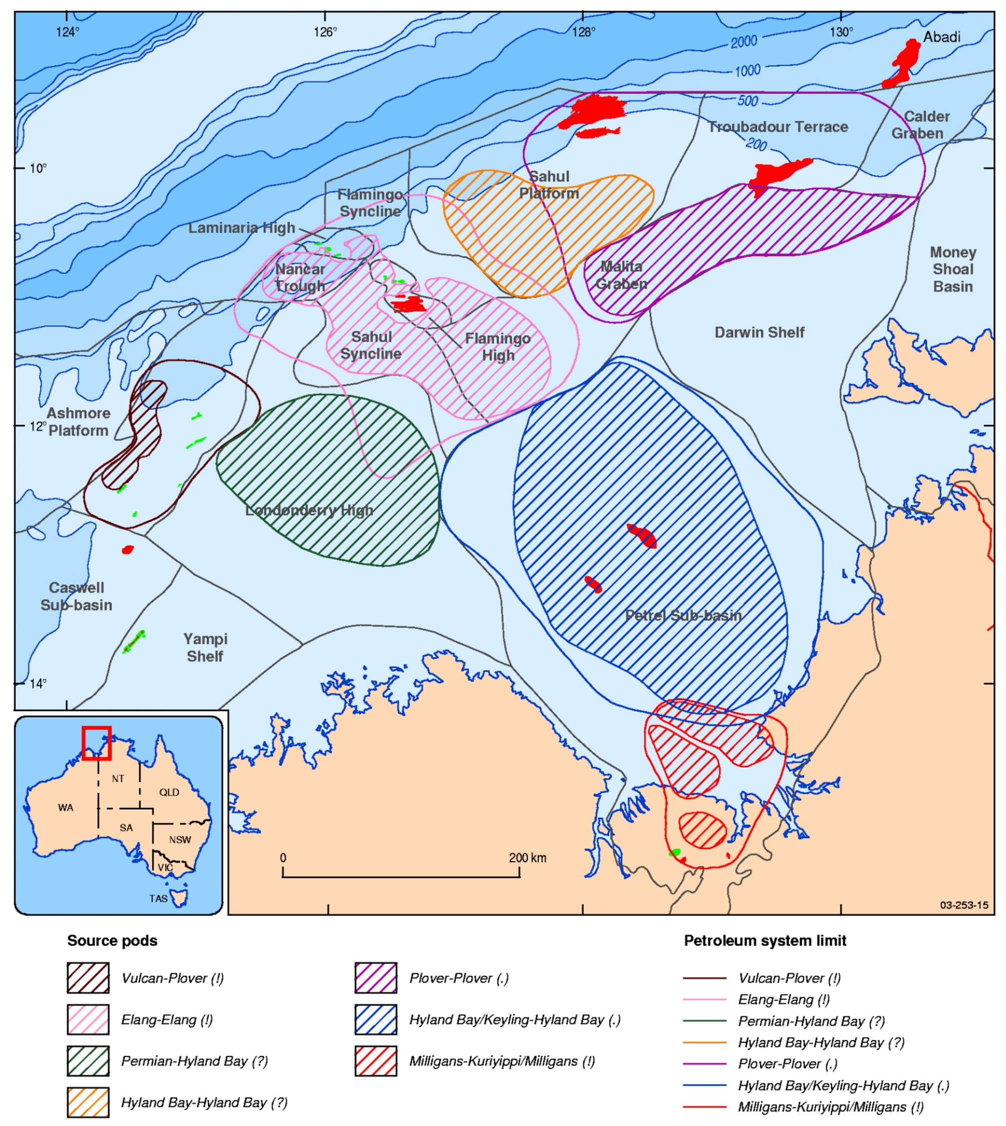


Figure 6: Petroleum systems of the Bonaparte Basin

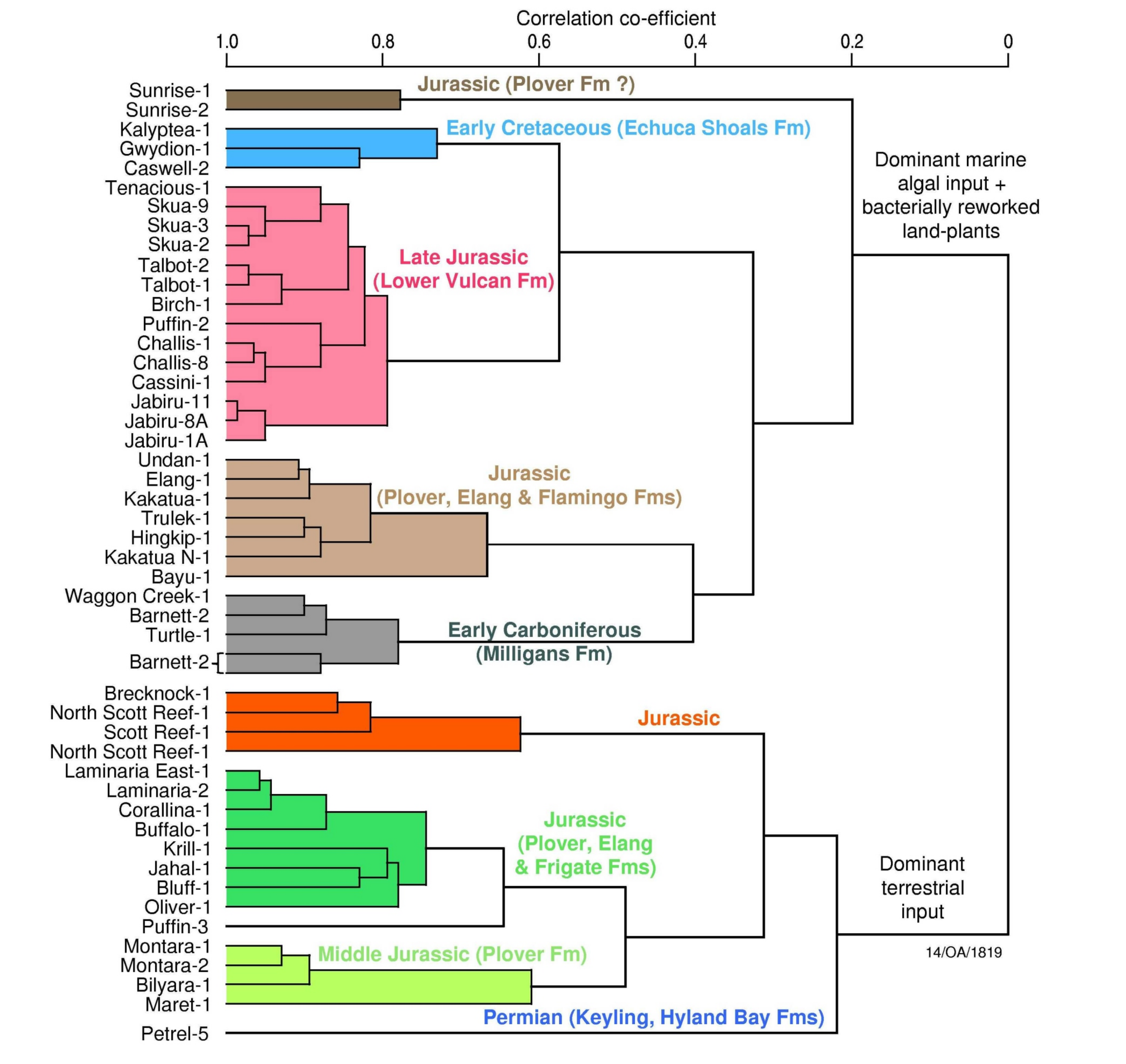


Figure 7: Dendrogram from hierarchical cluster analysis showing hydrocarbon families (Edwards et al., 2004)

Australian Government
Geoscience Australia

Petroleum Systems of the Bonaparte Basin

1. JURASSIC VULCAN-PLOVER (!) PETROLEUM SYSTEM (Vulcan Sub-basin)

The Jurassic Vulcan-Plover (!) Petroleum system is primarily located in the Vulcan Sub-basin of the Bonaparte Basin and extends a short distance onto the Ashmore Platform to the west and the Londonderry High to the east.
The Vulcan Sub-basin is a north-east trending Mesozoic extensional depocentre composed of a complex series of horsts, grabens and terraces. The main depocentres within the Vulcan Sub-basin are the Swan and Paqualin grabens and the Cartier trough.

Source pods in the region are restricted to the Swan and Paqualin grabens (with some potential in the Cartier Trough). There are two main sources in the region; the marine dominated Late Jurassic Lower Vulcan Formation and the more terrestrial Early-Middle Jurassic Plover Formation. The Lower Vulcan Formation is the dominant source for both oil and gas in the region. Geohistory modelling suggests the following expulsion history:

1) Late Jurassic to Early Cretaceous gas and oil generation. Only gas was expelled during at this time (generative expulsion).
2) Tertiary oil and gas expulsion (compaction expulsion).

The restricted distribution of the source pods indicates migration pathways of up to 40km for established accumulations. Reservoirs in the Vulcan Sub-basin are the Late Triassic Challis and Nome Formations, Early-Middle Jurassic Plover Formation, Late Jurassic Vulcan Formation and Late Cretaceous Puffin Formation, with the Plover Formation being the primary exploration target. The Echuca Shoals Formation forms the regional seal.
The Vulcan Sub-basin is a well-established hydrocarbon province with commercial discoveries at Cassini, Challis, Jabiru and Skua. Non-commercial discoveries include: Audacious, Bilyara, Birch, Delamare, East Swan, Eclipse, Halcyon, Keeling, Maple, Maret, Montara, Oliver, Padthaway, Pengana, Puffin, Swan, Swift, Tahbilk, Talbot and Tenacious.

Petroleum System Characteristics

Source	Vulcan Formation
Reservoir	Plover Formation
Seal	Echuca Shoals Formation
Source Quality	Oil and gas prone
Source Type	Marine source with varying terrestrial input
System Age	Jurassic
Expulsion	Late Jurassic-Early Cretaceous (gas), Late Tertiary (oil and gas)
Traps	Horst blocks, delta sands, shoreface sands, basin fans
Risk	Fault seal, available migration pathways
Key References	Barrett, A.G., Hinde, A.L., & Kennard, J.M., 2004. Undiscovered resource assessment methodologies and application to the Bonaparte Basin. In: Ellis G.K., Baillie P.W. and Munson T.J. (Eds) Timor Sea Petroleum Geoscience. Proceedings of the Timor Sea Symposium, Darwin, Northern Territory, 19-20 June 2003. Northern Territory Geological Survey, Special Publication 1.

Edwards, D.S., Preston, J.C., Kennard, J.M. , Boreham, C.J. , Van Aarssen, B.G.K, Summons, R.E., & Zumberge, J.E., 2004. Geochemical characteristics of hydrocarbons from the Vulcan Sub-basin, western Bonaparte Basin. In: Ellis G.K., Baillie P.W. and Munson T.J. (Eds) Timor Sea Petroleum Geoscience. Proceedings of the Timor Sea Symposium, Darwin, Northern Territory, 19-20 June 2003. Northern Territory Geological Survey, Special Publication 1.

Kennard, J.M., Deighton, I., Edwards, D.S., Colwell, J.B., O'Brien, G.W., & Boreham, C.J., 1999. Thermal history modelling and transient heat pulses: New insights into the hydrocarbon expulsion and "hot flushes" in the Vulcan Sub-basin, Timor Sea. The APPEA Journal, 39(1), 177-207.

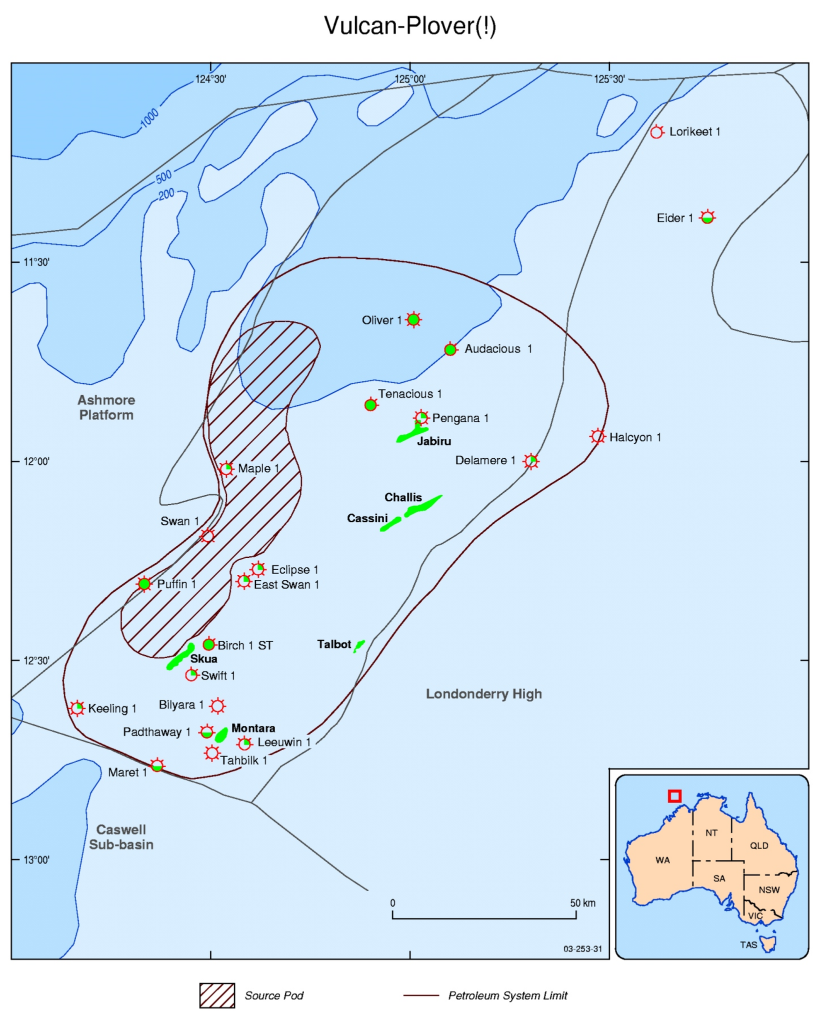


Figure 1: Spatial extent of the Jurassic Vulcan-Plover (!) petroleum system. The petroleum system is restricted to the southern and central parts of the Vulcan Graben. The limit of the source pod is based on geohistory modelling by Kennard et al. (1999).

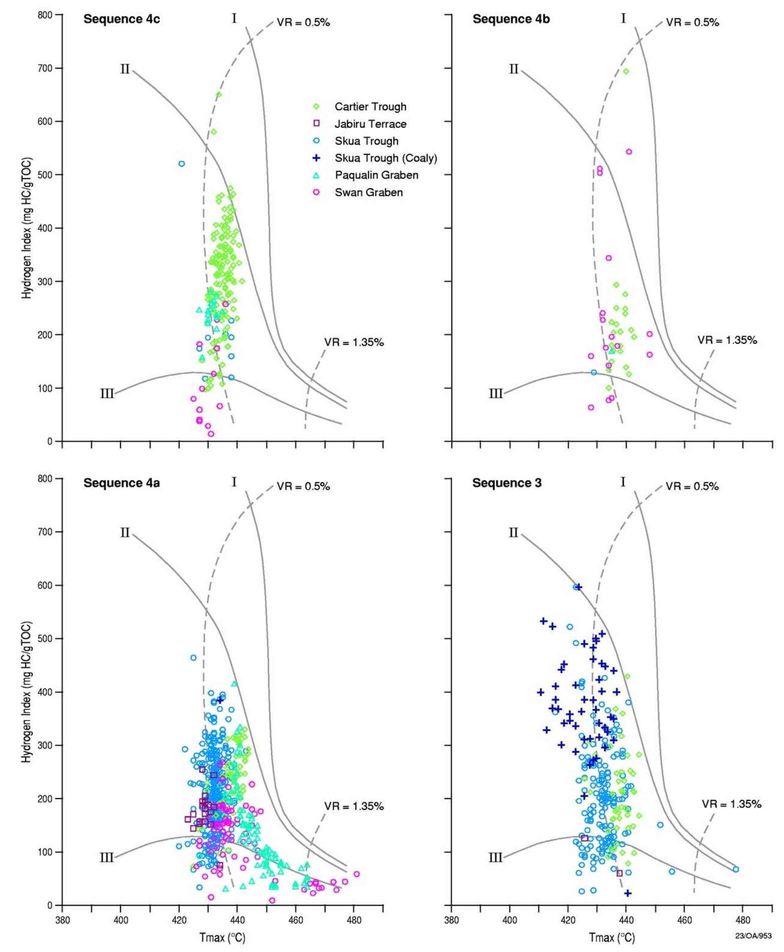


Figure 2: Rock-Eval pyrolysis data plots for potential source rocks in the Plover (Sequence 3) and Vulcan Formations (Sequence 4a, 4b and 4c). The Plover Formation has both oil and gas prone source rocks with Type II, III and IV kerogens. The Lower Vulcan Formation is both oil and gas prone with Type II, III and IV kerogens. It has moderate to good generative potential throughout the Skua Trough, Swan and Paqualin grabens and is leaner in the Cartier Trough.

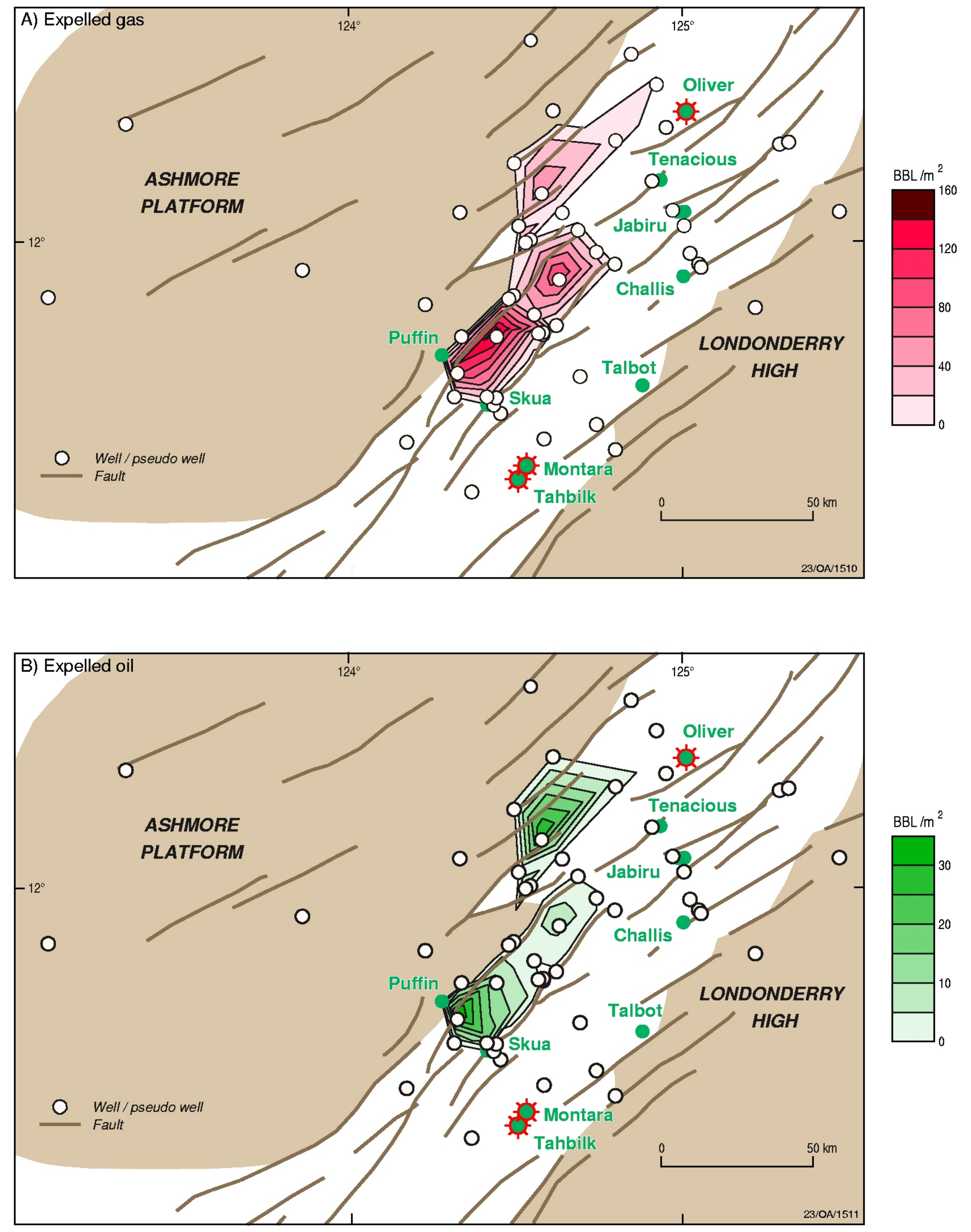


Figure 3: Map of hydrocarbon expulsion from source Unit 4a (Lower Vulcan Formation). A) Gas expulsion. B) Oil expulsion.

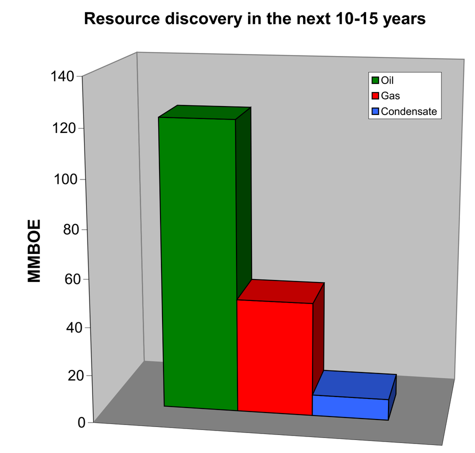


Figure 4: Geoscience Australia (Austplay) estimates of the recoverable hydrocarbons to be discovered in the next 10-15 years in the Jurassic Vulcan-Plover (!) petroleum system. Based on the work of Barrett et al. (2004).

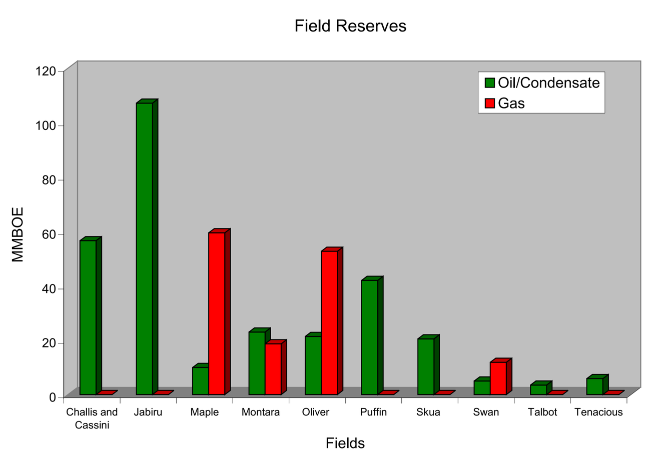


Figure 5: Field reserves for the Jurassic Vulcan-Plover (!) petroleum system. All reserve numbers are sourced from the Northern Territory Government Department of Business, Industry and Resource Development. Reserves/resources are estimated by the Department and exploration companies.

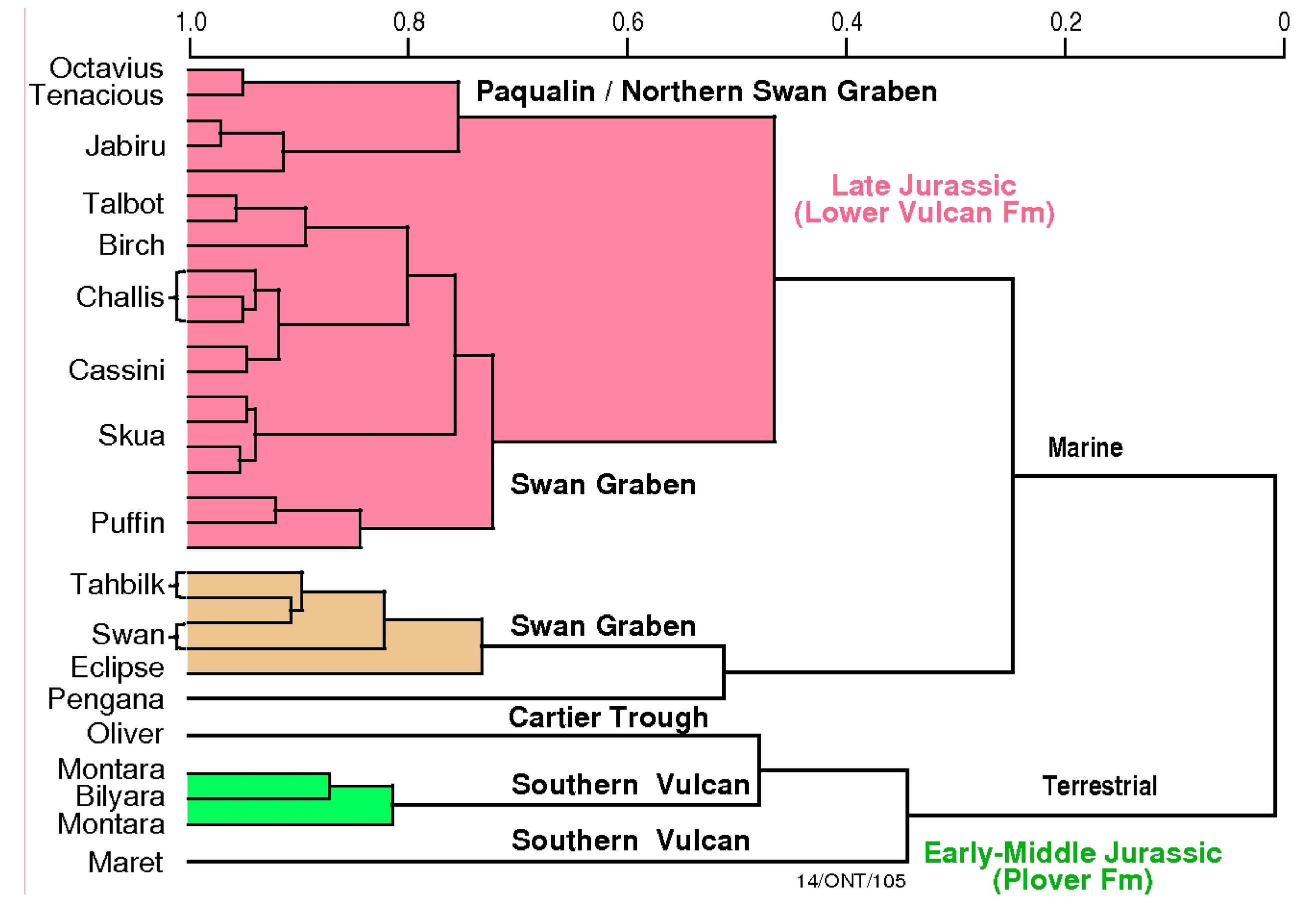


Figure 6: Dendrogram of the Vulcan Sub-basin oils and condensates.

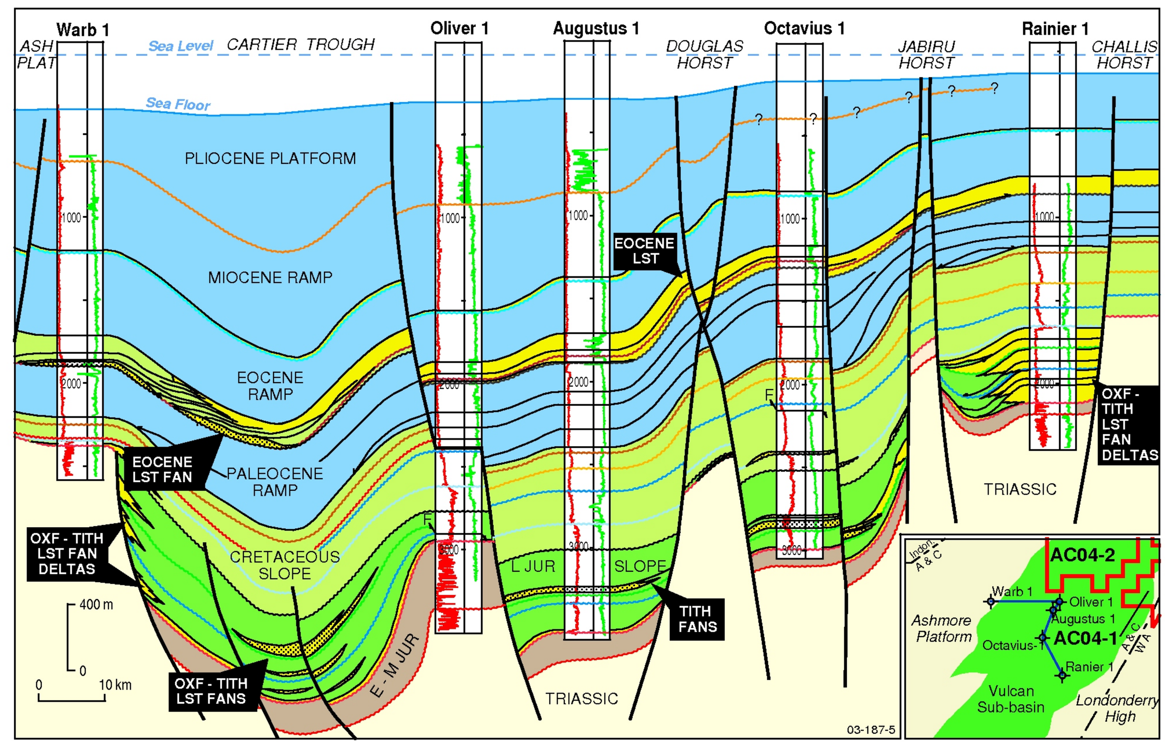


Figure 7: Schematic cross-section and sequence correlations through the northern Vulcan Sub-basin.

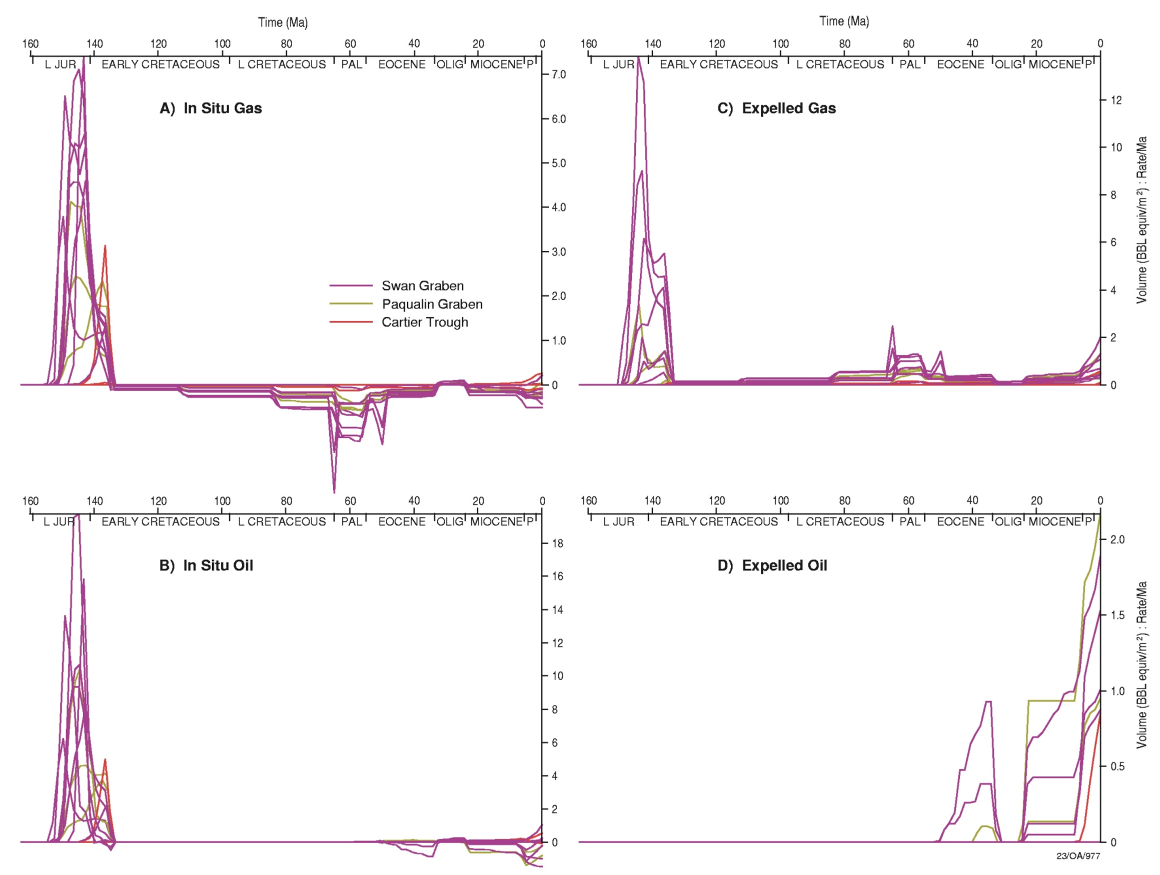


Figure 8: Hydrocarbon generation and expulsion models for the Lower Vulcan Formation. A) Rate of in-situ gas formation (positive values) and gas expulsion (negative values). B) Rate of in-situ oil formation (positive values) and oil expulsion (negative values). C) Rate of gas expulsion. D) Rate of oil expulsion. The main phase of gas expulsion occurred in the Late Jurassic - Early Cretaceous. This coincided with the main phase of gas generation and has been classed as "generative expulsion". There was no coinciding expulsion of oil with the main oil generative phase. Oil expulsion occurred in the mid-late Tertiary during burial and compaction (compactional expulsion).

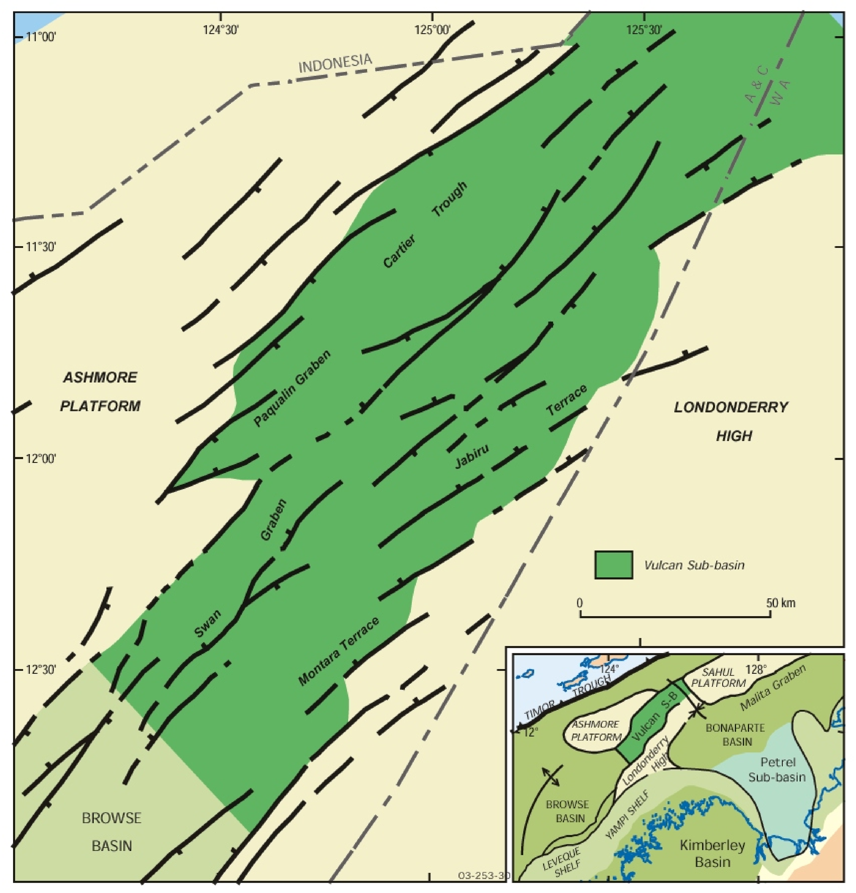


Figure 9: Structural elements of the Vulcan Sub-basin. The main hydrocarbon generating depocentres in the Vulcan Sub-basin are the Swan and Paqualin grabens and the Cartier Trough.

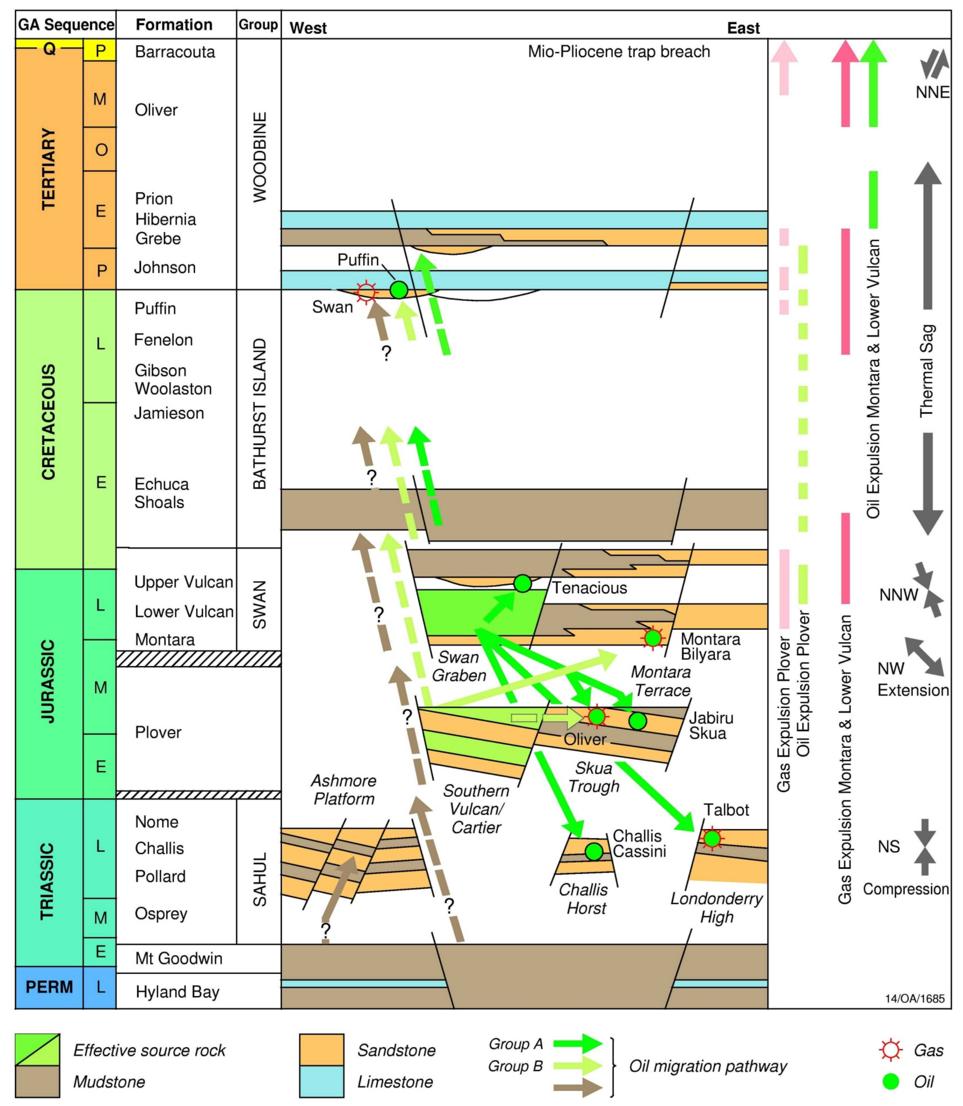


Figure 10: Schematic diagram of the Jurassic Vulcan-Plover (!) petroleum system.

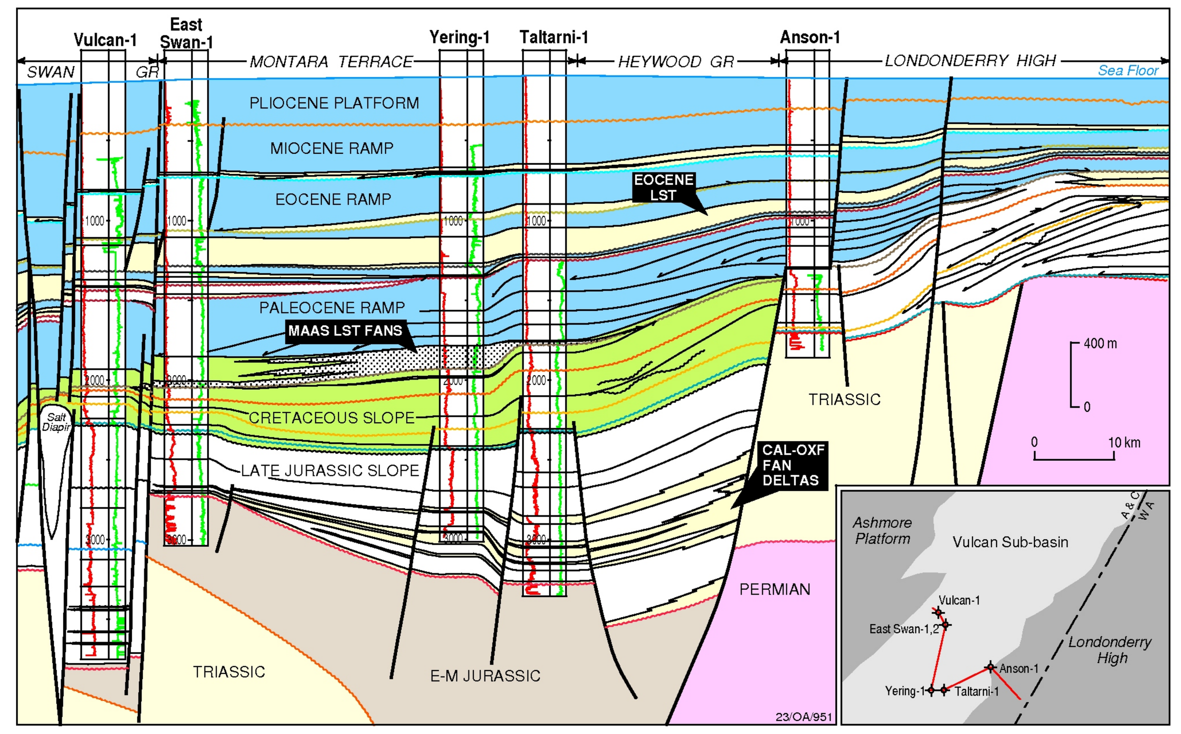


Figure 11: Schematic cross-section and sequence correlations through the southern Vulcan Sub-basin.

Australian Government

Geoscience Australia

Petroleum Systems of the Bonaparte Basin

Published by Geoscience Australia, Department of Industry, Tourism and Resources, Canberra, Australia. Issued under the authority of the Minister for Industry, Science and Resources.

Geocat: 61365

2. JURASSIC ELANG-ELANG (!) PETROLEUM SYSTEM (Sahul Syncline, Flamingo High)

The Jurassic Elang-Elang (!) petroleum system is located in the northern region of the Bonaparte Basin, extending across the Nancar Trough, Sahul Syncline, Laminaria High, Flamingo High and Flamingo Syncline, as well as the flanks of the adjacent Londonderry High and Sahul Platform.

The Nancar Trough and Sahul Flamingo synclines act as source pods sourcing the adjacent structural highs. Source rocks in the northern Bonaparte Basin include the Flamingo Group and the Elang, Frigate and Plover formations. The Elang Formation is the dominant source for hydrocarbons and is mature for generation and expulsion in the Sahul Syncline and the Flamingo High. The structural complexity of the area means migration paths are generally short (with a possible exception being Jahal) with restricted access to suitable reservoirs. Reservoirs include the Plover and Elang formations with the Elang Formation being a primary exploration target. Reservoirs are sealed intraformationally or by the Echuca Shoals Formation regional seal.

The system has well established hydrocarbon potential with commercial discoveries including: Bayu-Undan (gas/condensate), Buffalo, Corallina, Elang, Kakatua and Laminaria (oil). Other discoveries include: Ascalon, Avocet, Bluff, Buller, Coleraine, Eider, Flamingo, Fohn, Jahal, Krill, Kuda Tasi, Lorikeet, Rambler and Saratoga.

Petroleum System Characteristics

Source	Elang Formation
Reservoir	Elang Formation
Seal	Echuca Shoals Formation (regional seal), Flamingo and Frigate Formations
Source Quality	Oil and gas prone
Source Type	Marine with variable terrestrial influence
System Age	Jurassic
Expulsion	Unknown
Traps	Structural highs, horst complexes, tilted fault blocks, stratigraphic
Risk	Fault re-activation
Key References	Barrett, A.G., Hinde, A.L., & Kennard, J.M., 2004. Undiscovered resource assessment methodologies and application to the Bonaparte Basin. In: Ellis G.K., Baillie P.W. and Munson T.J. (Eds) Timor Sea Petroleum Geoscience. Proceedings of the Timor Sea Symposium, Darwin, Northern Territory, 19-20 June 2003. Northern Territory Geological Survey, Special Publication 1.
	Preston, J.C., & Edwards, D.S., 2000. The petroleum geochemistry of oils and source rocks from the Northern Bonaparte Basin, offshore northern Australia. APPEA Journal 40(1), 257-282.

Elang-Elang (!)

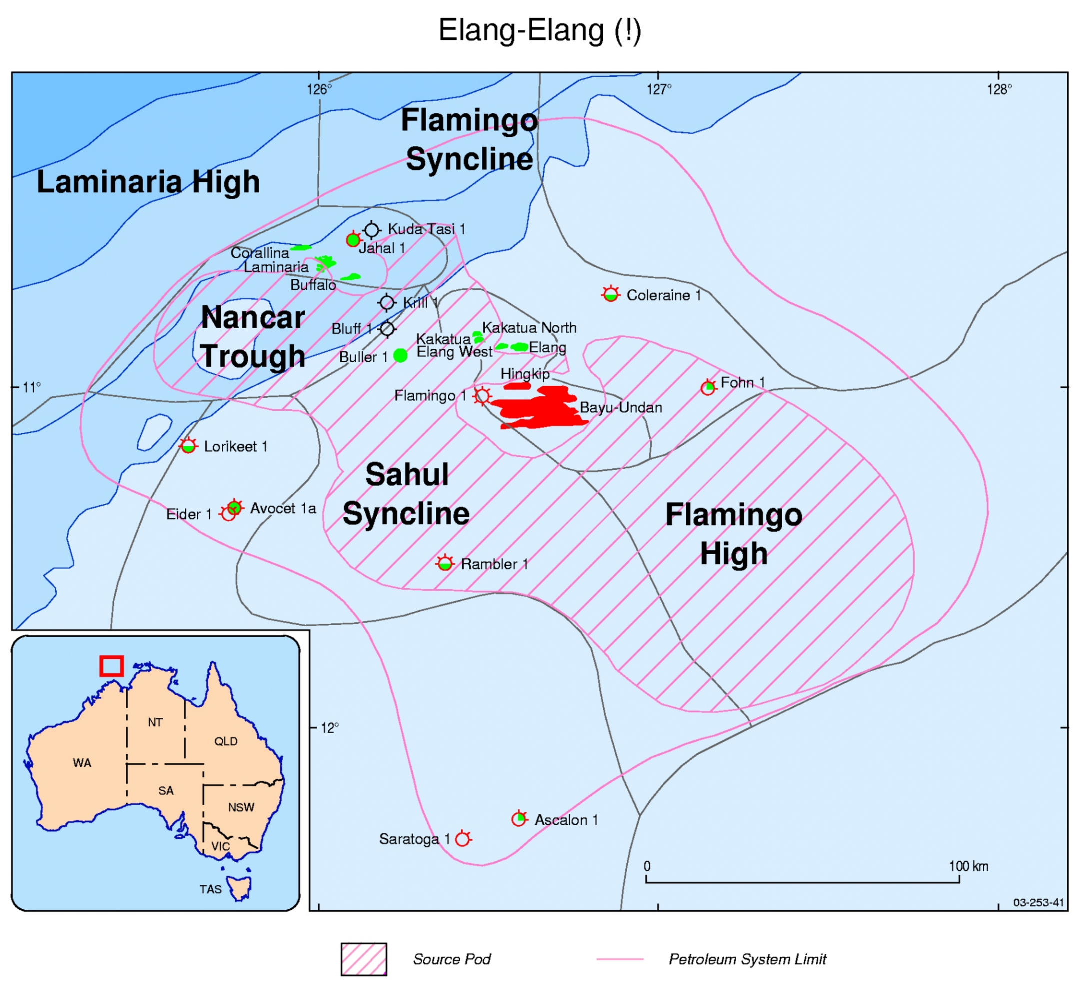


Figure 1: Spatial extent of the Jurassic Elang-Elang (.) petroleum system, showing hydrocarbon accumulations and shows attributed to the system. The source pod has been defined based on work by Preston and Edwards (2000) and structural elements of the area. The petroleum system limit is an envelope enclosing wells attributed to the system.

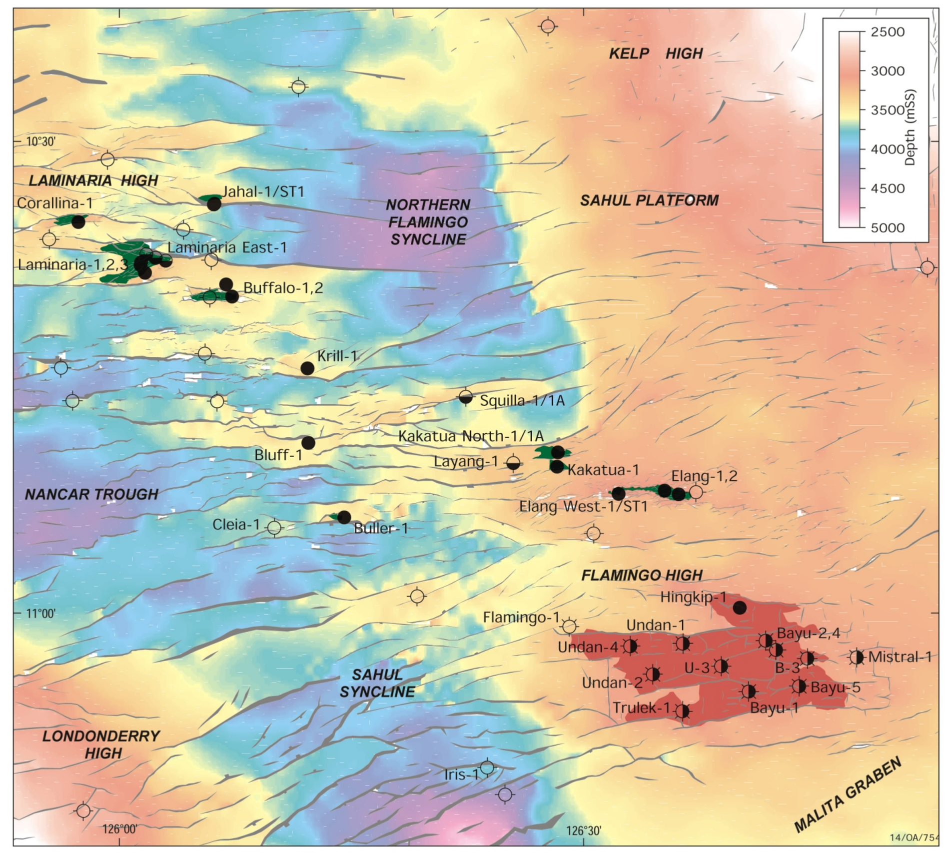


Figure 2: Structure contour map of the "Top Elang" surface. The Echuca Shoals Formation, Flamingo Group and Frigate Formation form a thick claystone sequence the base of which is mapped as the "Top Elang" surface and represents the regions top porosity. The source rock contribution to hydrocarbon fields in the Northern Bonaparte Basin is largely determined by maturity and access to suitable reservoirs. The thick claystones overlying the Top Elang surface restrict access to the underlying Elang and Plover formations. The interbedded nature of the Elang and Plover formations means that these units are effective sources in this region. The Frigate and Flamingo units contribute where possible, with a Flamingo influence in the southeastern region (where the Frigate Formation has been eroded) and a Frigate Formation influence in the northwestern area.
The structure contour map at the "Top Elang" surface emphasises Late Jurassic depocentres and highs in part of the Northern Bonaparte Basin. Oil fields are shown in dark green and gas/condensate fields are shown in red.

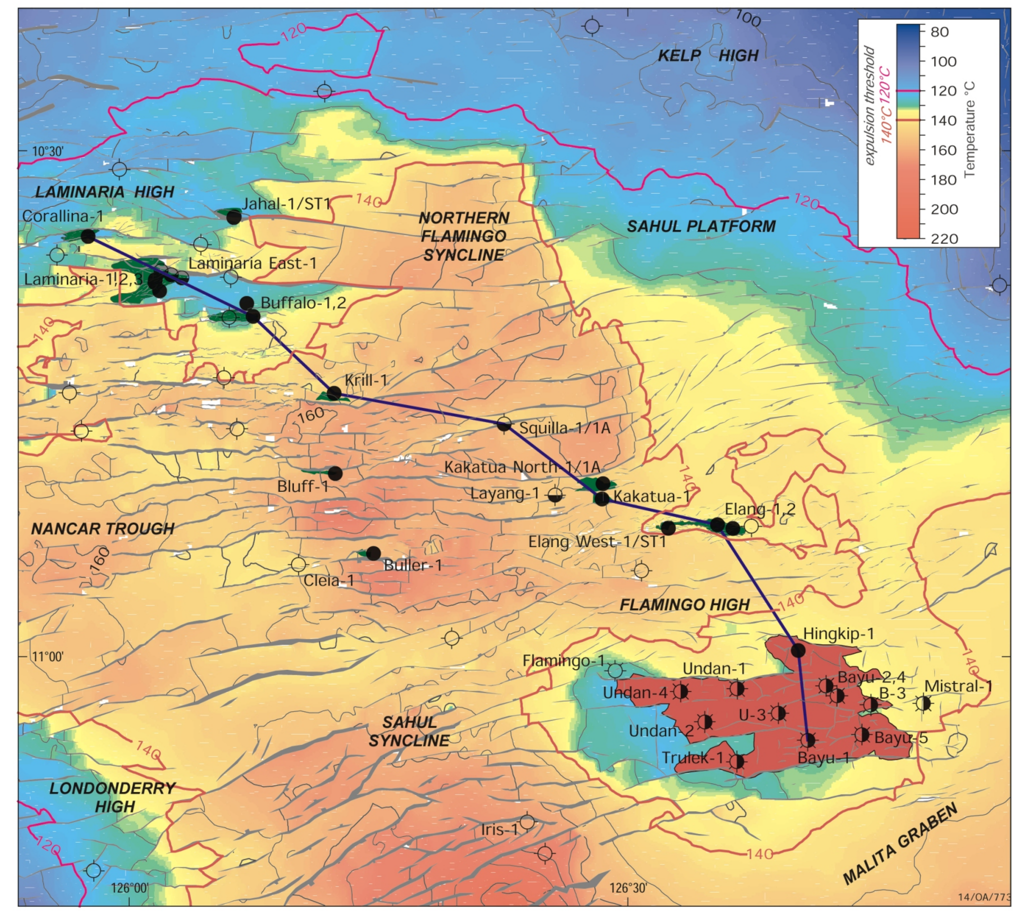


Figure 3: Temperature map of the "Top Elang" surface, showing 120°C and 140°C isotherms which are the effective limit for expulsion of hydrocarbons from Elang/Plover formations and the basal Frigate Formation, respectively. Also shown is the line-of-section detailed in Figure 5 (Corallina to Bayu 1). Field compositions on the Flamingo High indicate a more marine input into the system, likely sourced from the Flamingo Group. The Laminaria High hydrocarbons have a stronger terrestrial input probably from the Frigate Formation. The fields in between the two structures have intermediate compositions. Oil fields are shown in dark green and gas/condensate field are shown in red.

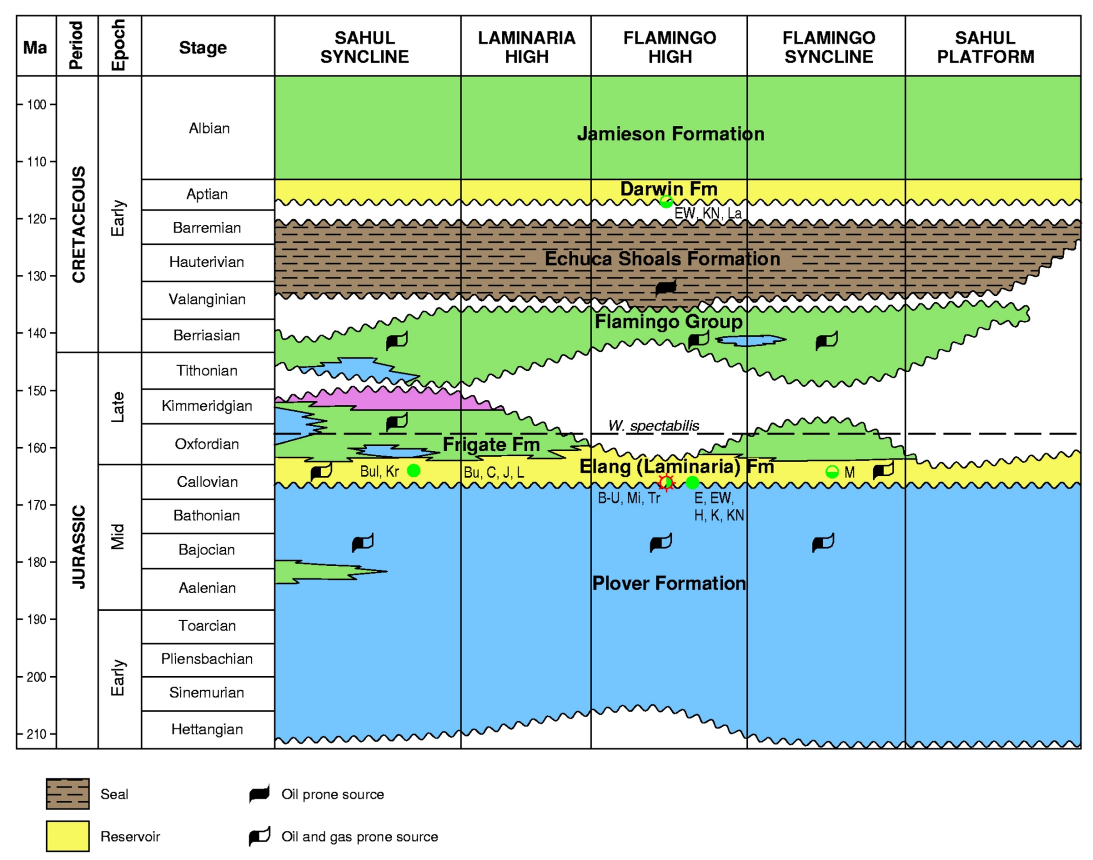


Figure 4: Generalised stratigraphy of the Northern Bonaparte Basin with major play elements of the region shown including seal, reservoir and source. The Laminaria and Flamingo highs act as loci for hydrocarbon accumulation from the Flamingo and Sahul synclines. Input from the depocentres is variable with the Frigate formation contributing to the northwestern accumulations and the Flamingo Group contributing to the southeastern accumulations where the Frigate Formation is largely absent due to erosion. The dominant sources for all accumulations is the Plover and Elang formations.

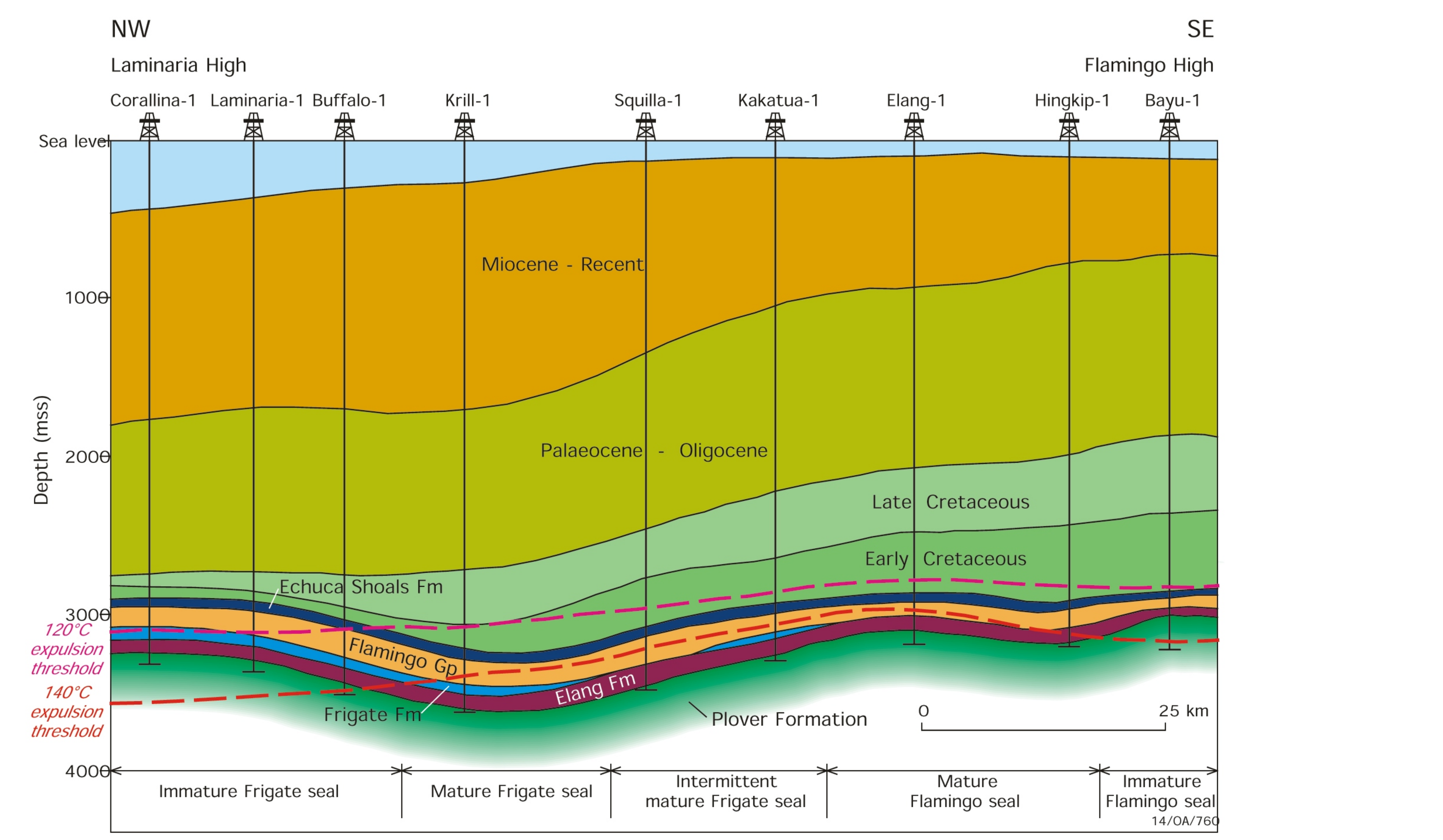


Figure 5: Schematic cross-section through the Northern Bonaparte showing the approximate 120°C and 140°C isotherms at selected well locations. Average expulsion from the Elang-Plover Formations occurred at 127-131°C. The Frigate and Flamingo units had average expulsion temperatures of 144-146°C.

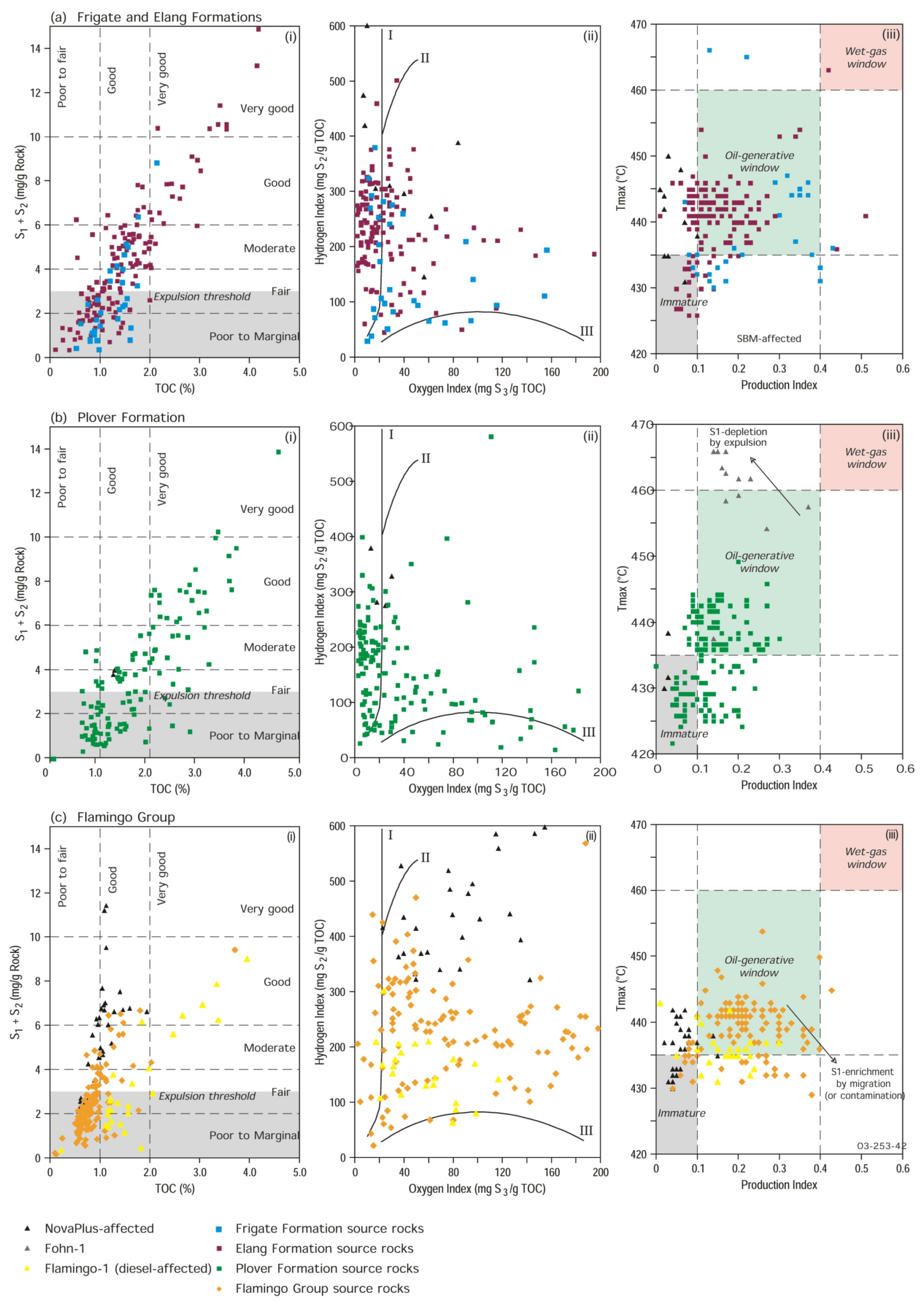


Figure 6: Rock-Eval pyrolysis data plots for potential Jurassic source rocks in the Northern Bonaparte Basin. A) Frigate and Elang formations. B) Plover Formation. C) Flamingo Group. Data from: Bayu 1, Cleia 1, Corallina 1, Elang 2 and 3, Elang West 1, Flamingo 1, Fohn 1, Kakatua 1, Laminaria 1, Laminaria East 1, Mistral 1, Squilla 1 and Undan 1. The Elang (a) and Plover (b) formations contain organic rich sediments with TOC up to 4%. The Frigate Formation (a) and Flamingo Group (c) are leaner with TOC rarely above 1-1.5% (ignoring diesel contaminated sediments). The Elang and Plover formations are both oil and gas prone and mature throughout the Sahul Syncline, Flamingo Syncline and Flamingo High.

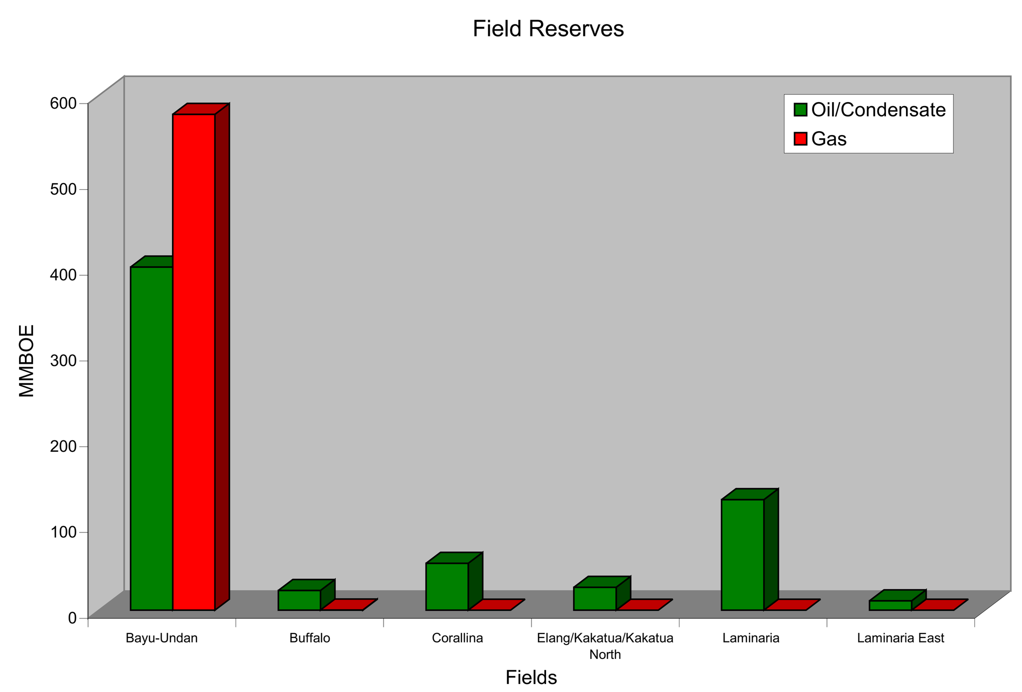


Figure 7: Field reserves for the Elang-Elang (.) petroleum system. All reserve numbers are sourced from the Western Australian Geological Survey and the Northern Territory Government Department of Business, Industry and Resource Development. Reserves/resources are estimated by the Department and exploration companies.

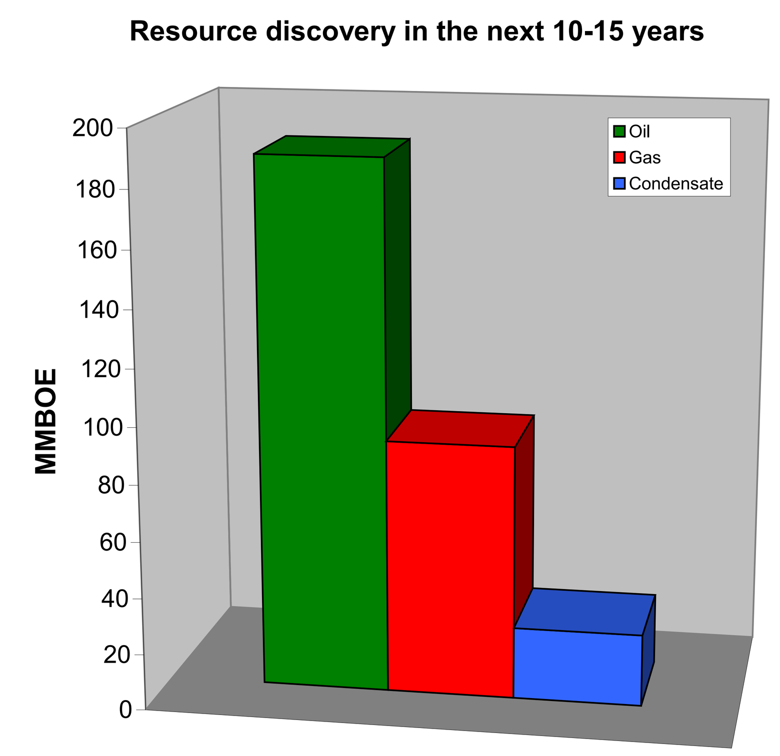


Figure 8: Geoscience Australia (Austplay) estimates of the recoverable hydrocarbons to be discovered in the next 10-15 years in the Elang-Elang (.) petroleum system. Based on the work of Barrett et al. (2004).

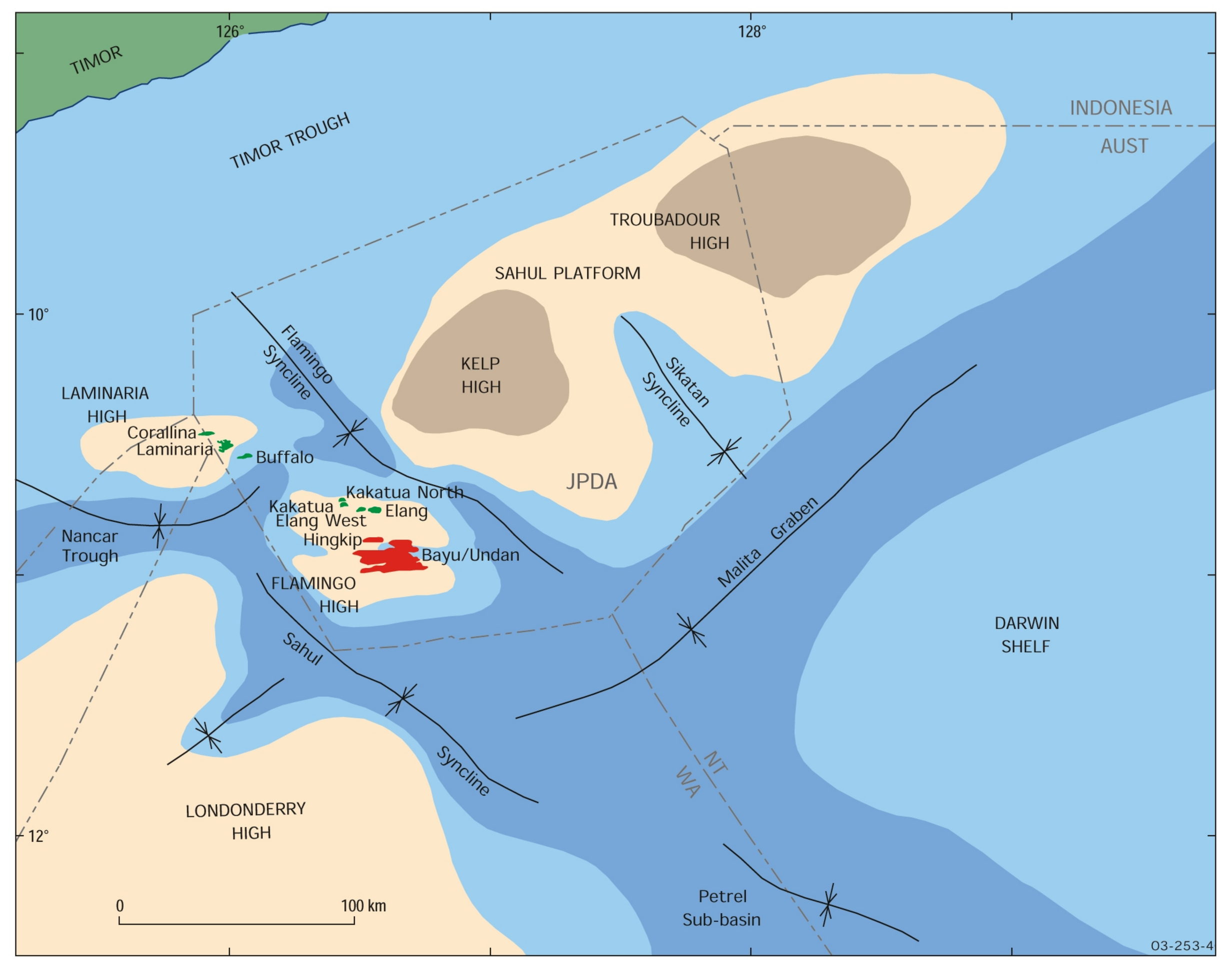


Figure 9: Structural elements of the Northern Bonaparte Basin.

Australian Government
Geoscience Australia

Petroleum Systems of the Bonaparte Basin

Published by Geoscience Australia, Department of Industry, Tourism and Resources, Canberra, Australia. Issued under the authority of the Minister for Industry, Science and Resources.

Geocat: 61365

3. JURASSIC PLOVER-PLOVER (.) PETROLEUM SYSTEM (Malita Graben, Sahul Platform)

The Jurassic Plover-Plover (.) petroleum system extends north from the Malita Graben across the Sahul Platform and Troubadour Terrace, with the northern limit defined politically by the boundary with Indonesia.
The Sahul Platform is a large northeast trending basement high comprised of tilted fault blocks and horsts. The structure is overlain by less than 5 km of Late Permian to Cainozoic rocks.

The Malita Graben is a north-east oriented trough that contains a thick Mesozoic to recent section exceeding 10 km in thickness and is the main "source kitchen" for this petroleum system. The primary source for hydrocarbons is the oil and gas prone Plover Formation. This section is mature for gas generation within the graben and mature oil source pods are likely on the shallower northern graben flank. The Plover Formation entered the oil window in the mid-Cretaceous. Other potential hydrocarbon sources include the Late Jurassic Flamingo Group and the Early Cretaceous Echuca Shoals Group.

The primary reservoir is the Plover Formation. Other good quality reservoirs include the Flamingo Group and the Late Cretaceous sandstones of the Bathurst Island Group. The Bathurst Island Group also forms a regional seal with basal claystones and siltstones.

This system has excellent prospectivity for gas with four gas/condensate discoveries in the region: Chuditch, Evans Shoal, Sunrise and Troubadour. The Abadi field (5 tcf of gas) is also a member of this system but lies within Indonesian waters.

Petroleum System Characteristics

Source	Plover Formation
Reservoir	Plover Formation
Seal	Bathurst Island Group, intraformational
Source Quality	Gas prone with minor liquids
Source Type	Marine mudstones and coal with terrestrial input
System Age	Jurassic
Expulsion	Mid-Cretaceous (oil) through to Tertiary (dry gas)
Traps	Horst blocks, tilted fault blocks, faulted anticlines, Stratigraphic
Risk	Gas flushing of oil accumulations, Co_2
Key References	Acreage Release 2002

Barrett, A.G., Hinde A.L., & Kennard, J.M., 2004. Undiscovered resource assessment methodologies and application to the Bonaparte Basin. In: Ellis G.K., Baillie P.W. and Munson T.J. (Eds) Timor Sea Petroleum Geoscience. Proceedings of the Timor Sea Symposium, Darwin, Northern Territory, 19-20 June 2003. Northern Territory Geological Survey, Special Publication 1.

Longley, I.M., Bradshaw, M.T., & Hebberger J., 2000. Australian petroleum provinces of the 21st century. PESA Journal 28, 21-42.

Miyazaki, S., 1997. Australia's southeastern Bonaparte Basin has plenty of potential. Oil & Gas Journal, 95 (16), 78- 81.
Seggie R.J., Ainsworth R.B., Johnson D.A., Koninx J.P.M., Spaargaren B. & Stephenson P.M., 2000. Awakening of a sleeping giant: Sunrise-Troubadour gas-condensate field. APPEA Journal 40(1), 417-435.

Plover-Plover (.)

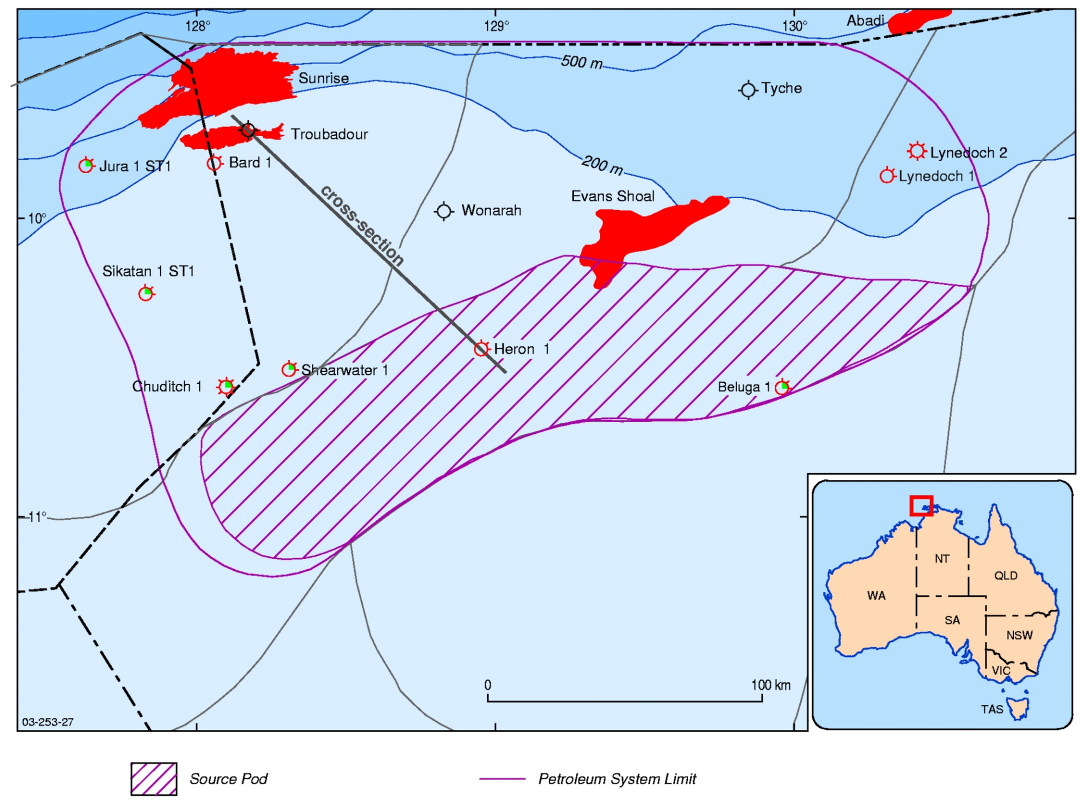


Figure 1: Spatial extent of the Jurassic Plover-Plover (.) petroleum system. This map displays hydrocarbon accumulations and shows thought to have been sourced from the Plover Formation. The source pod has been defined as the extent of the Malita Graben. The petroleum system limit is an envelope enclosing the discoveries attributed to the system and the Malita Graben. The cross-section refers to Figure 4.

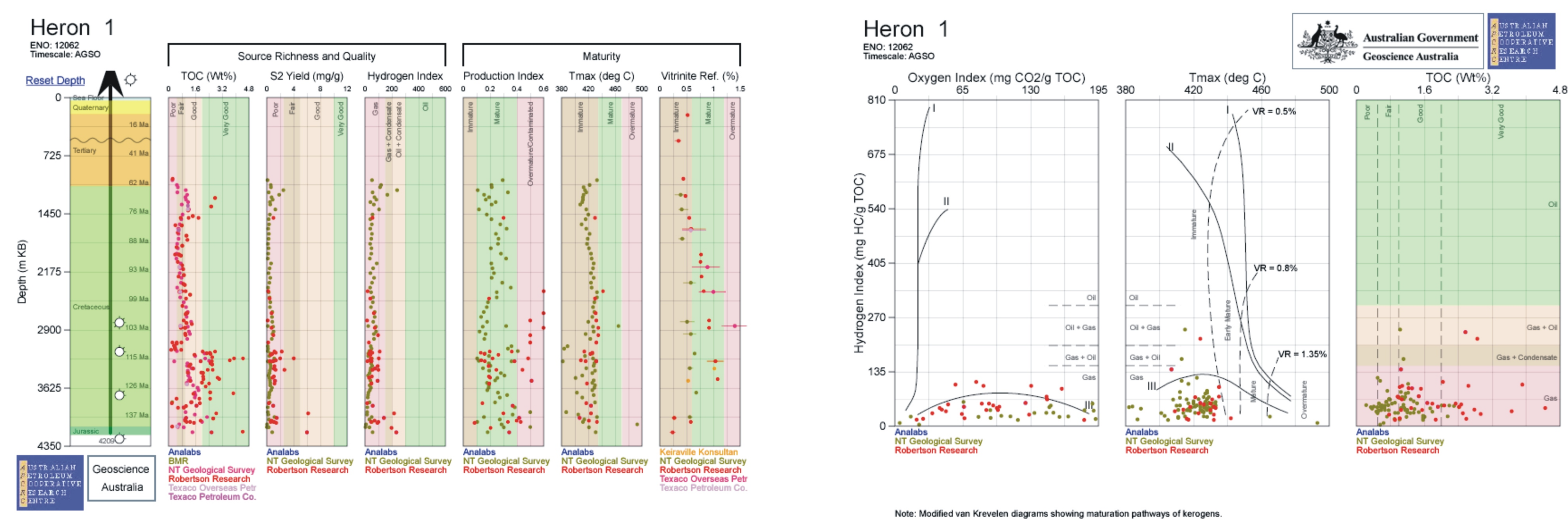


Figure 2: Source rock potential in Heron 1. Heron 1 is one of the few wells drilled within the Malita Graben source kitchen. Only the very top of the principal reservoir and source (Plover Formation) was intersected. The data points shown refers to the Cretaceous Bathurst Island Group (>1030 m) and Late Jurassic Flamingo Group (>3150 m). The sediments generally have fair to good potential for gas, with the lower Bathurst Island Group being good to very good (TOC >2%). The source rocks contain Type III kerogen (terrestrial) and are mature for hydrocarbon generation.

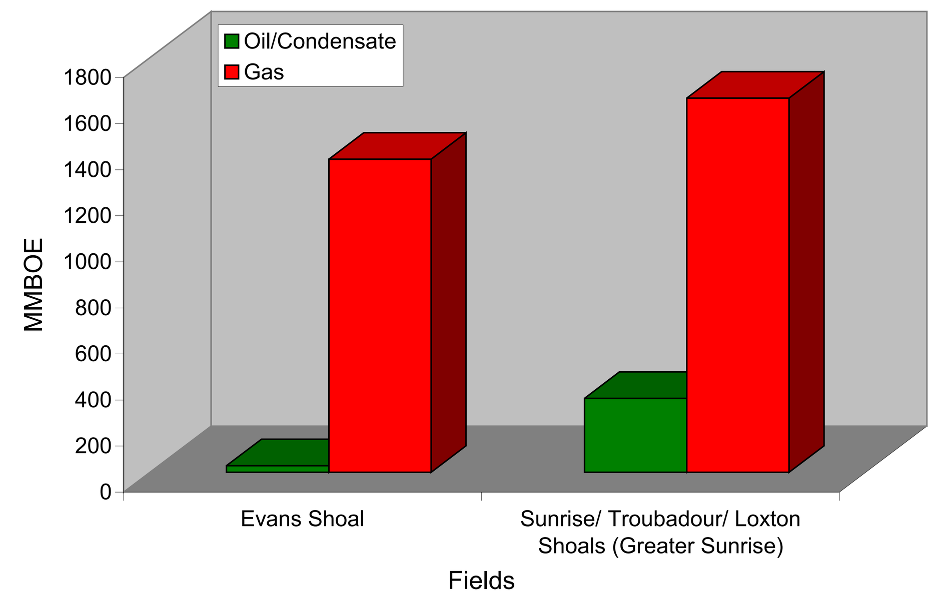


Figure 3: Field reserves for the Plover-Plover Petroleum System (.). All reserve numbers are sourced from Northern Territory Government Department of Business, Industry and Resource Development. Reserves/resources are estimated by the Department and exploration companies.

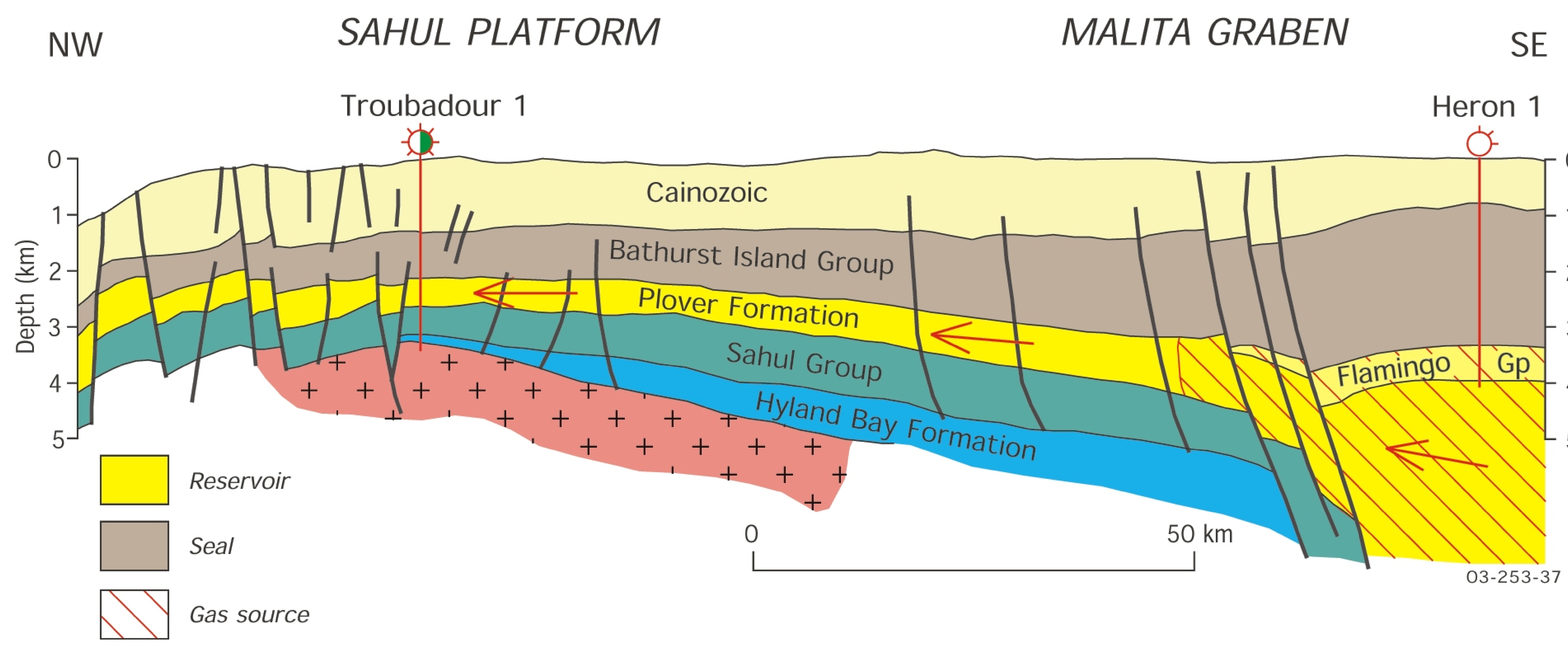


Figure 4: Cross-section, Troubadour 1 to Heron 1. Gas is generated and expelled from the Malita Graben. Migration occurs up structural highs (such as the Sahul Platform) with trapping in horsts, tilted fault blocks and faulted anticlines. The Plover Formation acts as both a source and reservoir with the Bathurst Island Group acting as a regional seal.

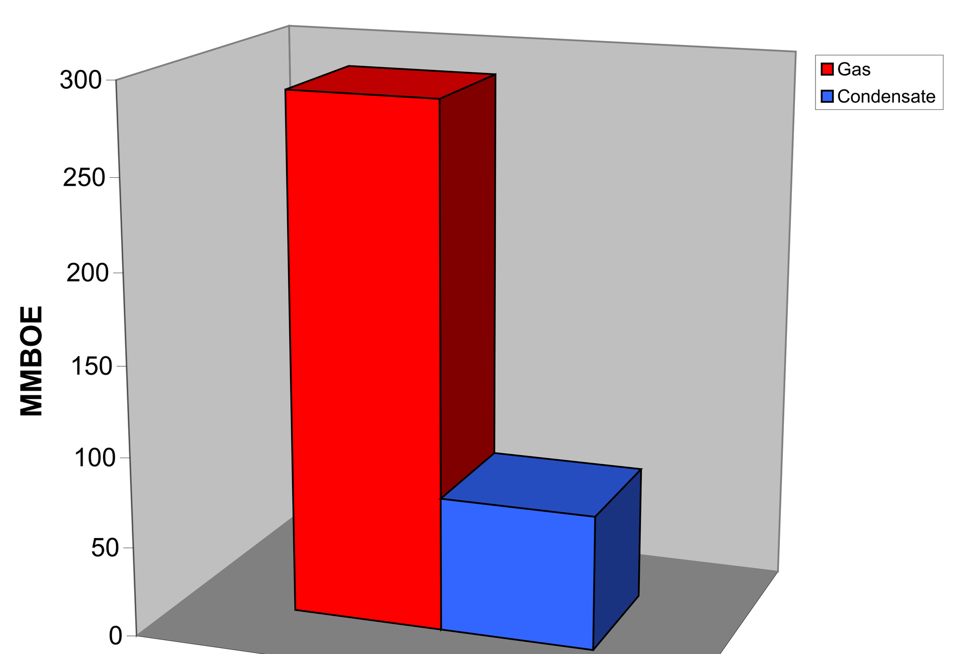


Figure 5: Geoscience Australia (Austplay) estimates of the recoverable hydrocarbons to be discovered in the next 10-15 years in the Jurassic Plover-Plover (.) petroleum system. Based on the work of Barrett et al. (2004).

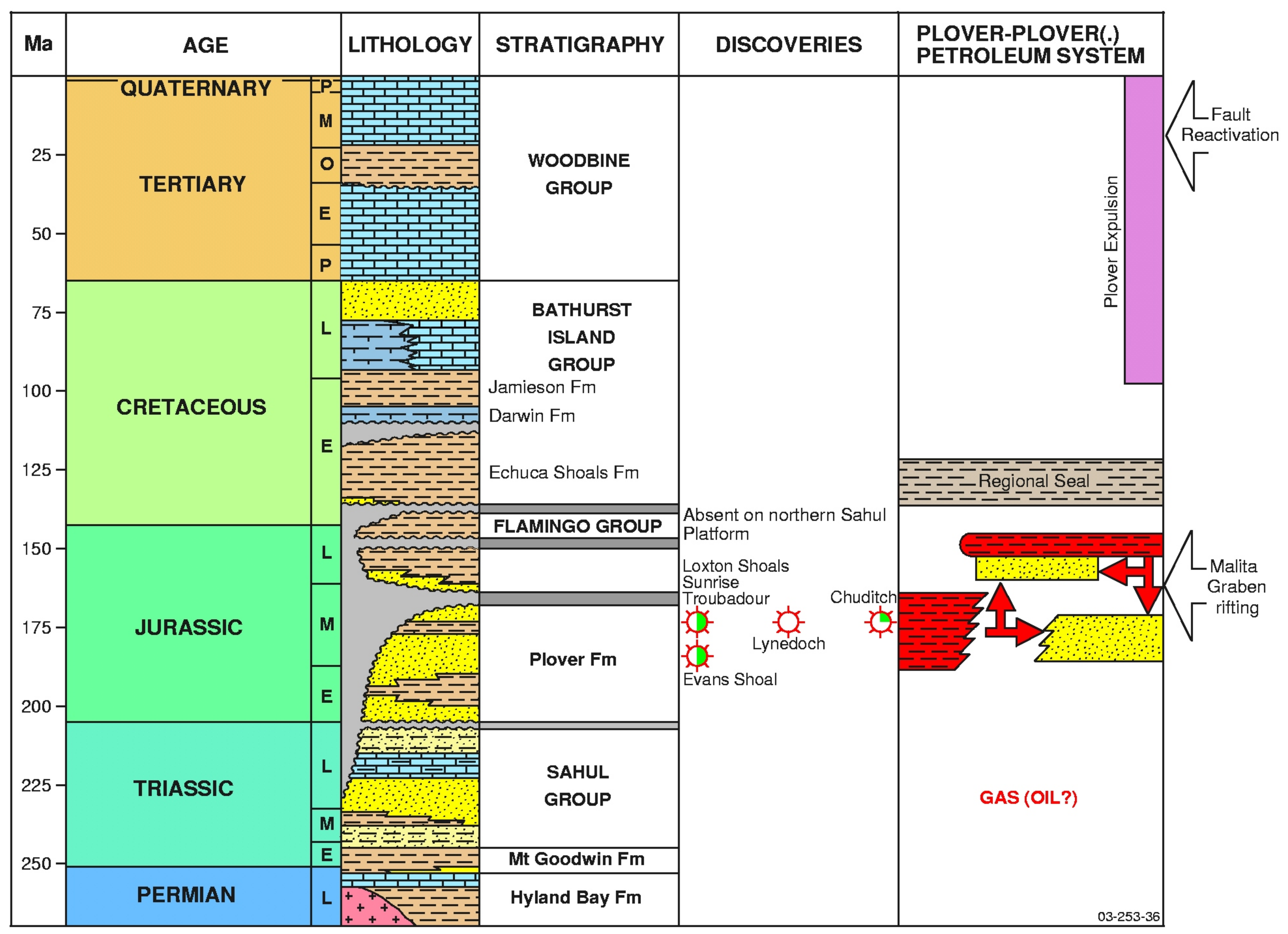


Figure 6: Schematic diagram of the Plover-Plover (.) petroleum system.

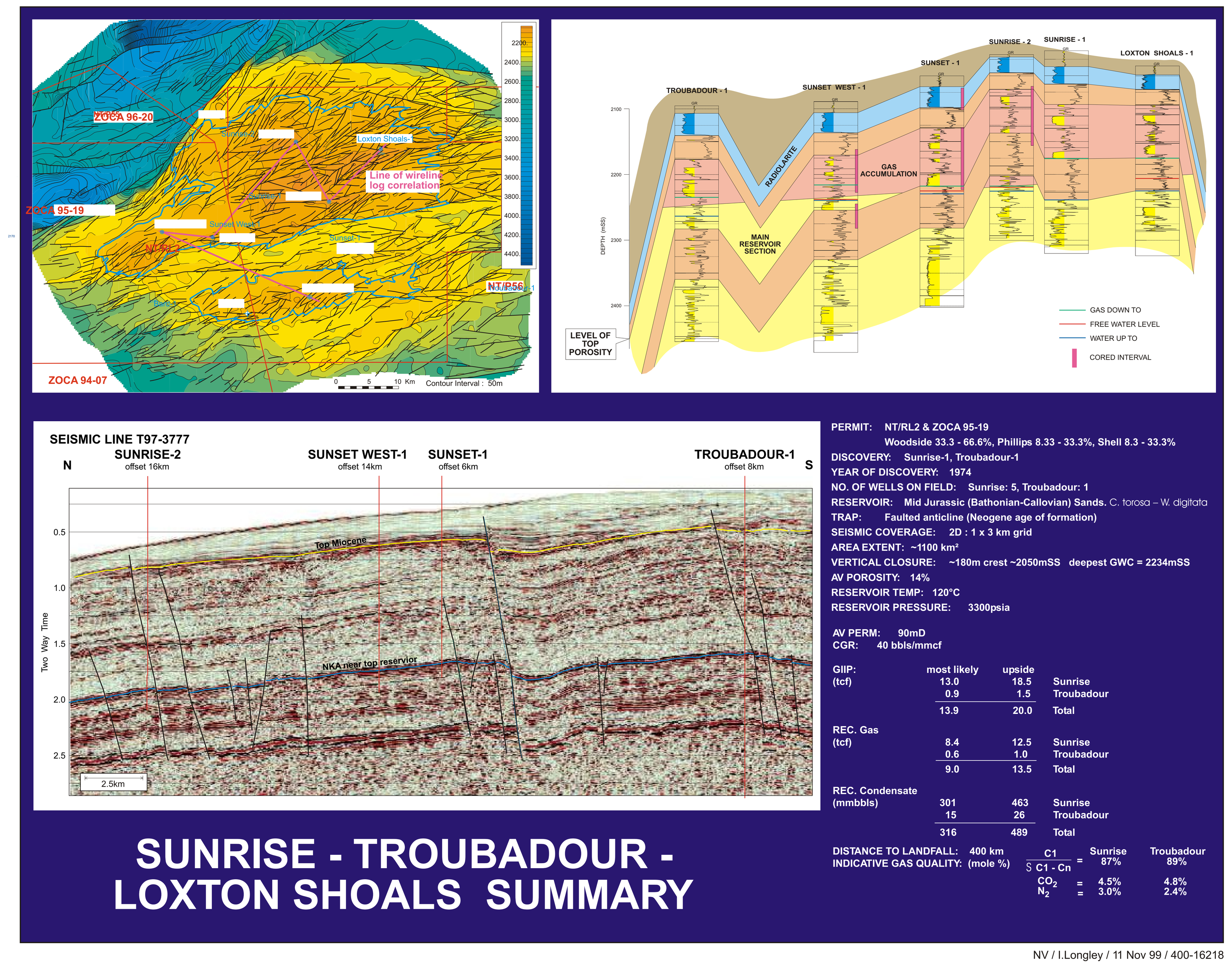


Figure 7: Summary of the Sunrise - Troubadour - Loxton Shoals gas and condensate accumulation.

Australian Government
Geoscience Australia

Petroleum Systems of the Bonaparte Basin

Geocat: 61365

4. PERMIAN HYLAND BAY-HYLAND BAY (?) PETROLEUM SYSTEM (Kelp High)

The Permian Hyland Bay-Hyland Bay (?) petroleum system is located on the Kelp High, a structural high on the Sahul Platform, in the Bonaparte Basin.

The Sahul Platform is a large northeast trending basement high comprised of tilted fault blocks and horsts. The structure is overlain by less than 5 km of Late Permian to Cainozoic section. The Kelp High is located to the west and consists of crestal east-west trending horst blocks with flanks composed of numerous tilted fault blocks.

There has been one gas discovery on the Kelp High at Kelp Deep 1 in the Hyland Bay Formation. The gas was assessed to be very tight and non-producible under conventional conditions. The gas is highly mature dry gas and has been interpreted to be from a land plant rich source rock such as the Hyland Bay Formation. It has been inferred from this discovery that the Permo-Carboniferous sequence is prospective. Barrett et al. (2004) did not anticipate any drilling in this system in the next 10 to 15 years.

Petroleum System Characteristics

Source	? Hyland Bay Formation
Reservoir	Hyland Bay Formation
Seal	Mt Goodwin Formation
Source Quality	Gas prone
Source	Mudstones
System Age	? Permian
Expulsion	? Tertiary
Traps	Horsts, tilted fault blocks, anticlines and stratigraphic traps.
Risk	Fault seal failure
Key References	Acreage Release 2003

Barrett, A.G., Hinde, A.L., & Kennard, J.M., 2004. Undiscovered resource assessment methodologies and application to the Bonaparte Basin. In: Ellis G.K., Baillie P.W. and Munson T.J. (Eds) Timor Sea Petroleum Geoscience. Proceedings of the Timor Sea Symposium, Darwin, Northern Territory, 19-20 June 2003. Northern Territory Geological Survey, Special Publication 1

Whittam, D.B., Norvick, M.S., & McIntyre, C.L., 1996. Mesozoic and Cainozoic tectonostratigraphy of western ZOCA and adjacent areas. APPEA Journal 36 (1), 209-232.

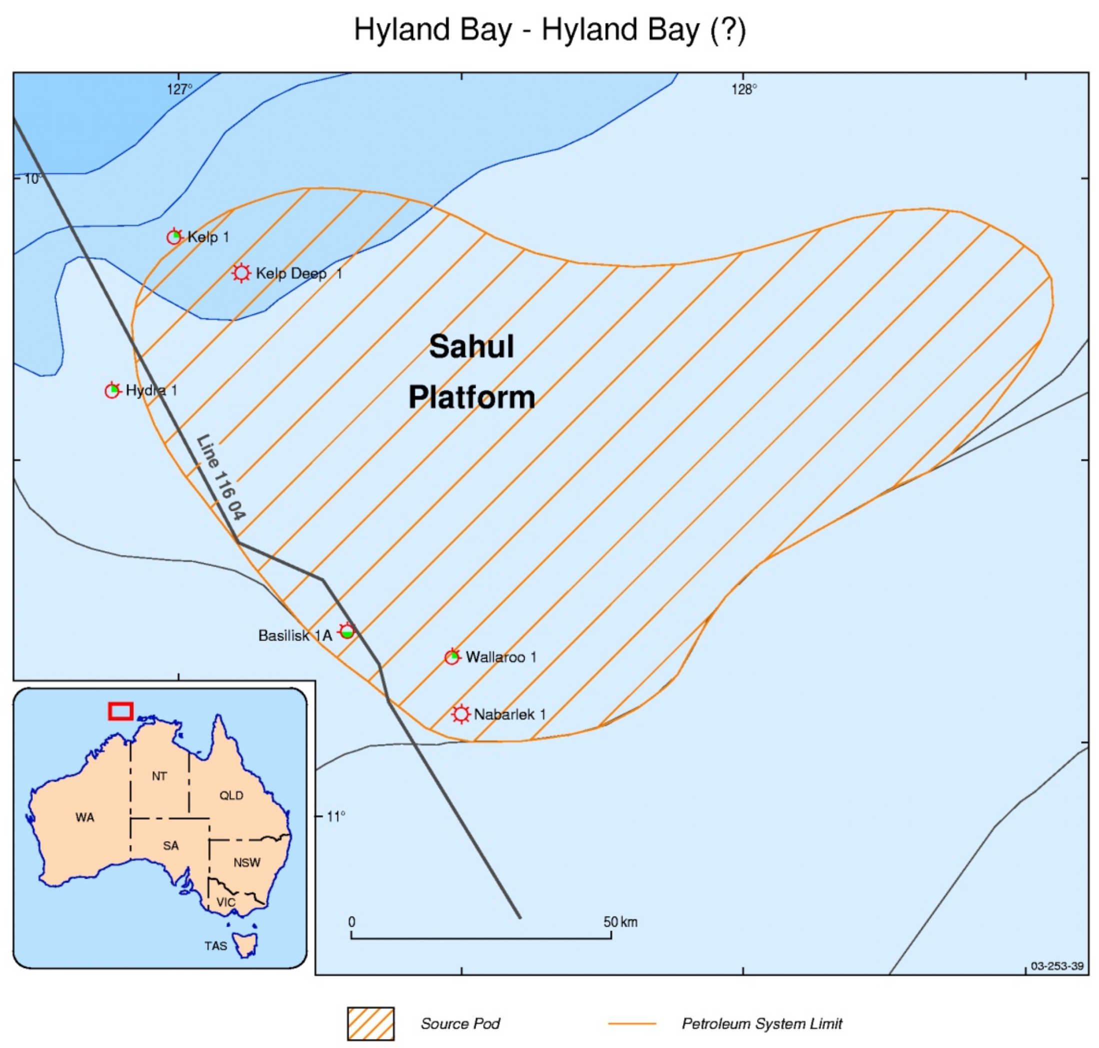


Figure 1: Spatial extent of the Permian Hyland Bay-Hyland Bay (?) petroleum system. The limit of the petroleum system and source pod is poorly understood as the system is defined by only one well: Kelp Deep 1. The northeast limit is based on the inferred depositional limit of the Permian. The seismic line shown refers to Figure 2.

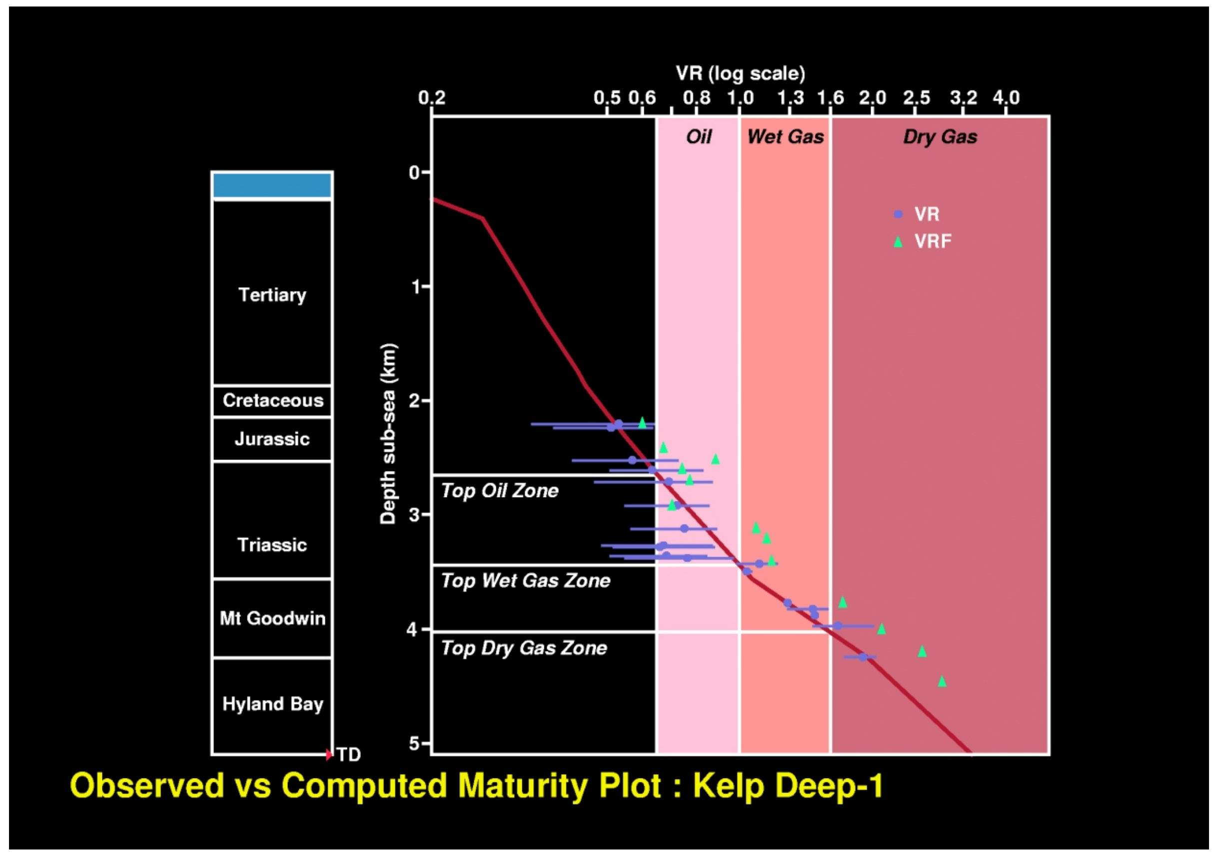


Figure 2: Observed vs computed maturity plot for Kelp Deep-1. The stratigraphic section intersected by the well indicates that the sediments are mature for hydrocarbon generation below the Jurassic section. The Hyland Bay Formation is mature for dry gas.

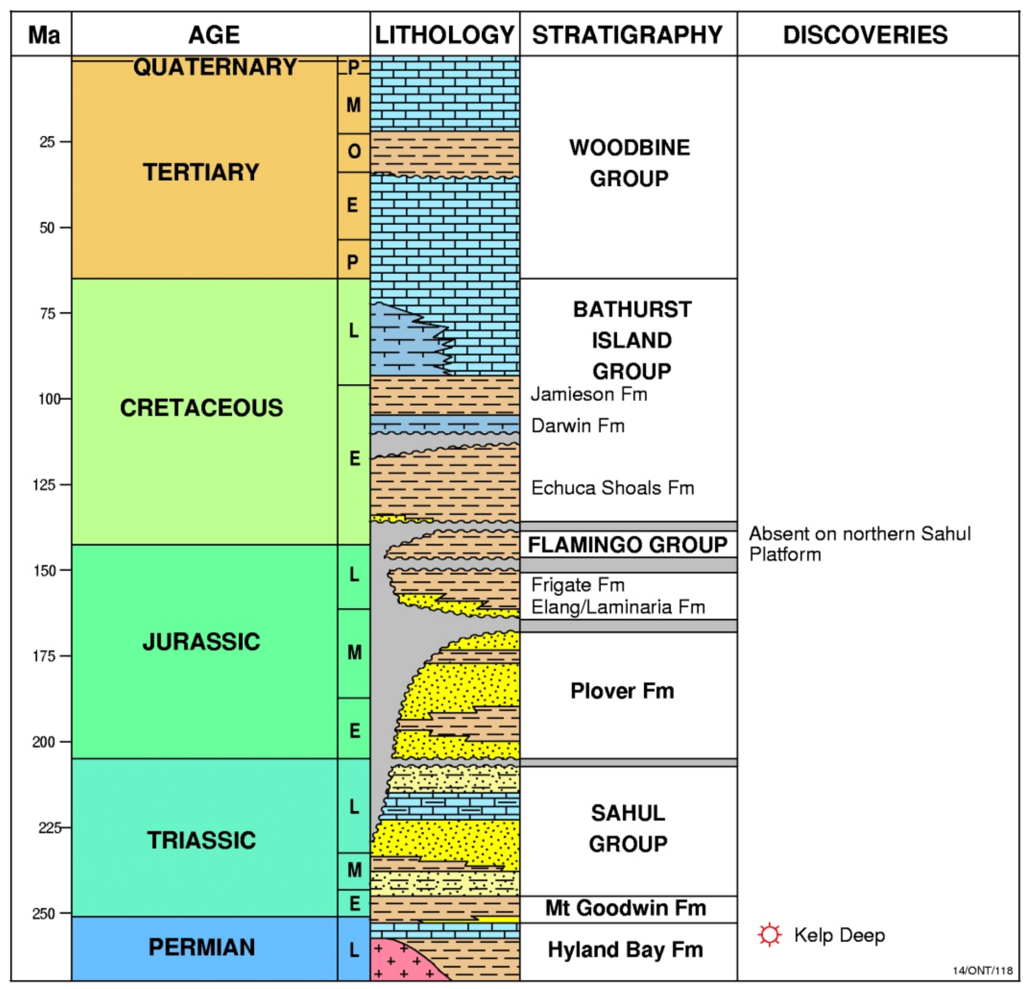


Figure 3: Stratigraphy of the northern Bonaparte Basin.

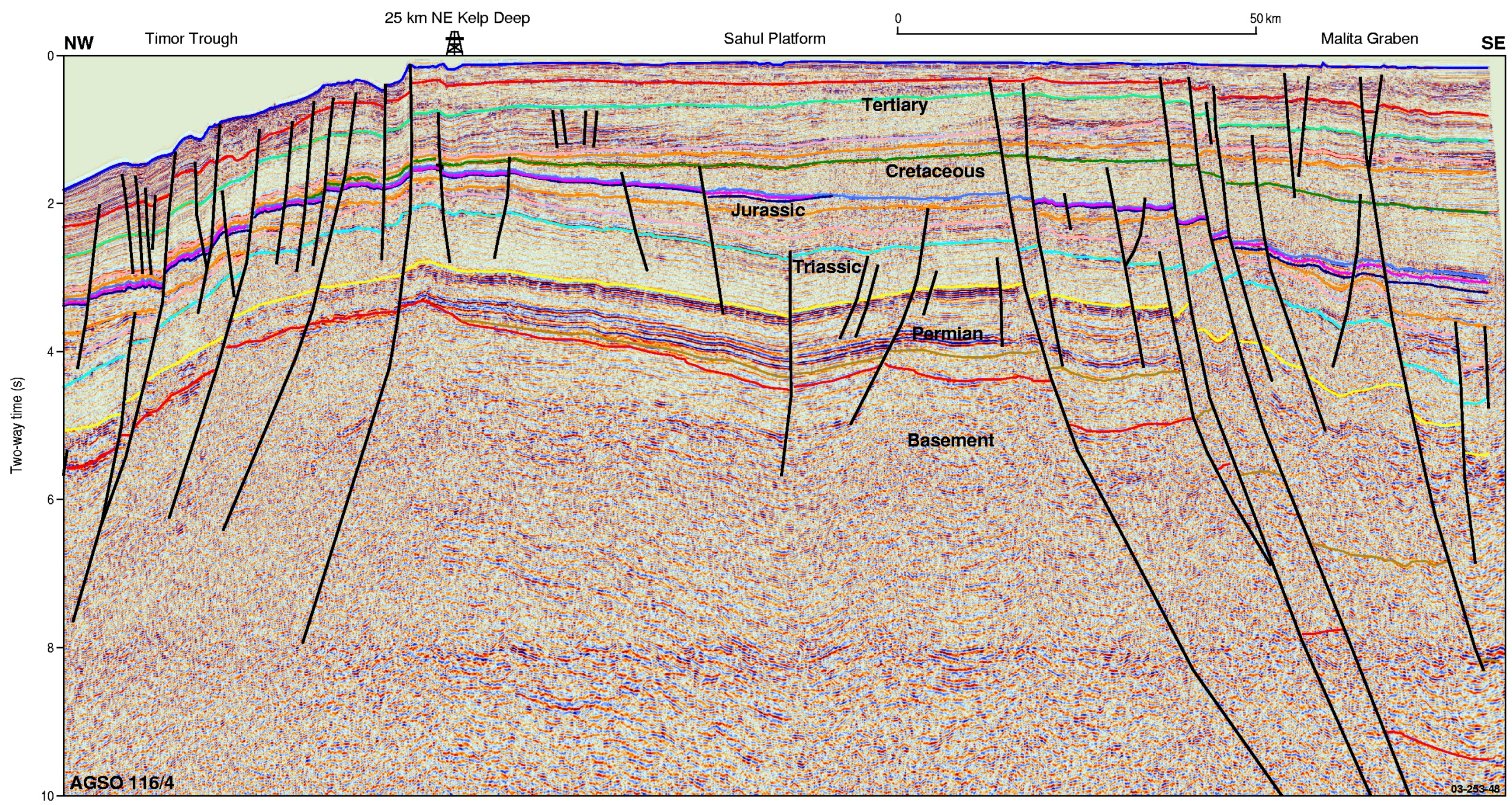


Figure 4: AGSO line 116_04. This seismic section shows the Malita Graben through to the Sahul Platform.

Australian Government
Geoscience Australia

Petroleum Systems of the Bonaparte Basin

Published by Geoscience Australia, Department of Industry, Tourism and Resources, Canberra, Australia. Issued under the authority of the Minister for Industry, Science and Resources.

Geocat: 61365

5. PERMIAN-HYLAND BAY (?) PETROLEUM SYSTEM (Londonderry High)

The Permian-Hyland Bay (?) petroleum system is located on the Londonderry High in the Bonaparte Basin. This system may be a continuation of the Hyland Bay/Keyling-Hyland Bay petroleum system in the Petrel Sub-basin. The Londonderry High is a northeast trending structural high comprising Triassic and Permo-Carboniferous units. These units are unconformably overlain by Jurassic or younger units. The petroleum system has a prospective inferred Permian source comprised of the Hyland Bay and Keyling Formations.

The Hyland Bay Formation is the primary reservoir in this region but other prospective targets include the Keyling Formation, Cape Londonderry Formation, Plover Formation and the Flamingo Group. The Bathurst Island Group is the regional seal.

This petroleum system has proven hydrocarbon potential with two gas discoveries at Prometheus and Rubicon. Oil stains occur at Torrens 1 in the Hyland Bay Formation and oil bearing fluid inclusions occur in the Fossil Head and Kuriyippi Formations. Most of the wells drilled in the area have targeted fault-dependant traps that formed during Mesozoic rifting. Stratigraphic traps have good potential as future exploration targets.

Petroleum System Characteristics

Source	? Permian (Hyland Bay or Keyling Formations)
Reservoir	Hyland Bay Formation
Seal	Mt Goodwin Formation
Source Quality	Gas and ?oil prone
Source Type	Coaly mudstones, mudstones
System Age	Permian
Expulsion	? Mesozoic to Tertiary
Traps	Horsts, tilted fault blocks, stratigraphic, anticlines
Risk	Fault seal failure, lack of oil charge.
Key References	Acreage Release 2003

Barrett, A.G., Hinde, A.L., & Kennard, J.M., 2004. Undiscovered resource assessment methodologies and application to the Bonaparte Basin. In: Ellis G.K., Baillie P.W. and Munson T.J. (Eds) Timor Sea Petroleum Geoscience. Proceedings of the Timor Sea Symposium, Darwin, Northern Territory, 19-20 June 2003. Northern Territory Geological Survey, Special Publication 1.

Brincat, M.P., O'Brien, G.W., Lisk, M., De Ruig, M., & George, S.C., 2001. Oil charge history of the northern Londonderry High: implications for trap integrity and future prospectivity. APPEA Journal 41(1), 483-495.

Kennard, J.M., Edwards, D.S., Boreham, C.J., Gorter, J.D., King, M.R., Ruble, T.E., & Lisk, M., 2000. Evidence for a Permian Petroleum System in the Timor Sea, Northwestern Australia. AAPG International Conference and Exhibition, Bali, 15-18th October 2000. Abstracts volume A45.

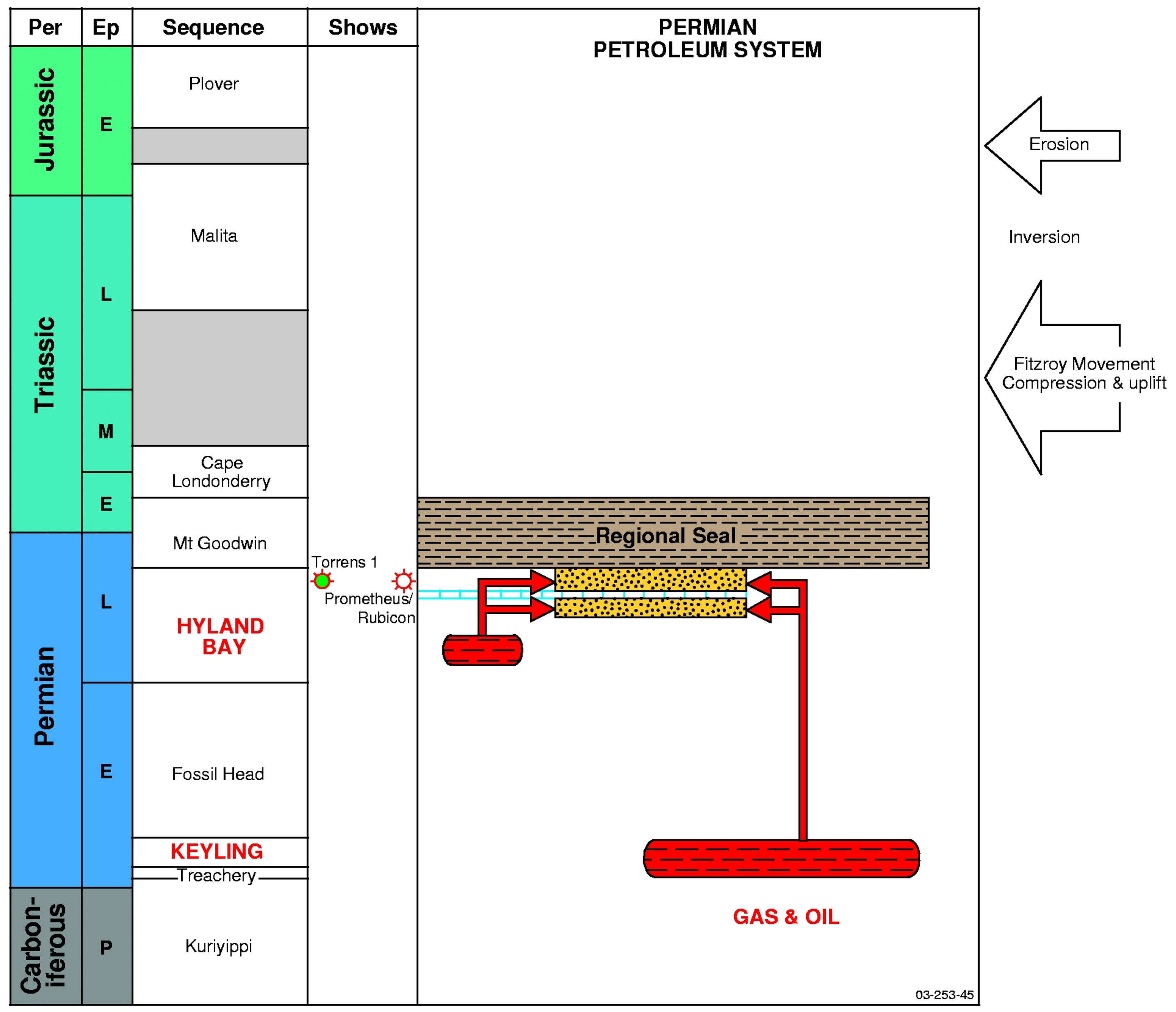


Figure 4: Schematic diagram of the Permian-Hyland Bay (?) petroleum system.

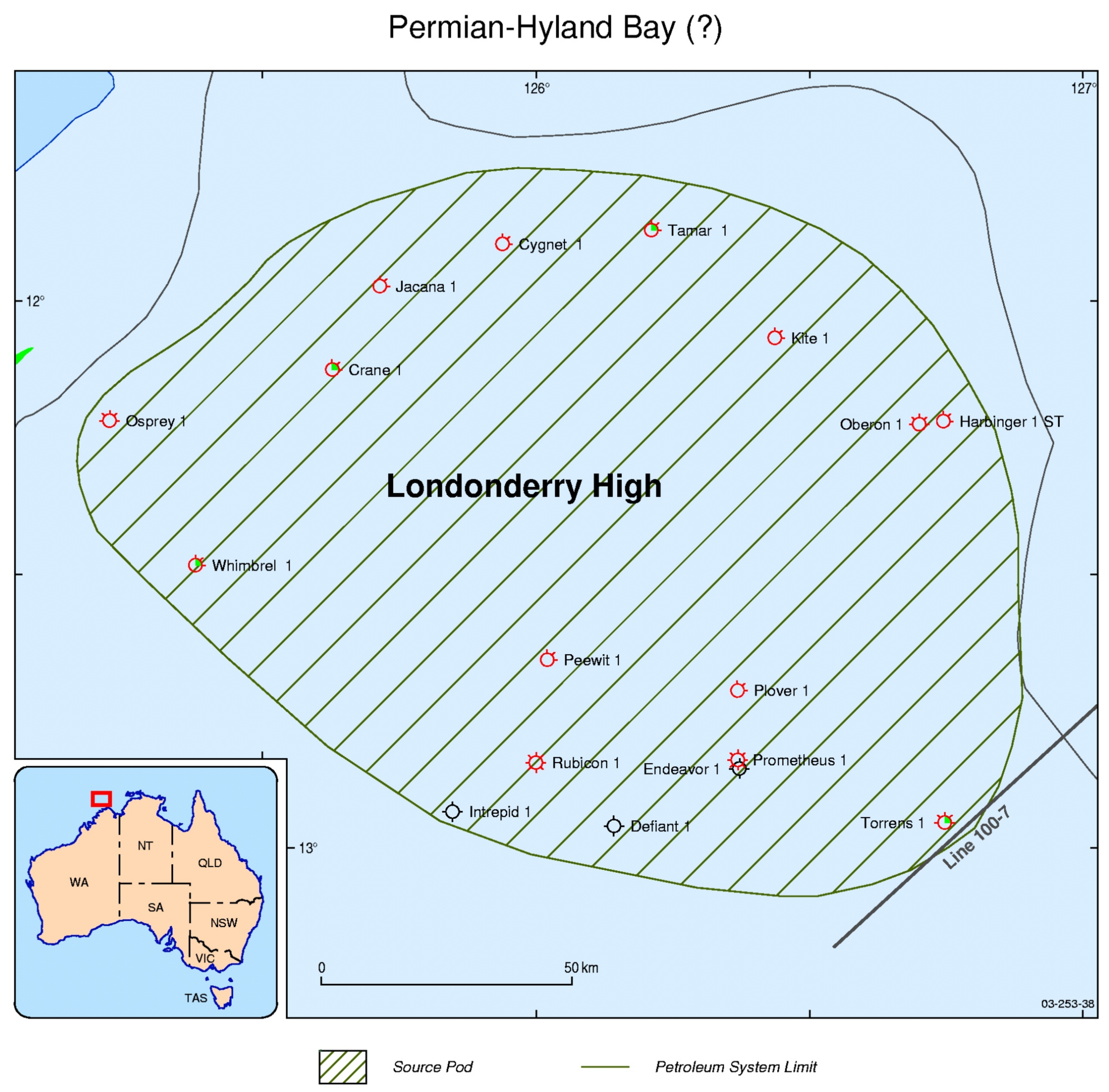


Figure 1: Spatial extent of the Permian-Hyland Bay (?) petroleum system. This map displays hydrocarbon accumulations and shows thought to have been sourced from Permian Formations. The petroleum system and source pod limit has been defined within the Londonderry High, as encompassing shows attributed to the system. This system is possibly a continuation of the Hyland Bay/Keyling-Hyland Bay petroleum system in the Petrel Sub-basin but was separated due to the differing structural styles of the two areas. The seismic line shown refers to Figure 3.

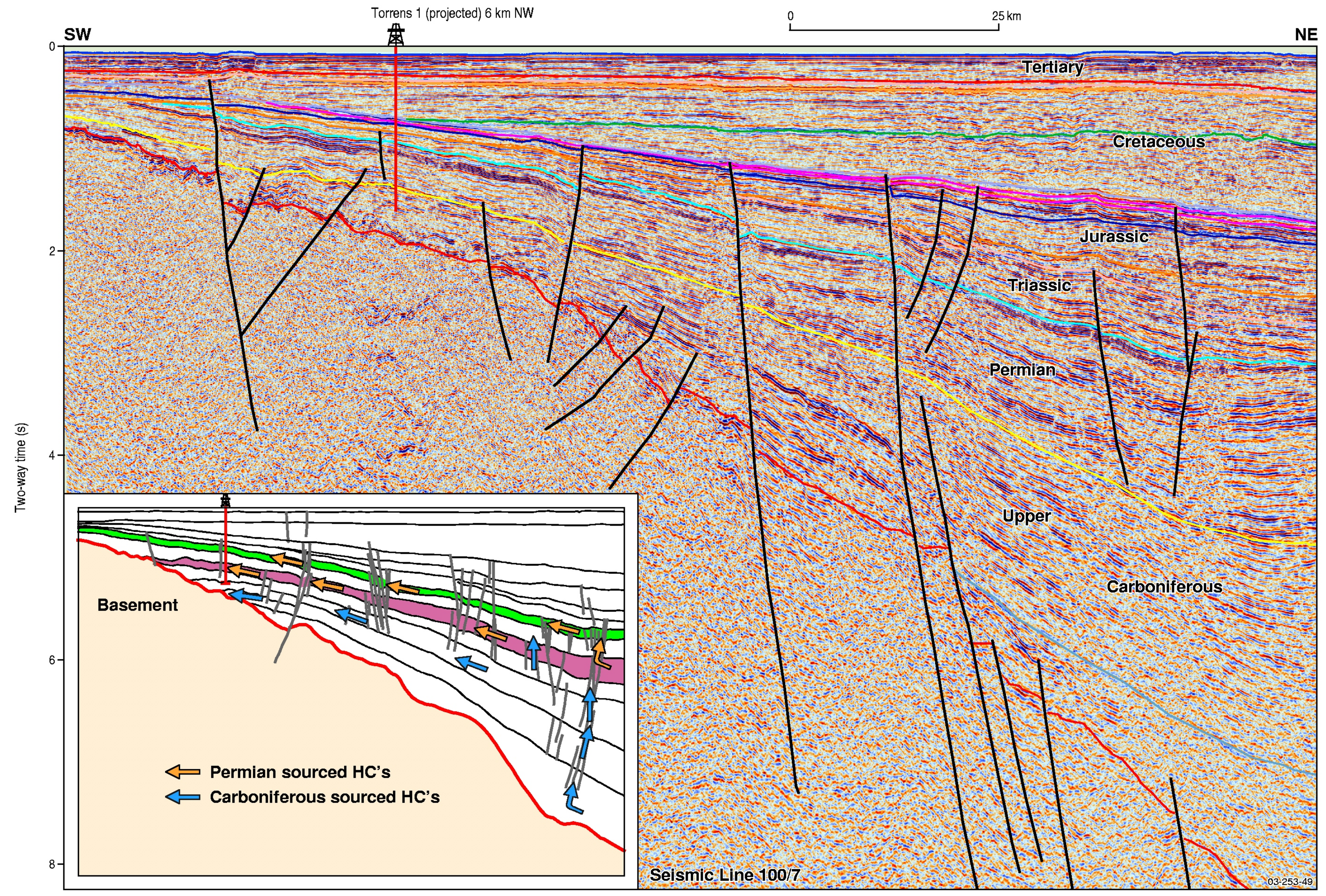


Figure 3: AGSO line 100/7 with Torrens 1 projected. At Torrens 1 an oil stains were discovered in the Hyland Bay Formation.The hydrocarbons were probably sourced from Palaeozoic sediments.

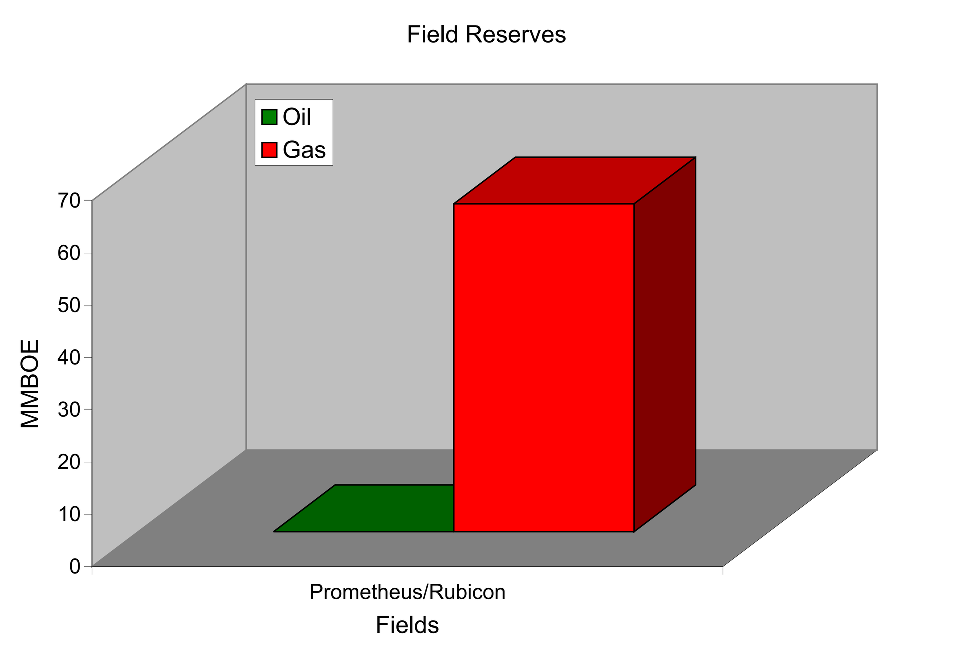


Figure 5: Field reserves for the Permian-Hyland Bay (?) petroleum system. All reserve numbers are sourced from the Western Australian Geological Survey.

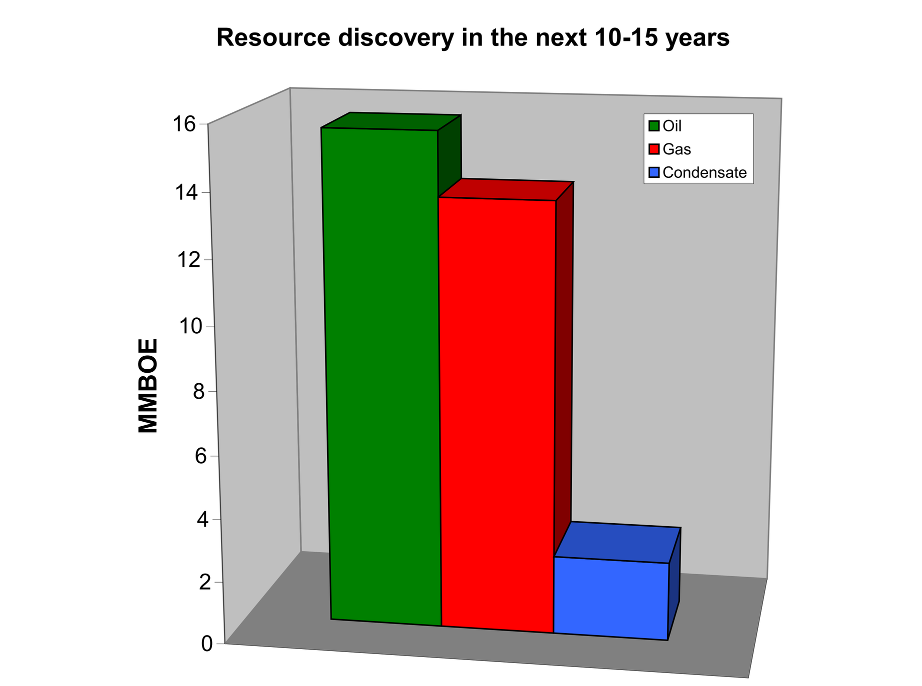


Figure 6: Geoscience Australia (Austplay) estimates of the recoverable hydrocarbons to be discovered in the next 10-15 years in the Permian-Hyland Bay (?) petroleum system. Based on the work of Barrett et al. (2004).

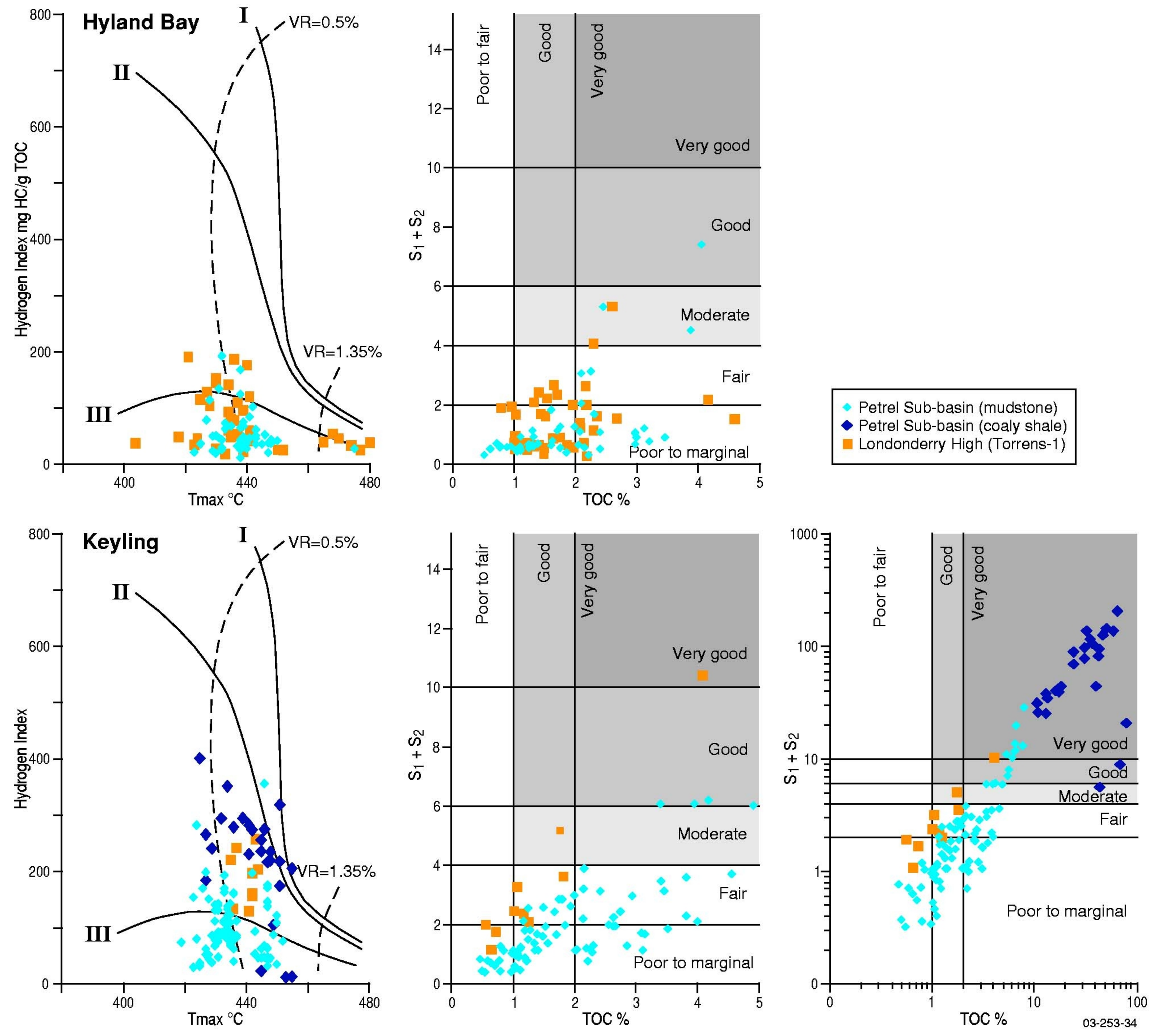


Figure 2: Rock-Eval pyrolysis data for potential Permian source rocks in the Petrel Sub-basin and Londonderry High. The Keyling Formation source quality ranges from dry gas prone Type III/IV kerogen to oil-condensate prone Type II/III kerogen. Coaly facies (mean TOC = 35%) have the potential to generate oil and gas but are thin and immature. The Hyland Bay Formation is gas prone with type III/IV kerogen and an overall poor generative potential.

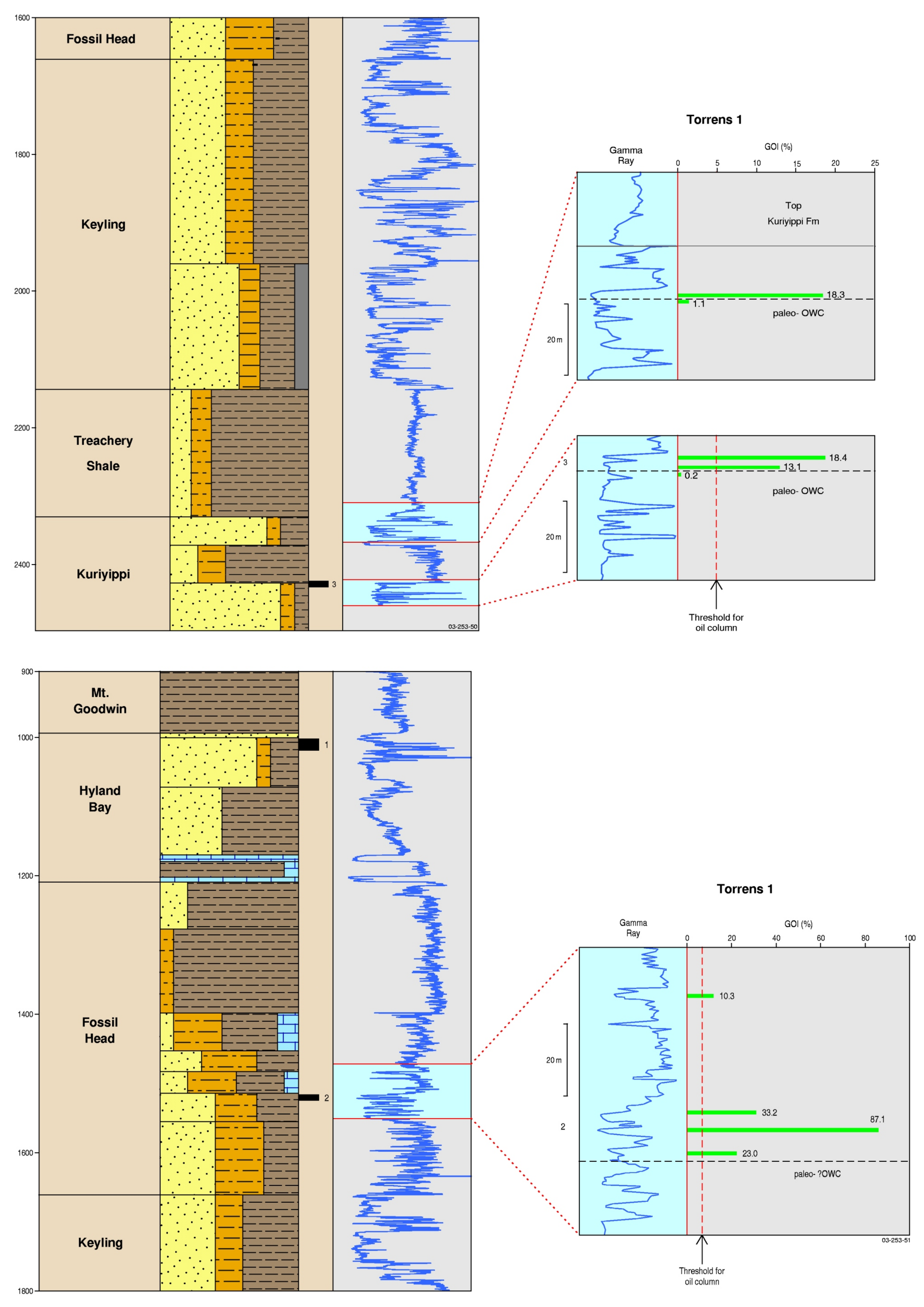


Figure 7: Palaeo oil columns in Torrens 1

Australian Government
Geoscience Australia

Petroleum Systems of the Bonaparte Basin

Published by Geoscience Australia, Department of Industry, Tourism and Resources, Canberra, Australia. Issued under the authority of the Minister for Industry, Science and Resources.

Geocat: 61365

6. PERMIAN HYLAND BAY/KEYLING-HYLAND BAY (.) PETROLEUM SYSTEM (Central Petrel Sub-basin)

The Permian Hyland Bay/Keyling-Hyland Bay (.) petroleum system is located within the central Petrel Sub-basin of the Bonaparte Basin.

The Petrel Sub-Basin is an asymmetric northwest trending rift of Late Devonian-Carboniferous age, containing up to 15 km of Palaeozoic and Mesozoic sediments.The dominant source rock in the central Petrel Sub-basin is the oil and gas prone Keyling Formation. Modelled expulsion from the Keyling Formation is widespread in the central and outer Petrel Deep, commencing in the Late Permian and peaking in the Early Triassic. Minor expulsion continued throughout the Late Triassic-Cretaceous. The distribution and thickness of the oil prone facies is poorly known but there are indications for an oil system with low confidence Synthetic Aperture Radar (SAR) slick anomalies east and southeast of the Petrel gas field.
Modelled gas expulsion from the Hyland Bay Formation is restricted to the outer part of the Petrel deep and the adjacent Malita Graben. Expulsion began in the Jurassic with peak expulsion in the mid-late Cretaceous. The formation is too lean to expel oil.

Jurassic units are important source sequences in other areas of the Bonaparte Basin but in the Petrel Sub-basin they are immature for hydrocarbon generation.The primary exploration target in this region is the deltaic Hyland Bay Formation with widespread sands. Reservoir distribution is considered a risk in this system. Typically reservoirs are thin, lenticular, isolated, low permeability and have high water saturation. The overlying Mt. Goodwin Formation forms a regional seal.

To date there has been no commercial hydrocarbon production in the Petrel Sub-basin. This gas-prone system has proven hydrocarbon potential with six gas discoveries; Blacktip, Fishburn, Leseuer, Penguin, Petrel and Tern. Development of the Petrel, Tern and Blacktip fields is being considered.

Petroleum System Characteristics

Source	Keyling and Hyland Bay Formation
Reservoir	Keyling and Hyland Bay Formation
Seal	Mount Goodwin Formation
Source Quality	Gas prone
Source Type	Coaly mudstones, mudstones
System Age	Permian
Expulsion	Keyling Formation - Late Permian to Early Cretaceous Hyland Bay Formation - Jurassic to Late Cretaceous
Traps	Faulted anticlines, salt diapir associated structures, stratigraphic
Risk	General perception that the Petrel Sub-basin lacks regionally extensive and high quality reservoirs
Key References	Acreage Release 2002.

Barrett, A.G., Hinde, A.L. & Kennard, J.M., 2004. Undiscovered resource assessment methodologies and application to the Bonaparte Basin. In: Ellis G.K., Baillie P.W. and Munson T.J. (Eds) Timor Sea Petroleum Geoscience. Proceedings of the Timor Sea Symposium, Darwin, Northern Territory, 19-20 June 2003. Northern Territory Geological Survey, Special Publication 1.

Kennard, J.M., Deighton, I., Edwards, D.S., Boreham, C.J., & Barrett A.G., 2002. Subsidence and thermal history modelling: New insights into hydrocarbon expulsion fro multiple petroleum systems in the Petrel Sub-basin, Bonaparte Basin. The Sedimentary Basins of Western Australia 3: Proceedings of the Petroleum Exploration Society of Australia Symposium, Perth,WA, 2002, 409-437.

Hyland Bay/Keyling - Hyland Bay (.)

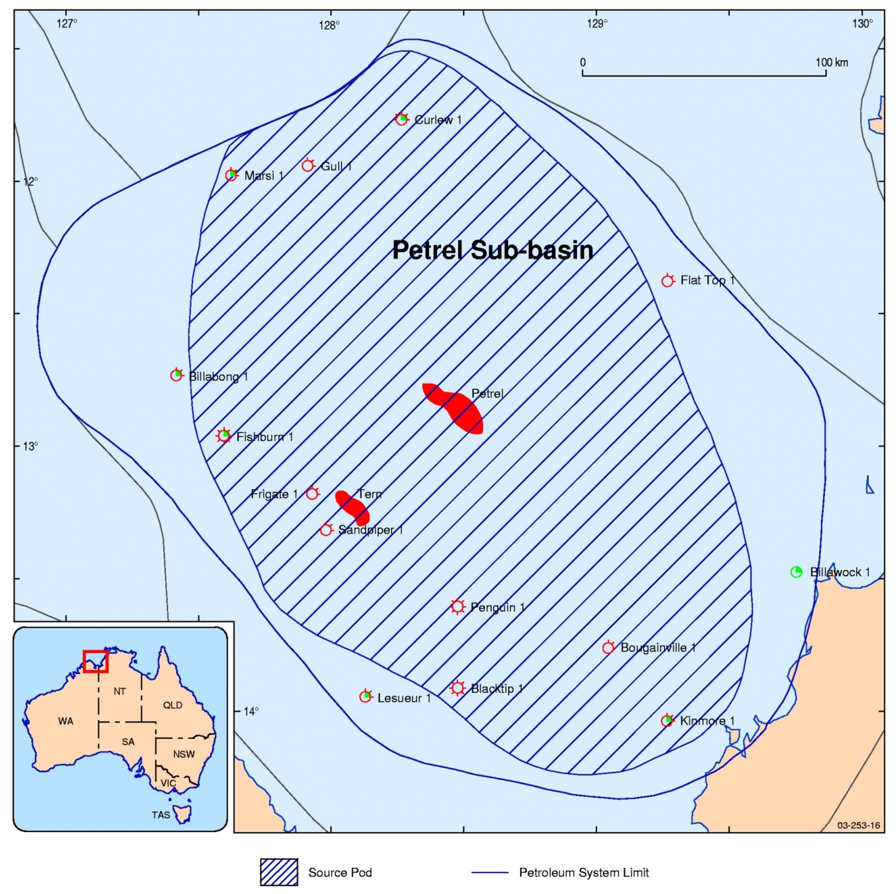


Figure 1: Spatial extent of the Hyland Bay/Keyling-Hyland Bay (.) petroleum system. The source pod limit is based on thermal maturation modelling by Kennard et al. (2002). The petroleum system limit has been confined to the Petrel Sub-basin.

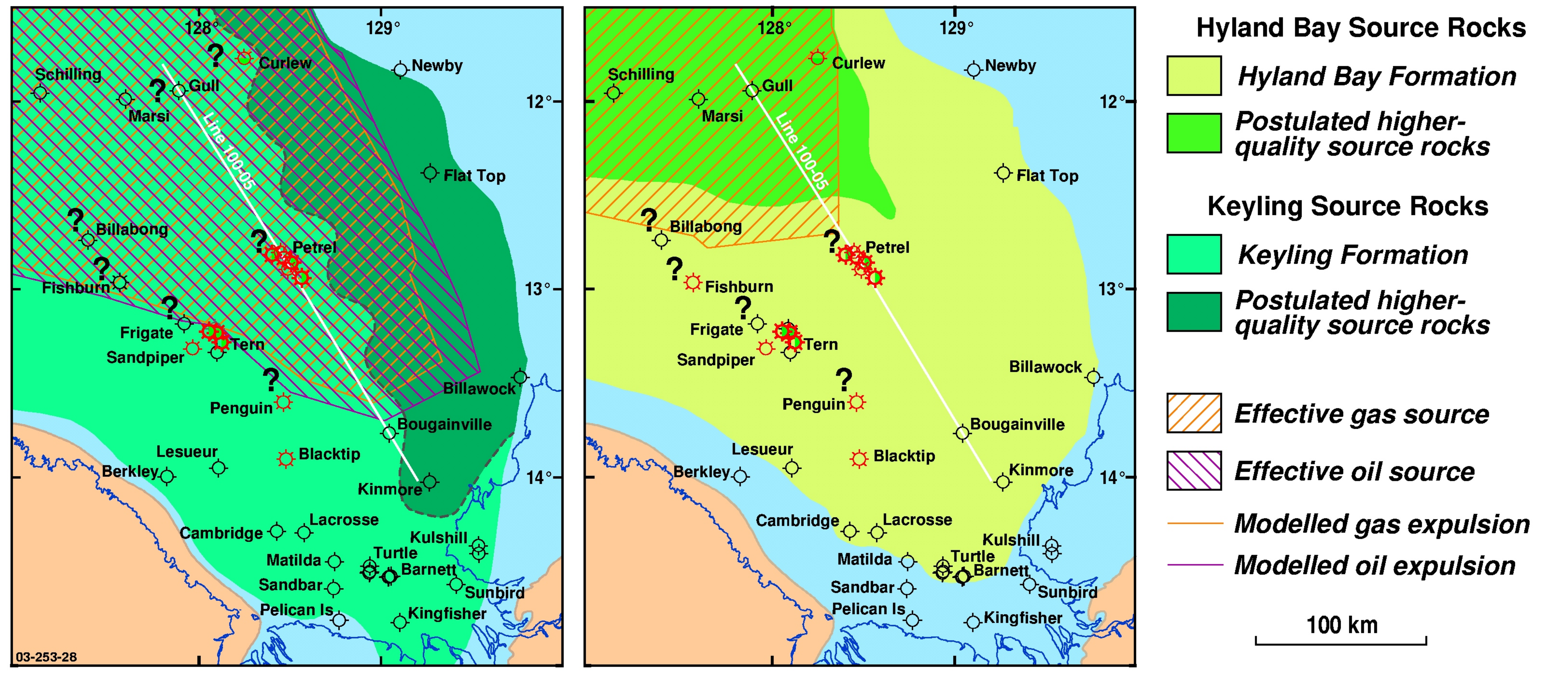


Figure 2: Permian Hyland Bay/Keyling-Hyland Bay (.) petroleum system map showing hydrocarbon accumulations and shows thought to have been sourced from either the Keyling or Hyland Bay Formations. Expulsion from the Keyling Formation is widespread in the central and outer Petrel Deep. Gas expulsion from Hyland Bay Formation is more restricted to the outer part of Petrel deep and the adjacent Malita Graben. The seismic line shown refers to Figure 4.

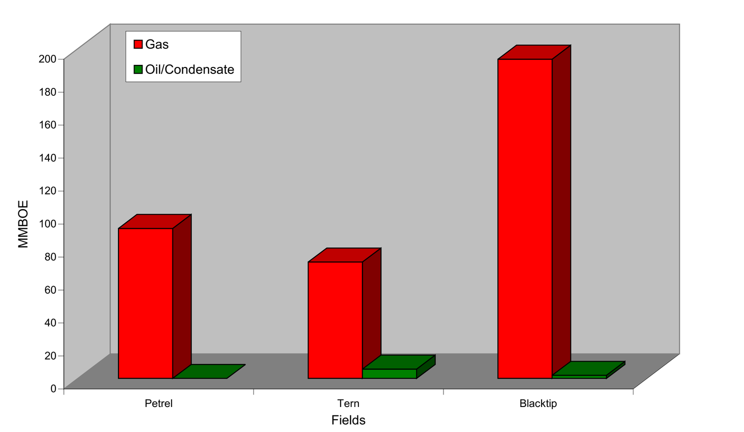


Figure 3: Field reserves for the Permian Hyland Bay/Keyling-Hyland Bay (.) Petroleum system. All reserve numbers are sourced from the Western Australian Geological Survey and Northern Territory Government Department of Business, Industry and Resource Development. Reserves/resources are estimated by the Department and exploration companies.

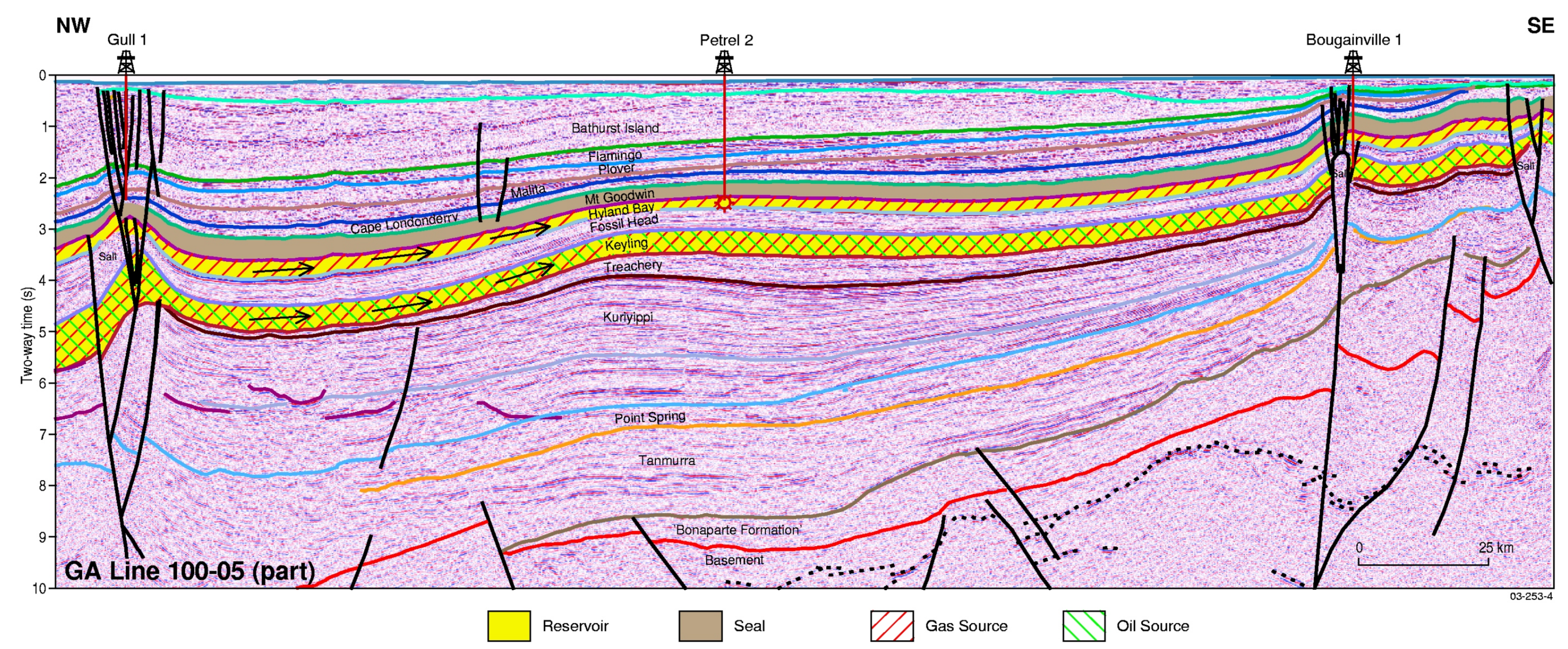


Figure 4: GA seismic line 100-05 (part) transect of the Petrel Sub-basin. This seismic line displays an example of the play elements for the Permian Hyland Bay/Keyling-Hyland Bay (.) petroleum system. The Keyling (gas and possibly oil) and the Hyland Bay (gas) formations act as both source and reservoirs within the area. The hydrocarbons are trapped by the Mt Goodwin Formation regional seal and migrate into structures such as the Petrel/Tern inversion anticlines. The Bougainville-1 well is an example of a salt diaper play. Unfortunately at this location only gas indications were found within the well. Trap types in this region include salt related plays, faulted anticlines, large scale inversion anticlines and stratigraphic traps/pinchouts.

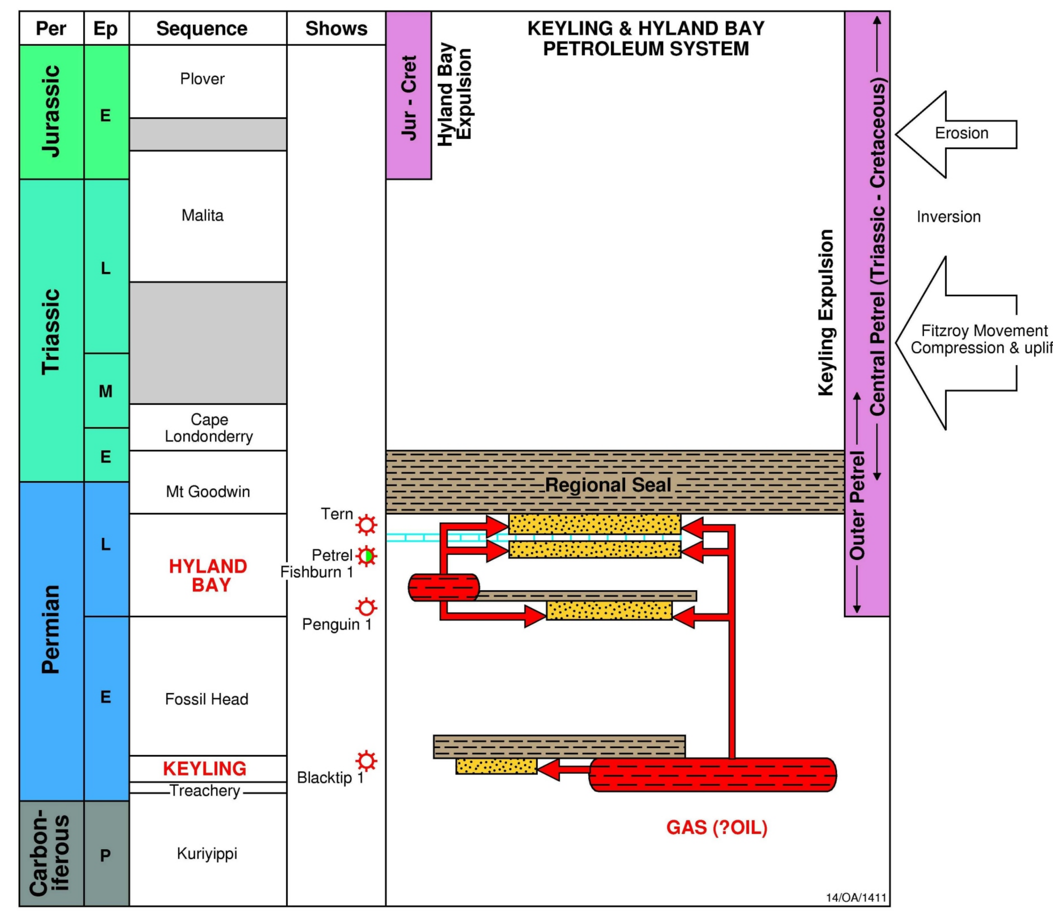


Figure 5: Schematic diagram of the Permian Hyland Bay/Keyling-Hyland Bay (.) petroleum system.

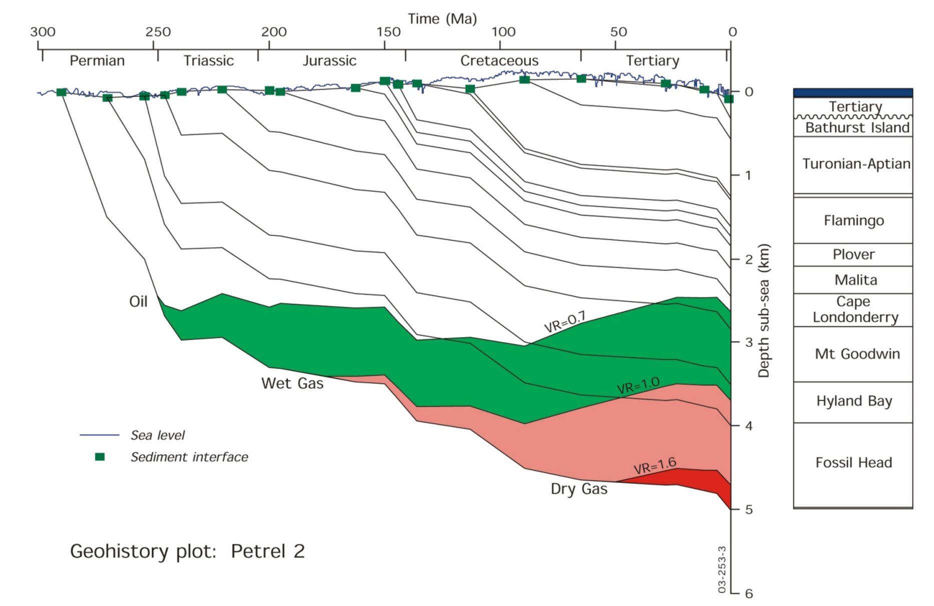


Figure 6: Geohistory plot for the Petrel 2 well. At this location the Hyland Bay Formation has been at sufficient depths since the mid Cretaceous for oil and gas generation, but this unit is gas prone.

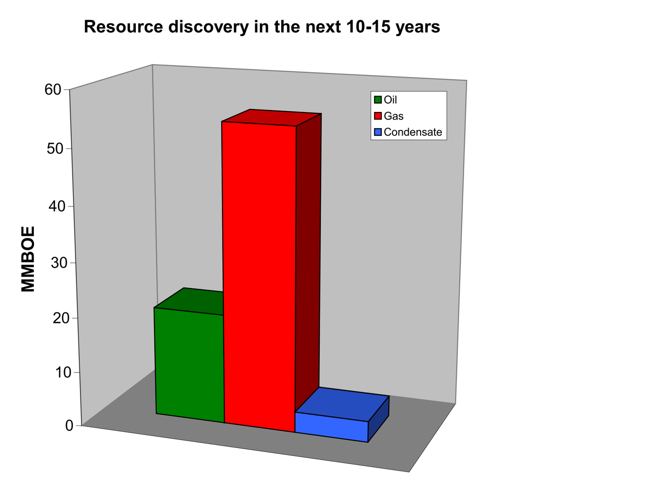


Figure 7: Geoscience Australia (Austplay) estimate of the recoverable hydrocarbons to be discovered in the next 10-15 years in the Permian Hyland Bay/Keyling-Hyland Bay (.) petroleum system. Based on the work of Barrett et al. (2004).

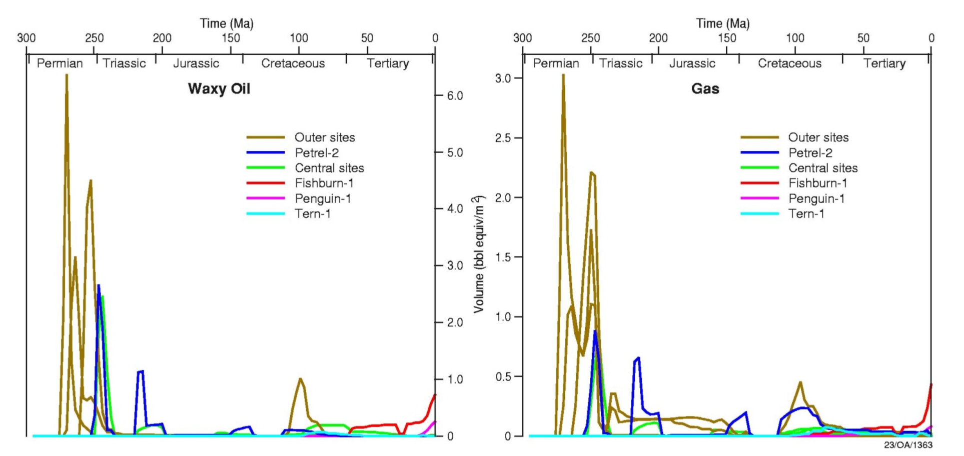


Figure 8: Modelled oil and gas expulsion time plots for the Keyling Formation source unit. Expulsion from the Keyling Formation is widespread in the central and outer Petrel Deep (Figure 2), commencing in the Late Permian and peaking in the Early Triassic. Minor expulsion continued throughout the Late Triassic-Cretaceous. The oil prone facies thickness and distribution is poorly known and to date no oil discoveries have been made.

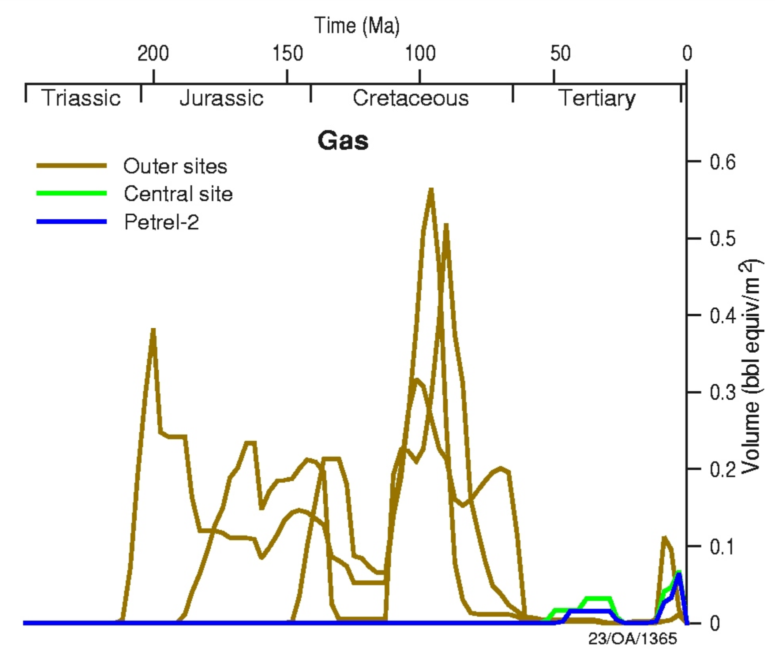


Figure 9: Modelled gas expulsion time plots for the Hyland Bay source unit. Gas expulsion from Hyland Bay is restricted to outer part of Petrel deep and the adjacent Malita Graben. Expulsion occurred in the Jurassic to Cretaceous.

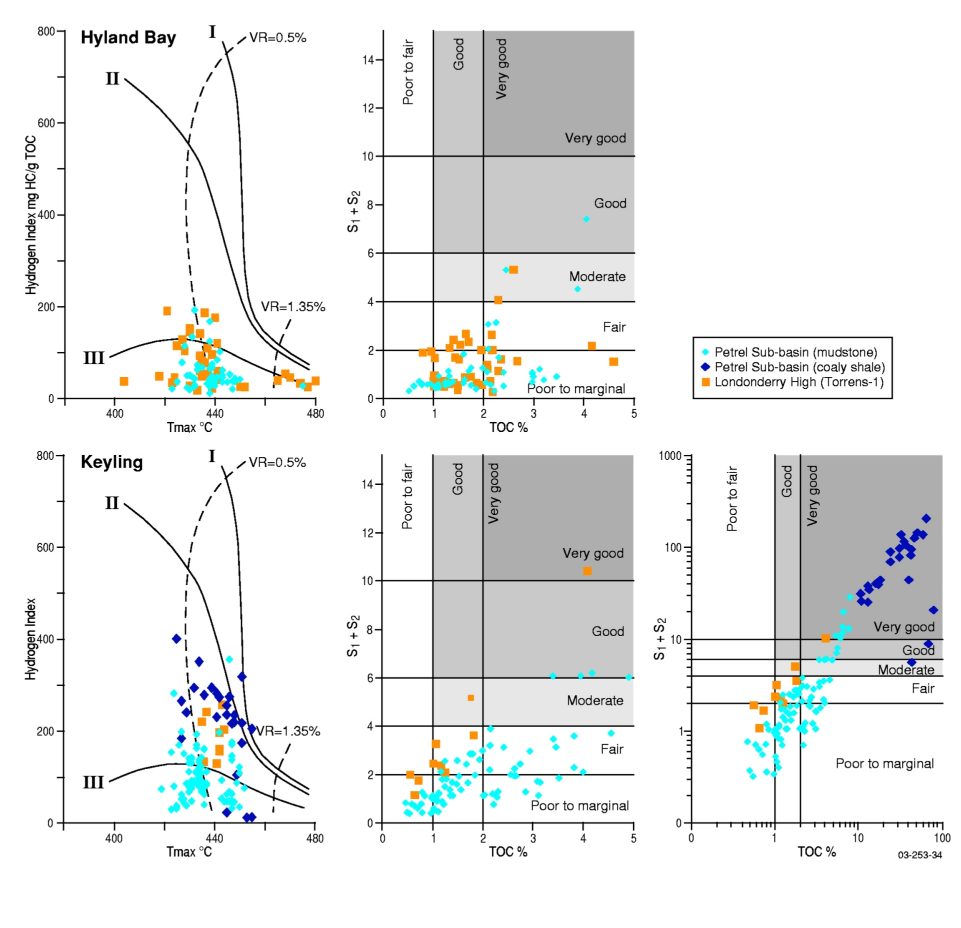


Figure 10: Rock-Eval pyrolysis data for potential Permian source rocks in the Petrel Sub-basin. The Keyling Formation source quality ranges from dry gas prone Type III/IV kerogen to oil-condensate prone Type II/III kerogen. Coaly facies (mean TOC = 35%) have the potential to generate oil and gas but are thin and lean. The Hyland Bay Formation is gas prone with type III/IV kerogen and an overall poor generative potential.

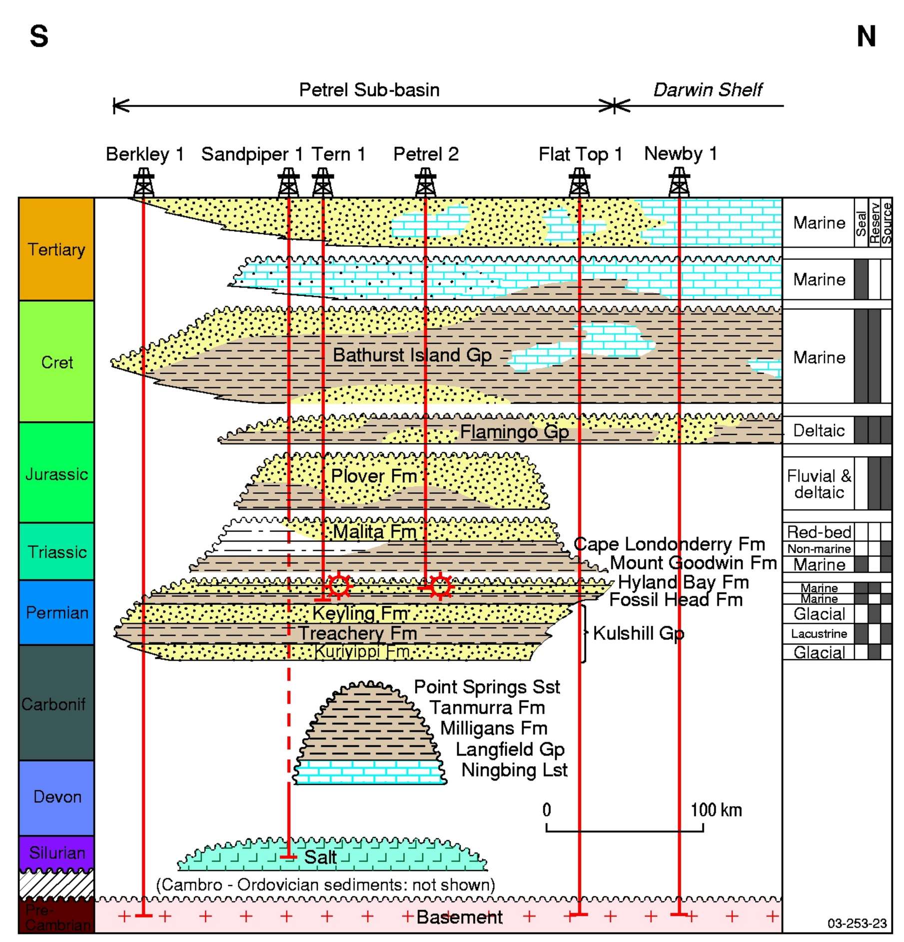


Figure 11: Chronostratigraphy; Petrel Sub-basin.

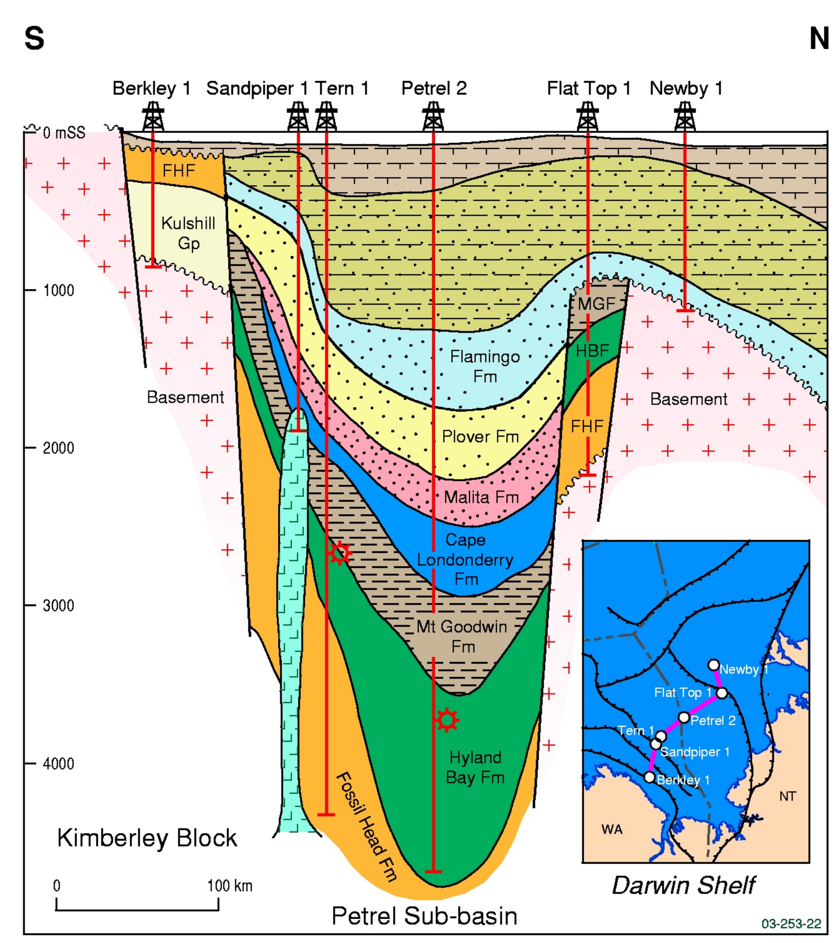


Figure 12: Cross-section; Petrel Sub-basin.

Petroleum Systems of the Bonaparte Basin

Published by Geoscience Australia, Department of Industry, Tourism and Resources, Canberra, Australia. Issued under the authority of the Minister for Industry, Science and Resources.

Geocat: 61365

7. PERMO-CARBONIFEROUS MILLIGANS-KURIYIPPI/MILLIGANS (!) PETROLEUM SYSTEM (Southern Petrel Sub-basin)

The Carboniferous Milligans-Kuriyippi/Milligans (!) petroleum system is located in the Southern Petrel Sub-basin of the Bonaparte Basin.

The Petrel Sub-Basin is an asymmetric northwest trending rift of Late Devonian-Carboniferous age, containing up to 15 km of Palaeozoic and Mesozoic sediments. In the Southern Petrel Sub-basin the most significant source rock is the oil and gas prone Early Carboniferous Milligans Formation. Modelled expulsion from the formation is restricted to two offshore depocentres immediately north and south of the Turtle-Barnett High. Hydrocarbon expulsion commenced in the Late Carboniferous, peaking in the Early Permian. Minor expulsion continued through the Permian and Early-Middle Triassic.

The primary reservoirs in the region are the Milligans and Kuriyippi formations. The Tanmurra Formation and Point Spring Sandstone also have reservoir potential. These reservoirs are sealed intraformationally or by the Treachery Shale regional seal. Traps include faulted and drape anticlines, horsts, stratigraphic onlap and downlap, mounded low stand fans, carbonate mounds and associated drape.

The petroleum system has well established hydrocarbon potential with 11 discoveries: Barnett, Turtle (offshore), Bonaparte, Garimala, Kulshill, Ningbing, Pelican Island, Spirit Hill, Vienta, Waggon Creek and Weaber (onshore).
Recent work by Gorter et al., 2004 has indicated that the Early Carboniferous Langfield Formation of the Bonaparte Group is the more likely source for hydrocarbons in this region. This is based on a re-assessment of the stratigraphic ages of samples in well NBF-1002.

Petroleum System Characteristics

Source	Milligans Formation
Reservoir	Milligans and Kuriyippi Formation
Seal	Treachery Shale, Intraformational
Source Quality	Oil and gas prone
Source Type	Marine mudstones
System Age	Carboniferous
Expulsion	Late Carboniferous to Middle Triassic
Traps	Faulted and drape anticlines/horsts
Risk	Source distribution·
Key References	Barrett, A.G., Hinde, A.L., & Kennard, J.M., 2004. Undiscovered resource assessment methodologies and application to the Bonaparte Basin. In: Ellis G.K., Baillie P.W. and Munson T.J. (Eds) Timor Sea Petroleum Geoscience. Proceedings of the Timor Sea Symposium, Darwin, Northern Territory, 19-20 June 2003. Northern Territory Geological Survey, Special Publication 1.

Gorter, J.D., Mckirdy, D.M., Jones, P.J., & Playford, G., 2004. Reappraisal of the Early Carboniferous Milligans Formation source rock system in the southern Bonaparte Basin, northwestern Australia. Australia . *In:* Ellis G.K., Baillie P.W. and Munson T.J. (Eds) *Timor Sea Petroleum Geoscience. Proceedings of the Timor Sea Symposium*, Darwin, Northern Territory, 19-20 June 2003. Northern Territory Geological Survey, Special Publication 1.

Kennard, J.M., Deighton, I., Edwards, D.S, Boreham, C.J., & Barrett, A.G., 2002. Subsidence and thermal history modelling: New insights into hydrocarbon expulsion from multiple petroleum systems in the Petrel Sub-basin, Bonaparte Basin. The Sedimentary Basins of Western Australia 3: Proceedings of the Petroleum Exploration Society of Australia Symposium, Perth, WA, 2002, 409-437.

Miyazaki, S., 1997. Australia's southeastern Bonaparte Basin has plenty of potential. Oil & Gas Journal, 95 (16), 78-81.

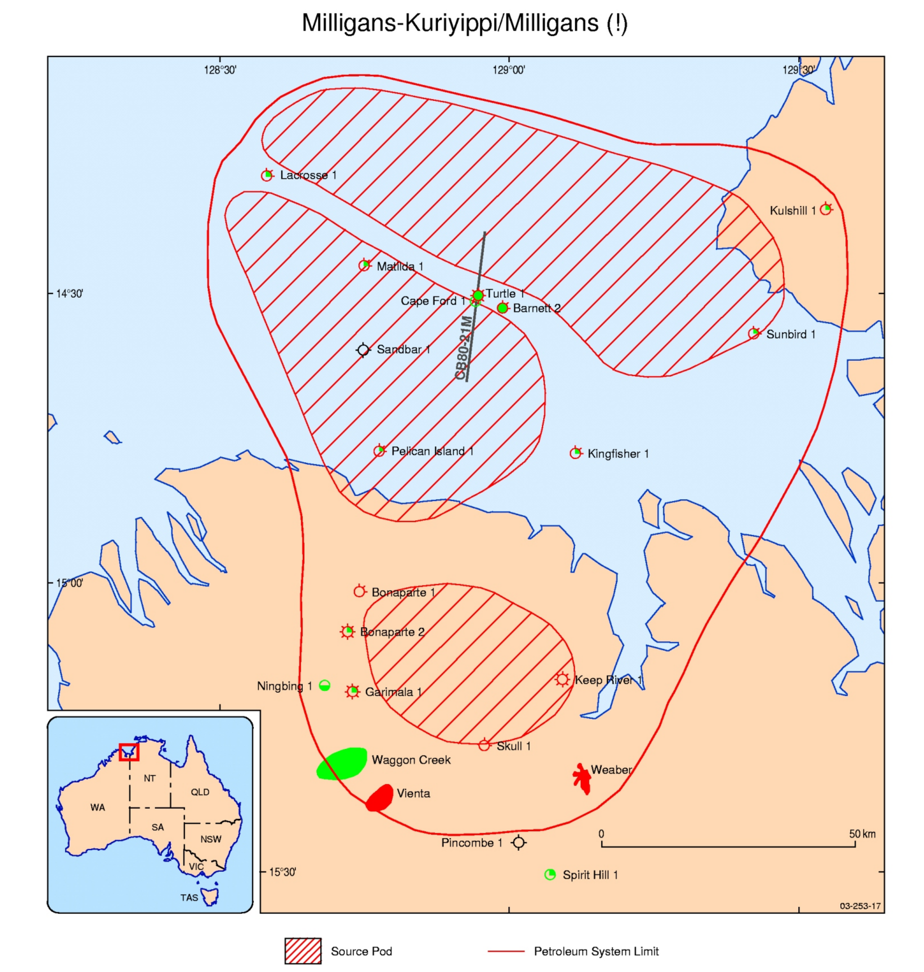


Figure 1: Spatial extent of the Carboniferous Milligans-Kuriyippi/Milligans (!) petroleum system. The source pods are based on modelling by Kennard et al. (2002). The petroleum system limit has been determined as an envelope that encompasses known hydrocarbon occurrences and shows. The seismic line shown refers to Figure 5.

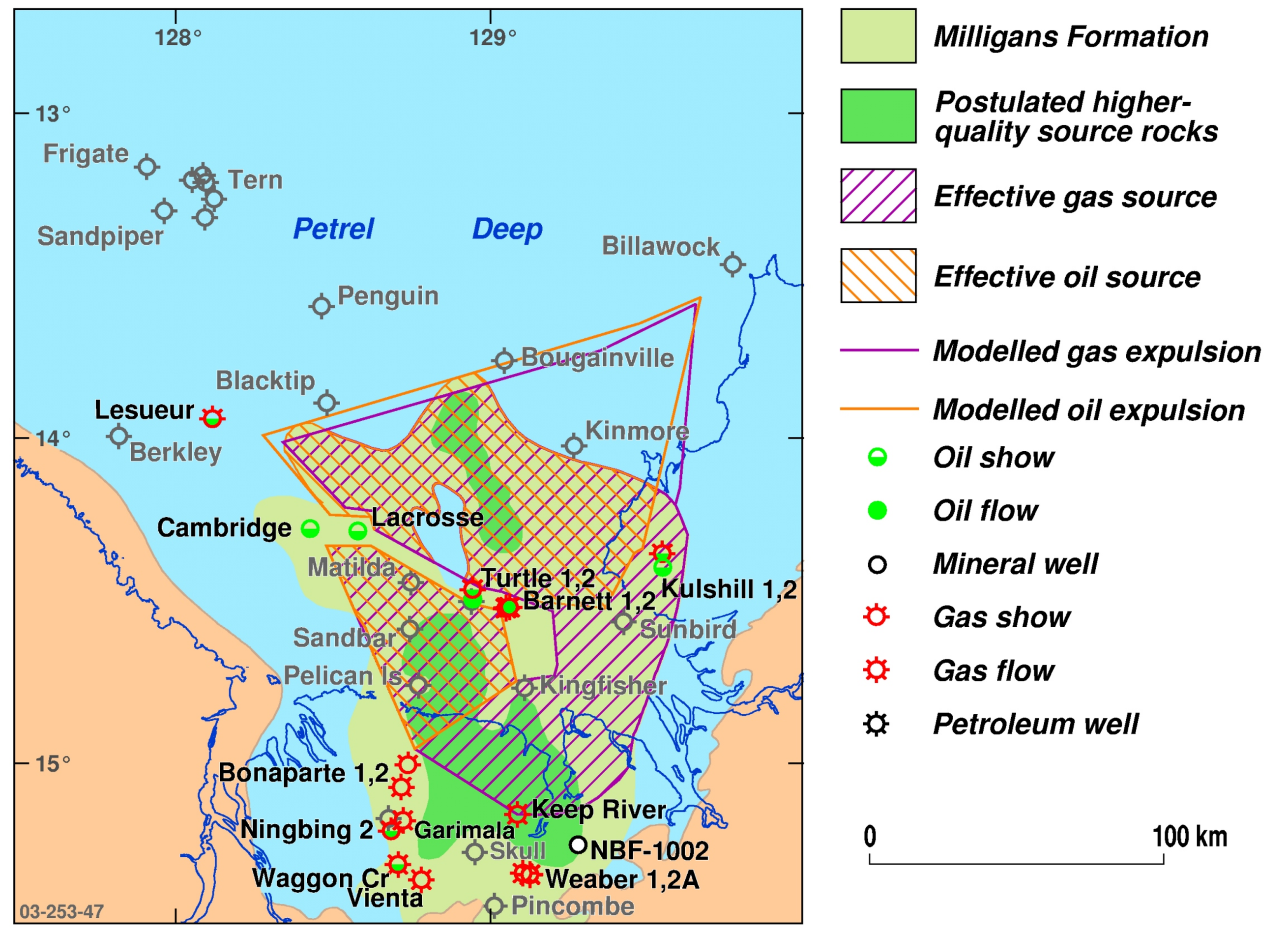


Figure 2: Early Carboniferous petroleum system map showing hydrocarbon accumulations and shows thought to have been sourced from the Milligans based on modelling by Kennard et al. (2002). This figure shows the effective oil and gas source distribution.

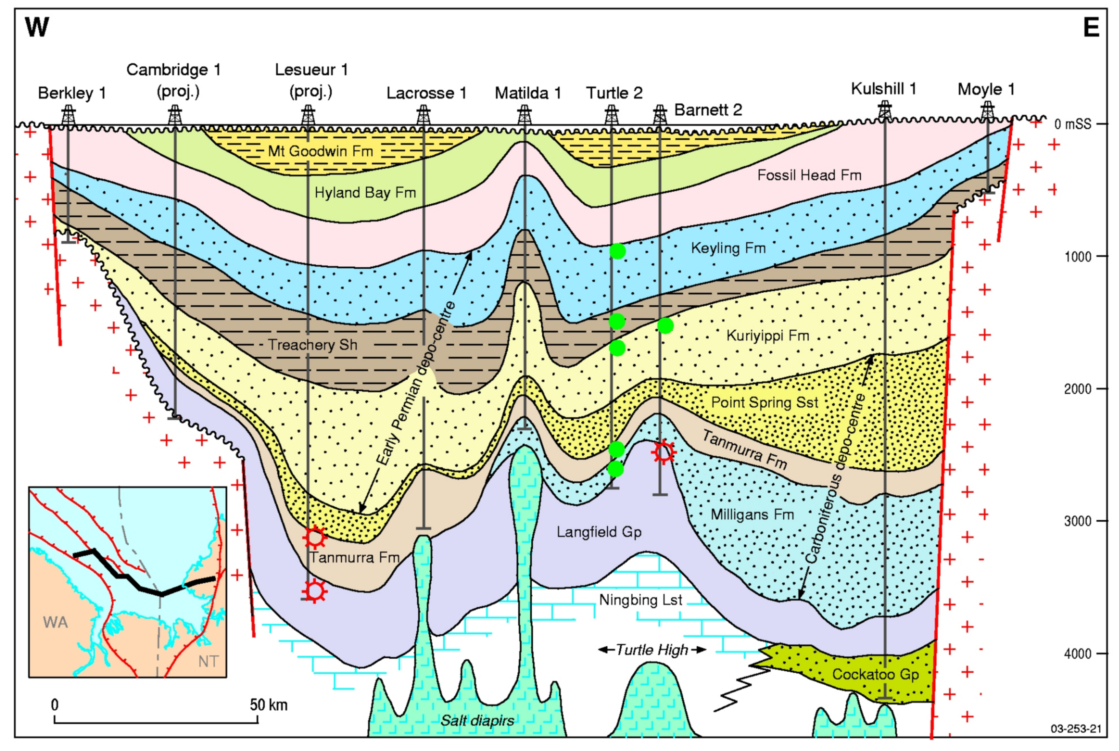


Figure 3: Cross-section of the Southern Petrel Sub-basin

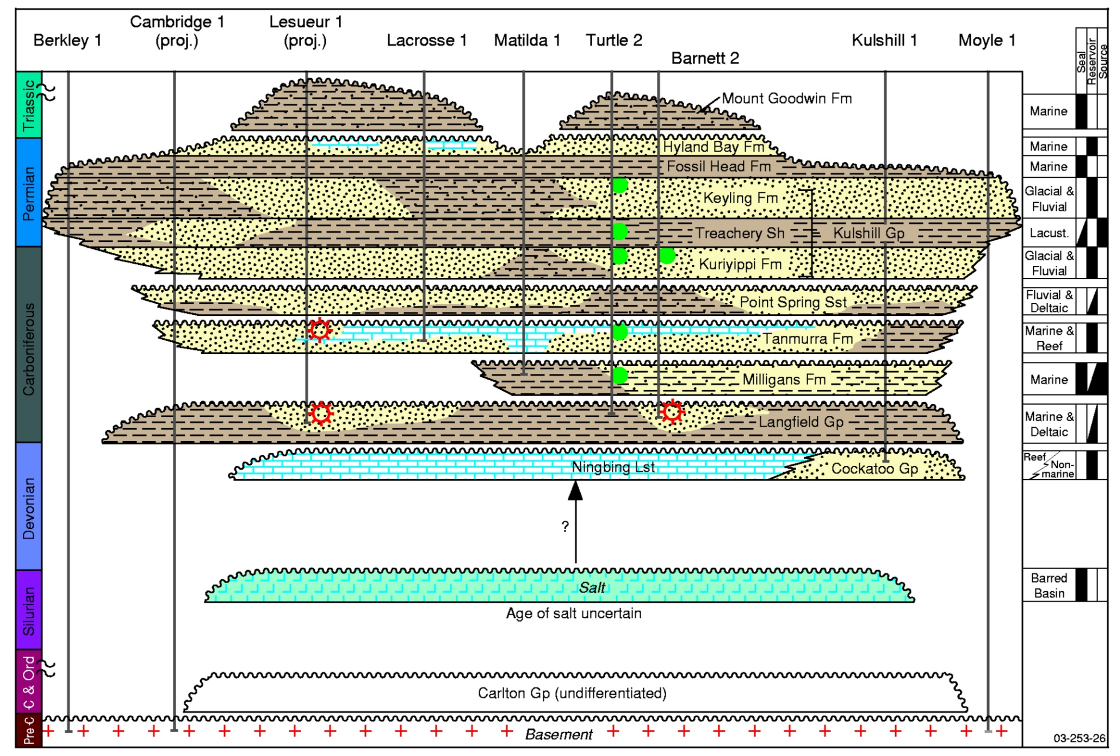


Figure 4: Chronostratigraphy of the Southern Petrel Sub-basin

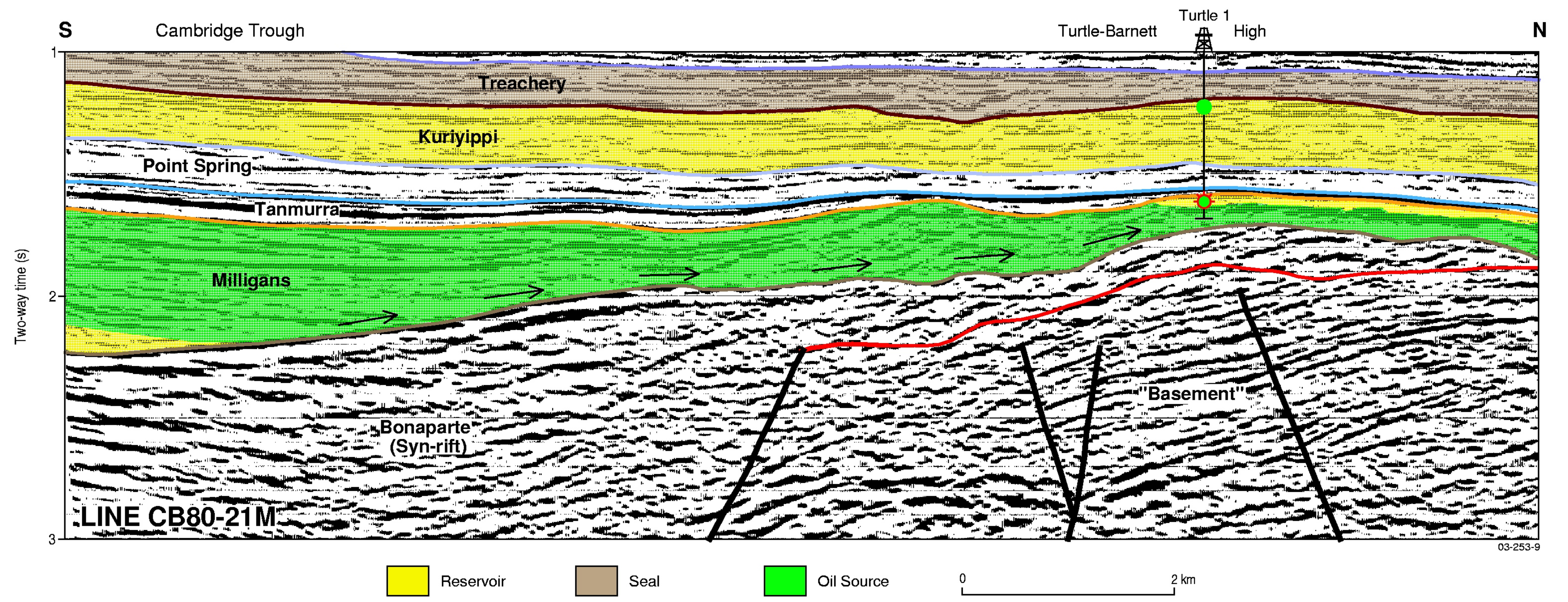


Figure 5: Seismic line CB80-21M. This cross-section displays an example of the play elements for the Carboniferous Milligans-Kuriyippi/Milligans (!) petroleum system. The Milligans Formation (gas and oil prone) acts as both source and reservoir within the area. The Kuriyippi Formation is also an important reservoir. The hydrocarbons are trapped intraformationally or by the Treachery Shale (regional seal). Play types include salt related plays, faulted anticlines, large scale inversion anticlines and stratigraphic traps/pinchouts.

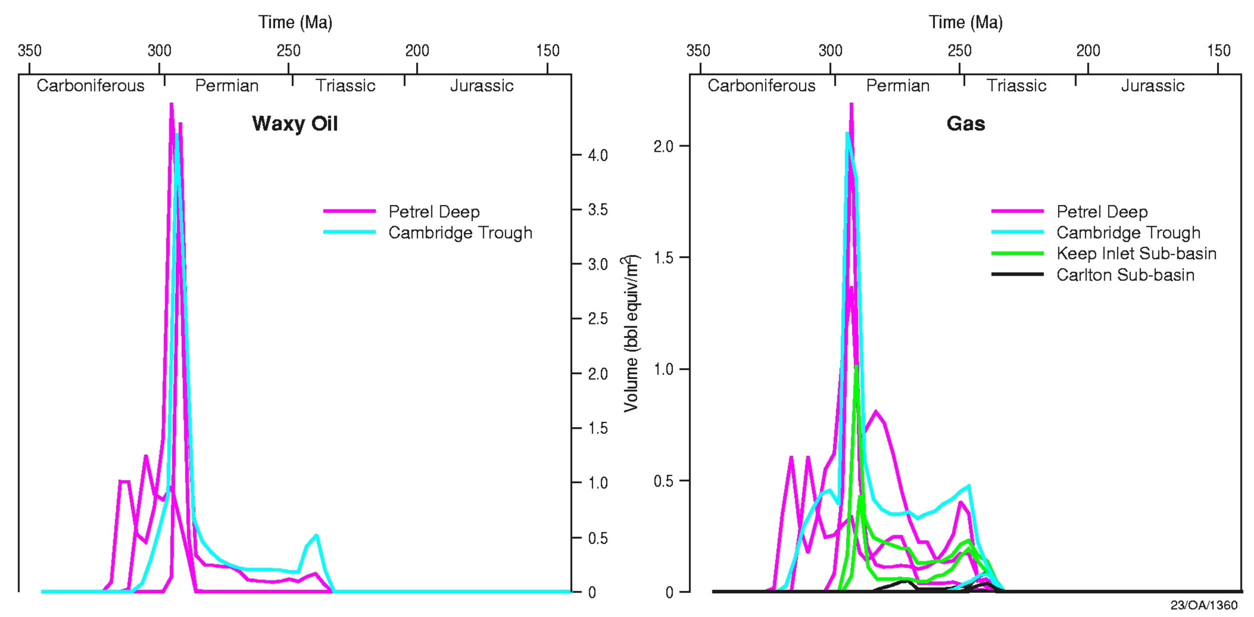


Figure 6: Modelled oil and gas expulsion time plots for the Milligans Formation source unit. Expulsion peaked in the Early Permian. Minor expulsion continued through the Permian and Early-Middle Triassic.

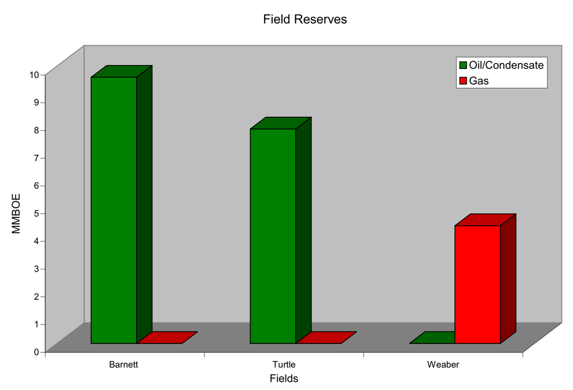


Figure 7: Field reserves for the Carboniferous Milligans-Kuriyippi/Milligans (!) petroleum system.All reserve numbers are sourced from the Western Australian Geological Survey and the Northern Territory Government Department of Business, Industry and Resource Development. Reserves/resources are estimated by the Department and exploration companies.

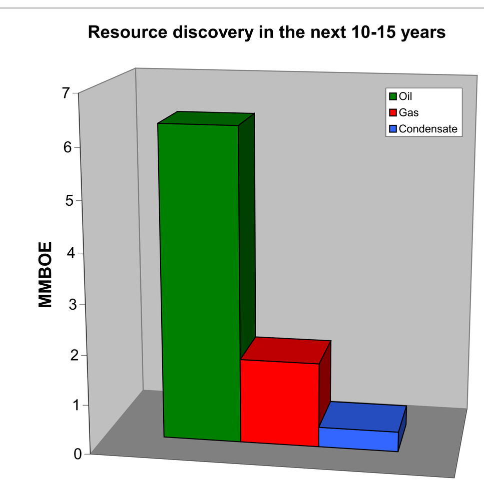


Figure 8: Geoscience Australia (Austplay) estimates of the recoverable hydrocarbons to be discovered in the next 10-15 years in the Carboniferous Milligans-Kuriyippi/Milligans (!) petroleum system. Based on the work of Barrett et al. (2004).

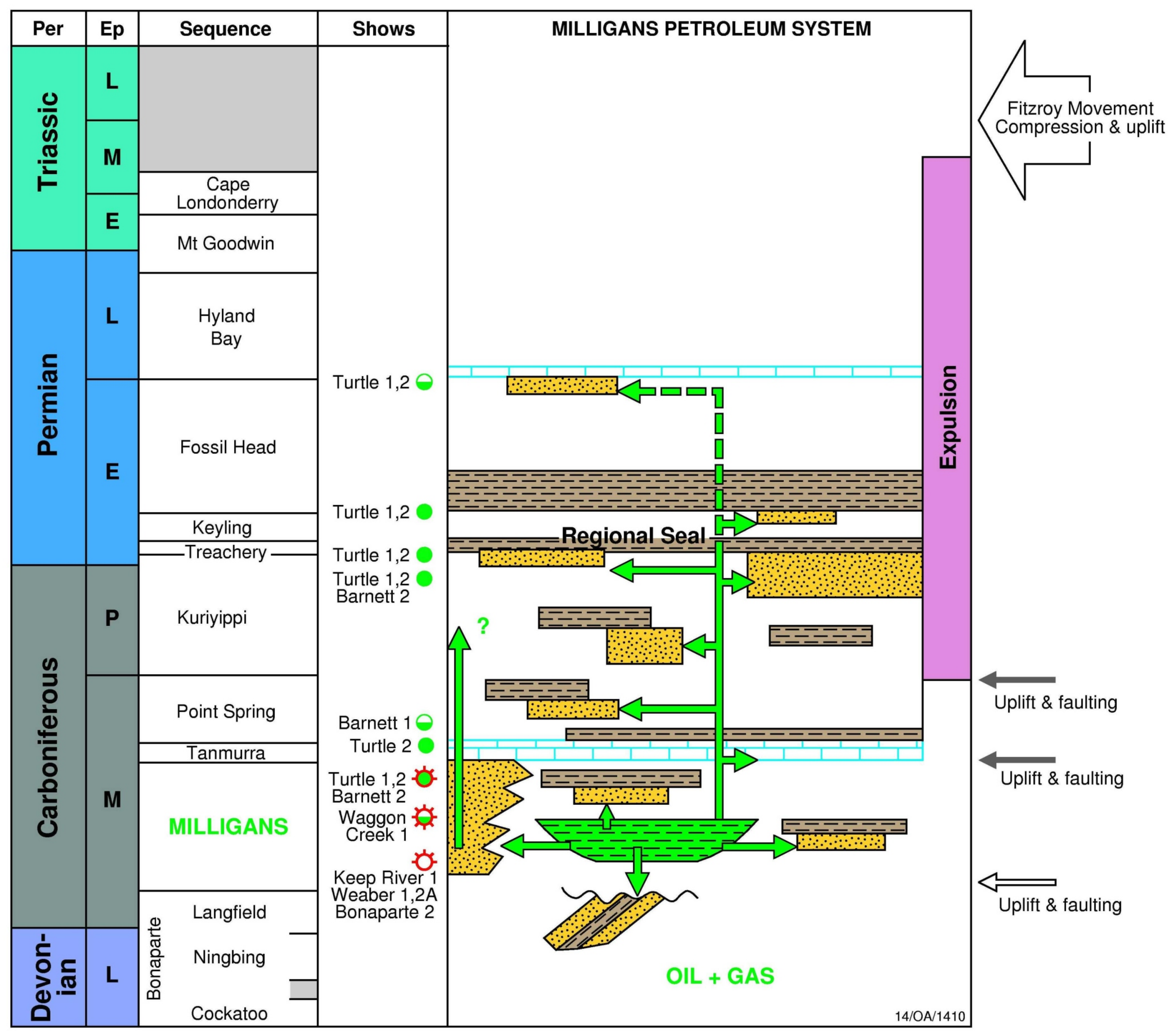


Figure 9: Schematic diagram of the Carboniferous Milligans-Kuriyippi/Milligans (!) petroleum system.

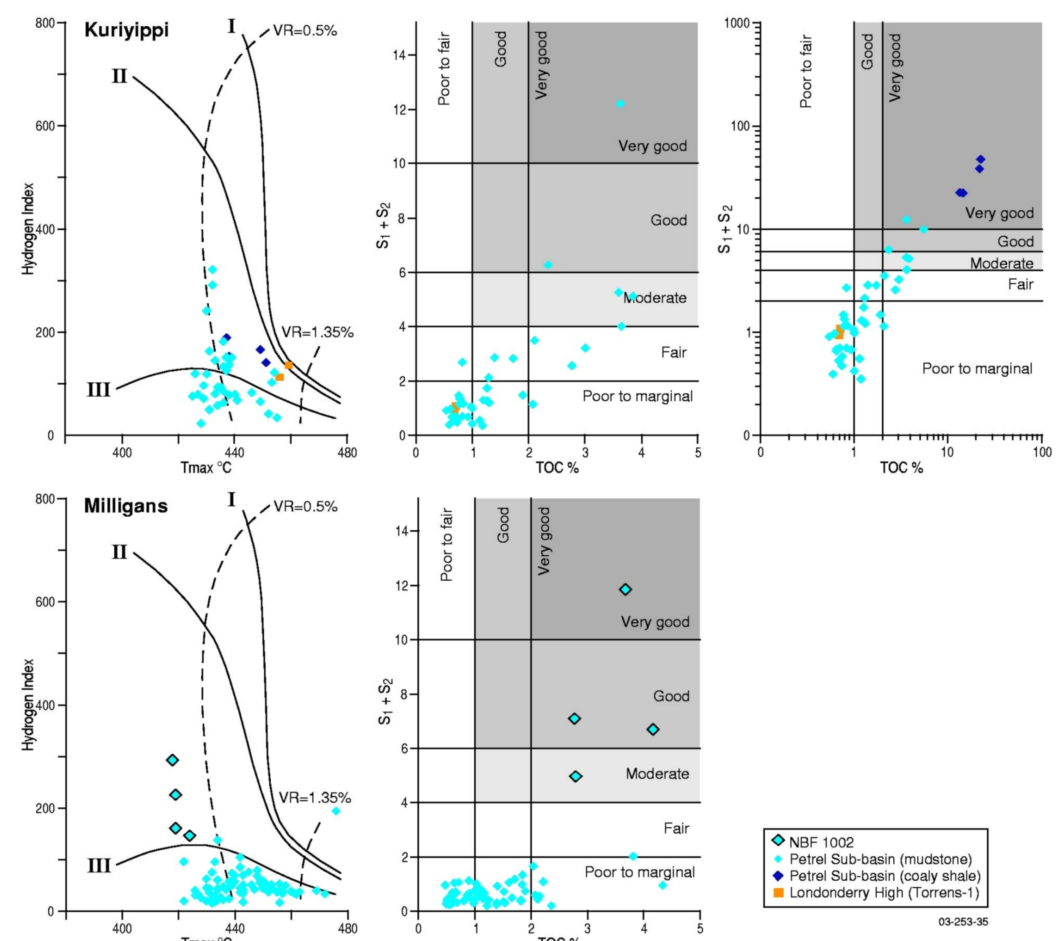


Figure 10: Rock-Eval pyrolysis data for potential Permo-Carboniferous source rocks in the Petrel Sub-basin. The offshore Milligans Formation source quality is overall poor with gas-prone Type III/IV kerogen (terrestrial source). Onshore analysis (NBF1002 mineral hole) contains higher quality oil-prone marine mudstones with Type II/III kerogen (marine influenced source). These samples have good source richness and moderately good source quality. The Kuriyippi Formation is gas prone with Type III/IV kerogen (terrestrial source). There is some minor liquids potential in the Petrel Deep.

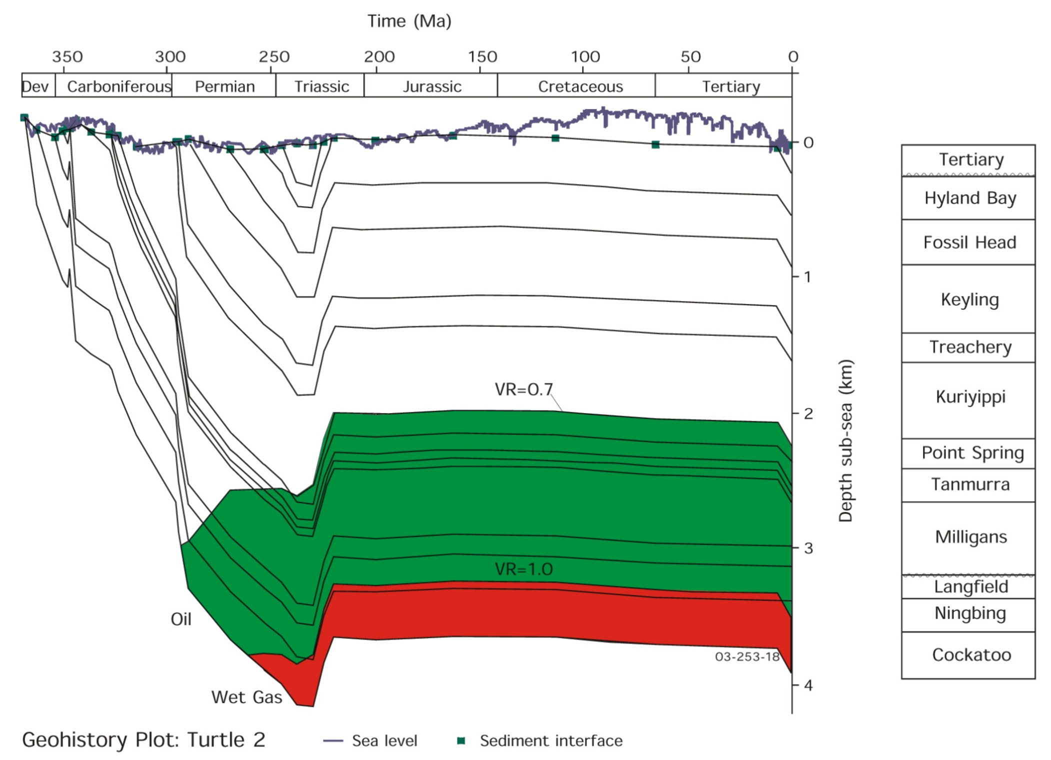


Figure 11: Geohistory plot for the Turtle 2 well. At this location the Milligans Formation has been at sufficient depths for oil generation since the Permian.

References

- Brincat, M.P., O'Brien, G.W., Lisk, M., De Ruig, M., & George, S.C., 2001. Hydrocarbon charge history of the northern Londonderry High: implications for trap integrity and future prospectivity. APPEA Journal 41(1), 483-495.
- Barrett, A.G., Hinde, A.L., & Kennard, J.M., 2004. Undiscovered resource assessment methodologies and application to the Bonaparte Basin. *In:* Ellis G.K., Baillie P.W. and Munson T.J. (Eds) *Timor Sea Petroleum Geoscience. Proceedings of the Timor Sea Symposium*, Darwin, Northern Territory, 19-20 June 2003. Northern Territory Geological Survey, Special Publication 1.
- Colwell, J. B., & Kennard, J. M., 1996. Petrel Sub-basin Study 1995-1996. AGSO Record 1996/40.
- Edwards, D.S., Kennard, J.M., Preston, J.C., Summons, R.E, Boreham, C.J., & Zumberge, J.E., 2000. Bonaparte Basin: geochemical characteristics of hydrocarbon families and petroleum systems. AGSO Research Newsletter, December 2000, 14-19.
- Edwards ,D.S., Preston, J.C., Kennard, J.M. , Boreham, C.J. , Van Aarssen, B.G.K, Summons, R.E., & Zumberge, J.E. , 2004. Geochemical characteristics of hydrocarbons from the Vulcan Sub-basin, western Bonaparte Basin. *In:* Ellis G.K., Baillie P.W. and Munson T.J. (Eds) *Timor Sea Petroleum Geoscience. Proceedings of the Timor Sea Symposium*, Darwin, Northern Territory, 19-20 June 2003. Northern Territory Geological Survey, Special Publication 1.
- Gorter, J.D., Mckirdy, D.M., Jones, P.J., & Playford, G., 2004. Reappraisal of the Early Carboniferous Milligans Formation source rock system in the southern Bonaparte Basin, northwestern Australia. Australia . *In:* Ellis G.K., Baillie P.W. and Munson T.J. (Eds) *Timor Sea Petroleum Geoscience. Proceedings of the Timor Sea Symposium*, Darwin, Northern Territory, 19-20 June 2003. Northern Territory Geological Survey, Special Publication 1.
- Kennard, J.M., Deighton, I., Edwards, D.S, Boreham, C.J., & Barrett, A.G., 2002. Subsidence and thermal history modelling: New insights into hydrocarbon expulsion from multiple petroleum systems in the Petrel Sub-basin, Bonaparte Basin. The Sedimentary Basins of Western Australia 3: Proceedings of the Petroleum Exploration Society of Australia Symposium, Perth, WA, 2002, 409-437.
- Kennard, J.M., Deighton, I., Edwards, D.S., Colwell, J.B., O'Brien, G.W., & Boreham, C.J., 1999. Thermal history modelling and transient heat pulses: New insights into the hydrocarbon expulsion and "hot flushes" in the Vulcan Sub-basin, Timor Sea. The APPEA Journal, 39(1), 177-207.
- Kennard, J.M., Edwards, D.S., Boreham, C.J., Gorter, J.D., King, M.R., Ruble, T.E., & Lisk, M., 2000. Evidence for a Permian Petroleum System in the Timor Sea, Northwestern Australia. AAPG International Conference and Exhibition, Bali, 15-18th October 2000. Abstracts volume A45.

- Longley, I.M., Bradshaw, M.T., & Hebberger, J., 2000. Australian petroleum provinces of the 21st century. PESA Journal 28, 21-42.
- Miyazaki, S., 1997. Australia's southeastern Bonaparte Basin has plenty of potential. Oil & Gas Journal, 95 (16), 78-81.
- Mory, A.J., 1988. Regional Geology of the offshore Bonaparte Basin. *In:* Purcell P.G. and R.R. (Eds) *The North West Shelf, Australia: Proceedings of the Petroleum Exploration Society of Australia Symposium*, Perth, 1988, 287-310.
- Mory, A.J., 1991. Geology of the Offshore Bonaparte Basin, Northwestern Australia. Geological Survey of Western Australia, Report 29.
- O'Brien, G.W., Etheridge, M.A., Wilcox, J.B., Morse, M., Symonds, P., Norman, C., & Needham, D.J., 1993. The structural architecture of the Timor Sea, northwestern Australia: Implications for basin development and hydrocarbon exploration. APEA Journal 31(1), 258-278.
- Seggie, R.J., Ainsworth, R.B., Johnson, D.A. Koninx, J.P.M., Spaargaren, B., & Stephenson, P.M., 2000. Awakening of a Sleeping Giant: Sunrise-Troubadour gas condensate field. The APPEA Journal 40(1), 417-435.
- O'Brien, G.W., Etheridge, M.A., Willcox, J.B., Morse, M., Symonds P., Norman C., & Needham, D.J., 1993. The structural architecture of the Timor Sea, northwestern Australia: implications for basin development and hydrocarbon exploration. APEA Journal, 33(1), 258-279.
- Peters, K.E., 1986. Guidelines for evaluating petroleum source rock using programmed pyrolysis. American Association of Petroleum Geologists Bulletin, 70; 318-329.
- Preston, J.C & Edwards, D.S., 2000. The petroleum geochemistry of oils and source rocks from the Northern Bonaparte Basin, offshore northern Australia. APPEA Journal 40(1), 257-282.
- Release of Offshore Petroleum Exploration Areas Australia 2001-2004
- Seggie, R.J., Ainsworth, R.B., Johnson, D.A., Koninx, J.P.M., Spaargaren, B. & Stephenson, P.M., 2000. Awakening of a sleeping giant: Sunrise-Troubadour gas-condensate field. APPEA Journal 40(1), 417-435.
- Summons, R.E, Bradshaw, M.T., Crowley, J., Edwards, D.S., George, S.C. & Zumberge, J.E., 1998. Vagrant oils: Geochemical signposts to unrecognised petroleum systems. In: Purcell P.G. and R.R (Eds) *The Sedimentary Basins of Western Australia 2: Proceedings of the Petroleum Exploration Society of Australia Symposium*, Perth, WA, 1998, 169-184.
- US Geological Survey, 2000. US Geological Survey World petroleum assessment 2000 – Description and Results, USGS World Energy Assessment Team. USGS Digital Data Series DDS-60, 4 CD-ROM set.
- West, B.G & Passmore, V.L., 1994. Hydrocarbon Potential of the Bathurst Island Group, Northeast Bonaparte Basin, Implications for Future Exploration. APEA Journal, 34(1), 626-643
- Whittam, D.B., Norvick, M.S., & McIntyre, C.L., 1996. Mesozoic and Cainozoic tectonostratigraphy of western ZOCA and adjacent areas. APPEA Journal 36 (1), 209-232.