Evidence for a Permian Petroleum System in the Timor Sea, Bonaparte Basin, Northwest Australia

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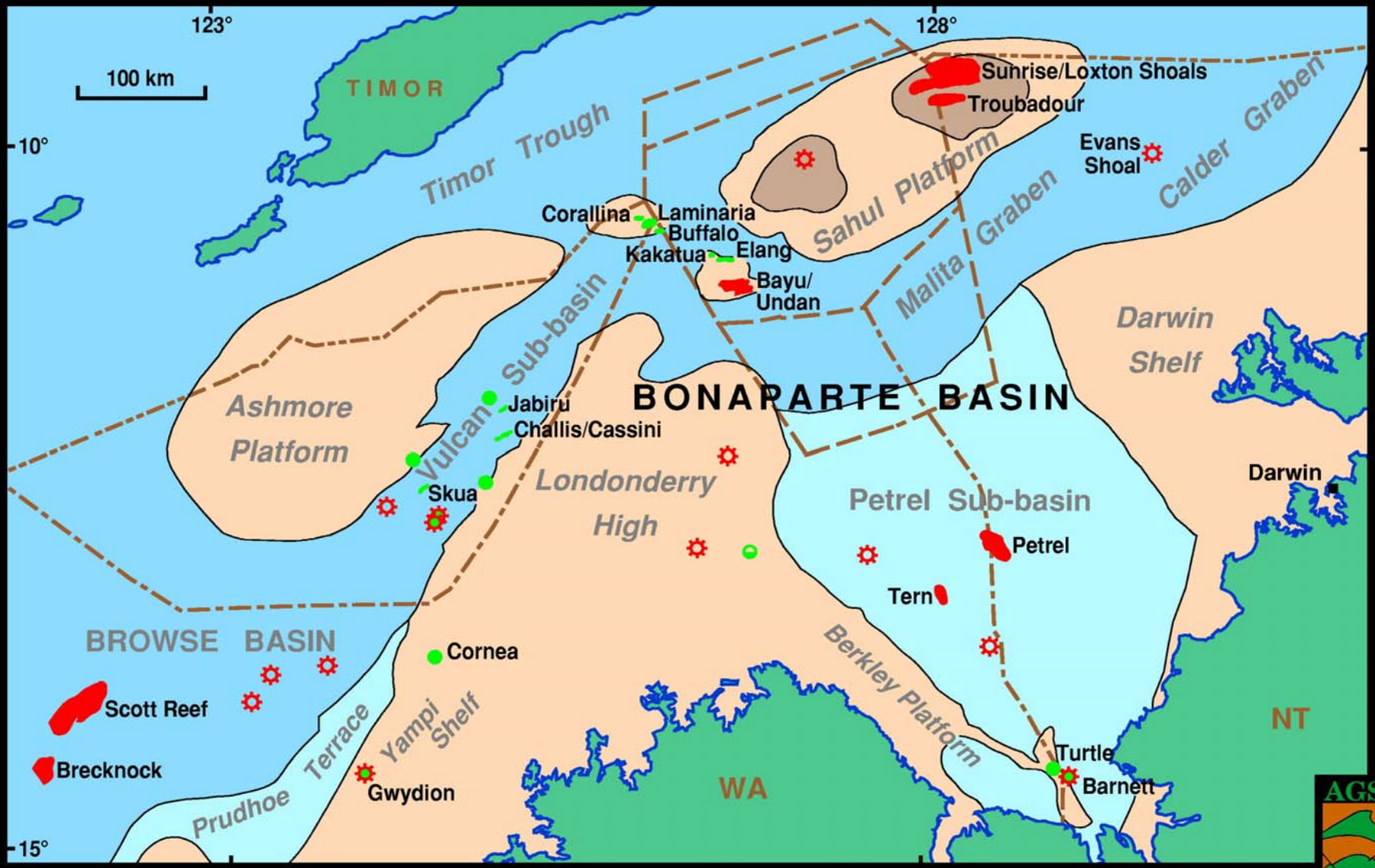
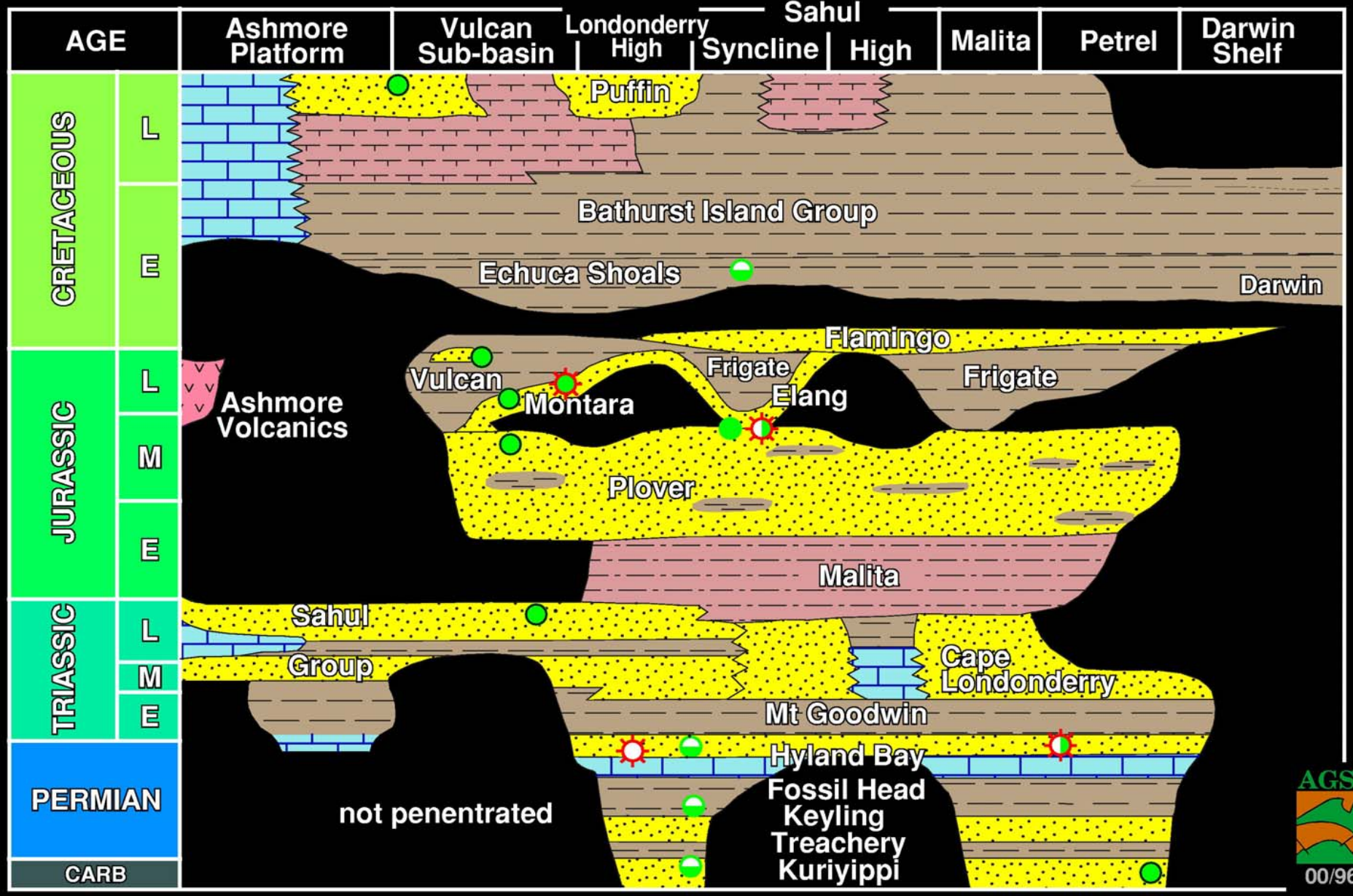
Mark Lisk

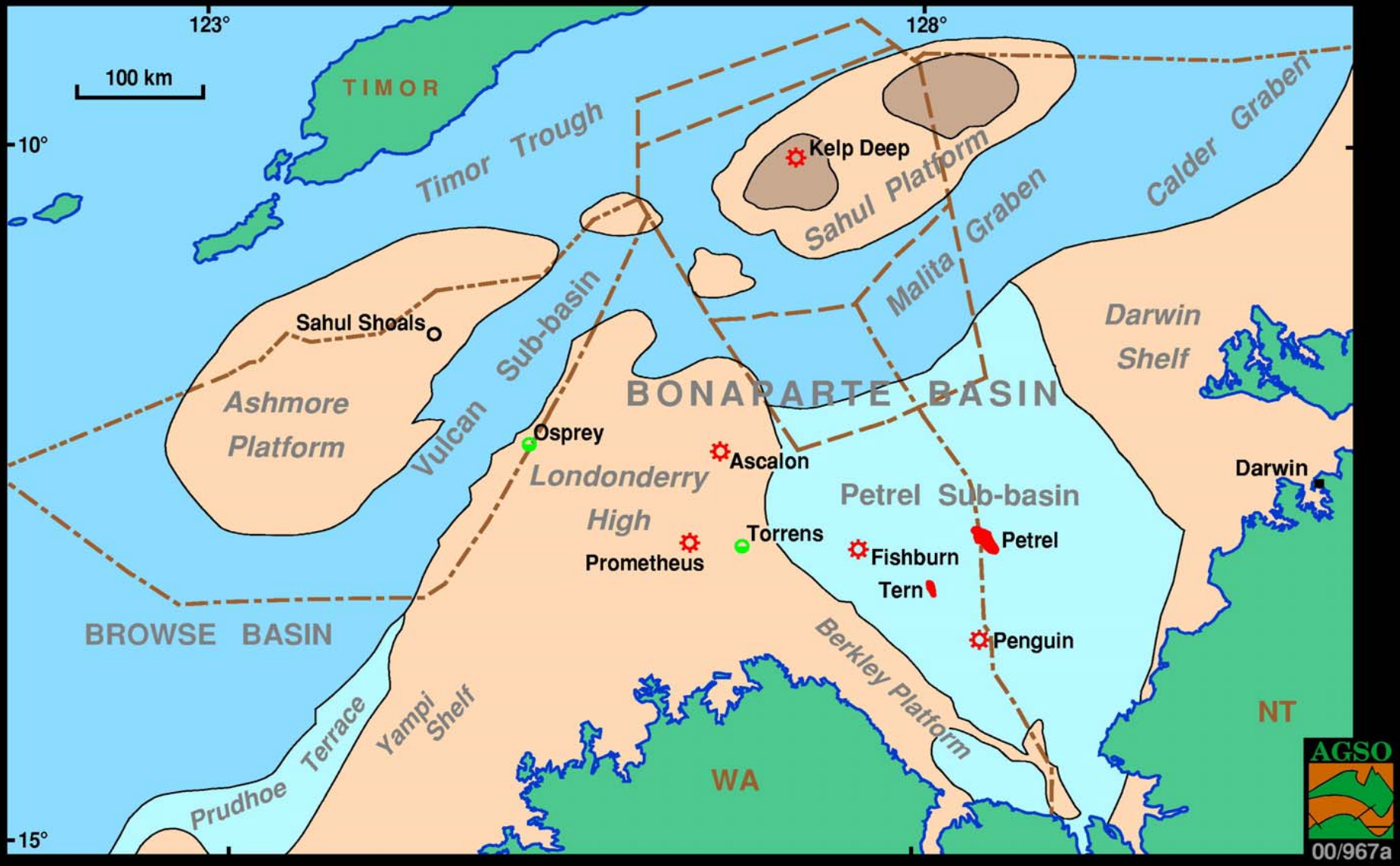
AUSTRALIAN PETROLEUM COOPERATIVE RESEARCH CENTRE

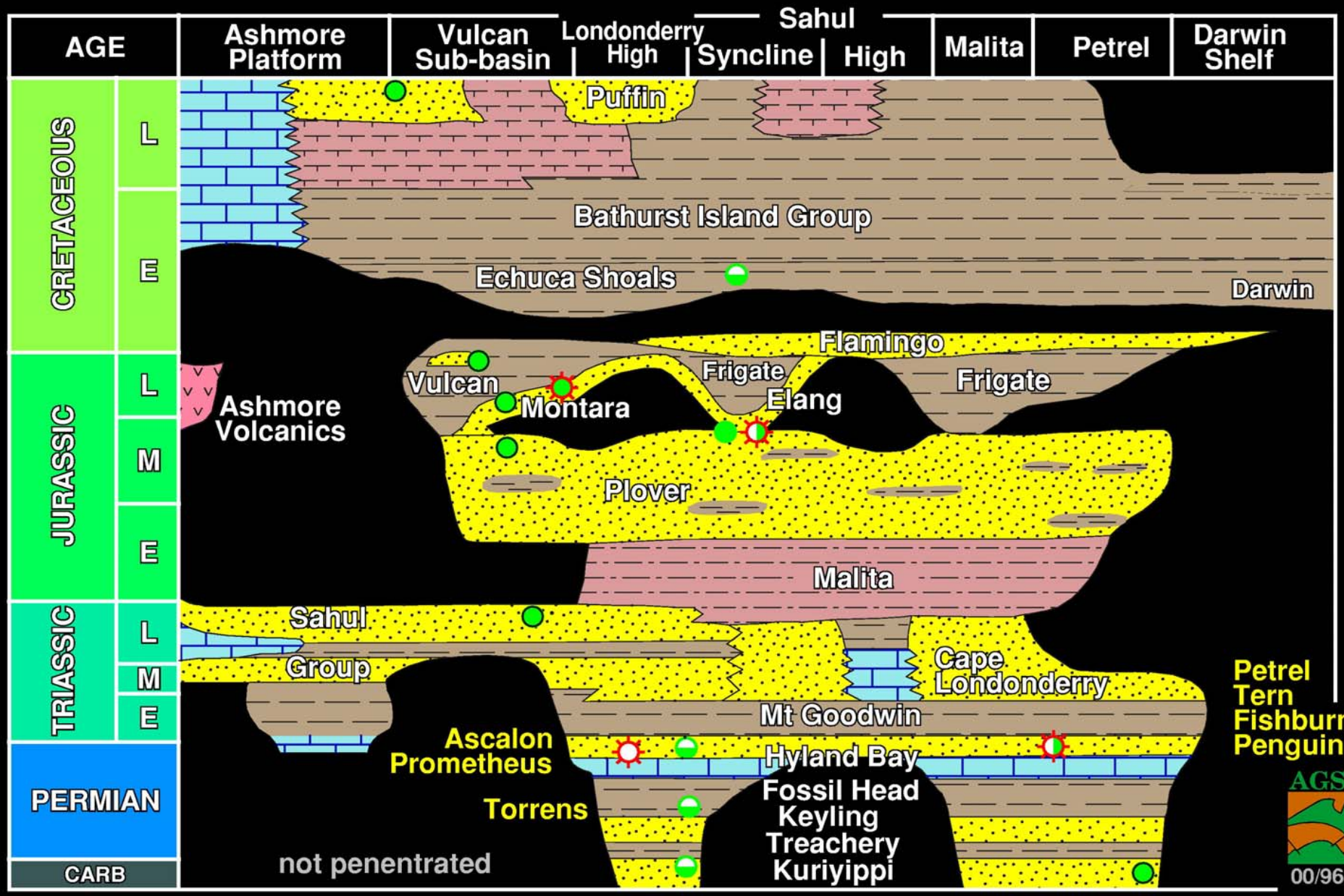
AGSO AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION


123°
128°
100 km
10°
15°
TIMOR
Timor Trough
Sunrise/Loxton Shoals
Troubadour
Evans Shoal
Calder Graben
Sahul Platform
Malita Graben
Corallina
Laminaria
Buffalo
Kakatua
Elang
Bayu/ Undan
Darwin Shelf
Ashmore Platform
Vulcan Sub-basin
Jabiru
Challis/Cassini
BONAPARTE BASIN
Skua
Londonderry High
Petrel Sub-basin
Petrel
Tern
Darwin
BROWSE BASIN
Cornea
Scott Reef
Brecknock
Prudhoe Terrace
Yampi Shelf
Gwydion
Berkley Platform
Turtle
Barnett
WA
NT
AGSO
00/966


AGE
Ashmore Platform
Vulcan Sub-basin
Londonderry High
Sahul
Syncline
High
Malita
Petrel
Darwin Shelf
CRETACEOUS
L
E
JURASSIC
L
M
E
TRIASSIC
L
M
E
PERMIAN
CARB
Puffin
Bathurst Island Group
Echuca Shoals
Darwin
Flamingo
Frigate
Frigate
Vulcan
Montara
Elang
Ashmore Volcanics
Plover
Malita
Sahul
Group
Cape Londonderry
Mt Goodwin
Hyland Bay
Fossil Head
Keyling
Treachery
Kuriyippi
not penentrated
AGSO
00/968

Permian Petroleum Discoveries

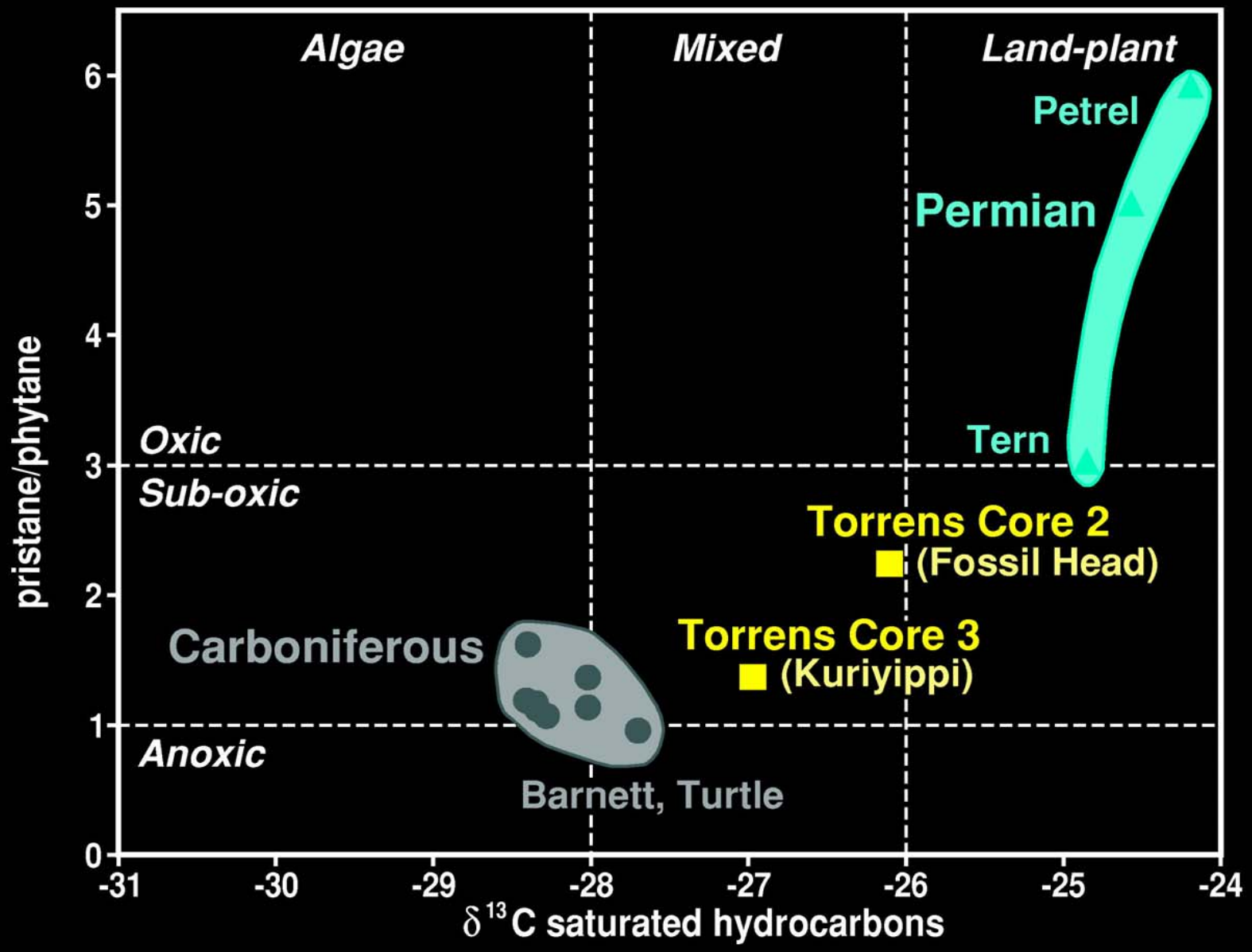



AGE
Ashmore Platform
Vulcan Sub-basin
Londonderry High
Sahul Syncline
Sahul High
Malita
Petrel
Darwin Shelf
CRETACEOUS
L
E
JURASSIC
L
M
E
TRIASSIC
L
M
E
PERMIAN
CARB
Puffin
Bathurst Island Group
Echuca Shoals
Darwin
Flamingo
Frigate
Frigate
Vulcan
Montara
Elang
Ashmore Volcanics
Plover
Malita
Sahul
Group
Cape Londonderry
Mt Goodwin
Ascalon
Prometheus
Hyland Bay
Torrens
Fossil Head
Keyling
Treachery
Kuriyippi
not penentrated
Petrel
Tern
Fishburn
Penguin
AGSO
00/968a

Evidence for a Permian Petroleum System

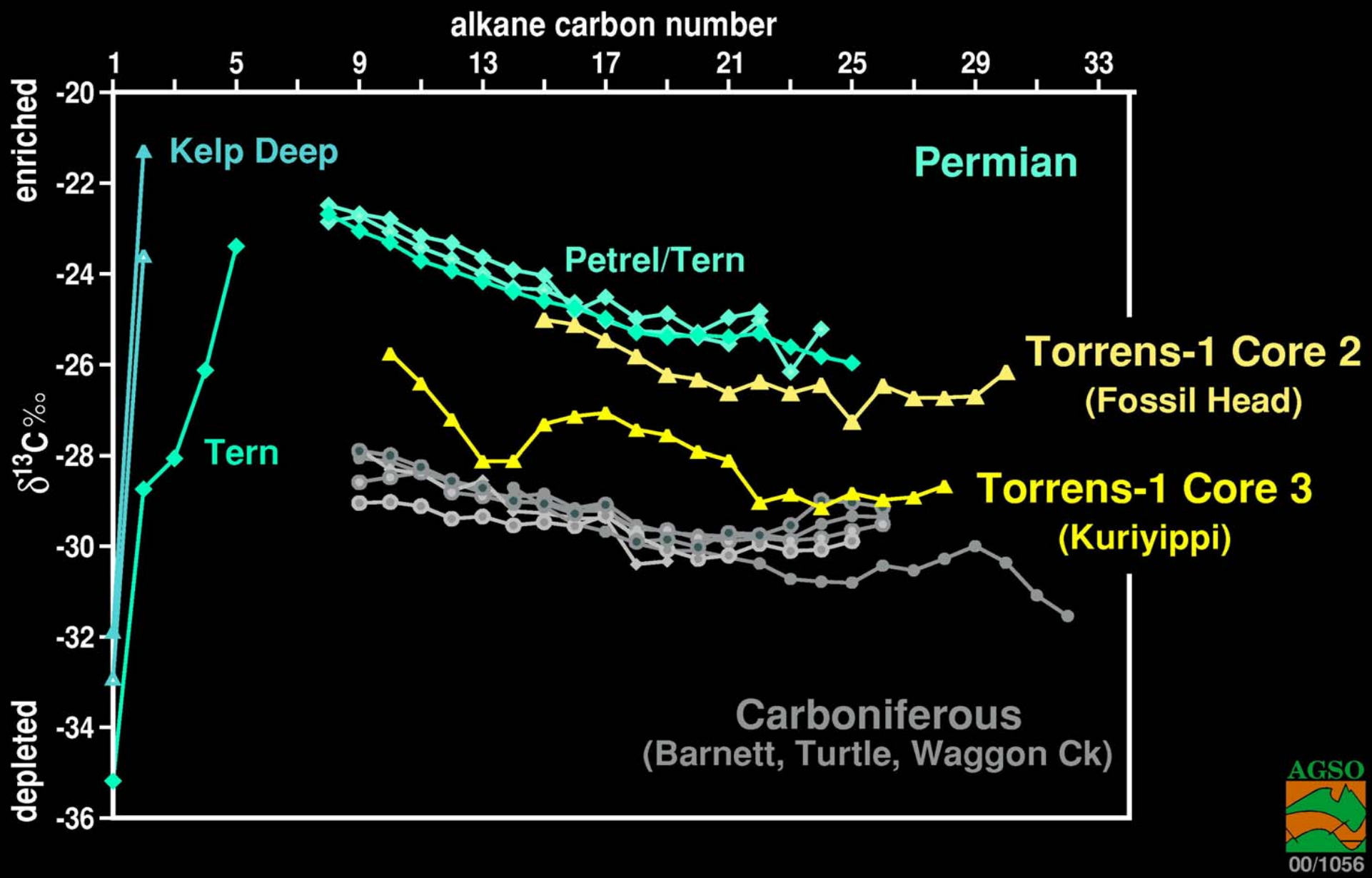
- Hydrocarbon geochemistry
- Source rock geochemistry
- Seismic anomalies - DHI’s
- Fluid inclusion analysis – GOI, MCI
- Maturation history modelling
- Prospectivity

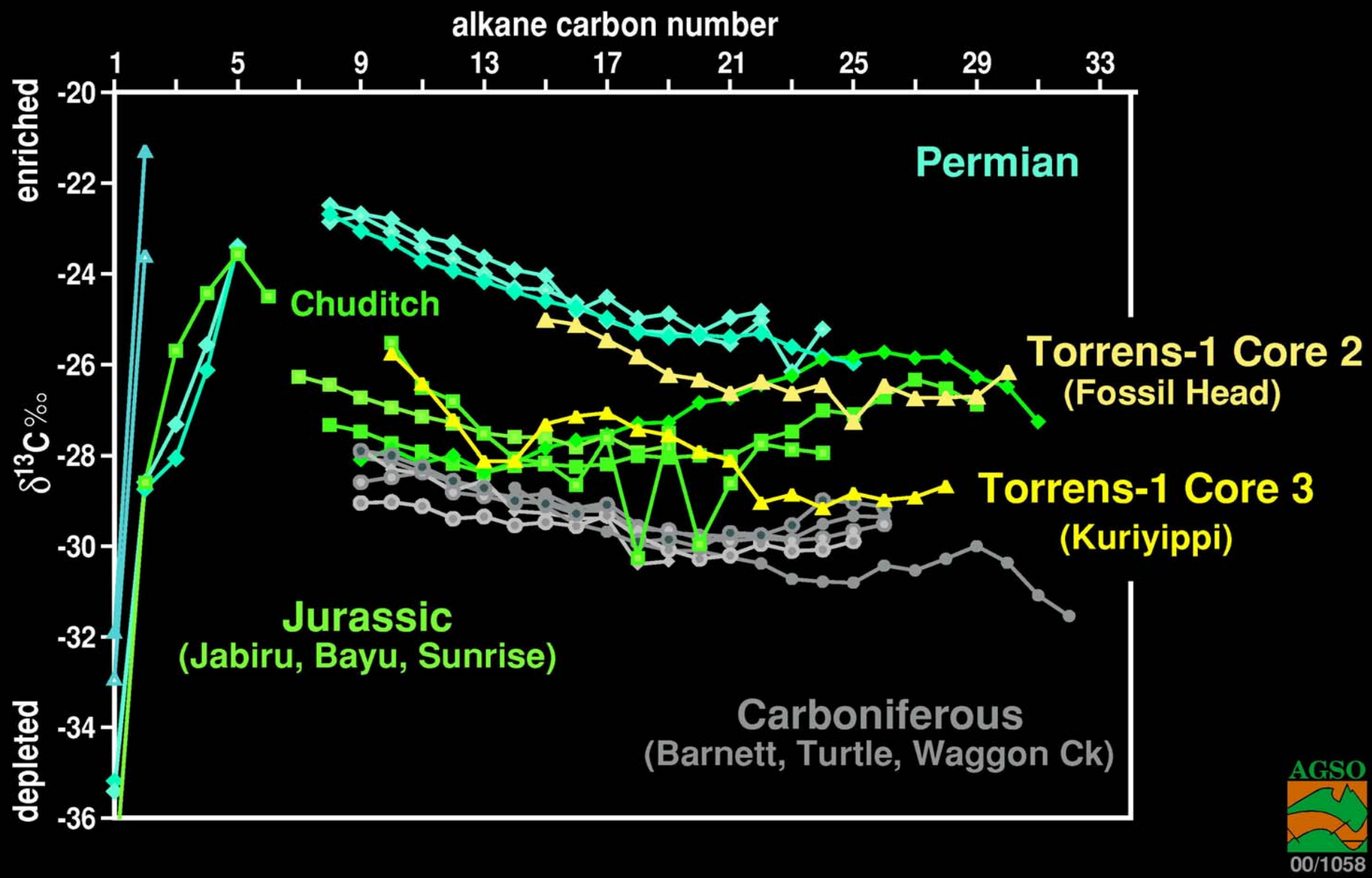
Palaeozoic Oils and Condensates

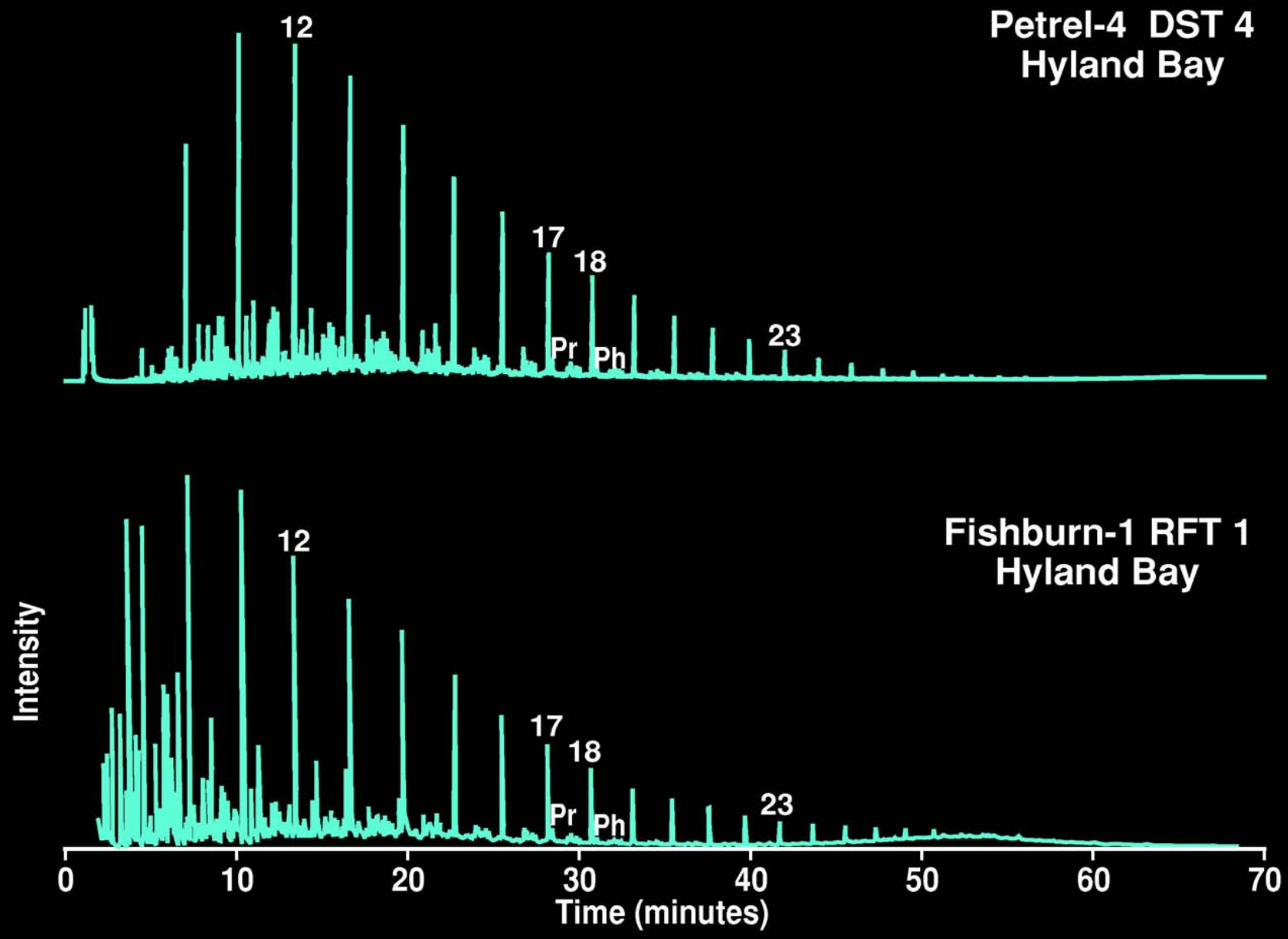


AGSO

00/1047

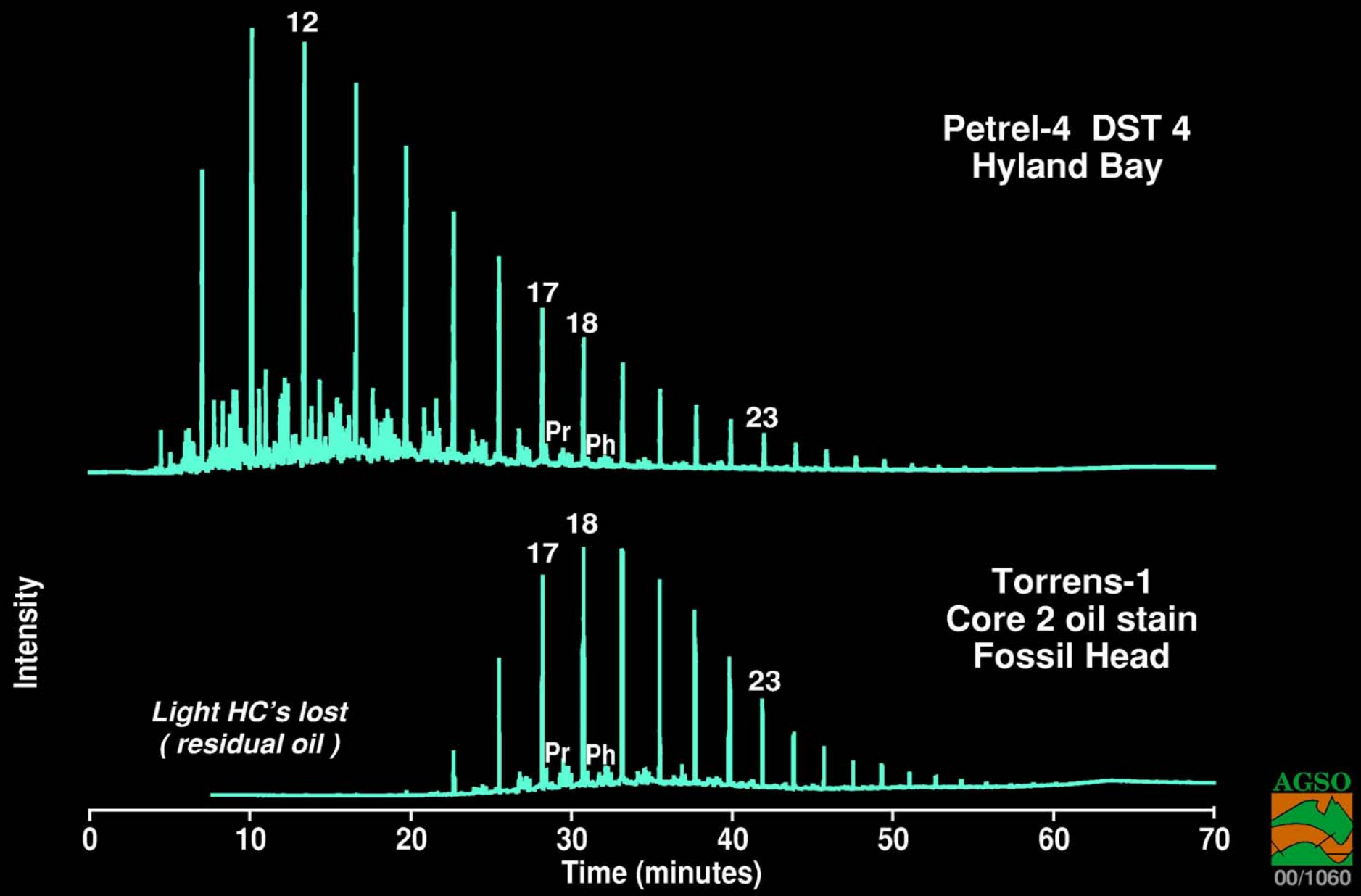

alkane carbon number
1
5
9
13
17
21
25
29
33
enriched
depleted
-20
-22
-24
-26
-28
-30
-32
-34
-36
δ13C ‰
Kelp Deep
Tern
Permian
Petrel/Tern
Torrens-1 Core 2
(Fossil Head)
Torrens-1 Core 3
(Kuriyippi)
Carboniferous
(Barnett, Turtle, Waggon Ck)
AGSO
00/1056


alkane carbon number
1
5
9
13
17
21
25
29
33
enriched
depleted
-20
-22
-24
-26
-28
-30
-32
-34
-36
δ13C ‰
Permian
Chuditch
Torrens-1 Core 2
(Fossil Head)
Torrens-1 Core 3
(Kuriyippi)
Jurassic
(Jabiru, Bayu, Sunrise)
Carboniferous
(Barnett, Turtle, Waggon Ck)
AGSO
00/1058


Petrel-4 DST 4
Hyland Bay
12
17
18
Pr
Ph
23
Fishburn-1 RFT 1
Hyland Bay
12
17
18
Pr
Ph
23
Intensity
0
10
20
30
40
50
60
70
Time (minutes)

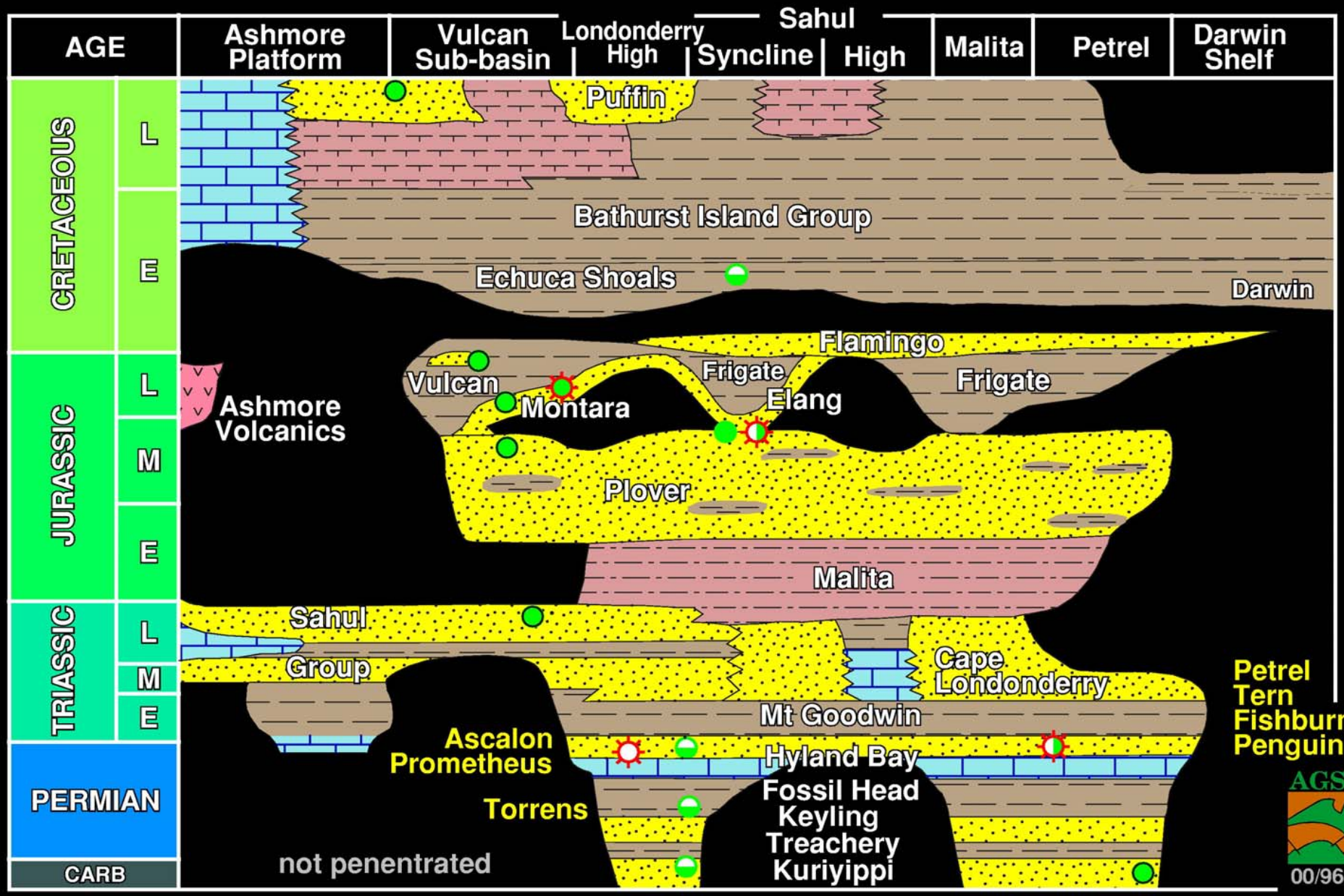
AGSO

00/1059

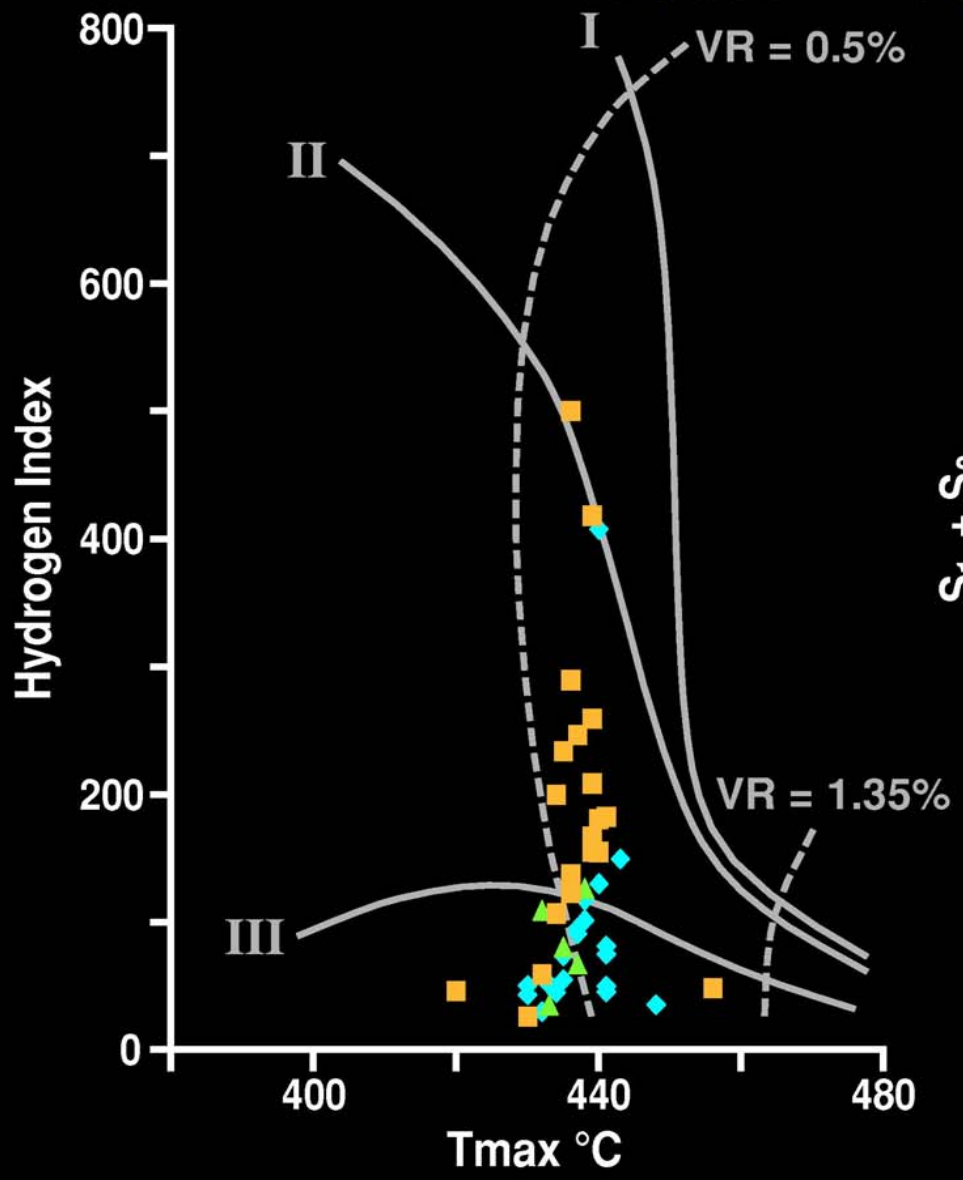

Petrel-4 DST 4
Hyland Bay
12
17
18
Pr
Ph
23
Torrens-1
Core 2 oil stain
Fossil Head
Light HC's lost
(residual oil)
Intensity
0
10
20
30
40
50
60
70
Time (minutes)
AGSO
00/1060

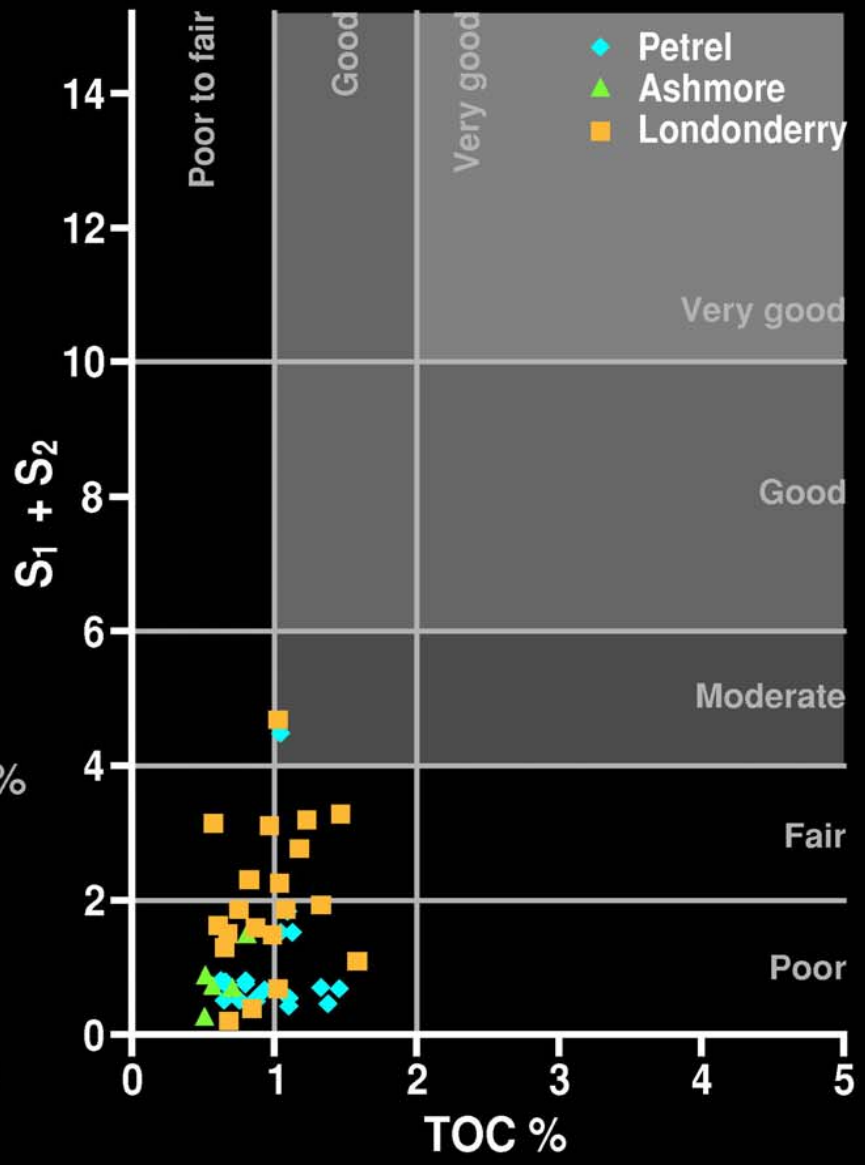
Evidence for a Permian Petroleum System

- Hydrocarbon geochemistry
- **Source rock geochemistry**
- Seismic anomalies - DHI's
- Fluid inclusion analysis – GOI, MCI
- Maturation history modelling
- Prospectivity


AGE
Ashmore Platform
Vulcan Sub-basin
Londonderry High
Sahul Syncline
Sahul High
Malita
Petrel
Darwin Shelf
CRETACEOUS
L
E
JURASSIC
L
M
E
TRIASSIC
L
M
E
PERMIAN
CARB
Puffin
Bathurst Island Group
Echuca Shoals
Darwin
Flamingo
Frigate
Frigate
Vulcan
Montara
Elang
Ashmore Volcanics
Plover
Malita
Sahul
Group
Cape Londonderry
Mt Goodwin
Ascalon
Prometheus
Hyland Bay
Torrens
Fossil Head
Keyling
Treachery
Kuriyippi
not penentrated
Petrel
Tern
Fishburn
Penguin
AGSO
00/968a

Mt Goodwin Source Rocks





AGSO

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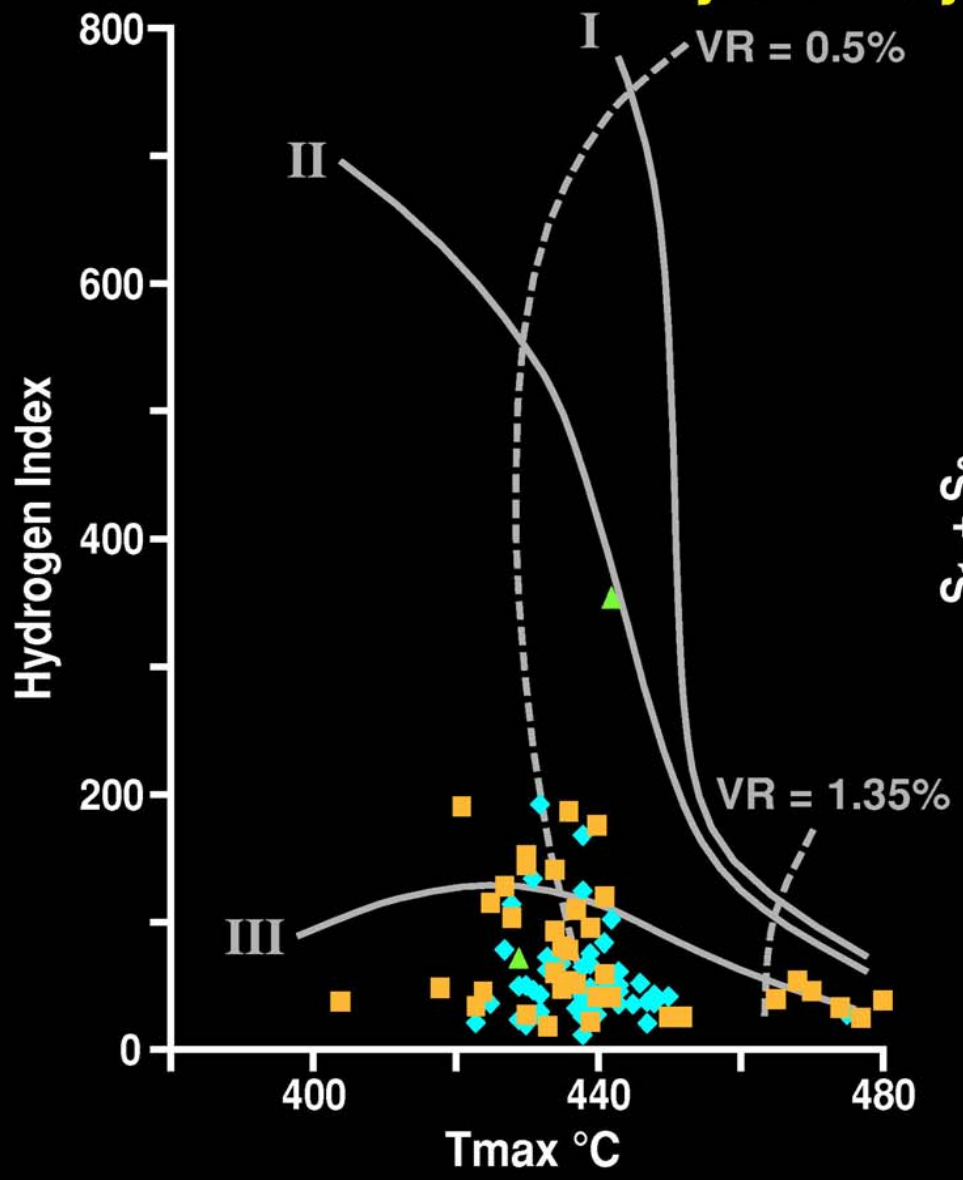
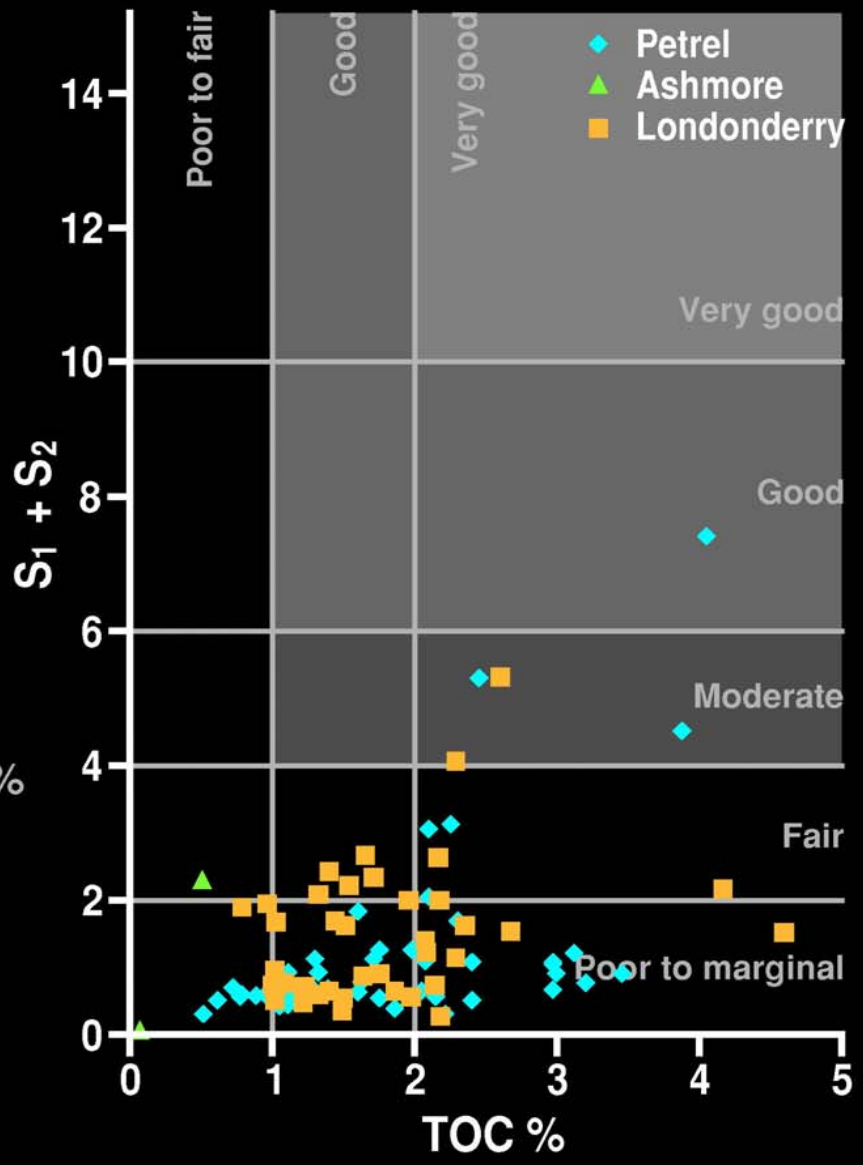
Hyland Bay Source Rocks





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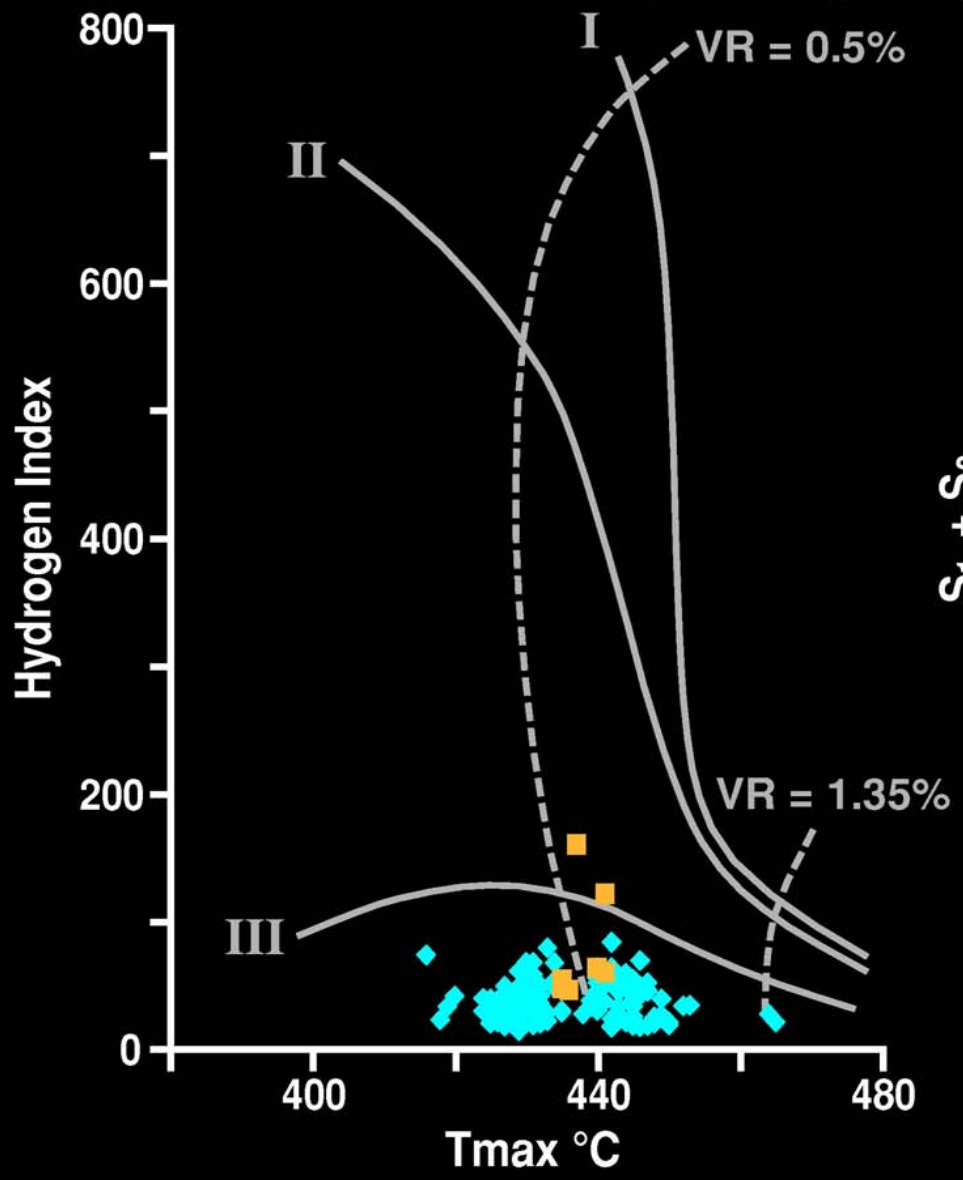
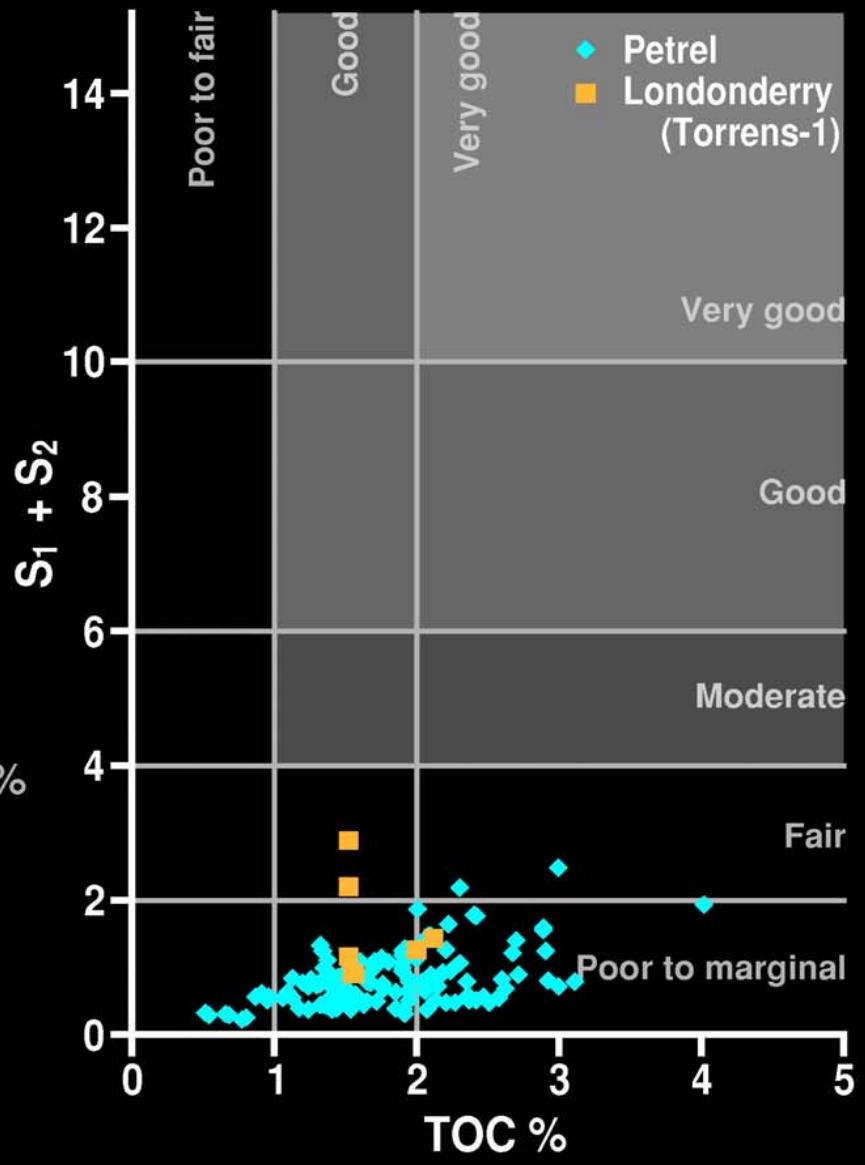
Fossil Head Source Rocks

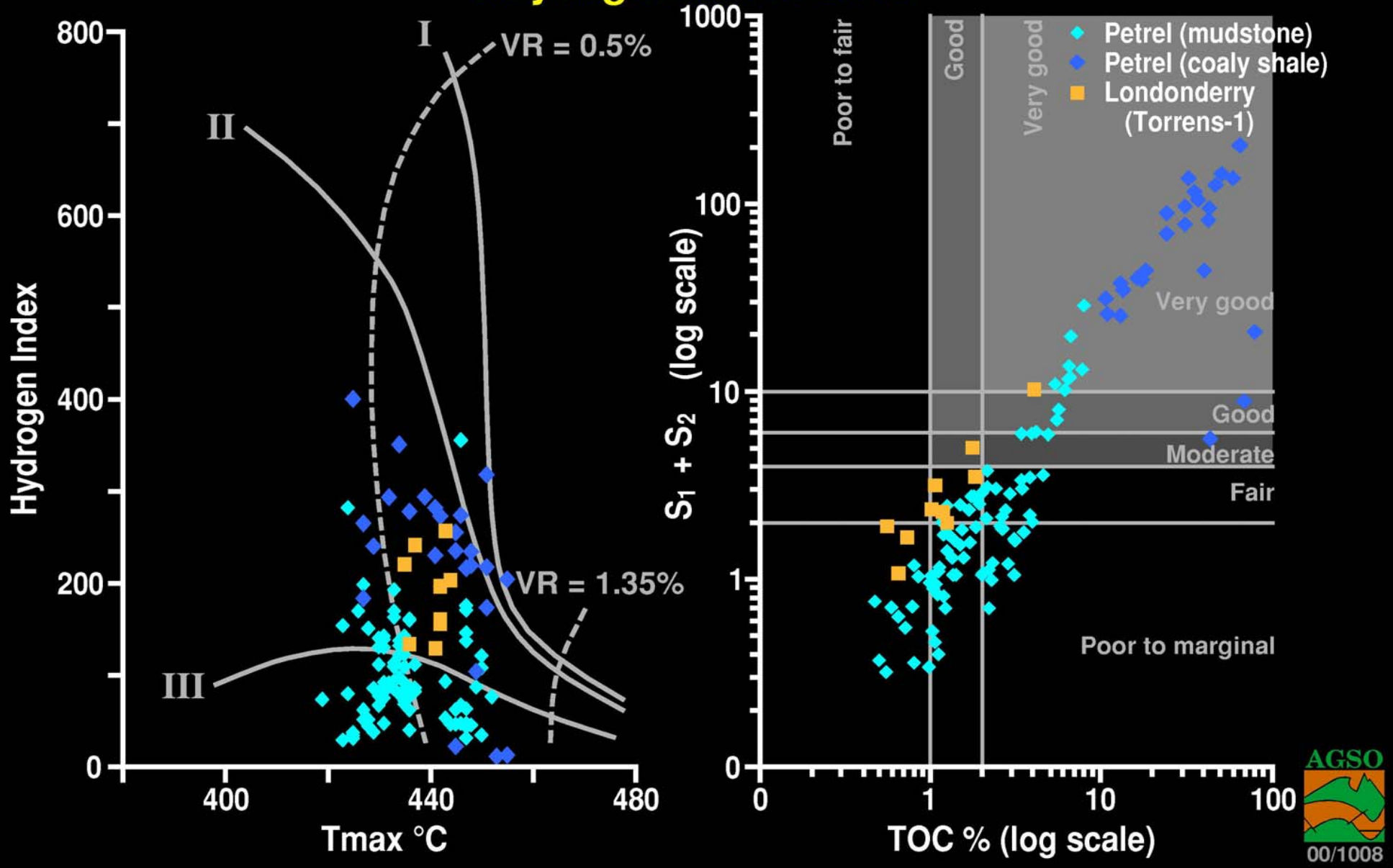




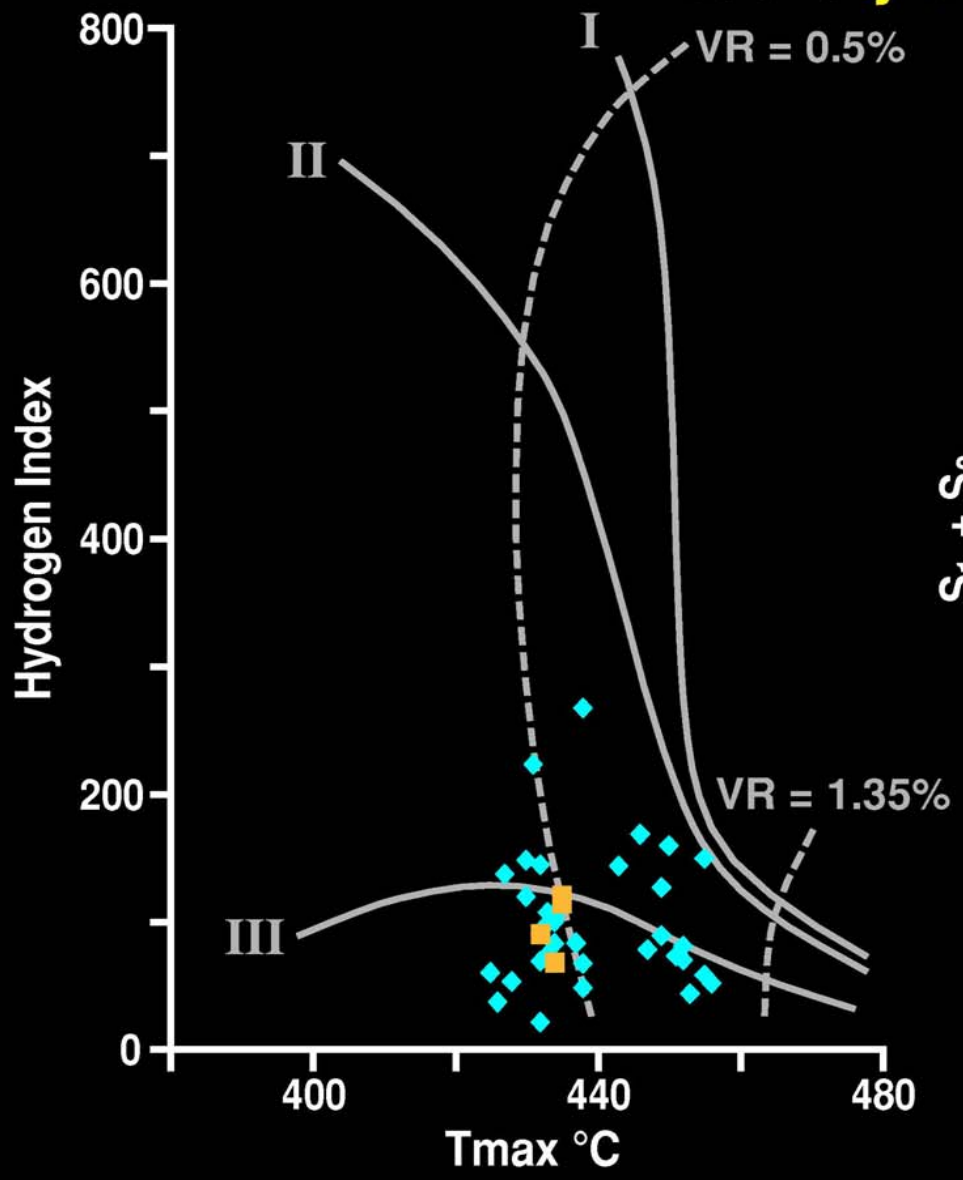
AGSO

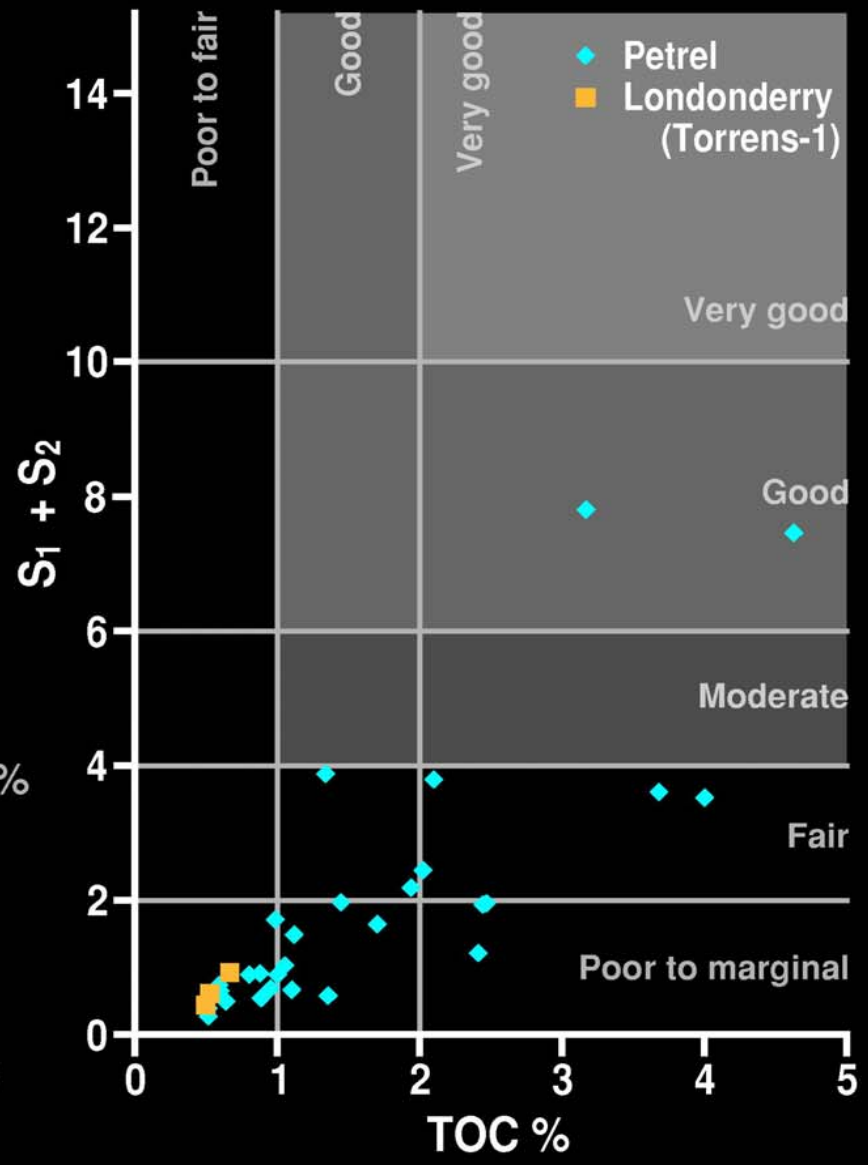
00/1007

Keyling Source Rocks



Treachery Source Rocks

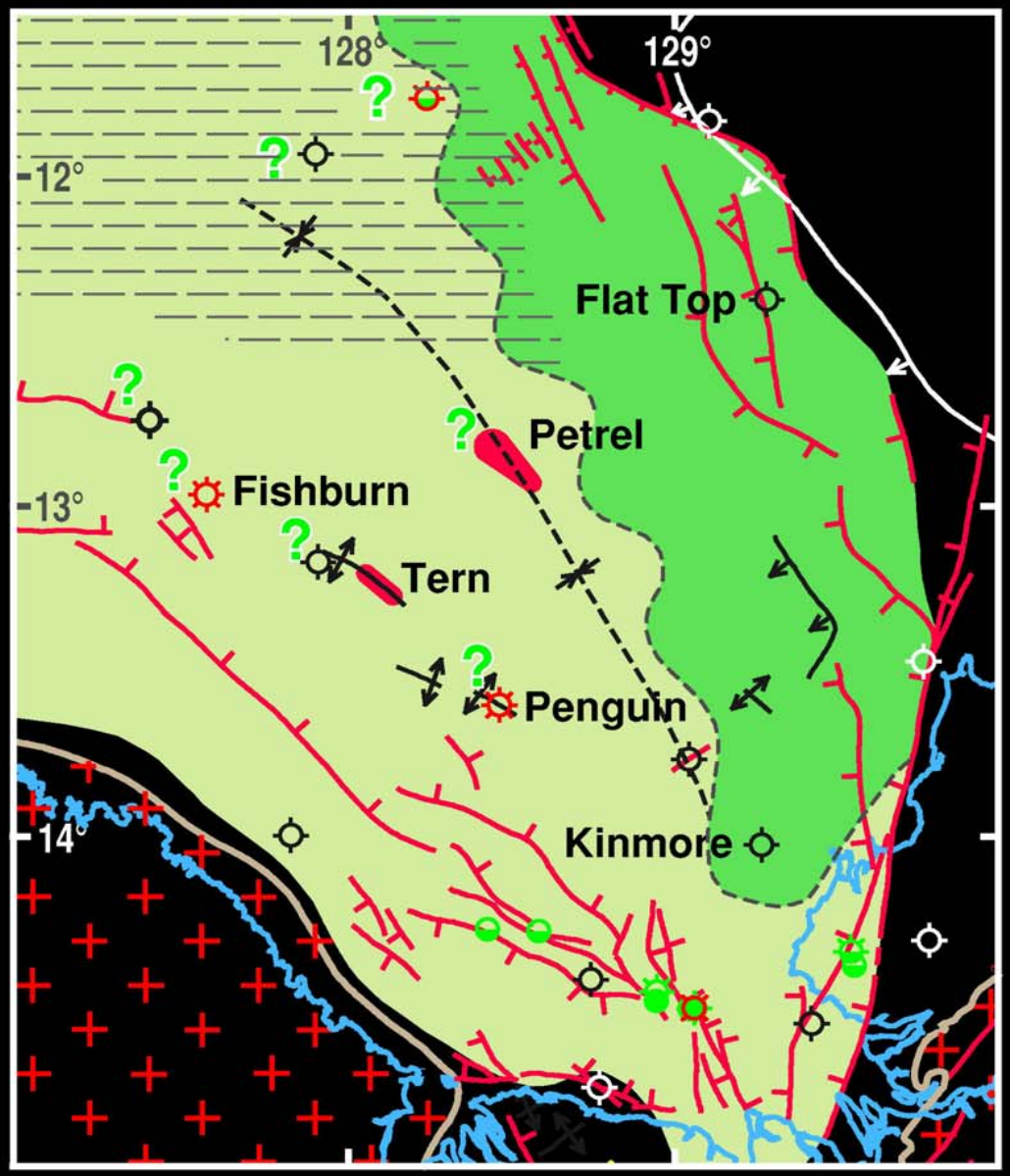




AGSO

00/1009

Permian Source Rocks



Permian

Postulated higher quality source pods

Keyling coaly shale

Hyland Bay

50 km

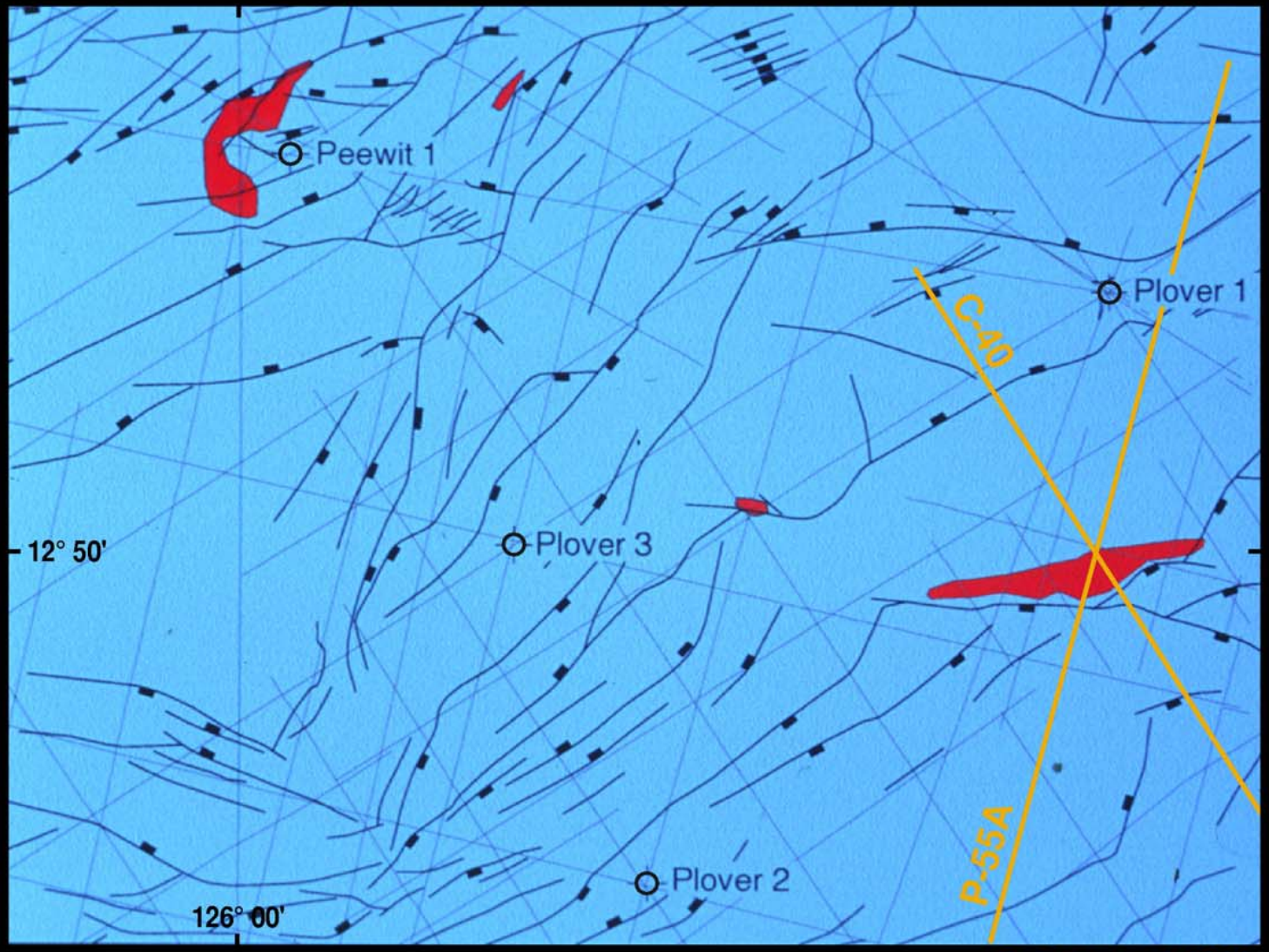
AGSO

00/1010

Evidence for a Permian Petroleum System

- Hydrocarbon geochemistry
- Source rock geochemistry
- **Seismic anomalies - DHI's**
- Fluid inclusion analysis – GOI, MCI
- Maturation history modelling
- Prospectivity

Intra Mt Goodwin Anomalies



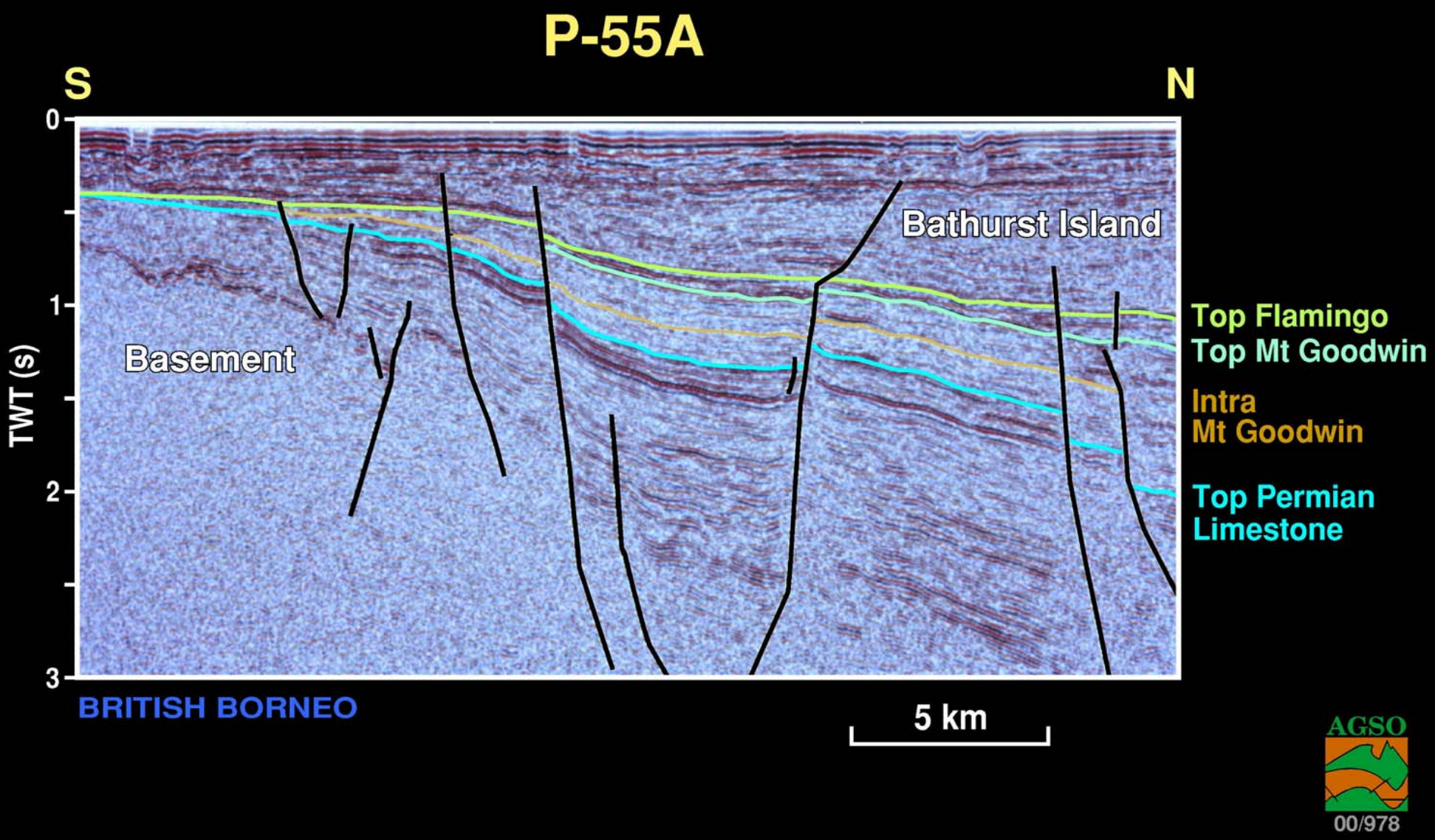
10 km

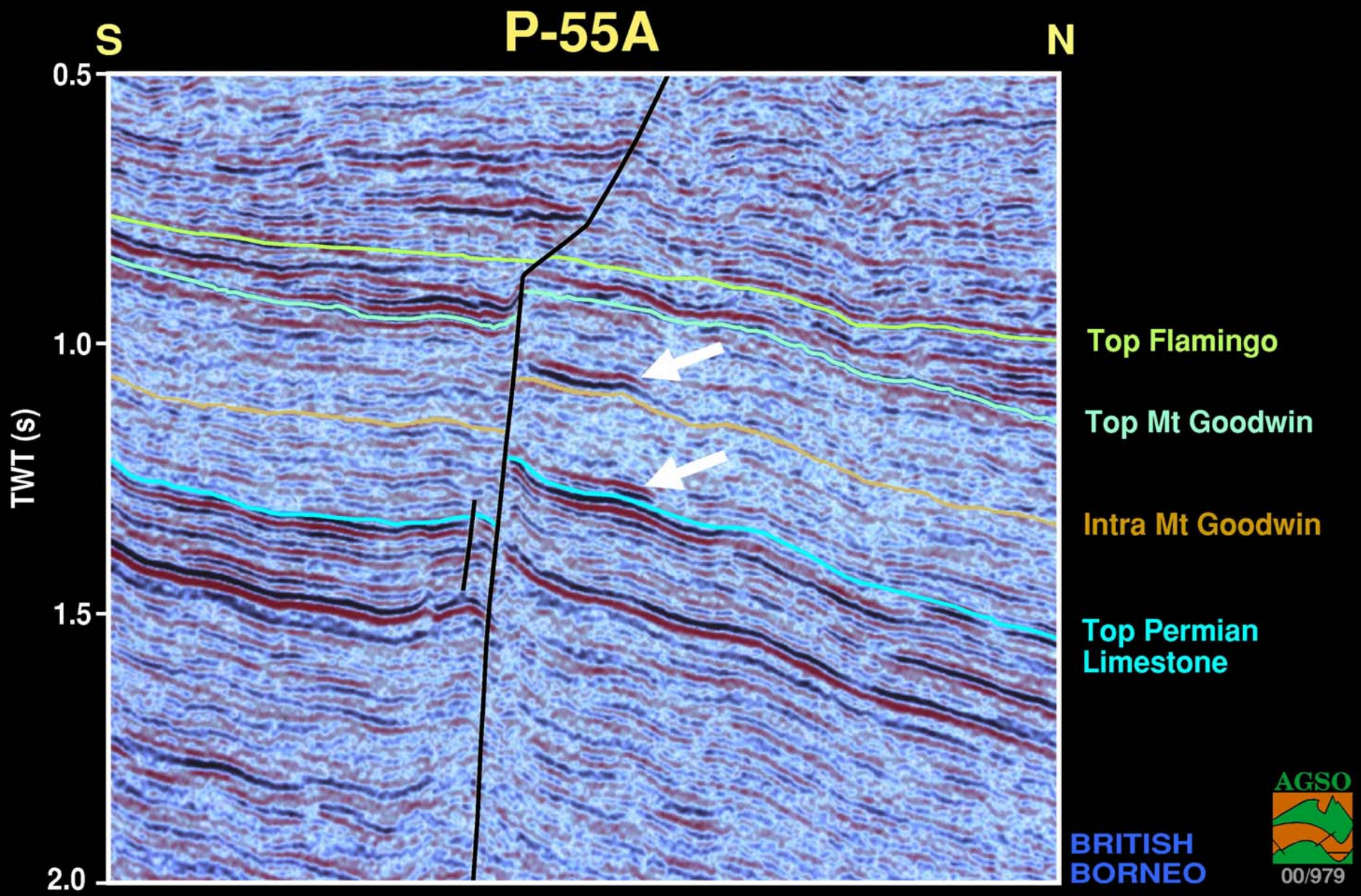
BRITISH BORNEO

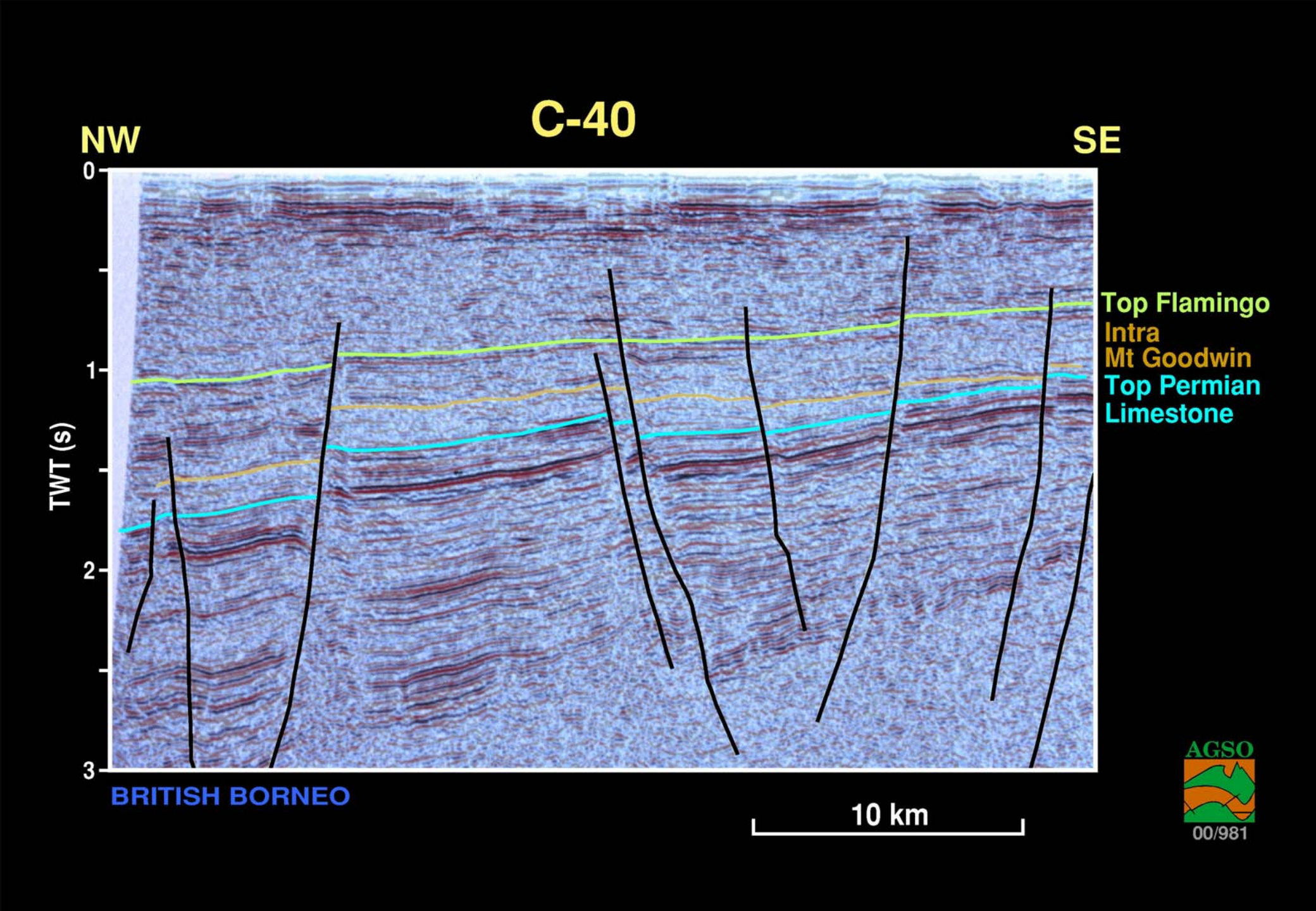
Gorter et al 1998

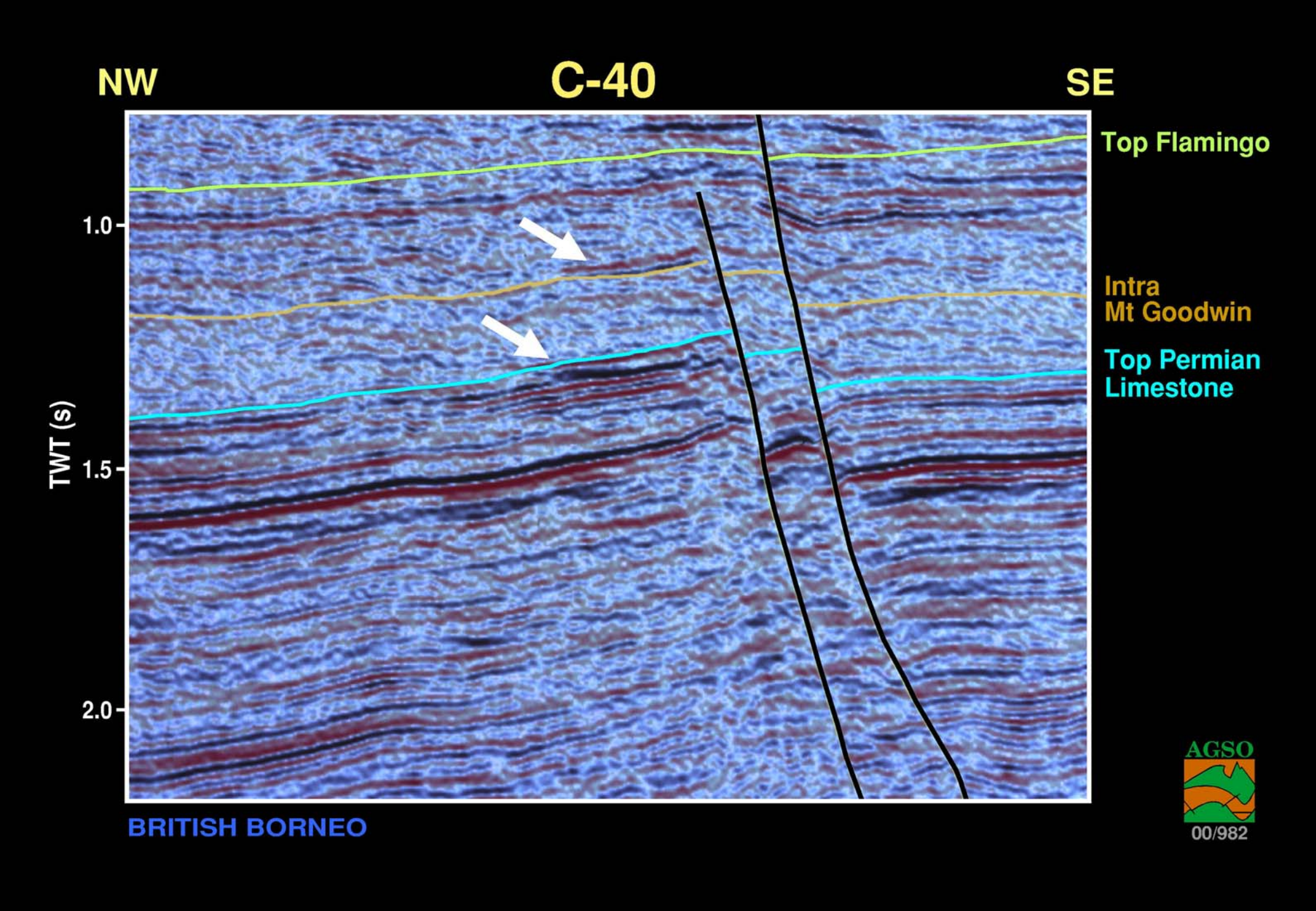
AGSO

00/983


P-55A
S
N
0
1
2
3
TWT (s)
Bathurst Island
Basement
Top Flamingo
Top Mt Goodwin
Intra
Mt Goodwin
Top Permian
Limestone
BRITISH BORNEO
5 km
AGSO
00/978


S
P-55A
N
0.5
1.0
1.5
2.0
TWT (s)
Top Flamingo
Top Mt Goodwin
Intra Mt Goodwin
Top Permian Limestone
BRITISH BORNEO
AGSO
00/979


C-40
NW
SE
0
1
2
3
TWT (s)
Top Flamingo
Intra
Mt Goodwin
Top Permian
Limestone
BRITISH BORNEO
10 km
AGSO
00/981


NW
C-40
SE
Top Flamingo
Intra
Mt Goodwin
Top Permian
Limestone
TWT (s)
1.0
1.5
2.0
BRITISH BORNEO
AGSO
00/982

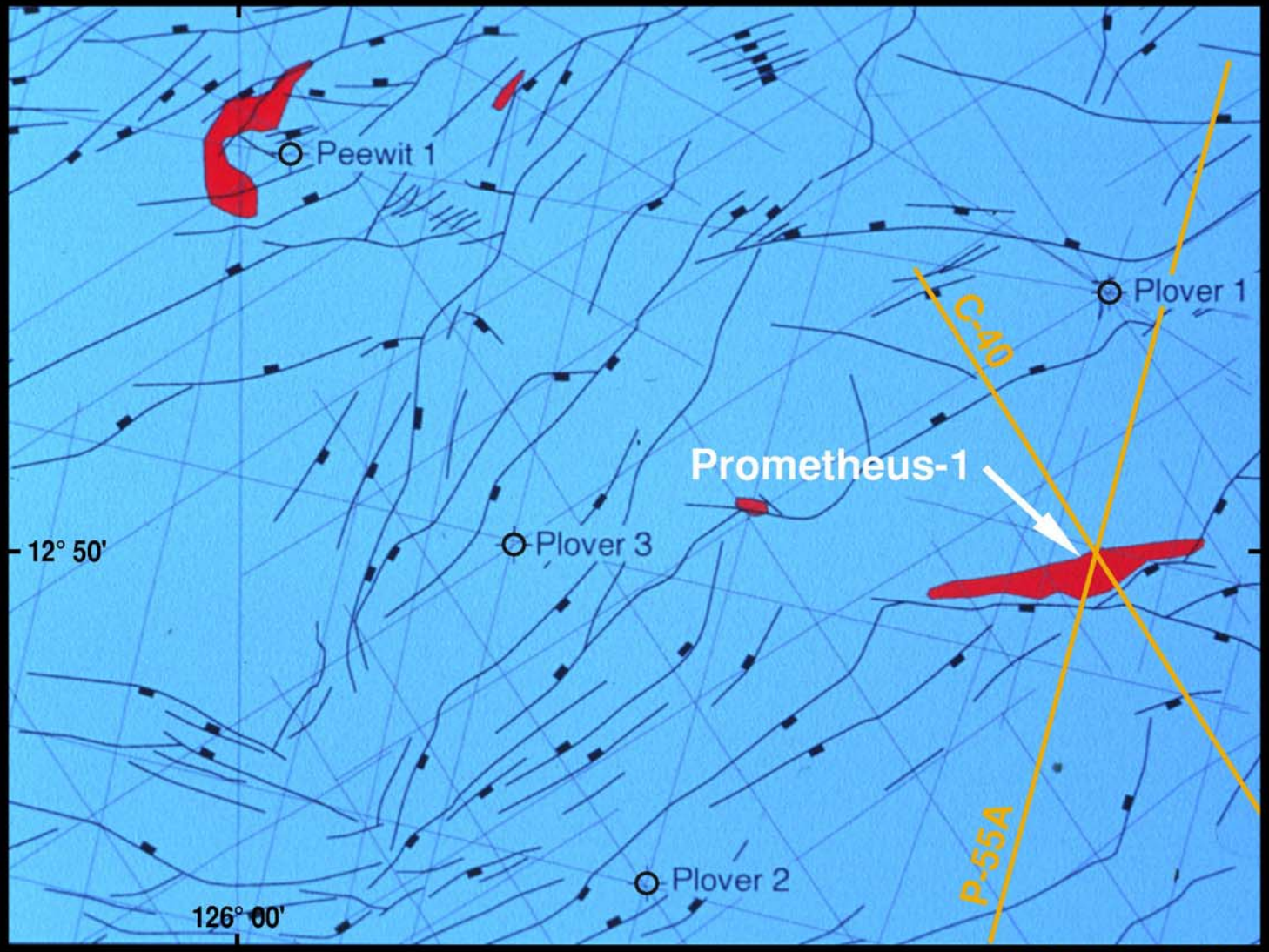
Seismic Anomalies – Interpreted as DHI's

- Bright spots & flat spots within sandstone units
  - Top Hyland Bay (top Permian)
  - Intra Mt Goodwin (Early Triassic)
- Associated with faulted structures
- Geographically limited
- Distribution conforms with mapped structural highs
- Modern seismic data, processed to preserve true amplitude

$\Rightarrow$ DHI of gas saturation (Gorter et al., 1998)

DHI confirmed by recent drilling (Prometheus-1)

Intra Mt Goodwin Anomalies



BRITISH BORNEO

Gorter et al 1998

AGSO

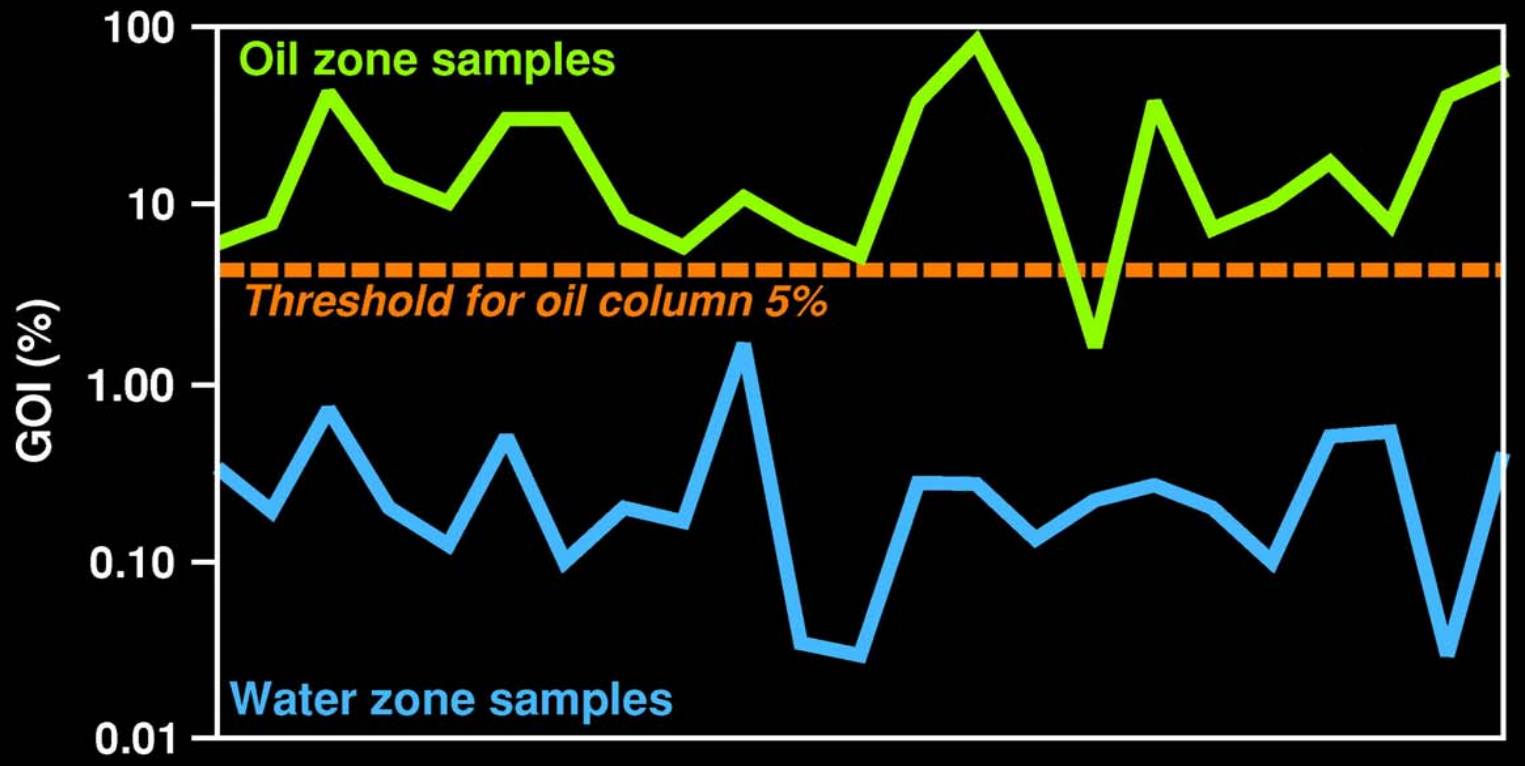
00/983a

Evidence for a Permian Petroleum System

- Hydrocarbon geochemistry
- Source rock geochemistry
- Seismic anomalies - DHI's
- **Fluid inclusion analysis – GOI, MCI**
- Maturation history modelling
- Prospectivity

Fluid inclusion Analysis: Grains with Oil Inclusions (GOI)

Oil-bearing inclusions trapped during cementation
Inclusions provide time-specific record of oil accumulation
GOI technique quantifies oil inclusion frequency (% GOI)
GOI threshold of 5% demonstrates an oil column



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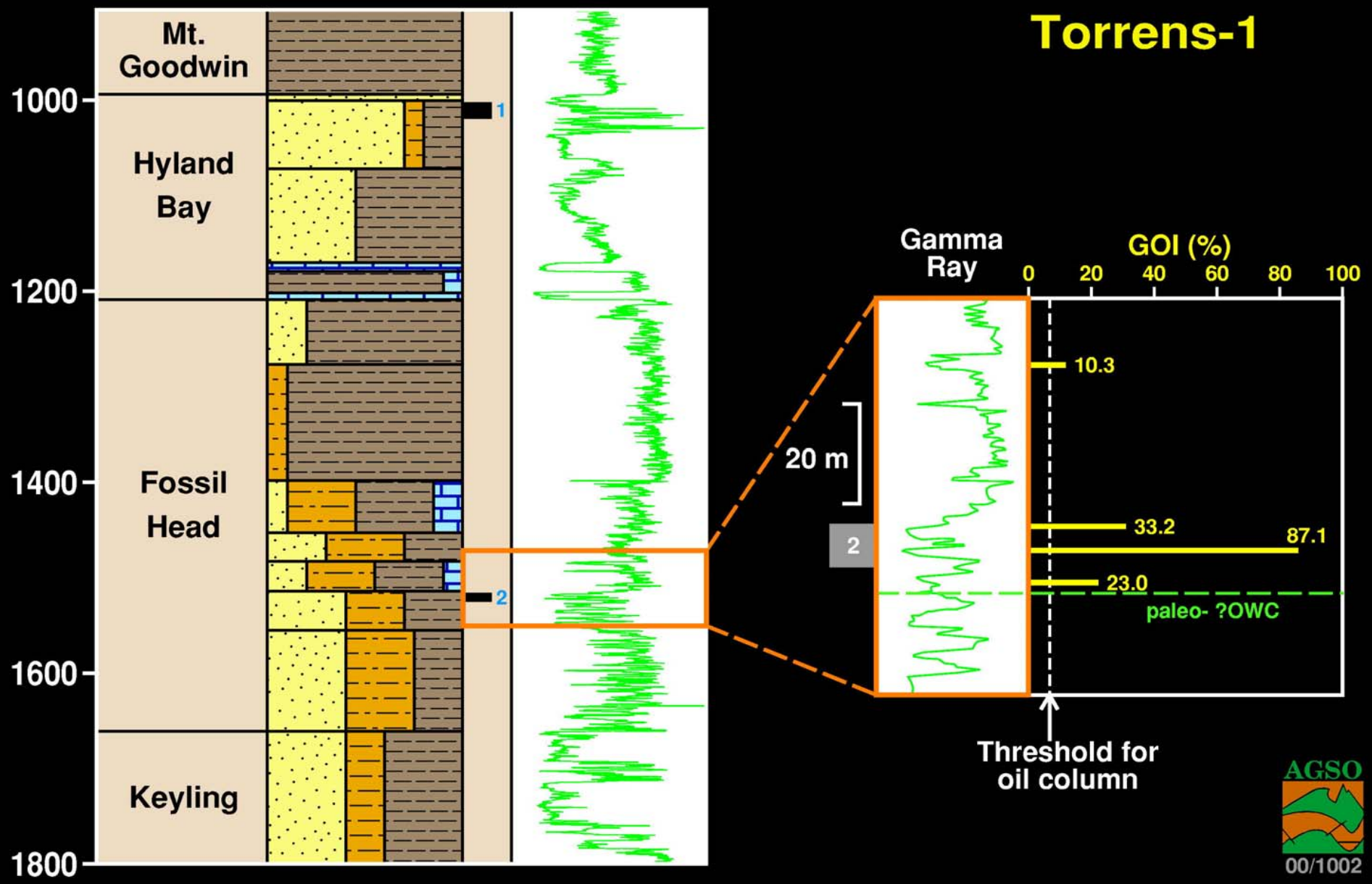
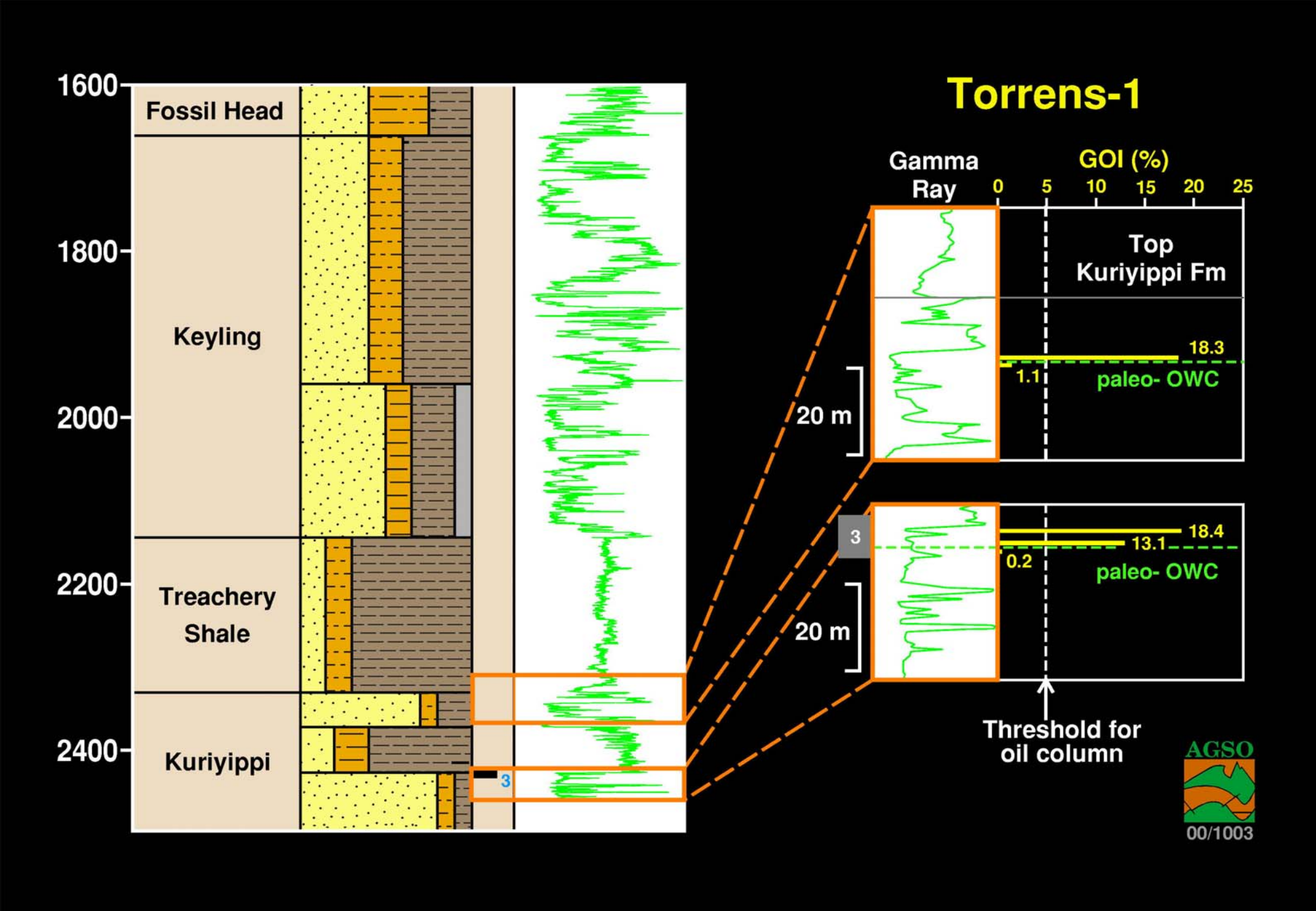

Torrens-1
Mt. Goodwin
Hyland Bay
Fossil Head
Keyling
1000
1200
1400
1600
1800
1
2
Gamma Ray
GOI (%)
0
20
40
60
80
100
20 m
10.3
33.2
87.1
23.0
paleo- ?OWC
Threshold for oil column
AGSO
00/1002


Torrens-1
1600
1800
2000
2200
2400
Fossil Head
Keyling
Treachery Shale
Kuriyippi
3
Gamma Ray
GOI (%)
0
5
10
15
20
25
Top Kuriyippi Fm
18.3
1.1
paleo- OWC
20 m
3
18.4
13.1
0.2
paleo- OWC
20 m
Threshold for oil column
AGSO
00/1003

Fluid Inclusion Analysis Torrens-1
Molecular Composition of Oil Inclusions (MCI)

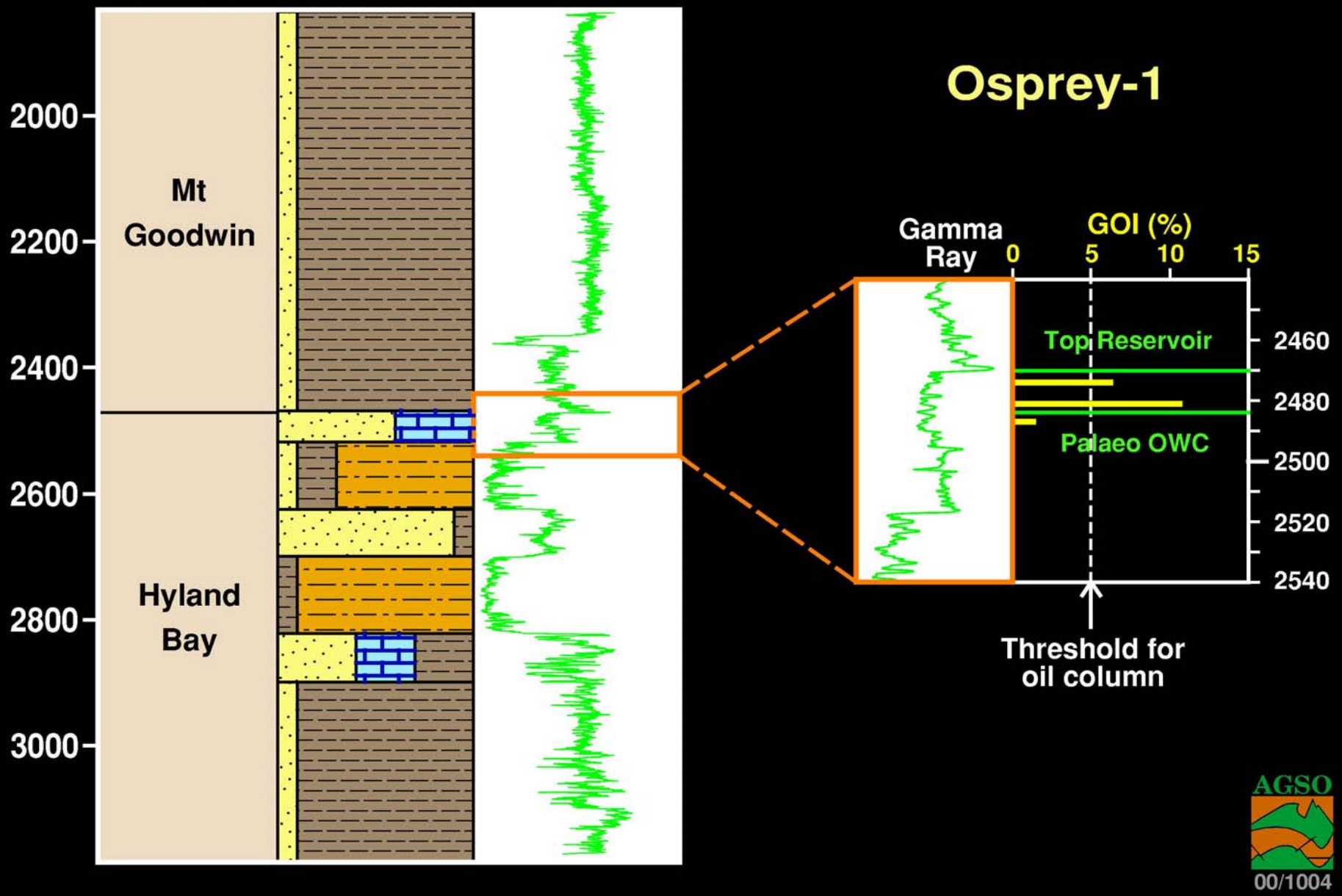
Geochemical analysis of oil inclusions:

- Gas chromatograms
- GC-MS Biomarker data

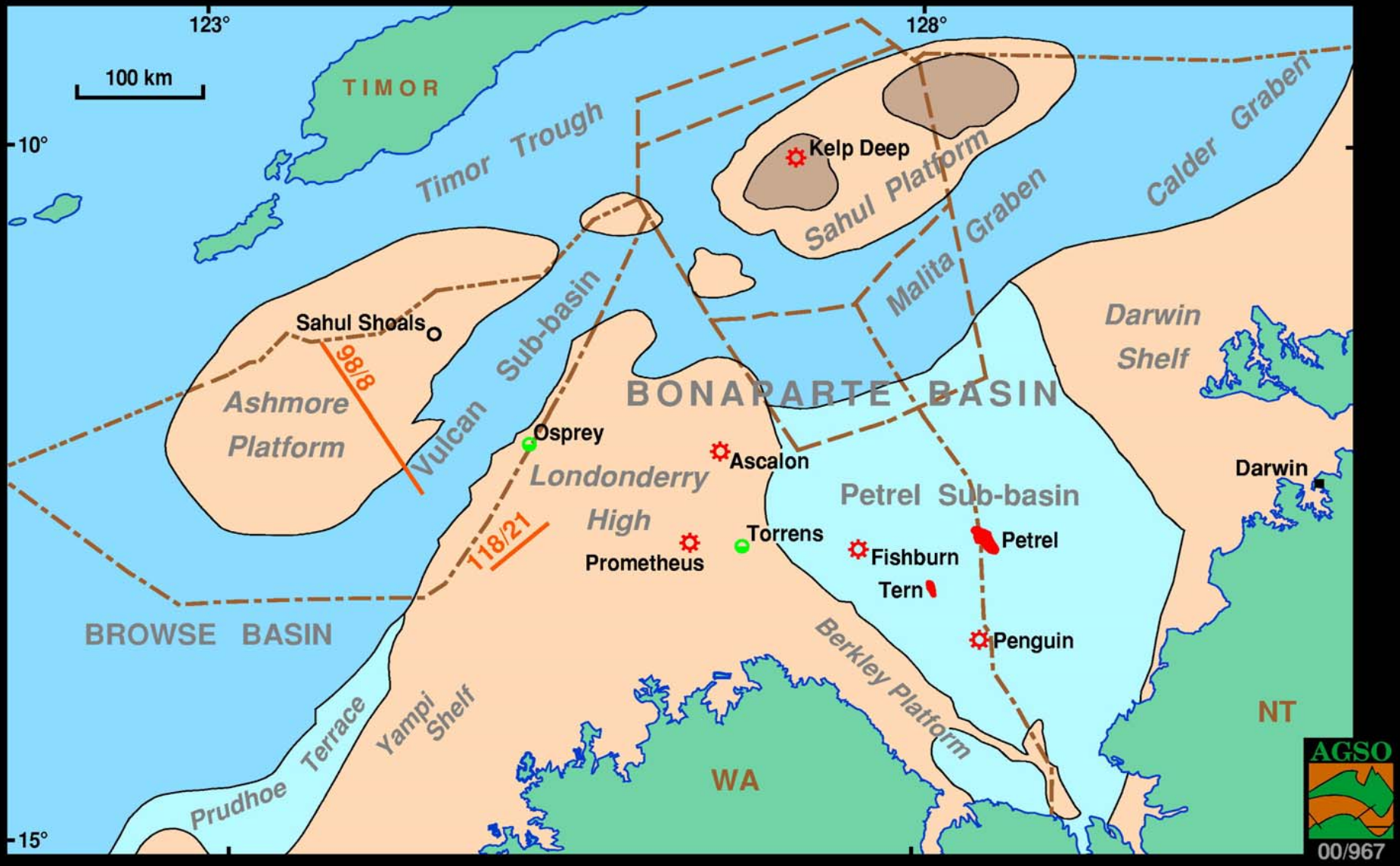
$\Rightarrow$ Inclusion oil & adjacent oil stains have similar composition & derived from same source

Fluid Inclusion Analysis Torrens-1
Molecular Composition of Oil Inclusions (MCI)

Core 1 (Hyland Bay) Core 2 (Fossil Head)	⇒	Terrestrial organic matter Permian deltaic-coastal source unit
Core 3 (Kuriyippi)	⇒	Marine organic matter Carboniferous marine source unit


Osprey-1
2000
2200
2400
2600
2800
3000
Mt Goodwin
Hyland Bay
Gamma Ray
GOI (%)
0
5
10
15
Top Reservoir
Palaeo OWC
2460
2480
2500
2520
2540
Threshold for oil column
AGSO
00/1004

Permian Petroleum Discoveries



Evidence for a Permian Petroleum System

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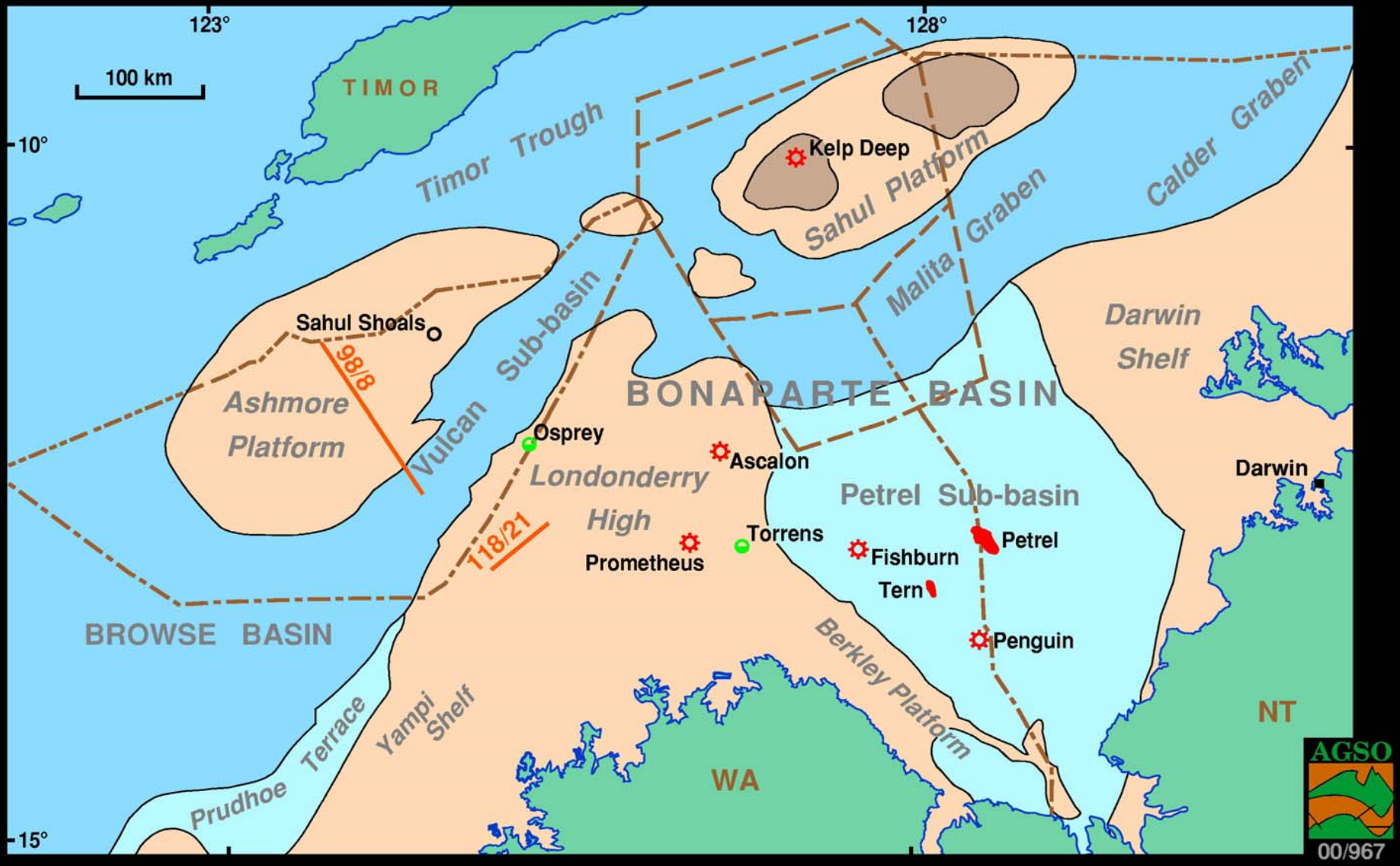
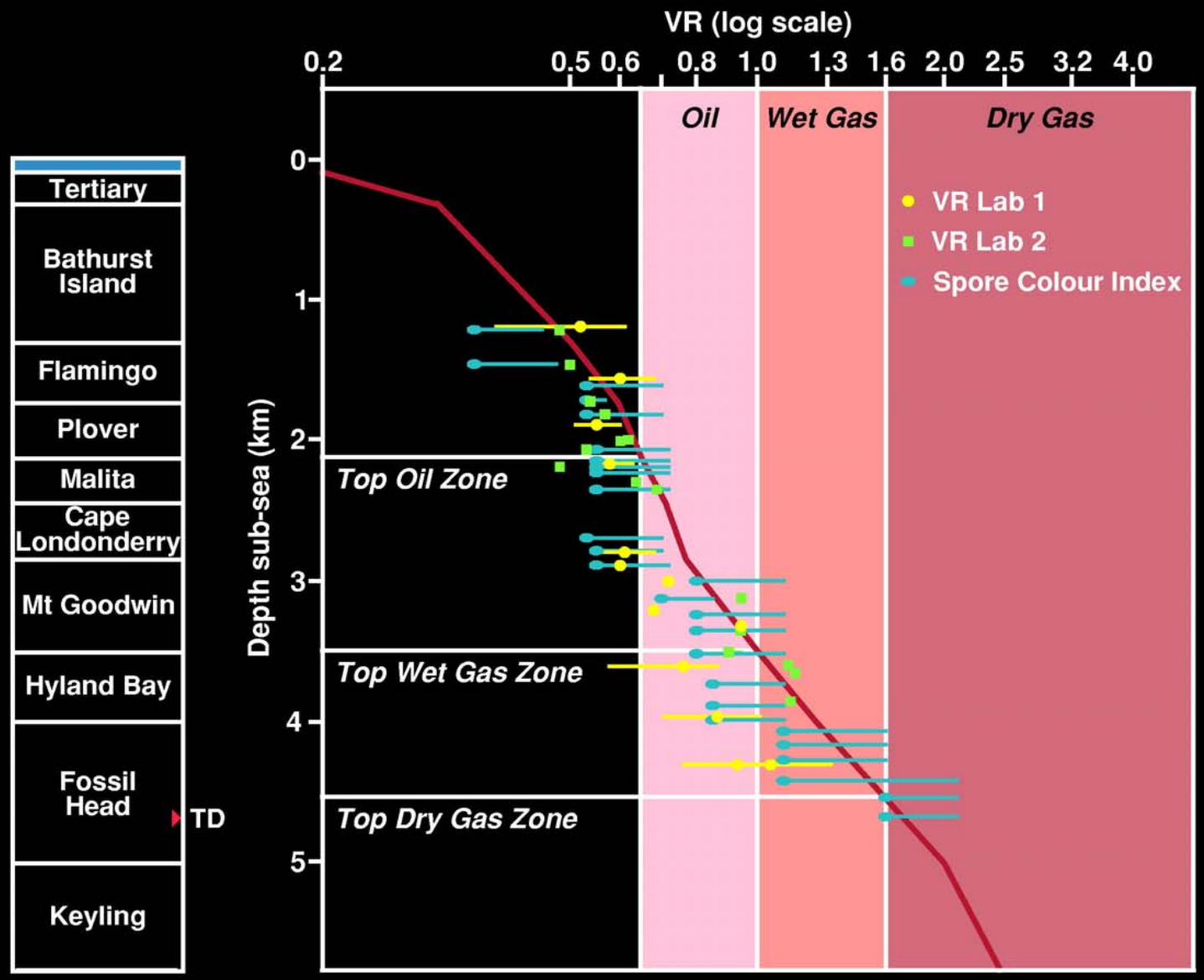
- Prospectivity

Permian Petroleum Discoveries

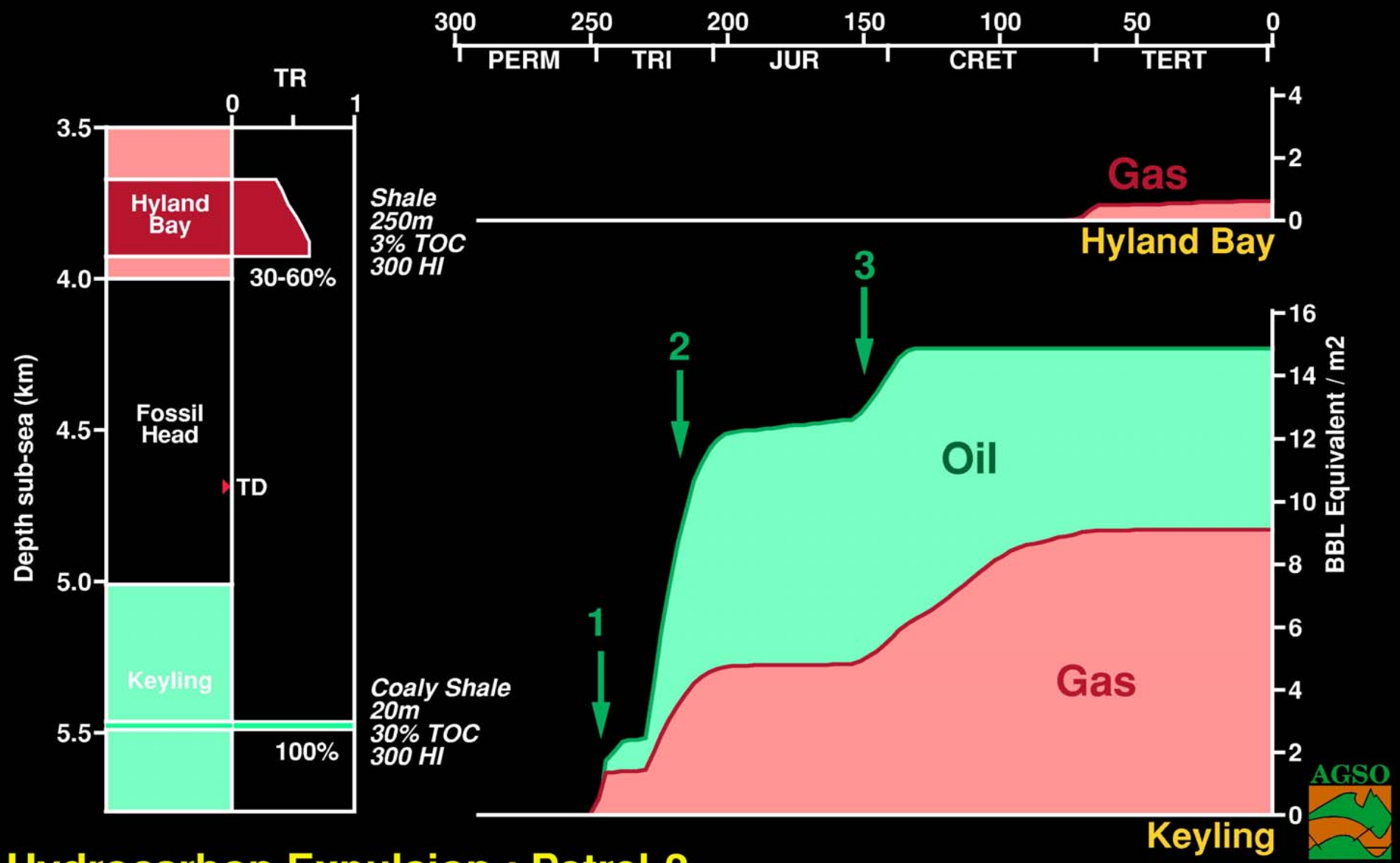




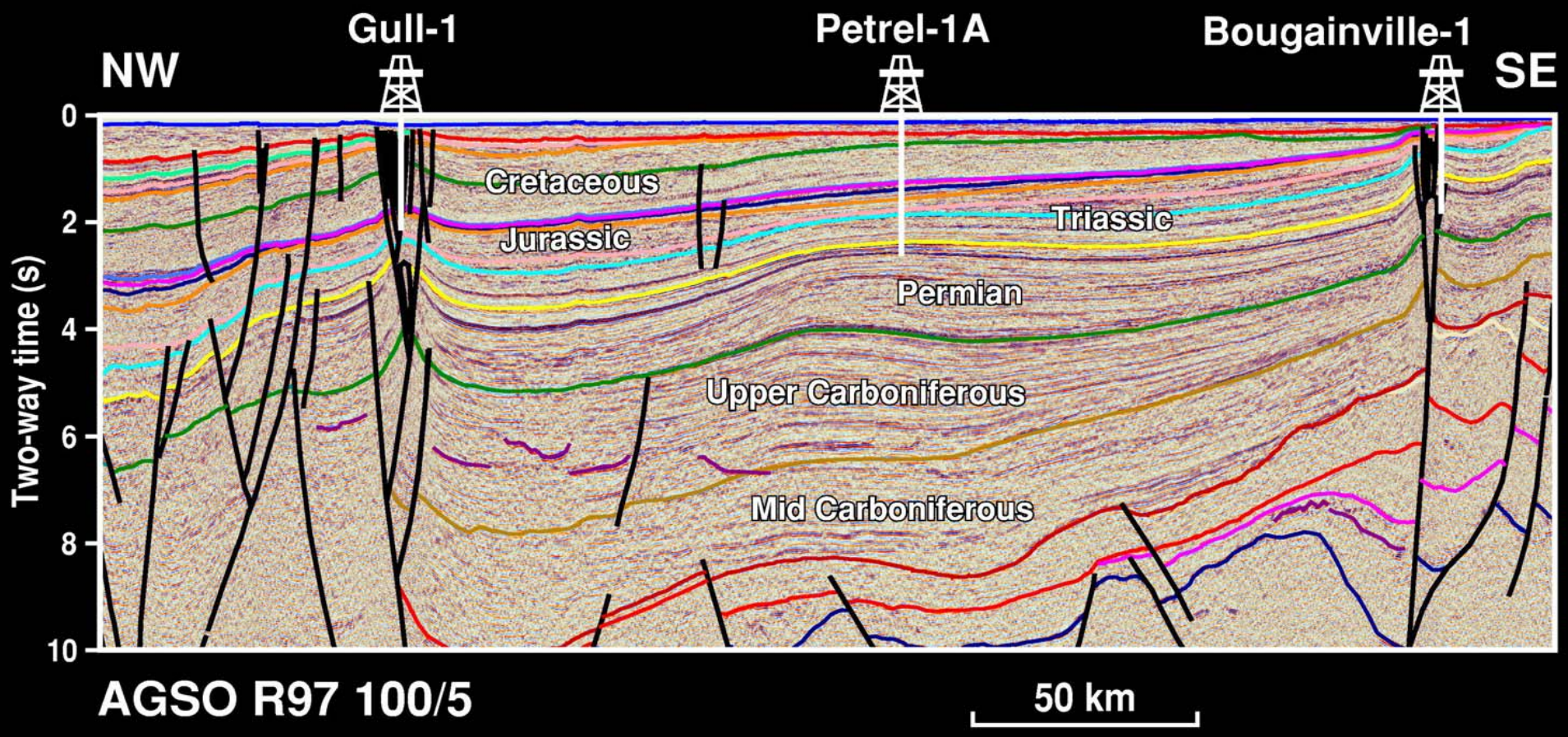
Observed vs Computed Maturity Plot : Petrel-2

AGSO

00/984

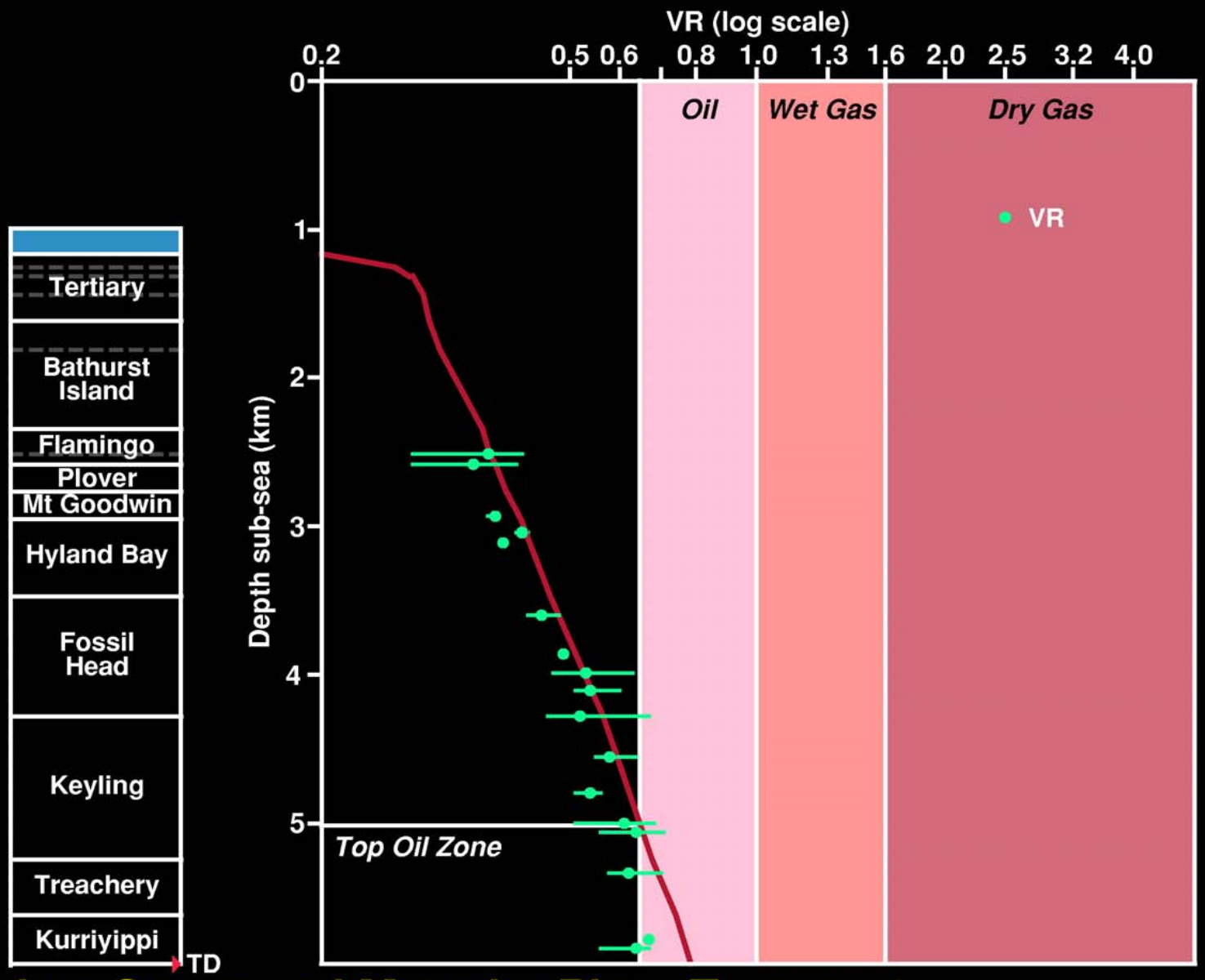


Hydrocarbon Expulsion : Petrel-2


NW
Gull-1
Petrel-1A
Bougainville-1
SE
Two-way time (s)
0
2
4
6
8
10
Cretaceous
Jurassic
Triassic
Permian
Upper Carboniferous
Mid Carboniferous
AGSO R97 100/5
50 km

AGSO

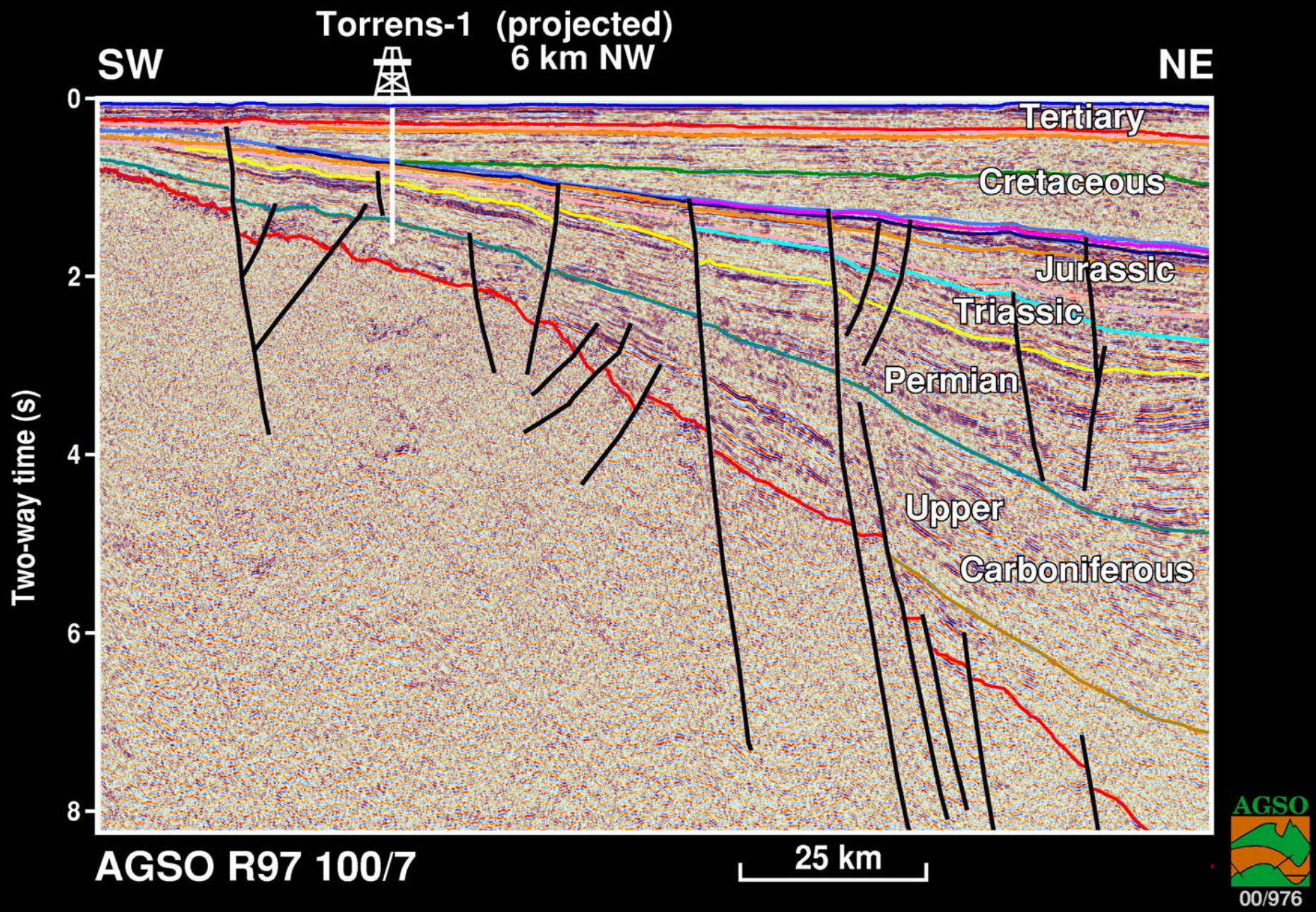
00/974

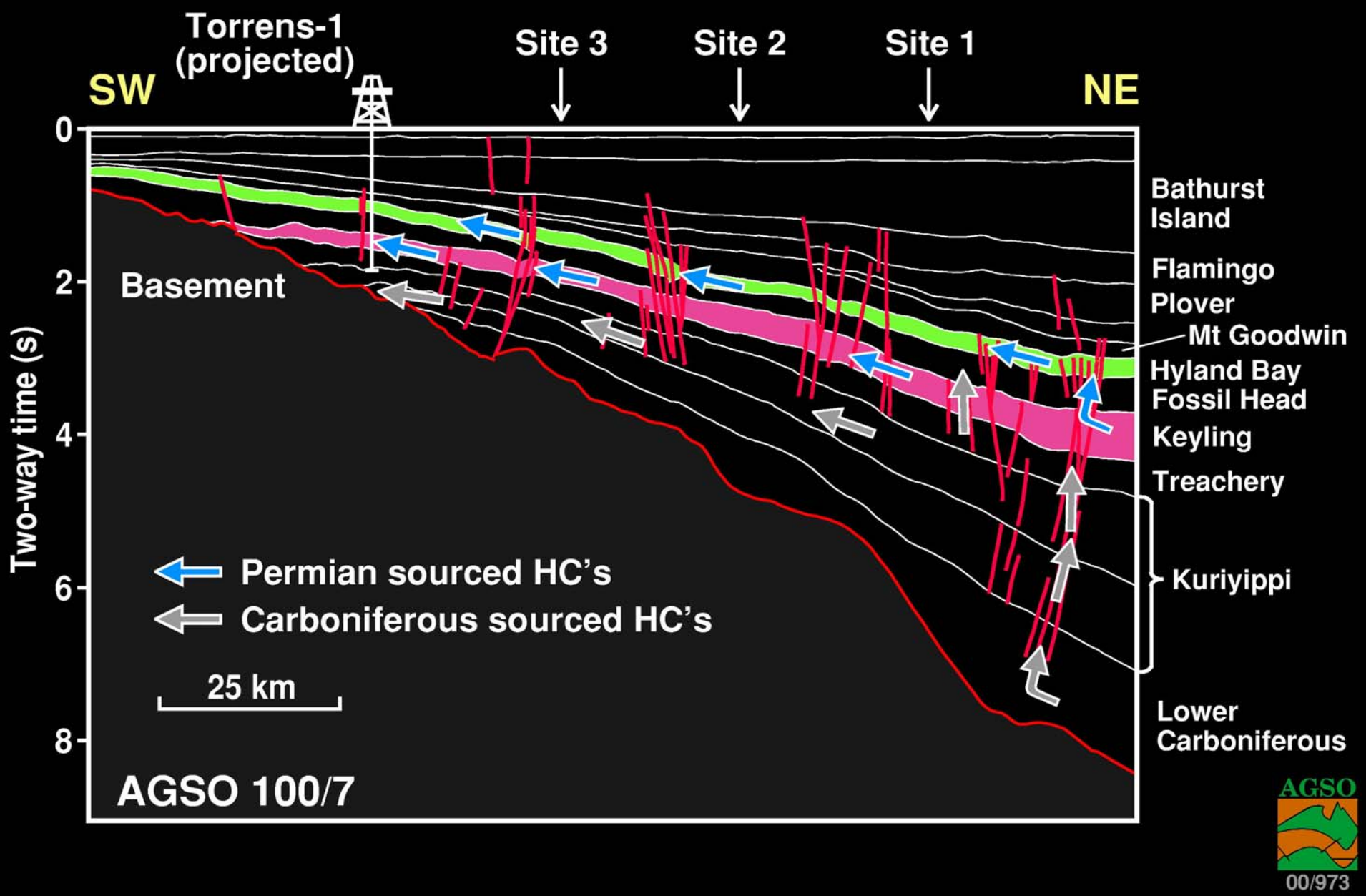


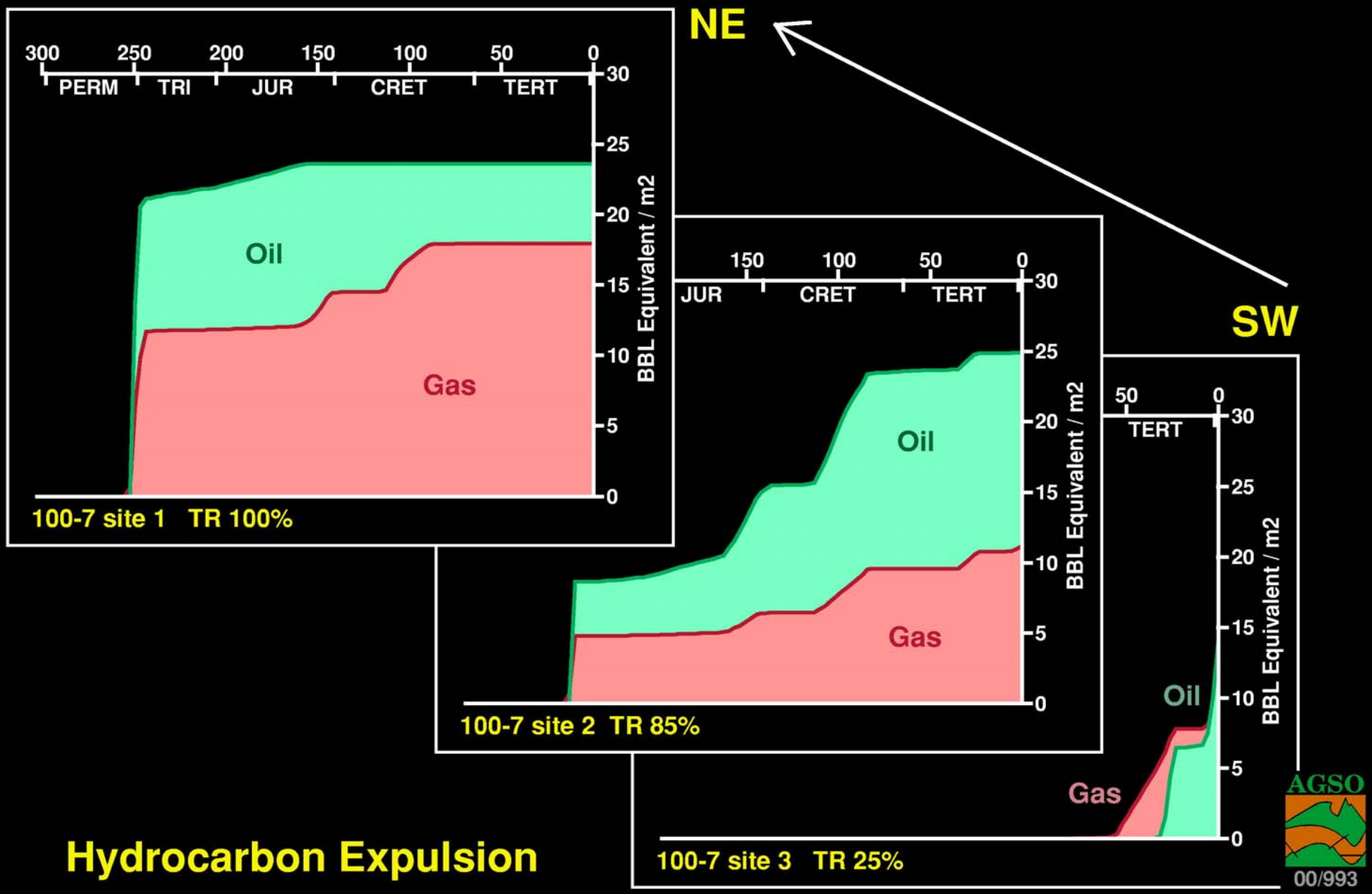
Observed vs Computed Maturity Plot : Torrens-1

AGSO

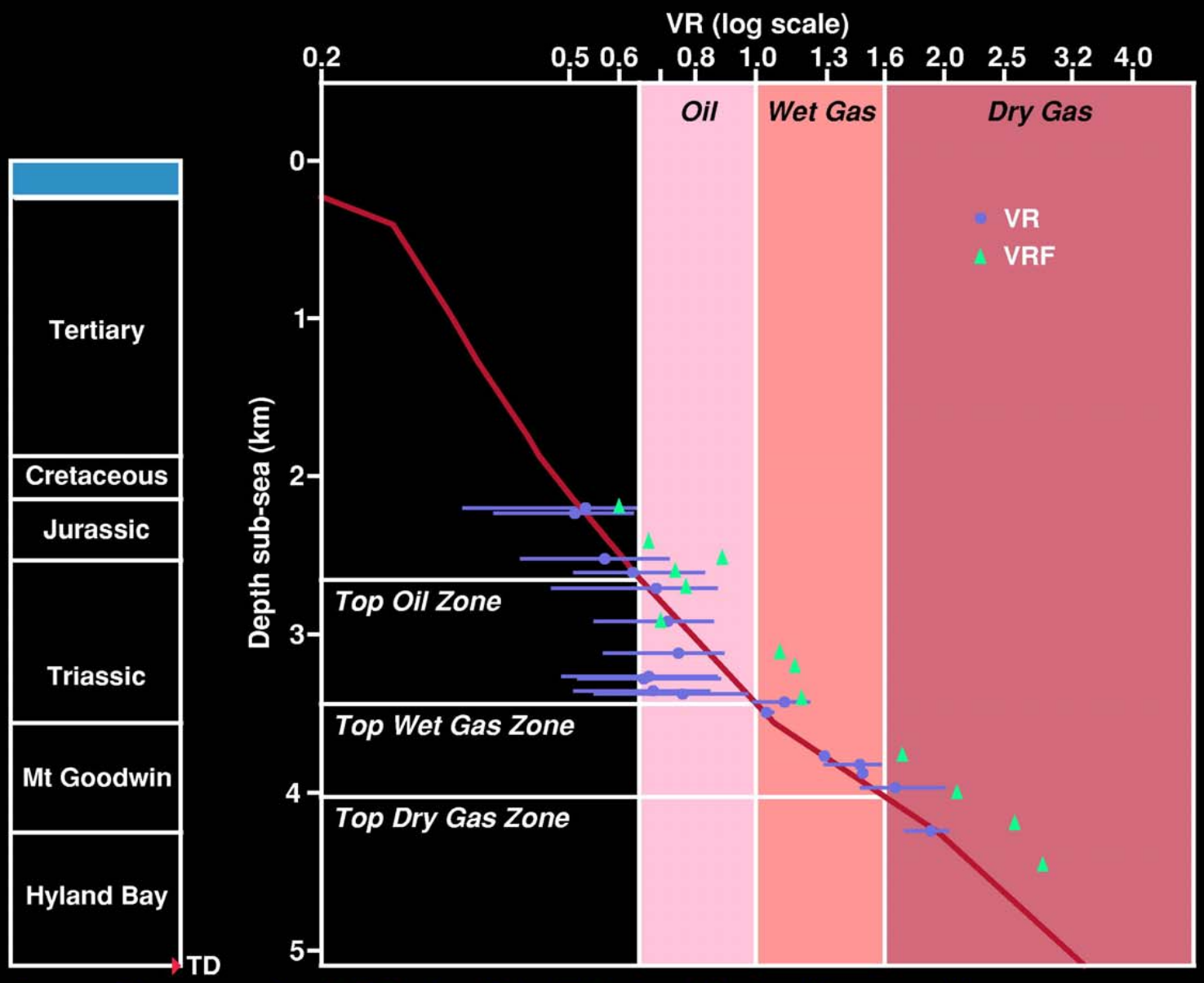
00/990


Torrens-1 (projected)
6 km NW
SW
NE
Tertiary
Cretaceous
Jurassic
Triassic
Permian
Upper
Carboniferous
Two-way time (s)
0
2
4
6
8
AGSO R97 100/7
25 km
AGSO
00/976


Torrens-1
(projected)
Site 3
Site 2
Site 1
SW
NE
0
2
4
6
8
Two-way time (s)
Basement
Bathurst
Island
Flamingo
Plover
Mt Goodwin
Hyland Bay
Fossil Head
Keyling
Treachery
Kuriyippi
Lower
Carboniferous
Permian sourced HC's
Carboniferous sourced HC's
25 km
AGSO 100/7
AGSO
00/973



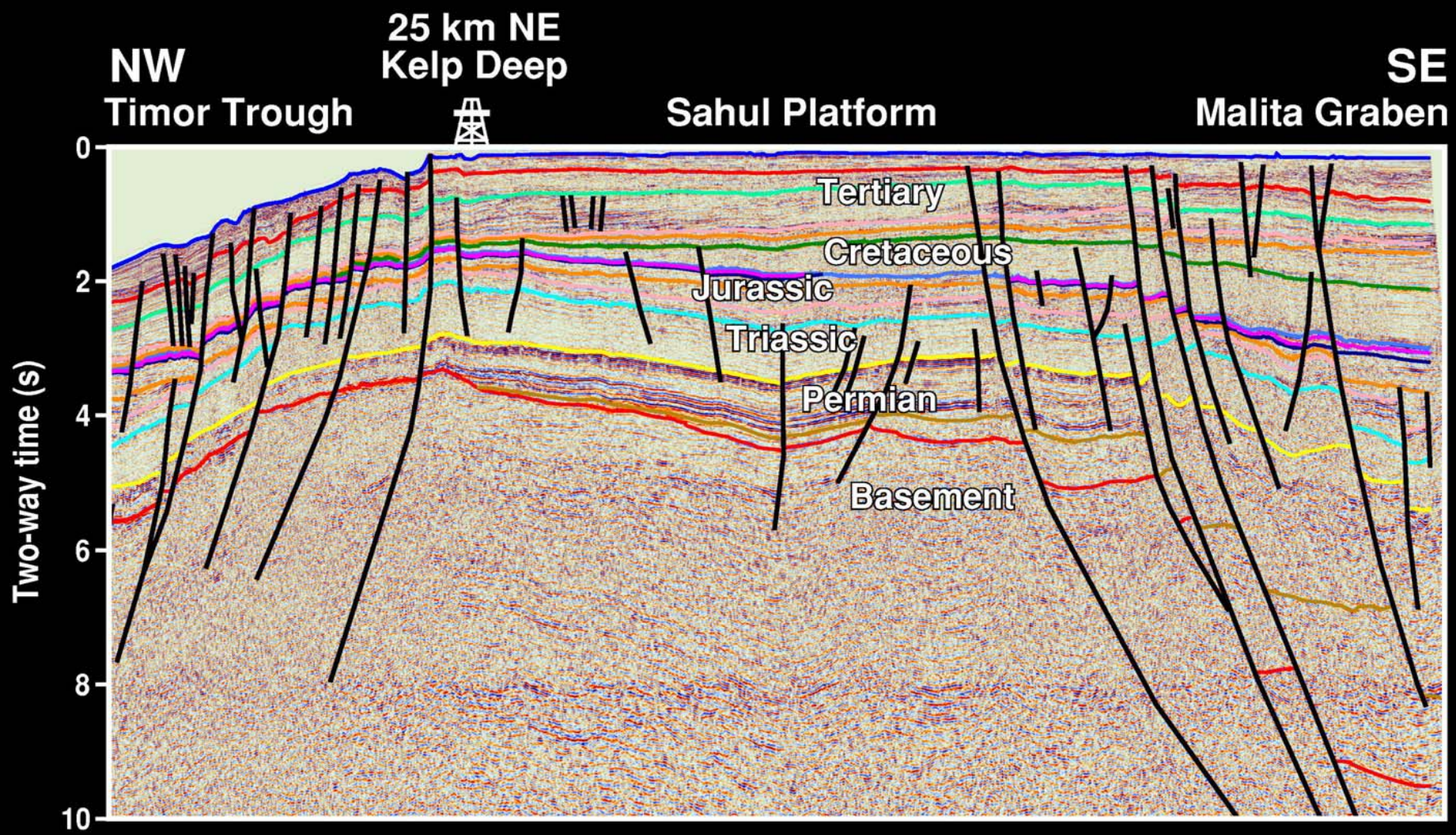
Hydrocarbon Expulsion



Observed vs Computed Maturity Plot : Kelp Deep-1

AGSO

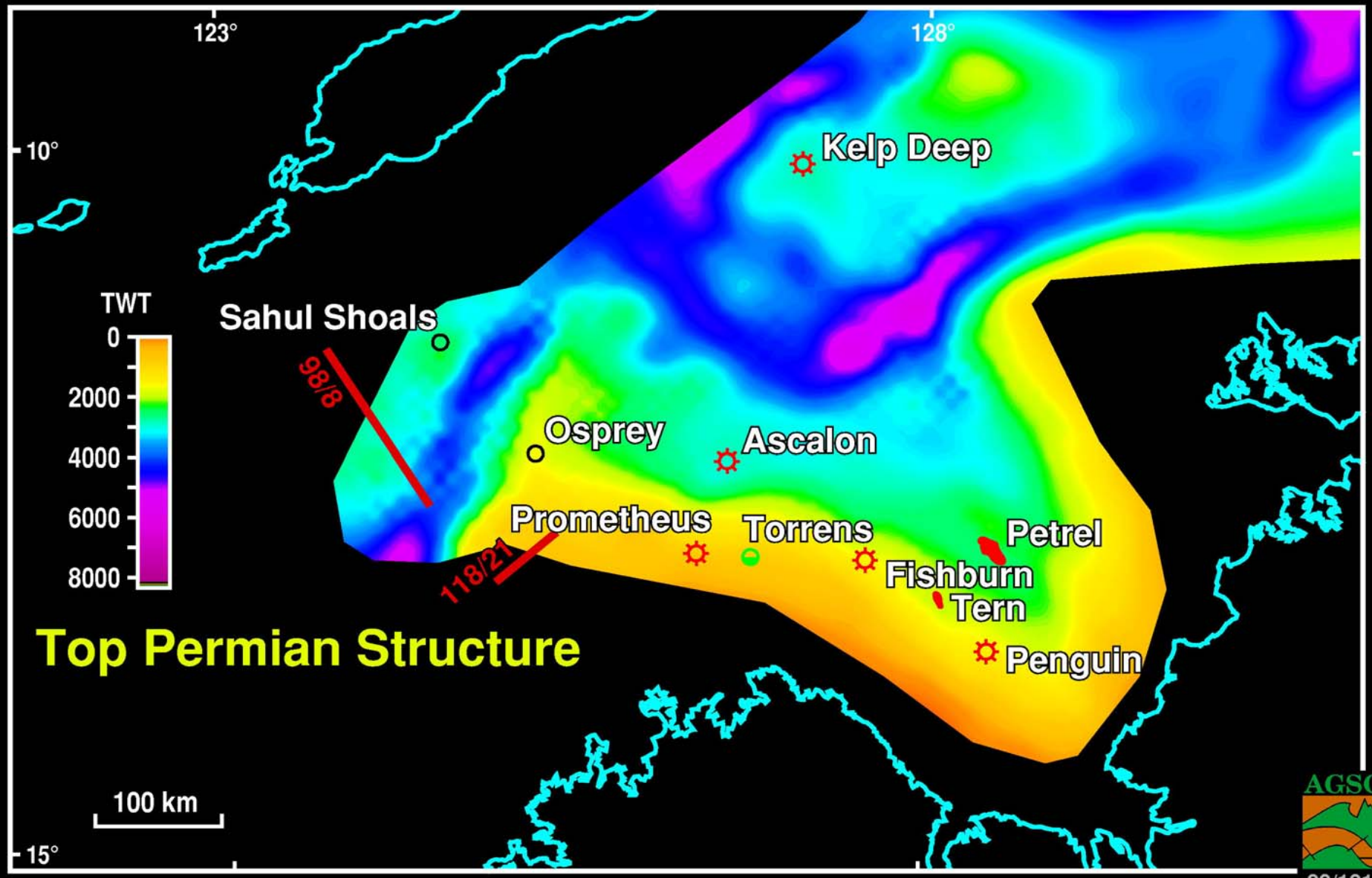
00/991

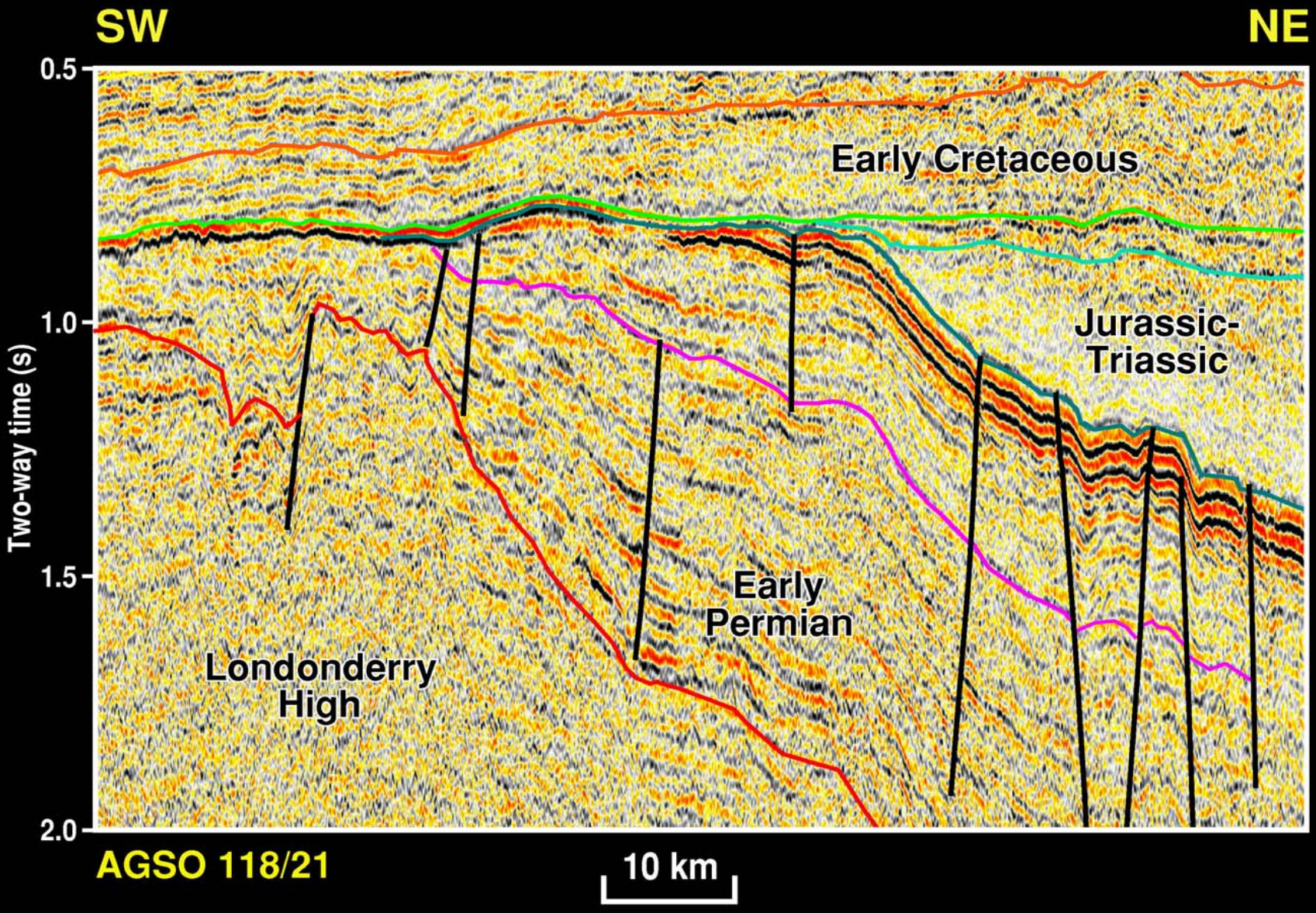

NW
Timor Trough
25 km NE
Kelp Deep
Sahul Platform
SE
Malita Graben
Two-way time (s)
0
2
4
6
8
10
Tertiary
Cretaceous
Jurassic
Triassic
Permian
Basement
AGSO 116/4
50 km

AGSO
00/975

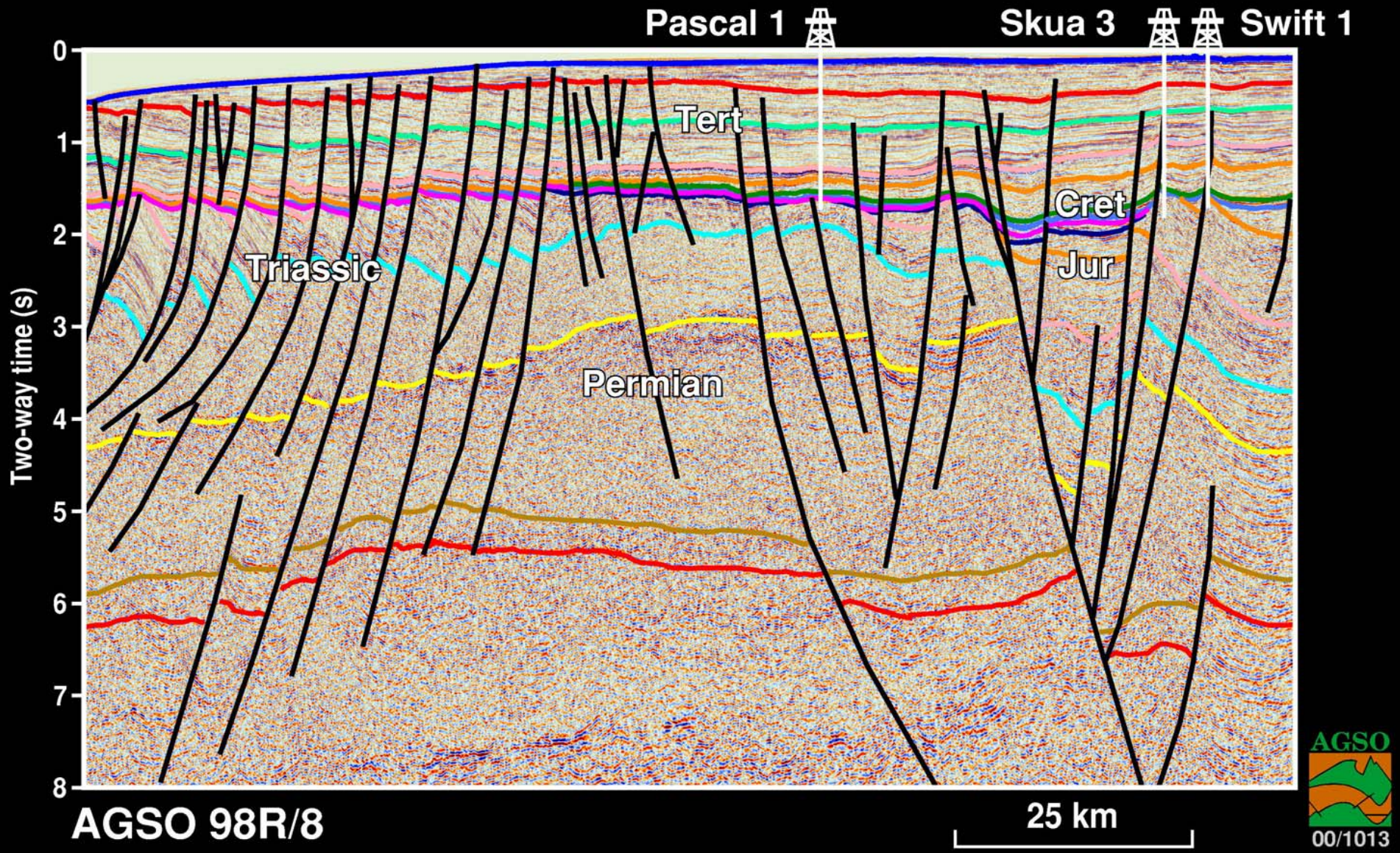
Evidence for a Permian Petroleum System

- Hydrocarbon geochemistry
- Source rock geochemistry
- Seismic anomalies - DHI's
- Fluid inclusion analysis – GOI, MCI
- Maturation history modelling
- **Prospectivity**


123°
128°
10°
15°
Kelp Deep
Sahul Shoals
TWT
0
2000
4000
6000
8000
98/8
Osprey
Ascalon
Prometheus
Torrens
Petrel
Fishburn
Tern
118/21
Penguin
Top Permian Structure
100 km
AGSO
00/1011


SW
NE
0.5
1.0
1.5
2.0
Two-way time (s)
Early Cretaceous
Jurassic-
Triassic
Early
Permian
Londonderry
High
AGSO 118/21
10 km

AGSO
00/1012


Pascal 1
Skua 3
Swift 1
Tert
Cret
Jur
Triassic
Permian
Two-way time (s)
0
1
2
3
4
5
6
7
8
AGSO 98R/8
25 km
AGSO
00/1013

SAR Anomalies

Confidential map

Conclusion

Widespread Permian petroleum system
Gas vs Liquid potential controlled by:

- Distribution of coaly shales
- Outboard marine source facies?
- Maturation history

Petrel Sub-basin	$\Rightarrow$	Gas / Condensate, ?Oil
Sahul Platform	$\Rightarrow$	Dry Gas
Londonderry High	$\Rightarrow$	Gas & Oil
Ashmore Platform	$\Rightarrow$	Unknown