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PRELIMINARY ASSESSMENT OF THE HYDROCARBON POTENTIAL OF THE SAHUL PLATFORM, BONAPARTE GULF BASIN, NORTHERN TERRITORY AND WESTERN AUSTRALIA

by

D.J. Forman and E.J. Riesz

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SUMMARY

A rapid assessment has been made of the hydrocarbon potential of the Sahul Platform. Prospects on, and around the Troubadour dome were assessed using the prospect by prospect method, utilising a Monte Carlo simulation computer programme. The resources of the nearby Kelp prospect were assessed (single value estimate) using a volumetric method. The results are summarised in Tables 1-3.

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INTRODUCTION

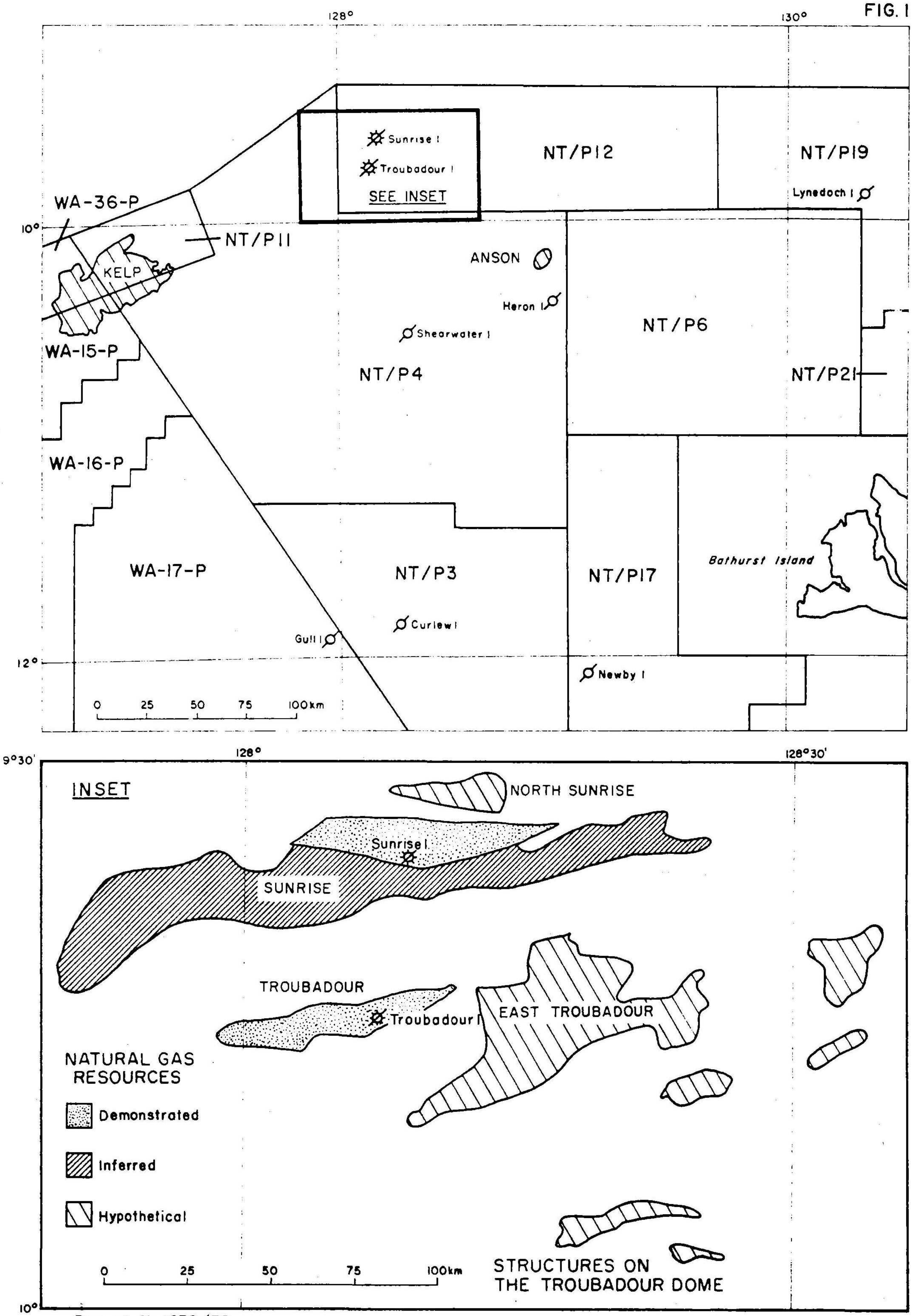
The hydrocarbon potential of the Sahul Platform has been rapidly assessed as the first step in a preliminary quantitative appraisal of the hydrocarbon potential of Australia. All relevant information (P(SL)A, confidential reports, etc.) available to BMR has been used to arrive at the conclusions presented in the report. Location of permits, exploration history, regional geology and geophysics, stratigraphy, and structure have been described by Riesz & Temple (in prep.).

Demonstrated resources of recoverable gas occur only in the Sunrise and Troubadour fields (Fig. 1), both of which are local culminations near the crest of a large dome. Inferred resources may occur in an extension to the Sunrise field. Undiscovered resources should occur mainly in other culminations adjacent to the Sunrise and Troubadour fields and in a major undrilled dome called 'Kelp'. Prospects less likely to contain significant petroleum occur on the Platform adjacent to its southern margin (i.e. Anson), in as yet undelineated fault traps on the Platform, and in speculative combined structural and stratigraphic traps. We have assessed the inferred resources of the Sunrise field, and the undiscovered resources in nearby prospects, at Kelp, and at Anson.

Quantitative assessment of undiscovered resources, has been achieved using the 'prospect by prospect' method (Riesz, 1978) in combination with the volumetric method. Parameters for calculation of the volume of gas resources were input either as single values or as ranges of weighted values, and resource estimates were produced in the form of cumulative probability curves for the individual prospects. The individual prospect distributions were then aggregated using Monte Carlo simulation.

Because of time limitations placed on the study, only those aspects of the geology that are of critical importance to the occurrence of petroleum are described.

FIG. 1



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PROSPECT LOCATION MAP

PLAY ASSESSMENT

Plays

The following plays are recognised on the Sahul Platform.

(1) Fold and fault traps containing Middle Jurassic deltaic, littoral, and marine sandstones sourced and sealed by both Middle Jurassic and Upper Jurassic claystone. Additional seal is provided by Cretaceous claystone unconformably overlying the Jurassic source and reservoir rocks.

(2) Combined structural and stratigraphic traps within the Jurassic sequence. These may be formed by abutment unconformity on the underlying Triassic sequence, and by unconformity beneath the overlying Cretaceous sequence.

Tests

Sunrise No. 1 (BOCAL, 1974b), Troubadour No. 1 (BOCAL, 1974a), Shearwater No. 1 (ARCO, 1974), and Flamingo No. 1 (ARCO, 1972), all tested the main play ((1) above).

Generation

Discoveries at Sunrise No. 1 and Troubadour No. 1 prove that recoverable hydrocarbons (mainly gas) have been generated. There were also indications of hydrocarbons (mainly gas) in the Jurassic sequence penetrated by Flamingo No. 1.

Organic matter

Light to dark grey Lower Triassic marine claystone in Troubadour No. 1 contains little total organic matter. The total organic carbon content of Middle to Lower Upper Triassic shallow marine and continental claystone is higher, particularly at the top where it is high to very high. Red beds were deposited during the Lower Jurassic, suggesting deposition under oxidising conditions and generally poor preservation of organic material. Interbedded coal may be a source for hydrocarbons. Abundant palaeontological material is reported from sections within the marine and continental claystone in the late Lower Jurassic to Upper Jurassic sequence of Troubadour No. 1. Sapropelic material is not abundant, but is common in three samples taken from the Middle Jurassic. Jurassic rocks in Flamingo No. 1 are rich in organic carbon, with sapropel predominant in several hundred feet of section at the horizon 2 unconformity (base Cretaceous unconformity).

Maturation

Spore maturation values indicated severe thermal diagenesis of the Triassic sequence at Troubadour No. 1. BOCAL spore maturation values ranging between 9 at higher stratigraphic levels and 11 at lower level are reported for the Jurassic sequence.

A high overall geothermal gradient of 4.37°C per 100 m has been calculated for Troubadour No. 1 by BOCAL (1974b). Depths and calculated formation temperatures for this well are listed below.

Depth R.T.	Calculated formation temperature
109 m	25.0°C
810 m	36.7°C
1570 m	66.7°C
2225 m	100°C
2496 m	115.6°C
2669 m	121.1°C
3096 m	143.3°C
3385 m	168.3°C

According to BOC, 115°C correlates with the orange to brown (BOCAL maturation 8) spore maturation boundary, to the threshold of significant hydrocarbon generation, and is close to the average temperature at which primary migration, due to clay mineral dehydration, occurs. BOCAL maturation levels 8 and 9 are thought to correspond loosely to the principal oil generation stage. Above these levels all hydrocarbons eventually crack to methane (about 160°C).

Present-day temperatures at Flamingo No. 1 are nearly equal to palaeotemperatures, and elevated soluble organic matter values have been obtained at the second stage dehydration level which extends down from the Cretaceous sediments into the Jurassic sand and shale sequence. Therefore generation and migration are thought to have occurred in these rocks, and cooling over geologic time appears minimal.

In conclusion, total organic yield is highest in the Upper Lower Jurassic to Upper Jurassic sequence. Sapropelic material is not known to be abundant. Spore maturation values at Troubadour No. 1 and Sunrise No. 1

probably cannot be used definitively, but they suggest the Triassic rocks are probably below the oil deadline and that the Jurassic sediments are within the zone of significant hydrocarbon generation.

Time of migration

Montmorillonite dehydration in the Flamingo well appears to extend above the unconformity into the Lower Cretaceous sediments. Present-day temperatures (if accurately determined) are nearly equal to those necessary to de-water montmorillonite (about 120° to 130°C), and hence migration from Jurassic source rocks to Jurassic reservoir rocks may be occurring at present.

An abrupt change in maturation levels (from 8 or 9 to 6) corresponds to the Jurassic-Cretaceous unconformity at Troubadour No. 1, and a similar change occurs at Sunrise No. 1. This may indicate that the palaeotemperatures beneath the unconformity were higher than present-day temperatures. However, present-day temperatures at Troubadour No. 1 are about 100°C in the reservoir section and a temperature of 115°C is reached at the base of the Upper Lower Jurassic to Upper Jurassic sequence. Unfortunately, the clay mineral dehydration zone in this well has not been determined and there is therefore no evidence of whether generation and primary migration have occurred in the vicinity of the well or not. Furthermore the geologic time over which the maximum formation temperatures have been operative at Sunrise No. 1 and Troubadour No. 1 is now known; therefore the temperature and time at which generation may have occurred is not known with certainty (see Cornelius, 1975). The evidence is not conclusive but it appears most likely that petroleum generation on the Sahul Platform began fairly recently and is operative at present.

Reservoir

Middle Jurassic deltaic, littoral, and marine sandstones are potential reservoirs on the Sahul Platform.

Troubadour No. 1 encountered 19 metres of net pay between 2204 and 2244 m in two marine bar sands with average porosity of 9 percent. Present-day formation temperatures are about 100°C.

Sunrise No. 1 encountered 18 metres of net pay between 2140 and 2206 m in two fine-grained sandstones with average porosities of 20 percent.

The lower reservoir is interpreted as a beach sand and the upper reservoir was probably a barrier bar. The sands were deposited during a marine transgression from the north. The palaeo-coastline may have had an easterly to southeasterly orientation.

Flamingo No. 1 encountered Jurassic sands of generally low porosity and permeability at 3415 m to 3701 m where present-day temperatures are about 130°C. Sandstones are generally very fine-grained and are stated to have been deposited in a more marine environment than in the Gull, Petrel, and Tern wells. Lack of porosity is partly due to the fine grain size, and partly a result of diagenetic evolution.

The Jurassic section in Shearwater No. 1 (from 3054 to 3330 m) contained generally fine-grained sandstones that are well cemented with a siliceous matrix. Calculated porosity is low throughout, generally in the 2 to 8 percent range, with occasional thin stringers reaching a maximum of 14 percent. Accurate log determinations of porosity are questionable, and there is a possibility of several thin, moderately porous, hydrocarbon-bearing intervals. The high degree of secondary silicification has resulted in an almost complete destruction of porosity and permeability, a common feature in the area at depths greater than 2750 m.

Structure and seal

Sunrise No. 1 and Troubadour No. 1 tested local culminations near the crest of a much larger domal structure. Shearwater No. 1 and Flamingo No. 1 tested structures nearer the southern margin of the Platform. In each well thick Jurassic and Cretaceous claystone overlies the Jurassic reservoir sequence. Because the seal is thick it may remain effective even where quite large faults cross it. Fault traps can therefore be as effective as anticlinal traps. Sunrise No. 1 tested a large fault trap. Troubadour No. 1, Shearwater No. 1, and Flamingo No. 1 tested faulted anticlines or fault associated anticlines. Therefore any fault or anticlinal trap that developed before migration of hydrocarbons is regarded as a valid target for exploration in this area.

Time of structural development

Because two, and perhaps three, of the four tests on the Sahul Platform discovered some hydrocarbons, the sequence of structural development with respect to migration of hydrocarbons appears generally favourable.

The P-Q* (Jurassic) isopach at Kelp shows thinning over the site of the present structure. The B-C (Triassic and Jurassic) isotime map of the Sunrise/Troubadour area shows thinning over the area, and also over a zone extending to the east. The major thinning in this area, appears to be east of the present culmination, but this conclusion should be checked using data for the P-Q interval from the Kendrew Cootamundra marine seismic survey (BOCAL, 1974c).

Interpretation of these two isopach maps indicates uplift of the two areas before or shortly after the Q horizon sediments were deposited late in the Upper Triassic. The Jurassic sediments thin over the uplift at least partly by abutment unconformity on the Triassic sediment. Part of the thinning may be due to late Jurassic or early Cretaceous erosion.

The M-P (near top Paleocene to near base Upper Cretaceous) isopach for the Kelp area shows regional thickening across and over the structure to the east and southeast. The A-B (Upper Cretaceous to Lower Cretaceous) isotime shows regional south-southeast thickening across the Sunrise-Troubadour area. There is no evidence therefore, of further structural growth of the earlier formed structures during this time.

The E-M (near base Miocene to near top Paleocene) isopach shows southerly thickening strata across the Kelp structure, although there is a thinner area to the north of the early structure, indicating uplift in this area.

The S-A (near base Tertiary? to Upper Cretaceous) isotime map shows major southerly and easterly thickening on the flanks of the Troubadour area and minor thickening to the north and west. The thinning (in time) coincides with the Sunrise and Troubadour structures and other local culminations and the easterly thickening, which is quite pronounced, suggests that the easterly part of the previously uplifted area has subsided, so that from the Upper Cretaceous onwards the major culmination probably lay at and near the Sunrise No. 1 and Troubadour No. 1 locations.

Horizon S (near base Tertiary? - Troubadour area) is closed at both the Sunrise and Troubadour discoveries. Horizon E (near base Miocene - Kelp area) shows no fignificant closure coincident with the culmination on the deeper P horizon.

* For a discussion on seismic horizons and relevant maps refer to Kendrew-Cootamundra (BOCAL, 1974c) and Tessa-Troubadour (BOCAL,1976a) final reports.

The differences and similarities between development of structure in the Troubadour and Kelp areas may be summarised as follows -

(1) Both are reflected by thinning of sediments below the P horizon reflecting either uplift late in the Triassic (most probably) and/or erosion from the crest in the Upper Jurassic. The crestal area of this earlier uplift in the Troubadour area may not have been coincident with the area of the present-day culminations, but further movement in the Upper Cretaceous may have moved the crest of the culmination to its present day position.

(2) An horizon near base Tertiary is deformed into a culmination approximately coincident with the Sunrise and Troubadour culminations on the P horizon, but there is no equivalent major culmination in the Tertiary of the Kelp area.

The Kelp structure has probably been in existence since late in the Triassic. The local culminations at Sunrise and Troubadour developed in the Miocene or later, but they are situated in an area that has been structurally elevated at least since the Upper Cretaceous.

ASSESSMENT OF TROUBADOUR AND SUNRISE IDENTIFIED RESOURCES

Demonstrated resources

The demonstrated resources of the Troubadour and Sunrise fields have been estimated by Ozimic (BMR, personal communication, 1977) and are tabulated below:-

Table 1 - Demonstrated petroleum resources of the Sahul Platform

	Sunrise m^3		Troubadour m^3	
	in place	recoverable	in place	recoverable
Natural gas	21.98×10^9	13.35×10^9	4.35×10^9	2.47×10^9
Sales gas	19.7×10^9	11.59×10^9	3.93×10^9	2.23×10^9
Condensate	1.06×10^6	0.38×10^6	0.715×10^6	0.26×10^6
LPG	8.2×10^6	4.75×10^6	0.547×10^6	0.30×10^6

Inferred resources

The inferred resources are situated in a fault block immediately to the south of the fault block tested by Sunrise No. 1 well.

Adjustment of gas/water contact for use on P horizon map: The reservoir sands in the Sunrise structure lie below the seismic "P" horizon, and are approximately conformable with it. The areal extent of the reservoir sands containing the inferred resources was calculated by effectively raising the top of the reservoir sand to the "P" horizon, and by measuring the area enclosed by a similarly raised inferred gas/water contact on the P horizon map. Errors in the calculation are expected both because a time contour map was used instead of a structure contour (depth) map, and because no allowance was made for a weak unconformity which occurs between the "P" horizon and the reservoir sands. The following tables illustrate the procedure used for determining reservoir areas for the demonstrated resources.

Sunrise structure - upper reservoir

	Depth (metres below MSL)	Two-way reflection time (seconds)
"P" horizon	2036	1.625
top reservoir	2111.5	1.663
reflection time difference		.038
gas/water contact	2217	1.720
measured level		1.682 (1.720 - .038)

Area of the upper sand containing the demonstrated resources could then be calculated using the 1.682 second contour on the "P" horizon map.

Sunrise structure - lower reservoir

	Depth (metres below MSL)	Two-way reflection time (seconds)
top reservoir	2176	1.699
reflection time difference		.074
gas/water contact	2217	1.720
measured level		1.646 (1.720 - .074)

Area of the lower sand containing the demonstrated resources could then be calculated using the 1.646 second contour on the "P" horizon map.

Area of reservoir: The gas/water contact established for the demonstrated resources at Sunrise No. 1 may not extend across the fault into the area of the inferred resources at the same level. We reason that the fault may form a seal, and that the two reservoirs may be independent. The gas/water contacts could then be at different levels for two reasons: displacement by faulting, or different degrees of filling of the two structures. The area of the reservoir may also be affected by unconformity pinchouts, loss of porosity, addition of new sands, interpretation and contouring errors, errors due to use of a time map instead of a depth map, and tilting of the gas/water contact.

The adjusted gas/water contact in the area of the inferred resources was thought to be higher than at Sunrise No. 1 (1.68 second two-way time for the upper sand) because the adjusted gas/water contact at Troubadour No. 1 is higher, suggesting a raising of the gas/water contact to the south. We have selected the 1.67 second contour as the most likely adjusted value for the upper sand for the inferred resources at Sunrise and have derived pessimistic, optimistic, upside, and downside values for the areas of the upper reservoir by contouring on the "P" horizon map. A similar procedure was followed for the lower reservoir. The results are summarised in the following table.

Areas of reservoirs

Upper reservoir		Lower reservoir		
adjusted gas/water contact (seconds)	area m^2	adjusted gas/water contact (seconds)	area m^2	weighting
1.70	3.143×10^8	1.67	1.888×10^8	0
1.68	2.261×10^8	1.65	1.568×10^8	0.8
1.67	1.888×10^8	1.64	0.655×10^8	1.0
1.65	1.048×10^8	1.62	0.126×10^8	0.8
1.64	0.785×10^8	1.61	0.076×10^8	0

Net pay thickness: The following ranges of net pay thickness were estimated.

upper sand thickness (m)	14	9	2
lower sand thickness (m)	15	9	2
weighting	0	1	0

Although the net pay of each of the two sands at Sunrise No. 1 is 9 m, the ranges reflect the possibility of lateral variations away from the well and the observed net pay thickness of non-correlative sands at Troubadour No. 1.

Porosity of reservoir: The following values for porosity were selected after consideration of the environment of the reservoir section at Sunrise No. 1 and Troubadour No. 1 (BOCAL; 1975, 1976b), and of the porosities of the reservoirs at Sunrise No. 1 and Troubadour No. 1. Both reservoirs have similar porosities where tested by the wells and hence the same range is assigned to both.

porosity	22%	20%	15%	8%
weighting	0	6	7	3

The eight percent value was chosen as the value below which the recovery of gas becomes technically impractical.

Reservoir pressure: Reservoir pressures at Sunrise No. 1 and Troubadour No. 1 are 3320 and 3375 p.s.i.g. respectively. A pressure of 3350 p.s.i.g. is assumed for the reservoir containing the inferred resources of the Sunrise structure.

Reservoir temperature: The reservoir temperature assumed, 690°R, is the same as used by BOCAL Pty Ltd in their reserve calculations. (Temperatures of 702°R were measured during drillstem testing at Troubadour No. 1 (BOCAL, 1974a). The reason for their choice of the 690°R value is unknown).

Water saturation: The water saturation at Sunrise No. 1 and Troubadour No. 1 are 30 percent and 42.5 percent respectively. The following range was assumed.

Sw	25%	32%	50%
weighting	0	1	0

Recovery factor: The same recovery factor (59 percent) as used by BOCAL Pty Ltd in their calculations of demonstrated resources of the Sunrise and Troubadour fields was used.

Gas deviation factor: A gas deviation factor of 0.93 was assumed; this value was used by BOCAL Pty Ltd in their calculations of demonstrated resources of the Sunrise and Troubadour fields.

Existence risk: The probability that significant amounts of recoverable natural gas will exist is estimated at 0.95. There is a very low probability of discovering significant recoverable oil (based on the nature of the source material).

Sales gas, condensate, and LPG: We have assumed the same sales gas/natural gas, condensate/natural gas, and LPG/natural gas ratios for the inferred resources as those derived by Ozimic for the Sunrise demonstrated resources.

Expectation of resources: A cumulative probability curve of resources has been produced (Fig. 2) using a computer program developed in BMR (Riesz, in prep.). The mean value of this assessment of these inferred resources of the Sahul Platform is tabulated below:-

Table 2 - Inferred petroleum resources of the Sahul Platform

	in place (m^3)	recoverable (m^3)
Natural gas	36.1×10^9	21.3×10^9
Sales gas	32.4×10^9	19.1×10^9
Condensate	1.74×10^6	0.62×10^6
LPG	13.5×10^6	7.80×10^6

ASSESSMENT OF UNDISCOVERED RESOURCES

Undiscovered resources could exist in prospects in the vicinity of Troubadour and Sunrise fields, along the southern margin of the Sahul Platform, and at the Kelp structure to the west of the Sunrise and Troubadour fields.

All of the prospects near the Troubadour and Sunrise fields, except one, are too small to be considered economic, even if the Sunrise and Troubadour fields were themselves economically viable. However, their in-place resources are calculated to assist in the later assessment of the potential of the Kelp structure.

Two of the prospects along the southern margin of the Sahul Platform have already been tested by Shearwater No. 1 and Flamingo No. 1, and proved to have inadequate reservoir capacity. There is, therefore, a very low probability that reservoir capacity will improve in the other prospects, considering that the potential reservoir sands were deposited in similar environments and subjected subsequently to similar high formation temperatures. The existence risk and reserve expectations of the Anson (A40) structure (Fig. 1) are calculated and demonstrate the low potential of this group of prospects.

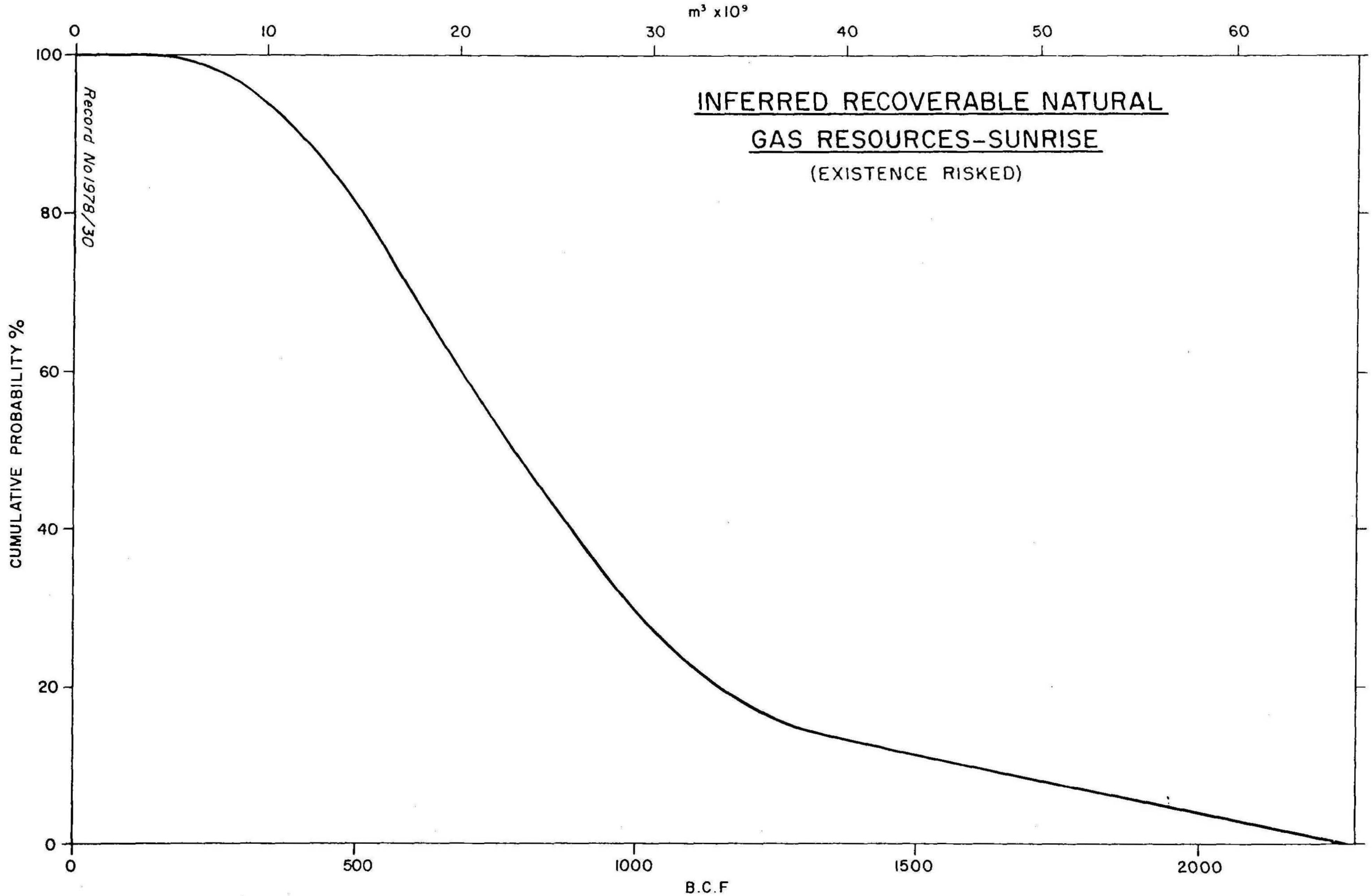

FIG.2

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Of the untested prospects the Kelp structure has the best chance of containing large recoverable gas resources.

Hypothetical resources near the Sunrise and Troubadour fields

East Troubadour structure: The east Troubadour structure (see Fig. 1) is an elevated fault block immediately to the east of the Troubadour structure. The following estimates were made for the various parameters:

Areas of reservoirs

Upper reservoir		Lower reservoir		
gas/water contact (reflection time in seconds)	area m^2	gas/water contact (reflection time in seconds)	area m^2	weighting
1.70	2.048×10^8	1.67	0.99×10^8	0
1.66	0.708×10^8	1.63	0	2
1.65	0.411×10^8	1.62	0	5
-	0	-	0	0

Net pay thickness (m)

upper pay	11	8	4
lower pay	16	11	6
weighting	0	1	0

Porosity of reservoirs

∅	15%	8.7%	7%
weighting	0	1	0.7

Water saturation

Sw	25%	42.5%	50%
weighting	0	1	0

The following single value estimates were made of the gas deviation factor (Z), reservoir temperature (T), reservoir pressure (P), and gas recovery factor (Rg). These estimates are the same as the values BOCAL Pty Ltd used in their calculations of demonstrated resources at Troubadour.

Z	T	P	Rg
0.93	$690^{o}R$	3363 p.s.i.g.	0.59

Existence risk

source	1	
thermal history	1	
reservoir	0.9	reservoir not present?
porosity	0.9	porosity too low?
trap and seal	0.9	trap not as mapped?
time of maturation/ structural growth	1.0	
overall risk	0.7	

A cumulative probability curve of resources, produced by computer processing of this data, is contained in Figure 3. The mean of this estimate is $6.7 \times 10^{9} m^{3}$ of recoverable natural gas. Sales gas, condensate and LPG resources are summarised in Table 3.

North Sunrise structure: The North Sunrise structure is a faulted anticline immediately to the north of the Sunrise structure. The following estimates were made for the various parameters:

Areas of reservoirs

Upper reservoir		Lower reservoir		
gas/water contact (reflection time in seconds)	area m^2	gas/water contact (reflection time in seconds)	area m^2	weighting
1.73	0.44×10^8	1.70	0.28×10^8	0
-	0.26	-	0.07×10^8	0.5
1.70	0.23×10^8	1.67	0.05×10^8	1
-	0	-	0	0

Net pay thickness (m)

top pay	20	10	4
bottom pay	15	8	3
weighting	0	1	0

Table 3 - Hypothetical petroleum resources of the Sahul Platform

	East Troubadour+		North Sunrise+		Anson+		Kelp**	
	in place	recoverable	in place	recoverable	in place	recoverable	in place	recoverable
Natural gas	$11.4x10^9$	$6.7x10^9$	$4.4x10^9$	$2.6x10^9$	$4.6x10^9$	$2.7x10^9$	$96.3x10^9$	$56.8x10^9$
Sales gas	$10.3x10^9$	$6.1x10^9$	$3.9x10^9$	$2.3x10^9$	$4.1x10^9$	$2.4x10^9$	$86.4x10^9$	$49.6x10^9$
Condensate	$1.8x10^6$	$0.68x10^6$	$0.21x10^6$	$0.08x10^6$	$0.31x10^6$	$0.12x10^6$	$6.49x10^6$	$2.34x10^6$
LPG	$1.43x10^6$	$0.78x10^6$	$1.64x10^6$	$0.95x10^6$	$1.53x10^6$	$0.88x10^6$	$31.99x10^6$	$18.45x10^6$

Volumes in m^3

+ Resource values in these categories are mean values only.

** Mean or modal estimate.

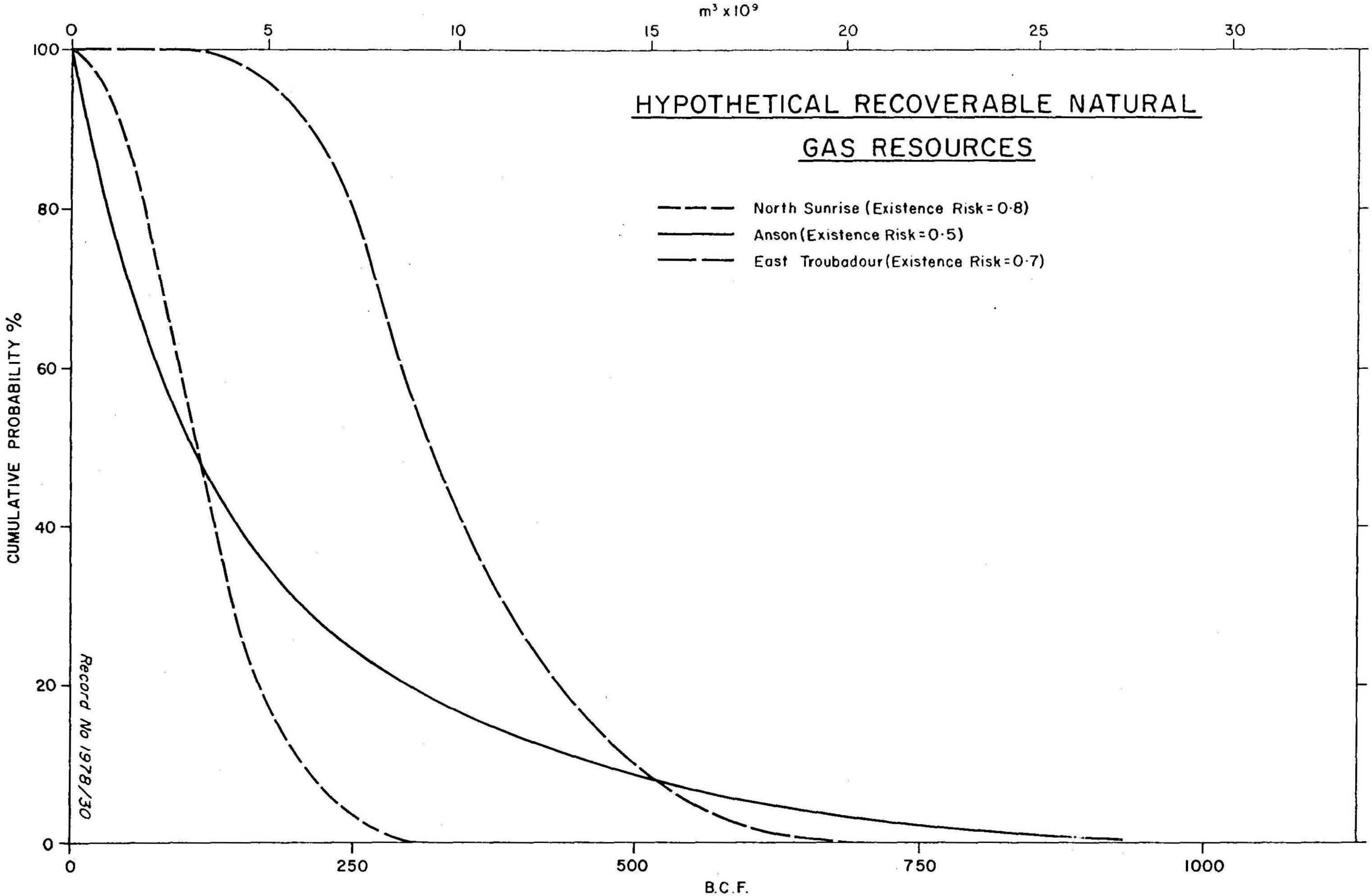
HYPOTHETICAL RECOVERABLE NATURAL GAS RESOURCES
North Sunrise (Existence Risk = 0·8)
Anson (Existence Risk = 0·5)
East Troubadour (Existence Risk = 0·7)
m³ x 10⁹
0
5
10
15
20
25
30
CUMULATIVE PROBABILITY %
100
80
60
40
20
0
B.C.F.
0
250
500
750
1000
Record No 1978/30

FIG.3

Porosity of reservoirs

ø	23%	20%	15%	8%
weighting	0	9	3	0

Water saturation

Sw	25%	30%	45%
weighting	0	1	0

Single values of (Z), (T), (P), and (Rg) were chosen. The same values were used to assess the demonstrated resources of the Sunrise field.

Z	T	P	Rg
0.93	690°R	3360 p.s.i.g.	0.59

Existence risk

source	1
thermal history	1
reservoir	1
porosity	0.9
trap and seal	0.9
time of maturation/structural growth	1.0
overall risk	0.8

A cumulative probability curve of resources, produced by computer processing of this data, is contained in Figure 3. The mean of this estimate is 2.6 x $10^9 m^3$ of recoverable natural gas. Estimates of sales gas, condensate, and LPG are given in Table 3.

Other small closed structures: Four small closed structures were planimetered at the 1.75 second reflection time interval on the P horizon map as this level gave the maximum closure on all the structures. The structures were assumed to be 100 percent filled because of their small size. None of these structures is large enough to be potentially economic, but an estimate of their in-place resources is needed for the volumetric estimation of the in-place resources of the Kelp structure. Therefore we lumped the structures together and treated them as one.

Area of reservoir

area (m^2)	1.8×10^8	0.6×10^8	0.3×10^8
weighting	0	1	0

Net pay thickness

thickness (m)	25	10	5
weighting	0	1	0

Porosity

ø	15%	9%	8%
weighting	0	1	0.5

Water saturation

Sw	25%	45%	50%
weighting	0	1	0

Single value estimates were made of (Z), (T), (P), and (Rg). These values were used in calculations of the demonstrated resources of the Sunrise and Troubadour fields.

Z	T	P	Rg
0.93	690°R	3360 p.s.i.g.	0.59

Existence risk (four structures)

source	1
thermal history	1
reservoir	0.9
porosity	0.8
trap and seal	0.9
time of maturation/structural growth	1.0
overall risk	0.65

The natural gas in the four small closed structures is not classified as a resource. The mean of the estimate obtained by computer processing is $4.3 \times 10^9 m^3$ of recoverable natural gas.

Hypothetical resources on the southern margin of the Sahul Platform (Anson only)

The Anson structure is considered in two parts. The northern part appears to be structurally closed on the reflection time contour map but has little relief. It may be the result of a velocity anomaly. The southern part is fault-controlled and is less likely to lose closure in time-depth conversion. The following estimates were made of the reservoir parameters and existence risk.

Volume of closure

The following volume estimates are based on closure at the respective time contours:

North structure		South structure		Total	
Reflection time interval (sec.)	Volume ($m^3 x 10^6$)	Reflection time interval (sec.)	Volume ($m^3 x 10^6$)	Volume ($m^3 x 10^6$)	weighting
2.30	3000	2.40	14200	17200	0
2.29	1580	2.30	4220	2130	1
2.27	160	2.27	550	160	0

Percent net pay

The potential reservoir rocks are sandstones within the Jurassic sequence beneath the basal Cretaceous unconformity. This sequence exhibited very low porosity in the nearest wells and the percent net pay has been weighted accordingly in the following range of estimates:

% Net pay	70%	10%	7%	3%
Weighting	0	.3	.7	0

Percent trap fill

% trap fill	25%	50%	100%
Weighting	0	1	0

Porosity

∅	14%	10%	8%
Weighting	0	1	0

Water saturation

Sw	25%	45%	50%
Weighting	0	1	0

Single value estimates of (Z), (T), (P), and (Rg) were made as follows:

Z	T	P	Rg
0.93	740°R	4300 p.s.i.g.	.59

Existence risk (northern and southern parts of structure)

source	1
thermal history	1
reservoir	0.5
trap and seal	1
time of maturation/structural growth	1
overall risk	0.5

The mean of this estimate is $2.7 \times 10^9 m^3$ of recoverable natural gas. Estimates of sales gas, condensate, and LPG are given in Table 3.

Hypothetical resources at Kelp

The volumetric method was used to estimate the undiscovered resources at Kelp, using the following reasoning.

1. The areas of closure on maps of the Troubadour dome and the Kelp structure, at the "P" (Base Upper Cretaceous) horizon were planimetered and found to indicate areas of 5148 and 5120 km^2 respectively.

2. At Troubadour No. 1 well, the upper half of the Jurassic interval ("P"-"Q") is considered to have the main source potential. In the absence of nearby well control, the source potential at Kelp is speculative. We have assumed that at Kelp the interval "P-Q" will contain the same proportion of source rock. The thicknesses of the "P"-"Q" isopach measured near the crests of the Troubadour and Kelp structures were about 450 m and 750 m respectively. Therefore the volume of potential source rock in the Kelp dome is estimated at 1.65 times that in the Troubadour dome.

3. Only a small proportion of the Troubadour "dome" appears to have it's potential reservoir filled with gas. The reason for this is assumed to be the lack of adequate source rocks in the area. If the hydrocarbon migration was relatively local (within the dome) and if the situation at Kelp is similar, then a likely estimate of the total volume of gas at Kelp (if any) would be 1.65 times larger than the total volume of gas in the Troubadour "dome".

4. The mean value of recoverable gas in the Troubadour dome is estimated as follows:

(Sunrise inferred, East Troubadour hypothetical, North Sunrise hypothetical, and other hypothetical structures)	-	$36\ 058 \times 10^6 m^3$
Sunrise demonstrated	-	$17\ 600 \times 10^6 m^3$
Troubadour demonstrated	-	$4\ 700 \times 10^6 m^3$
Total		$58\ 358 \times 10^6 m^3$

Thus the volume* of recoverable hydrocarbons in the Kelp structure is:

$$58\ 358 \times 1.65 = 96\ 290 \times 10^6 m^3$$

Corresponding estimates of sales gas, condensate, and LPG are given in Table 3.

RECOMMENDATION

The area should be reassessed as depth contour maps of the relevant seismic horizons are now available.

* One of us (D.J.F.) believes that this is a modal estimate of the Kelp resources; E.J.R. believes it is a mean estimate. This difference of opinion will need to be resolved in future studies.

REFERENCES

ARCO, 1972 - Flamingo No. 1 well completion report. Arco Australia Ltd, Company report (unpublished).

ARCO, 1974 - Shearwater No. 1 well completion report. Arco Australia Ltd, Company report (unpublished).

BOCAL, 1974a - Troubadour No. 1 well completion report. BOC of Australia Ltd, Company report (unpublished).

BOCAL, 1974b - Sunrise No. 1 well completion report. BOC of Australia Ltd, Company report (unpublished).

BOCAL, 1974c - Kendrew Cootamundra marine seismic survey offshore NW Australia final report. BOC of Australia Ltd, Company report (unpublished).

BOCAL, 1975 - Troubadour No. 1 environmental analysis. BOC of Australia Ltd, Company report (unpublished).

BOCAL, 1976a - Tessa Troubadour marine seismic survey offshore NW Australia final report. BOCAL Pty Ltd, Company report (unpublished).

BOCAL, 1976b - Sunrise No. 1 environmental analysis. BOCAL Pty Ltd, Company report (unpublished).

CORNELIUS, C.D., 1975 - Geothermal aspects of hydrocarbon exploration in the North Sea area. Norges Geologiske Undersokelse, 316, 29-67.

RIESZ, E.J., in preparation - SIMULAT, a computer program for the 'prospect by prospect' method of estimating petroleum resources using Monte Carlo simulation. Bureau of Mineral Resources, Australia, Record 1978/2 (unpublished).

RIESZ, E.J., & TEMPLE, P.R., in preparation - An Appraisal of petroleum exploration title areas WA-36-P, NT/P4, NT/P6, NT/P11, NT/P12, NT/P19. Bureau of Mineral Resources, Australia, Record (unpublished).