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### A PRELIMINARY ESTIMATE OF THE UNDISCOVERED PETROLEUM RESOURCES OF AUSTRALIA

~~Restricted~~

by

C.S. ROBERTSON

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### SUMMARY

In November 1977 the Petroleum Exploration Branch, Bureau of Mineral Resources, made a preliminary assessment of the undiscovered recoverable resources of petroleum in Australia. This assessment was based on current knowledge of about 40 basins and areas onshore and offshore around Australia, but was not derived from detailed quantitative analysis of individual prospects or plays. The assessment resulted in mean estimates of 410 million cubic metres (2.6 billion barrels) of undiscovered oil and 920 billion cubic metres (32 trillion cubic feet) of gas.

## 1. INTRODUCTION

The Petroleum Assessment Section of the Petroleum Exploration Branch has among its functions the responsibility for assessing Australia's potential petroleum resources. A major part of its program for 1977 to 1979 consists of an assessment of the undiscovered resources of oil and gas in the Australian region. In November 1977 the three Basin Assessment Groups of the Petroleum Assessment Section co-operated to produce a preliminary assessment based on current knowledge. The aims of this preliminary assessment were:

1. To provide an interim BMR assessment which could serve as a check on estimates available from other sources.
2. To provide a 'baseline' estimate with which later BMR estimates based on more detailed analysis or additional exploration could be compared.
3. To give the assessment groups experience in making and aggregating probabilistic estimates.
4. To indicate which areas were of most significance with respect to undiscovered resources.

## 2. METHOD

The method of assessment employed was a rapid and approximate one which involved only a few days of effort by each of the groups involved. Consequently the estimates arrived at should be used with caution and with the clear understanding that they are only preliminary.

More than 40 different basins and areas constituting the more prospective regions of the Australian continent, the continental shelf, and adjacent submarine plateaus are included in the assessment (Tables 1a to 1c). Each basin assessment group assessed those areas assigned to it for review and assessment according to BMR Program for 1977 to 1979.

It is emphasised that this assessment is concerned only with undiscovered petroleum. None of the quantities of oil or gas quoted in this Record include petroleum already discovered. Furthermore the estimates given relate to quantities of oil and gas believed to be economically recoverable now or in the foreseeable future (20 to 25 years from 1977). There was no detailed analysis of the economics of recovery, but estimates were made with this criterion in mind.

TABLE 1a - UNDISCOVERED OIL

Basin	Exist- ence risk	Minimum		Most likely		Maximum		Existence risk x mean estimate	
		$10^6$ bbl	$10^6$ m <sup>3</sup>	$10^6$ bbl	$10^6$ m <sup>3</sup>	$10^6$ bbl	$10^6$ m <sup>3</sup>	$10^6$ bbl	$10^6$ m <sup>3</sup>
Exmouth Plateau	0.2	300	48	3000	477	10000	1590	956	152
Carnarvon	0.8	100	16	300	48	1000	159	401	64
Browse	0.3	100	16	900	143	2000	318	322	51
Bonaparte Gulf	0.5	100	16	300	48	1000	159	252	40
Gippsland	1.0	30	5	100	16	200	32	117	19
Pedirka	0.3	50	8	250	40	500	80	86	14
Amadeus	1.0	20	3	75	12	130	21	80	13
Perth	0.3	10	2	100	16	500	80	67	11
Carnarvon Terrace & Houtman Sub- basin	0.1	50	8	500	79	1000	159	55	9
Bowen	0.5	20	3	70	11	150	24	43	7
Cooper	1.0	15	2	30	5	60	10	38	6
Surat	1.0	10	2	35	6	50	8	35	6
Canning	0.1	50	8	100	16	500	80	24	4
Capricorn	0.1	50	8	100	16	300	48	16	3
Eromanga	0.1	20	3	100	16	250	40	13	2
Queensland off- shore plateaus	0.01	200	32	1000	159	2000	318	11	2
Galilee	0.1	30	5	80	13	200	32	11	2
Papuan (Aust)	0.1	50	8	70	11	100	16	8	1
Halifax	0.05	50	8	100	16	300	48	8	1
Arrowie	0.1	20	3	70	11	150	24	8	1
Ngalia	0.1	40	6	50	8	80	13	6	1
Adavale	0.1	20	3	40	6	100	16	6	1
Money Shoal	0.03	100	16	100	16	200	32	4	1
Hillsborough	0.05	50	8	60	10	100	16	4	1
Otway	0.05	40	6	60	10	100	16	3	1

TABLE 1a (cont'd)

Basin	Exist- ence risk	Minimum		Most likely		Maximum		Existence risk x mean estimate	
		$10^6$ bbl	$10^6$ m <sup>3</sup>	$10^6$ bbl	$10^6$ m <sup>3</sup>	$10^6$ bbl	$10^6$ m <sup>3</sup>	$10^6$ bbl	$10^6$ m <sup>3</sup>
Bass	0.05	40	6	50	8	80	13	3	0
Bremer	0.01	50	8	60	10	70	11	1	0
Georgina	0.01	40	6	50	8	60	10	1	0
Sorell	0.01	50	8	50	8	50	8	1	0
Polda	0.01	50	8	50	8	50	8	1	0
Great Australian Bight region	0.01	50	8	70	11	100	16	1	0
Officer	0.01	50	8	50	8	50	8	1	0
Drummond	0.01	20	3	30	5	50	8	0	0
Clarence-Moreton	0	-	-	-	-	-	-	-	-
Sydney	0	-	-	-	-	-	-	-	-
Arckaringa	0	-	-	-	-	-	-	-	-
Darling-Bancannia	0	-	-	-	-	-	-	-	-
Maryborough	0	-	-	-	-	-	-	-	-
Miso	0	-	-	-	-	-	-	-	-
Laura	0	-	-	-	-	-	-	-	-
Carpentaria	0	-	-	-	-	-	-	-	-
Murray	0	-	-	-	-	-	-	-	-
Valley River	0	-	-	-	-	-	-	-	-

TABLE 1b - UNDISCOVERED GAS

BASIN	Exist- ence risk	Minimum		Most likely		Maximum		Existence risk <del>Mean</del> estimate	
		$10^{12}$ ft <sup>3</sup>	$10^9$ m <sup>3</sup>	$10^{12}$ ft <sup>3</sup>	$10^9$ m <sup>3</sup>	$10^{12}$ ft <sup>3</sup>	$10^9$ m <sup>3</sup>	$10^{12}$ ft <sup>3</sup>	$10^9$ m <sup>3</sup>
Browse	1.0	2.0	57	15.0	425	30.0	849	17.0	475
Carnarvon	1.0	2.0	57	10.0	283	20.0	566	11.3	321
Bonaparte Gulf	1.0	2.0	57	6.0	170	12.0	340	7.0	198
Perth	0.8	1.0	28	3.0	85	8.0	227	3.5	98
Cooper	1.0	0.5	14	1.5	42	5.0	142	2.5	70
Gippsland	1.0	0.5	14	1.5	42	4.0	113	2.2	61
Pedirka	0.5	0.5	14	1.8	51	4.0	113	1.1	31
Amadeus	1.0	0.5	14	0.7	20	1.2	34	0.8	23
Canning	0.2	0.2	6	2.5	71	6.0	170	0.6	18
Bowen	1.0	0.2	6	0.5	14	1.0	28	0.6	17
Bass	0.8	0.2	6	0.4	11	1.5	42	0.6	17
Adavale	0.8	0.2	6	0.3	9	0.8	23	0.4	11
Surat	1.0	0.1	3	0.2	6	0.5	14	0.3	8
Papuan (Aust)	0.5	0.2	6	0.5	14	1.0	28	0.3	8
Eromanga	0.2	0.2	6	1.0	28	2.0	57	0.2	6
Clarence- Moreton	0.5	0.2	6	0.3	9	0.5	14	0.2	5
Capricorn	0.1	0.3	9	0.5	14	2.0	57	0.1	3
Money Shoal	0.1	0.3	9	0.5	14	2.5	71	0.1	3
Great Australian Bight region	0.1	0.2	6	0.5	14	2.0	57	0.1	3
Georgina	0.2	0.2	6	0.3	9	0.8	23	0.1	3
Halifax	0.05	0.2	6	1.0	28	2.5	71	0.1	2
Ngalia	0.1	0.2	6	0.4	11	1.0	28	0.1	2
Bremer	0.1	0.2	6	0.3	9	1.0	28	0.1	2
Otway	0.1	0.1	3	0.8	23	1.5	42	0.1	2
Sydney	0.1	0.1	3	0.5	14	1.5	42	0.1	2
Hillsborough	0.05	0.2	6	0.4	11	0.6	17	0.0	1
Galilee	0.1	0.2	6	0.3	9	0.8	23	0.0	1
Polda	0.1	0.2	6	0.3	9	0.4	11	0.0	1
Sorell	0.1	0.2	6	0.3	9	0.5	14	0.0	1
Drummond	0.1	0.1	3	0.2	9	0.5	14	0.0	1
Arckaringa	0.1	0.2	6	0.3	9	0.6	17	0.0	1
Maryborough	0.1	0.2	6	0.3	9	0.4	11	0.0	1
Arrowie	0.05	0.1	3	0.3	9	0.6	17	0.0	1
Darling- Bancannia }	0.05	0.1	3	0.3	9	0.5	14	0.0	0
Officer	0.01	0.4	12	0.6	18	1.6	46	0.0	0
Wiso	0.02	0.2	6	0.3	9	0.5	14	0.0	0
Laura	0	-	-	-	-	-	-	-	-
Carpentaria	0	-	-	-	-	-	-	-	-
Murray	0	-	-	-	-	-	-	-	-
Daly River	0	-	-	-	-	-	-	-	-



TABLE 1c - UNDISCOVERED GAS IN DEEP WATER

BASIN	Existence risk	Minimum		Most Likely		Maximum		Existence risk x mean estimate	
		$10^{12} \text{ ft}^3$	$10^9 \text{ m}^3$	$10^{12} \text{ ft}^3$	$10^9 \text{ m}^3$	$10^{12} \text{ ft}^3$	$10^9 \text{ m}^3$	$10^{12} \text{ ft}^3$	$10^9 \text{ m}^3$
mouth plateau	0.4	2.0	57	30.0	849	100.0	2832	19	543
owse Basin	1.0	2.0	57	15.0	425	30.0	849	17	475
rnarvon terrace and utman sub-basin	0.2	0.3	8	5.0	142	12.0	340	1	35
eensland offshore plateaus	0.01	2.0	57	10.0	283	15.0	425	0.1	3

For each basin or area considered, the estimates of undiscovered resources were arrived at by a two-step process. Firstly, an estimate was made of the probability that the basin had generated economically recoverable oil ( $p$  = existence risk,  $0 < p \leq 1.0$ ). A similar probability was estimated independently for gas. Then, assuming that recoverable oil and/or gas did occur in the basin ( $p > 0$ ), three-point estimates were made of the quantity of undiscovered oil and gas likely to be found in the basin as follows:

- (1) An estimate was made of the minimum amount of oil, **such** that it was considered that there was about a 95% chance that the actual quantity would exceed this. A similar estimate was made for gas.

Since the estimates were of economically recoverable petroleum, it was necessary that minimum estimates for particular areas should not be less than the amount of petroleum which would be contained in one field of economic size.

- (2) An estimate was made of the maximum amount of oil, such that it was considered that there was about a 95% chance that the actual quantity would be less than this. A similar estimate was made for gas.
- (3) Estimates were made of the quantities of oil and gas most likely to occur.

From the three-point estimates described above the mean estimates of undiscovered oil and undiscovered gas were computed for each basin assuming a simple, triangular probability distribution. The product of the existence risk  $p$  and the mean estimate then gave the 'expected value' (Newendorp, 1975) for the quantity of undiscovered oil or gas in the basin (Tables 1a to 1c).

The existence risk for each basin was estimated after consideration of factors such as the occurrence of source rocks, reservoir rocks, trapping mechanisms, and suitable maturation history. However, in most cases probabilities were not assigned to each of these factors individually, but rather the combined effect of these factors was assessed mentally in making a subjective estimate of existence risk for a basin. Where there had been a discovery of economically recoverable petroleum in a basin the existence risk was taken to be 1.0.

Estimates of the quantities of **undiscovered oil and gas likely** to be found were based on factors such as the size of the basin, thickness

of prospective sediments, and abundance and sizes of potential traps. Quantities of undiscovered petroleum were estimated mentally without actual mathematical calculation of volumes. To do this it was necessary to draw on knowledge of petroleum occurrences elsewhere.

Initial estimates for the various basins and regions of Australia were made as described above by the three basin assessment groups, each group covering about one-third of the total basins according to its areas of responsibility assigned in the 1977 BMR Program. Then the supervisors of the three groups met with the author, and the estimates for the various individual basins were compared and discussed with a view to reaching a consensus on acceptable estimates for all basins. Although estimates of undiscovered resources differed very greatly between basins there was generally good agreement between supervisors on the relative prospectivities of basins and the likely quantities of undiscovered resources in those basins. The extent of this agreement tends to support the validity of the method employed here for a rapid, preliminary assessment.

The three-point estimates for oil and gas for the various areas were then aggregated in a number of different combinations using a Monte Carlo simulation technique implemented by computer, using routines from the program SIMULAT (Riesz, 1978).

### 3. RESULTS

The basin-by-basin estimates of the likely quantities of undiscovered oil and gas agreed on above, with some minor rationalisation by the author, are shown in Tables 1a to 1c.

In Table 1c estimates of undiscovered gas in four offshore areas covered by water deeper than 200 m are shown separately from the majority of gas estimates. These areas, which together are considered likely to contain very significant amounts of gas, are separated from the others because the technology for economically recovering gas in deep water has not yet been proved and there is some doubt as to whether it will be proved in the next 20 to 25 years. The undiscovered gas of Table 1c has been aggregated separately because it is not presently considered a resource. Estimates for gas resources shown elsewhere in this Record do not include the gas deposits that may occur in the four deep-water areas unless specifically stated.

Estimates of total undiscovered resources of oil and gas are shown in Figures 1 to 3 in the form of cumulative probability curves, which express the probabilities that more than a given quantity of oil or gas will be found.

Figure 1 indicates that there is an 80% chance that more than 180 million cubic metres (1100 million barrels) of oil remain to be discovered, and that there is a 20% chance that there is as much as 560 million cubic metres (3500 million barrels) of undiscovered oil. The mean estimate or 'expected value' is 410 million cubic metres (2600 million barrels.) There is about a 50/50 chance that further exploration would result in a doubling of Australia's remaining demonstrated economic resources (NEAC, 1978).

Figure 2 indicates that the outlook for future gas discoveries is considerably brighter than for oil discoveries. There is an assessed 80% chance of finding at least 780 billion cubic metres (28 trillion cubic feet) of additional gas and there is a 20% chance that as much as 1050 billion cubic metres (37 trillion cubic feet) may remain to be discovered. The mean estimate or expected value for undiscovered gas is 920 billion cubic metres (32 trillion cubic feet). These estimates for gas do not include possible undiscovered gas in deep-water areas such as the Exmouth Plateau and Browse Basin, where the economics of gas production are questionable. Figure 3 indicates that large additional amounts of gas could occur in these areas. The mean estimate or expected in value for this undiscovered gas in water deeper than about 200 m is 1050 billion cubic metres (37 trillion cubic feet).

Table 2 shows the risked mean estimates of undiscovered oil and gas for the whole of Australia and for various geographical regions in both metric and traditional units. The division of undiscovered resources between onshore and offshore regions shows that the offshore areas are considered much more prospective than onshore areas. Approximately 84% of undiscovered oil and 74% of undiscovered gas are expected to occur offshore.

The table also indicates that the Northwest Shelf contains a major proportion of the nation's undiscovered petroleum resources. This region is expected to contain ten times the undiscovered oil resources of the industrial states of southeastern Australia - NSW, Victoria, and South Australia, and three and a half times the gas resources expected to be discovered in those states. The remoteness of the Northwest Shelf from the industrial states in the southeast poses special problems of transport if and when the resources in the northwest are proved and when the local resources in the southeast are exhausted.

Fig.1

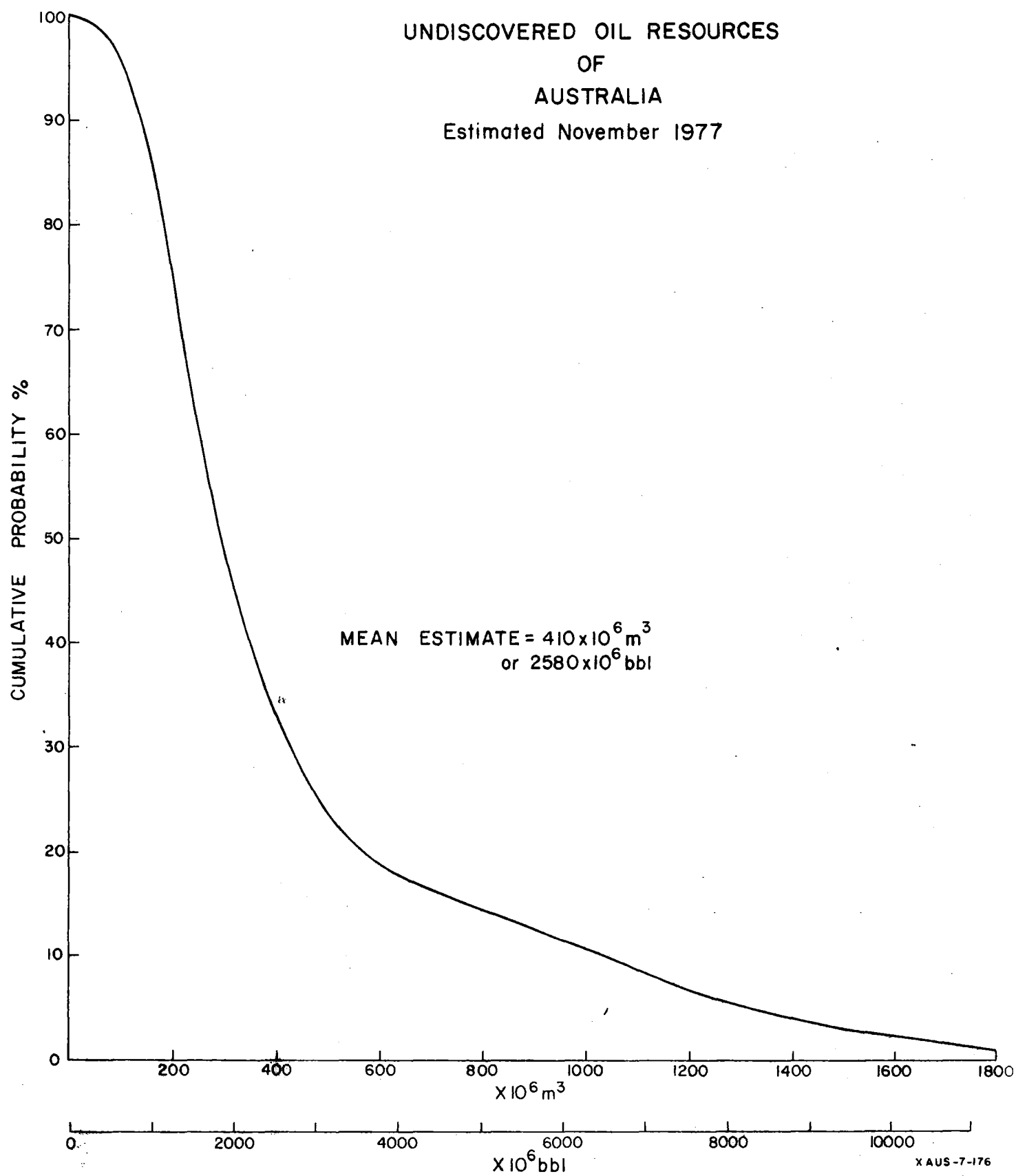


Fig. 2

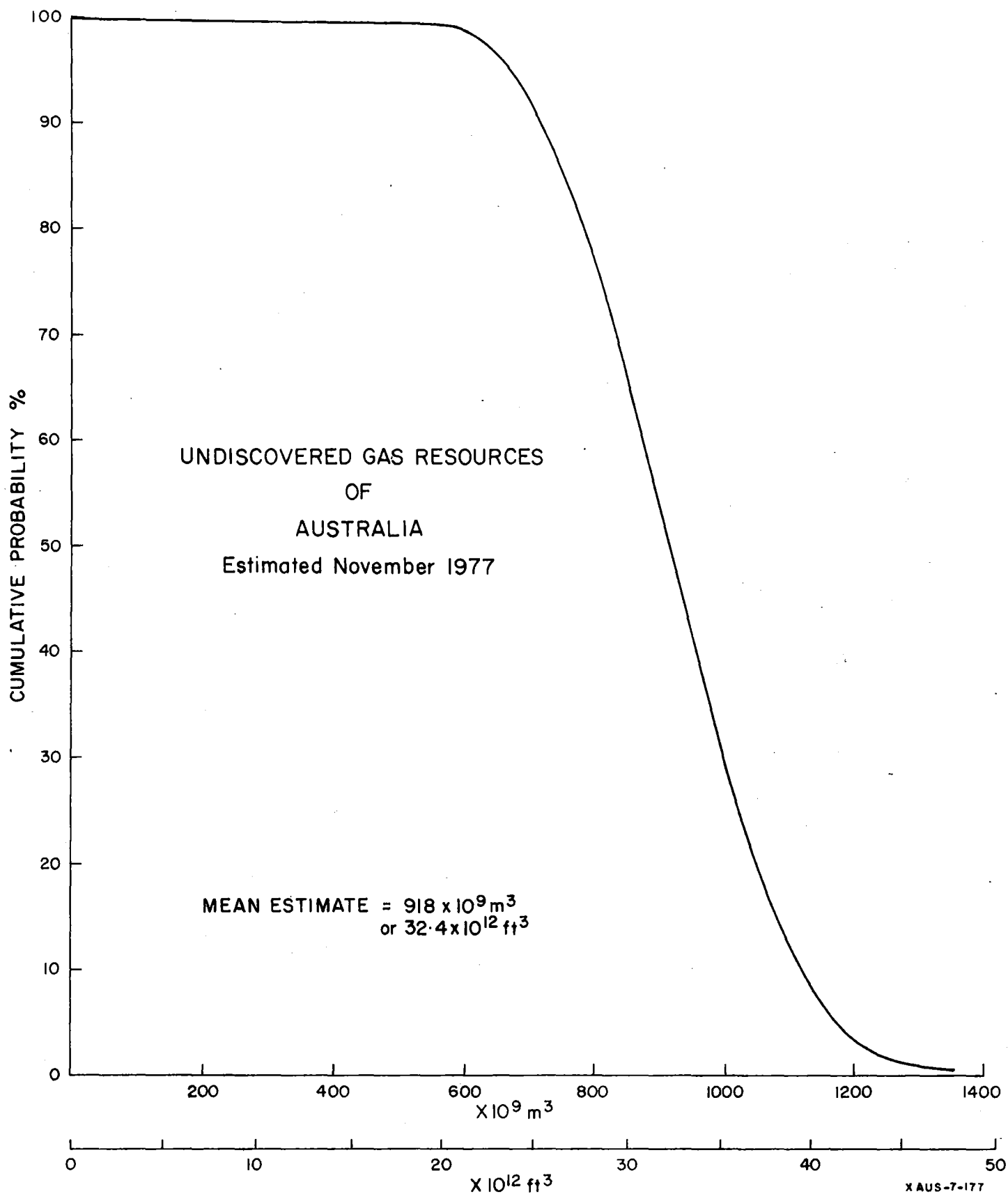


Fig.3

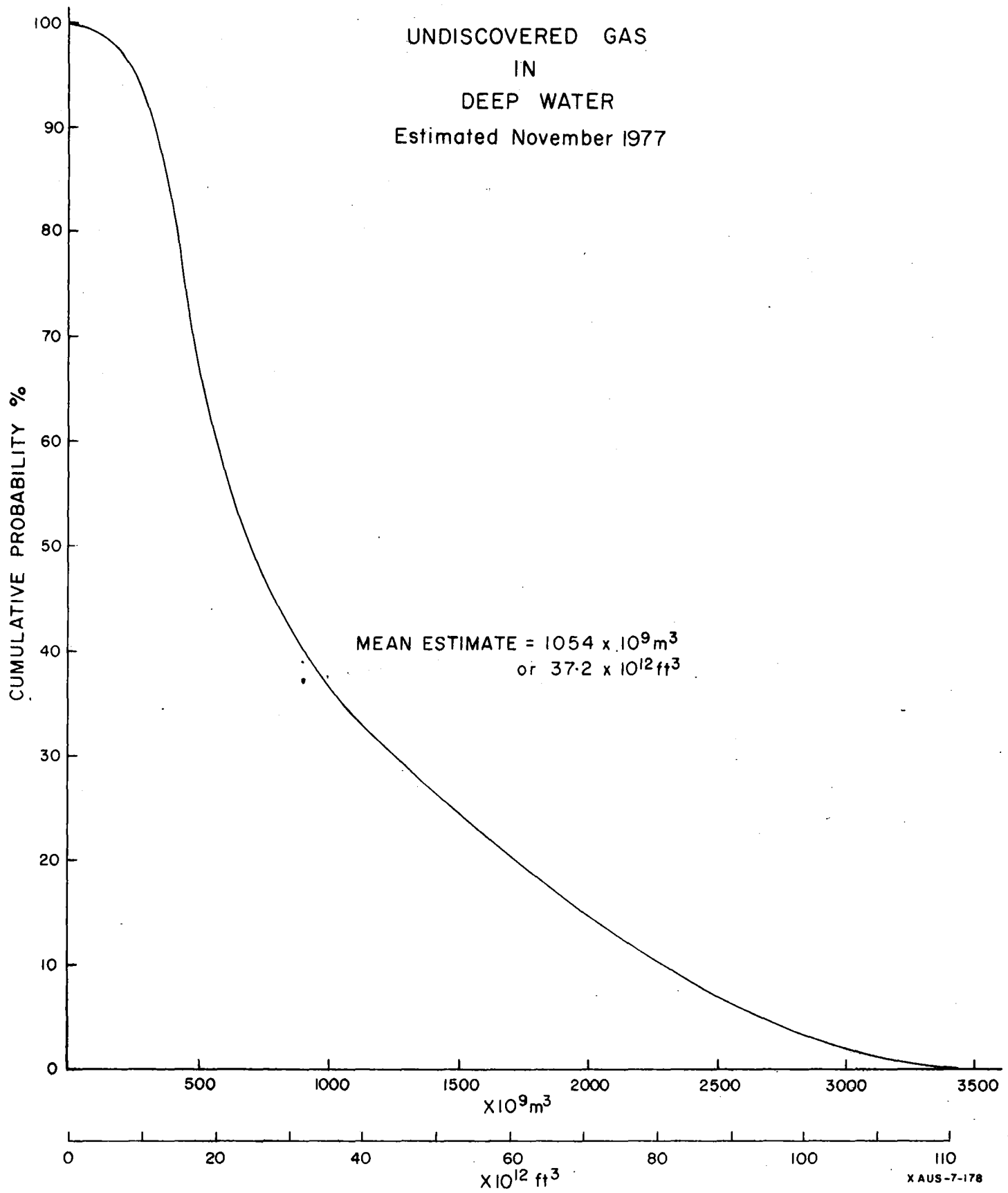


TABLE 2.

RISKED MEAN ESTIMATES OF UNDISCOVERED OILAND GAS BY GEOGRAPHICAL REGIONS

November 1977

Region	Risked mean estimate for oil		Risked mean estimate for gas	
	$10^6$ bbl	$10^6$ m <sup>3</sup>	$10^{12}$ ft <sup>3</sup>	$10^9$ m <sup>3</sup>
Whole of Australia (excluding gas in deep water)	2580	410	32.4	918
Deep water areas (gas only)			37.2	1054
Australia - onshore	406	65	8.4	238
Australia - offshore	2174	345	24.0	680
Northwest Shelf	1947	309	18.3	518
NSW + Vic + SA	195	31	5.1	142
Western Australia	1955	310	19.0	538
Northern Territory	250	40	5.1	145
Queensland	177	28	2.6	75
Victoria	121	19	2.3	65
South Australia	74	12	2.5	71
Tasmania	3	1	0.6	16
New South Wales	0	0	0.3	8



Finally, the breakdown of undiscovered petroleum resources by states in Table 2 highlights the preponderance of prospective discoveries in Western Australia, which is expected to contain about three times as much undiscovered oil and one and a half times as much gas as the remaining States and the Northern Territory combined. As far as the political divisions of Australia are concerned, the Northern Territory comes a poor second to Western Australia, but it is about twice as prospective as Queensland, Victoria, or South Australia. Tasmania and New South Wales seem to be much more poorly endowed with petroleum resources than all the other States.

Table 3 gives the mean estimates or expected values for undiscovered oil and gas resources in all areas considered (excluding gas in the deep-water areas of Table 1c), and separately for groups of basins or areas believed to contain the major part of undiscovered resources - i.e. the 15 most prospective, 10 most prospective and 5 most prospective basins for future petroleum discoveries. This table further illustrates the uneven distribution of resources between basins and the extent to which undiscovered resources are believed to be concentrated in relatively few areas. It may be noted, for example, that more than 90% of undiscovered oil and more than 90% of undiscovered gas are expected to reside in the 10 most prospective basins or areas, while all the remaining areas are expected to contribute only a minor proportion of resources.

Figure 4 illustrates in histogram form the relative prospectivities of various basins and areas. On this diagram, undiscovered gas resources have been converted to oil equivalents ( $6000 \text{ ft}^3$  of gas equivalent to 1 barrel of oil) and added to oil resources to provide a measure of total undiscovered petroleum resources in various areas. On this basis the Carnarvon Basin, Bonaparte Gulf Basin, and Exmouth Plateau are believed to be the most prospective areas at the present stage of exploration. If gas in waters deeper than 200 m were regarded as economically viable, then the Exmouth Plateau would become the most prospective area, followed by the Browse Basin and then the Carnarvon Basin.

#### 4. CONCLUSIONS

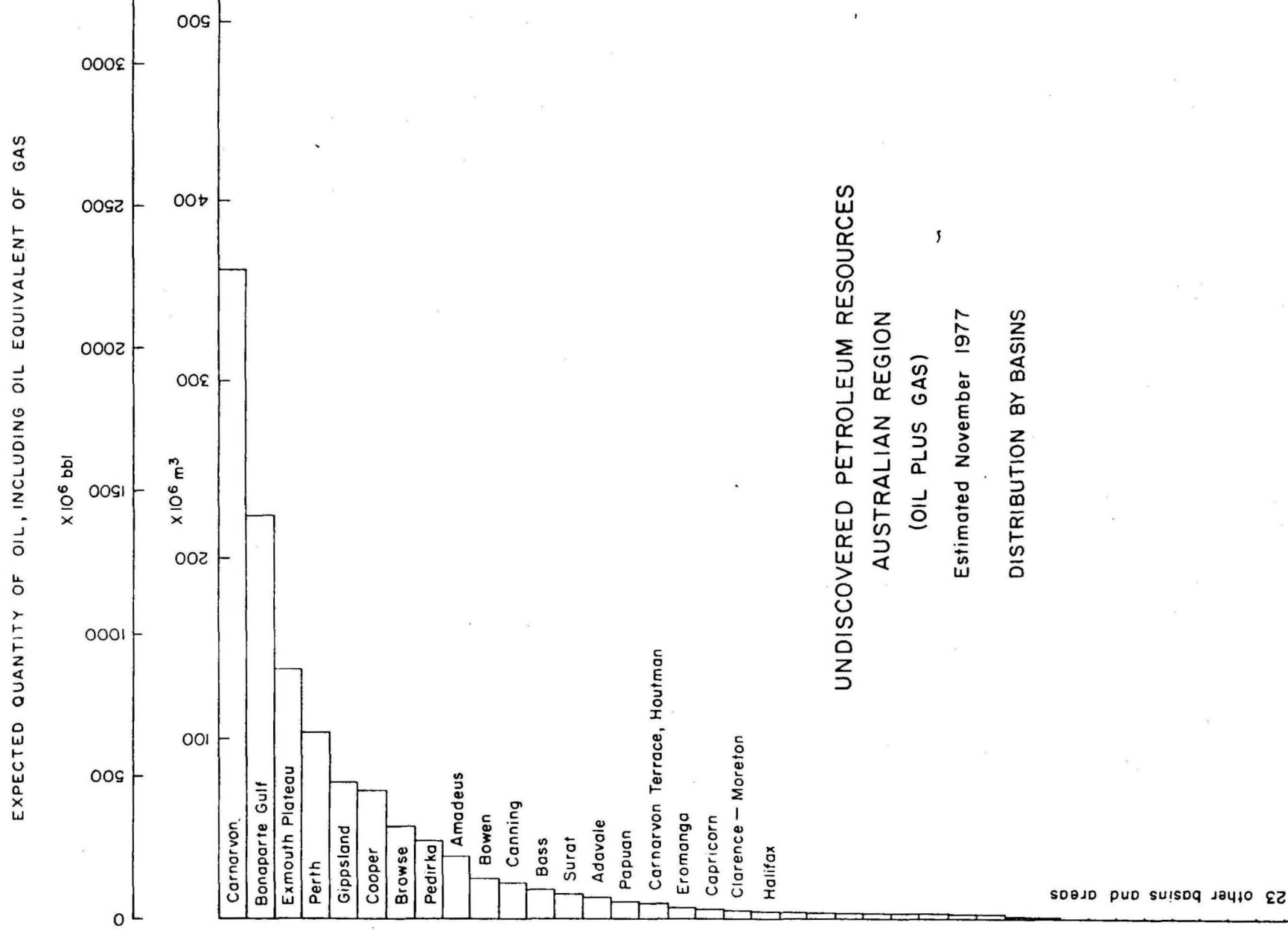
It was found that there was a considerable degree of consensus within the Petroleum Assessment Section about the potential for petroleum

TABLE 3

CONCENTRATION OF UNDISCOVERED PETROLEUM  
RESOURCES

SAMPLE	OIL			GAS		
	Risky mean estimate or expected value		Percentage of total	Risky mean estimate or expected value		Percentage of total
	$10^6$ bbl	$10^6$ m <sup>3</sup>		$10^{12}$ ft <sup>3</sup>	$10^9$ m <sup>3</sup>	
All basins or areas (except as in Table 1c )	2580	410	100	32.4	918	100
15 most prospective areas	2505	399	97	31.5	890	97
10 most prospective areas	2379	379	92	30.1	853	93
5 most prospective areas	2048	326	79	26.4	748	81

Fig. 4



discoveries in various areas. Although estimates for most areas were not based on detailed quantitative analysis, there was considerable 'feeling', based on current knowledge of areas, about the likelihood or otherwise of the occurrence of petroleum and the minimum and maximum quantities expected. Nevertheless it is recognised that there is room for argument over estimates for individual areas listed in Tables 1a to 1c, and those responsible for the estimates would certainly wish to modify the estimates after further consideration.

The estimates for individual areas may be subject to considerable errors, but if as is likely the estimates are in some cases too high and in others too low, it may be expected that there will be some cancellation of errors in the aggregates. The probable estimates for large groups of areas are therefore considered more reliable than the estimates for individual areas.

The only other known estimates of Australia's undiscovered resources of oil and gas were made by Esso Australia Ltd in 1976 and 1977 (Jeffries, 1976; Esso, 1977). The present assessment by BMR has produced a total estimate for petroleum (oil plus gas) which is not greatly dissimilar to that of Esso, although the assessors were in no way influenced by the earlier conclusions of Esso. However, Esso's mean estimate for undiscovered oil is about 40% more optimistic than the preliminary estimate by BMR, whereas their mean estimate for undiscovered gas is about 40% less optimistic than the preliminary BMR estimate, including gas in deep-water areas. Having regard to the limitations of methods of assessing undiscovered resources, it must be said that the agreement between the estimates of Esso and BMR is reasonably good.

The current assessment has reinforced the view that most of Australia's undiscovered petroleum resources are concentrated in a few areas. The most important of these are believed to be:

- Carnarvon Basin
- Bonaparte Gulf Basin
- Exmouth Plateau
- Perth Basin
- Gippsland Basin
- Cooper Basin
- Browse Basin
- Pedirka Basin
- Amadeus Basin
- Bowen Basin

The remaining 33 basins and areas included in the assessment are considered to contain less than 8 percent of total undiscovered resources. Of the ten basins listed above, the first five are considered likely to contain some 71 percent of total resources. It follows that, if it is desired to produce a more reliable estimate of overall petroleum resources remaining to be discovered, most of the available effort should be concentrated on the few areas with most potential. However, it is recognised that the geographical location of resources is also important, as relatively small resources close to large markets may be very significant, and the converse may also be true to some extent depending on development and transportation costs.

It should be noted that one of the areas considered to have great potential, the Exmouth Plateau, has not yet been drilled. Further exploration including drilling on the Plateau in the next few years could significantly alter the mean estimate of undiscovered oil resources, particularly if exploration results are discouraging. Exploration on such areas of high potential should be followed and evaluated closely so that an up-to-date assessment of Australia's petroleum resources may be maintained.

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