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CRUDE OIL CORRELATIONS IN THE PERTH AND CARNARVON BASINS

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ABSTRACT

Crude oil and condensate samples recovered during exploration drilling can provide valuable geochemical information which may be used in assessing the origin, accumulation, and present distribution of hydrocarbons in the exploration area.

Geochemical analysis of oils from Permian to Jurassic reservoirs in the northern part of the Perth Basin has shown them to be unique and virtually identical in composition. They are characterized by a high wax content and a low gasoline yield. This latter feature is explained by the immaturity of the source material and, in some cases, by water washing in the reservoir. Condensates from equivalent stratigraphic levels in the Gingin and Walyering fields are similar in composition.

Two families of oils occur in the Barrow Sub-basin of the Carnarvon Basin. Oils recovered from Cretaceous sediments (Windalia Radiolarite, Muderong Greensand, and Birdrong Sand) are naphthenic to aromatic, whereas those produced from the Jurassic Dingo Group are high wax oils of paraffinic to naphthenic base. In the Dampier Sub-basin, the Jurassic condensates of the Angel field are virtually identical in composition with the condensates and oil in Triassic reservoirs of the Rankin Trend. A common Jurassic source is likely for these hydrocarbons, which are also similar in composition to the Jurassic oils of the Barrow Sub-basin. Oil in a minor show from the Toolonga Calcilutite in the North Rankin No. 1 well strongly resembles the Windalia oil at Barrow Island.

A plot of correlation index against pristane to phytane ratio shows that the oils fall into distinct groups according to the nature of their source environment and degree of maturity.

INTRODUCTION

Recent work (Powell & McKirdy, 1972) has shown that Australian crude oils are light by world standards. They have API gravities greater than 35°, low sulphur and asphalt values, and are generally of paraffinic to naphthenic base. The compositional affinities of crude oils within certain sedimentary basins in Australia suggested that geochemical data might well serve as a basis for more detailed correlation studies in specific areas. Many attempts at crude oil correlation have been made using single parameters, e.g. carbon (Silverman & Epstein, 1958) and sulphur (Thode & Monster, 1971) isotopic ratios; relative concentrations of individual hydrocarbons (Welte, 1967), and trace element ratios (Hodgson, 1954). However, as pointed out by Barbat (1967), USBM correlation indices (together with sulphur and nitrogen assays) provide a chemical profile of the whole oil, and can therefore yield more information on the history and genetic relationships of crude oils. The efficacy of such an approach has been demonstrated in Libya (Byramjee & Vasse, 1969) and Canada (Rogers et al., 1971; Evans et al., 1971).

In the present investigation oil samples were examined from wells drilled in the Dandaragan Trough of the Perth Basin (Fig. 1) and the Barrow and Dampier Sub-basins of the Carnarvon Basin (Fig. 2). The analytical methods used were those described by Powell & McKirdy (1972).

PERTH BASIN

The tectonic elements, stratigraphy, and distribution of hydrocarbons in the Perth Basin have been summarized by Jones & Pearson (1972). Oil and gas-condensate discoveries in the northern part of the Perth Basin are confined to two areas of the Dandaragan Trough (Fig. 1).

North Dandaragan Trough

The hydrocarbons in this area, adjacent to the Dongara Saddle, comprise gas and oil. They occur in Permian to Jurassic reservoirs (Fig. 3). Only the gas is commercial and it occurs in the Dongara, Mondarra, and Yardarino fields (Fig. 1). The main reservoirs are located in the Basal Triassic Sandstone, which in part rests unconformably on Permian sediments. In each field the gas overlies an oil zone. Oil also occurs within the Triassic Kockatea Shale in the Mount Horner No. 1 and North Erregulla No. 1 wells, and in the Jurassic Cockleshell Gully Formation in the Erregulla No. 1 well.

Correlation curves (Fig. 4) show that the oils and condensates are highly paraffinic, and that they are clearly related. The corresponding pristane to phytane ratios fall in a very narrow range (1.0 - 1.5) and the API gravities of the oils show little variation (34.6 - 37.6°). All the oils are extremely waxy, being solid at room temperature. However, distillation data (Table 1) show that the oils from the Dongara, Mondarra and Yardarino fields are stripped of light ends (i.e. fractions boiling below 200°C) compared to those oils from the remaining wells. Elsewhere this feature has been attributed to water washing in the reservoir (Evans et al., 1971). The absence of low boiling components from these oils indicates that they are not in equilibrium with the overlying gas. This in turn could imply that the accumulation of the oil and the gas were separate events. Nevertheless, the similarity in the correlation curves and pristane to phytane ratios of the respective oils and condensates strongly suggests that they have a common or related source.

The relatively low yield of low-boiling fractions, even in those oils which have not been washed by water, and the lack of naphthenic components indicate that the oils have been little affected by thermal alteration. High wax oils are generally thought to be derived from terrestrial organic material (Hedberg, 1968). Oils which originate from land plant detritus are postulated to have high pristane to phytane ratios (Brooks et al., 1969). The pristane to phytane ratios of coals have been shown to increase from low values (1-3) in brown and sub-bituminous coals to appreciably higher values (7-10) in high volatile bituminous coals (Brooks et al., 1969). Mature oils of terrestrial origin in the Gippsland and Bowen-Surat Basins display high pristane to phytane ratios (Powell & McKirdy, 1972) and a higher proportion of naphthenic components. Thus, the waxy nature of the oils in the northern Dandaragan Trough, absence of naphthenic components, poor yield of light fractions, and low pristane to phytane ratios together indicate a source from terrestrial organic matter which has undergone little thermal alteration.

The Kockatea Shale is probably the source for the oils in this area. Although this formation is considered to have been deposited in a marine environment (Jones & Pearson, 1972), its organic content is of terrestrial origin (G. Demaison, personal communication). The oil in the Mount Horner No. 1 well occurs in sandstone lenses within the Kockatea Shale and is thought to be more or less in situ. The Basal Triassic Sandstone, the main reservoir formation, underlies the Kockatea Shale. If the Kockatea Shale is the source for the hydrocarbons it is difficult to envisage two periods of generation and migration, one for the oil and another for the gas. A more plausible explanation is that the oil was derived from the Kockatea Shale, whereas the dry gas originated in more thermally altered Permian Coal Measures downdip of its present location.

Central Dandaragan Trough

Gas/condensate is produced from the Gingin and Walyering fields, which are approximately 55 km apart in the central Dandaragan Trough (Fig. 1). Several unconnected sands within the Cockleshell Gully Formation are the producing zones. Two samples of condensate from different levels within the Gingin field were compared with two samples from equivalent stratigraphic intervals in the Walyering field. In each case the condensate from the greater depth contains a higher proportion of heavy hydrocarbons (Table 1). The correlation curves (Fig. 5) show that the samples from equivalent horizons are similar in composition, but that there are marked differences between the upper and lower levels within the same field. The pristane to phytane ratios of the two deeper condensates are similar (3.1 and 3.4). There is, however, an unexplained discrepancy in the values for the shallow samples (5.5 and 2.8). The most likely source for these condensates is the Cockleshell Gully Formation itself. This formation was deposited in a marginal marine to continental environment (Jones & Pearson, 1972).

The condensates are paraffinic to naphthenic and those from deeper levels have a high wax content. All show intermediate pristane to phytane ratios which, in combination with the other compositional data, indicate a mixed source.

CARNARVON BASIN

Oil and gas/condensate discoveries within the Carnarvon Basin (Fig. 2) are located in sediments ranging in age from Triassic to Cretaceous (Fig. 6).

Barrow Sub-basin

Oil has been recovered from both Jurassic and Cretaceous formations in the Barrow Sub-basin, but only that occurring in the Cretaceous is commercial. Samples were examined from the Windalia "Sand", the Muderong Greensand and three levels within the Barrow Group at Barrow Island (2044 m, 2013 m, and 1891 m in the Barrow No. 1 well). In addition, oils from the Birdrong Sand (Cretaceous) in the Flinders Shoals No. 1 well, and from two levels within the Jurassic (1739 m and 1800 m) of the Pasco No. 1 well were analysed.

The correlation curves (Fig. 7) indicate that the oils in the Barrow Sub-basin fall into two families. Those occurring in Cretaceous reservoirs are naphthenic to aromatic in composition, in contrast to the Jurassic oils, which are paraffinic-naphthenic and have a high wax content. The difference between the two groups of oils lies mainly in their proportion of straight-chain paraffins. Gas chromatograms of the saturated hydrocarbons isolated from the Jurassic oils are dominated by n-alkanes, although substantial amounts of naphthenic hydrocarbons are also present. The oils from Cretaceous reservoirs contain an extremely complex mixture of naphthenic hydrocarbons, with n-alkanes forming only a small fraction of the total (Powell & McKirdy, 1972).

The oil recovered from the Birdrong Sand in the Flinders Shoals No. 1 well is stripped of the lighter boiling components and has probably been water-washed in the reservoir. It is of interest that the Birdrong Sand is a prolific aquifer in this area. The Muderong Shale and Gearle Siltstone, both marine formations, are considered to be the source for the Cretaceous oils (Parry, 1967). The Muderong Greensand at Barrow Island yielded an oil that is very similar to the Windalia crude. The low pristane to phytane ratios (1.8 - 3.1) of these oils and their high correlation indices are consistent with a marine source. Nevertheless, their precise mode of origin remains a problem.

Modern theories of petroleum genesis envisage the generation of hydrocarbons at depth under the influence of elevated temperatures from organic-rich sediments (Phillipi, 1965). The Cretaceous oils in the Barrow Sub-basin appear to be examples of relatively shallow, low temperature generation. However, they yield a high proportion of light boiling components, which is not characteristic of the heavy asphaltic oils through to originate at shallow depths. The low permeability of the Windalia 'Sand' (Parry, 1967) precludes extensive migration in the reservoir from down dip, where more elevated temperatures might be expected to exist.

The origin of the oils in the deeper Jurassic reservoirs is less problematic. Their intermediate pristane to phytane ratios (3.3 - 3.5), paraffinic-naphthenic base and high wax content suggest a mixed marine and terrestrial source, in keeping with an origin in the marginal marine Jurassic sediments.

Dampier Sub-basin

Gas/condensate and oil are known fromTriassic, Jurassic, and Cretaceous formations within the Dampier Sub-basin (Fig. 6). The major gas/condensate discoveries (North Rankin No. 1, Goodwyn No. 1 and Rankin No. 1 wells) have been made in Triassic sediments of the Rankin Trend (Kaye et al., 1972). A thin oil column was encountered in the Rankin No. 1 well beneath the gas/condensate and a small amount of oil was recovered from the Toolonga Calcilutite (Cretaceous) in the North Rankin No. 1 well. Gas/condensate has been found in the Jurassic-Cretaceous Barrow Group at the Angel location and a non-commercial oil discovery was made in the same formation in the Legendre No. 1 well.

The correlation curves (Fig. 8) reveal a basic similarity in composition of the oils and condensates from both the Jurassic-Cretaceous and Triassic reservoirs. The close resemblance of the condensates from the Rankin Trend and the Angel field is particularly striking and a common source is likely.

The Rankin Platform is an uplifted Triassic fault block overlain unconformably by Cretaceous sediments. A fault with a downthrow to the southeast of up to 2 400 m separates it from a trough of Jurassic sediments (Kaye et al., 1972). The Madeleine-Dampier Anticlinal Trend, on which the Angel field is located, is formed of Jurassic sediments. The chemical evidence suggests that the hydrocarbons of the Rankin Trend, Angel field, and Legendre well have been generated in the Jurassic sediments in the troughs between the respective anticlinal trends. Subsequent migration updip led to their accumulation in Triassic sands on the Rankin Platform, and in Jurassic sands in the Angel and Legendre locations. Jurassic deltaic sediments encountered at depth in the Madeleine No. 1 and Dampier No. 1 wells are excellent source rocks (Powell & McKirdy, unpublished results) and the mixed non-marine and marine nature of their organic matter is consistent with the intermediate pristane to phytane ratios (3.3 - 4.3) observed in the oils. The Triassic sediments of the Rankin Trend are non-marine and show little evidence of source potential (Powell & McKirdy, unpublished results). The oils and condensates of the Dampier Sub-basin are slightly more naphthenic than the Jurassic oils in the Barrow Sub-basin and this may reflect a higher degree of maturity.

The small amount of oil recovered from the Toolonga Calcilutite in the North Rankin No. 1 well is of great interest since it occurs at approximately the same stratigraphic level as the commercial oil at Barrow Island. Its correlation curve (Fig. 8) and saturated hydrocarbon distribution show that it closely resembles the Barrow Windalia oil. This particular stratigraphic interval, therefore, may be prospective throughout the Barrow and Dampier Sub-basins.

PRISTANE TO PHYTANE RATIOS

In Fig. 9 the pristane to phytane ratios of all the oils examined in this study are plotted against the correlation index of their 250 - 300°C boiling fractions. The plot can be divided into distinct fields which correspond to different source environments and/or degrees of maturity. Those oils characterised by a high wax content and derived from terrestrial organic material have varying pristane to phytane ratios depending on the extent of maturation of the parent organic matter. The oils from the north Dandaragan Trough, Perth Basin, are considered to be immature. They have low correlation indices and low pristane to phytane ratios. More mature oils of terrestrial origin, such as those from the Bowen-Surat and Gippsland Basins (Fig. 9), have slightly higher correlation indices and high pristane to phytane ratios. Oils of marine origin, e.g. the Cretaceous oils from the Carnarvon Basin, are characterised by low wax contents, high correlation indices, and low pristane to phytane ratios. Oils associated with marginal marine to deltaic sediments, e.g. the Jurassic oils of the Carnarvon Basin and the Walyering and Gingin condensates in the Perth Basin, display intermediate pristane to phytane ratios, a paraffinic to naphthenic composition and, sometimes, a high wax content. They appear to have been derived from a mixture of terrestrial and marine organic matter.

SUMMARY

Geochemical studies of crude oils and condensates from the Perth and Carnarvon Basins have been used to correlate oils of similar type. Oils of different chemical composition, and therefore different origin, have been readily distinguished even where they occur in the same field, as at Barrow Island. Distillation revealed loss of light ends from oils in the northern Dandaragan Trough and in the Flinders Shoals No. 1 well. This is attributed to water washing and shows that in the Dongara, Mondarra and Yardarino reservoirs, the oil is not in equilibrium with the overlying gas. A separate source is postulated for the gas.

In conjunction with the geology, geochemical data can be used to distinguish likely source rocks and probably migration paths, as is now possible in the Dampier Sub-basin.

The present investigation illustrates how routine analysis of crude oil and condensate samples recovered during drilling can provide valuable clues to the origin and accumulation of hydrocarbons in an area undre exploration.

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TABLE 1 Distillation data for oils and condensates from the northern and central Dandaragen Trough.

% of oil by volume

Well of Field	Fraction 100°C	100-200°C	200-280°C	280-340°C	340°C
Northern					
Dongara	2.5	3.5	16.0	15.0	62.0
Erregulla	3.0	12.0	13.0	22.0	50.0
Mondarra	2.5	2.5	8.0	9.0	78.0
Mount Horner	4.0	17.0	16.0	14.0	49.0
North Erregulla	3.5	12.5	14.0	15.0	56.0
Yardarino	2.0	2.5	13.0	33.5	49.0
Central					
Gingin 1 (3867 m)	1.0	57.5	26.0	14.5	
Gingin 2 (4302 m)	1.0	29.0	23.0	20.0	27.0
Walyering 1 (3370 m)	12.5	54.5	17.0	20.0	
Walyering 2 (3984 m)	8.5	43.5	21.0	12.5	14.5

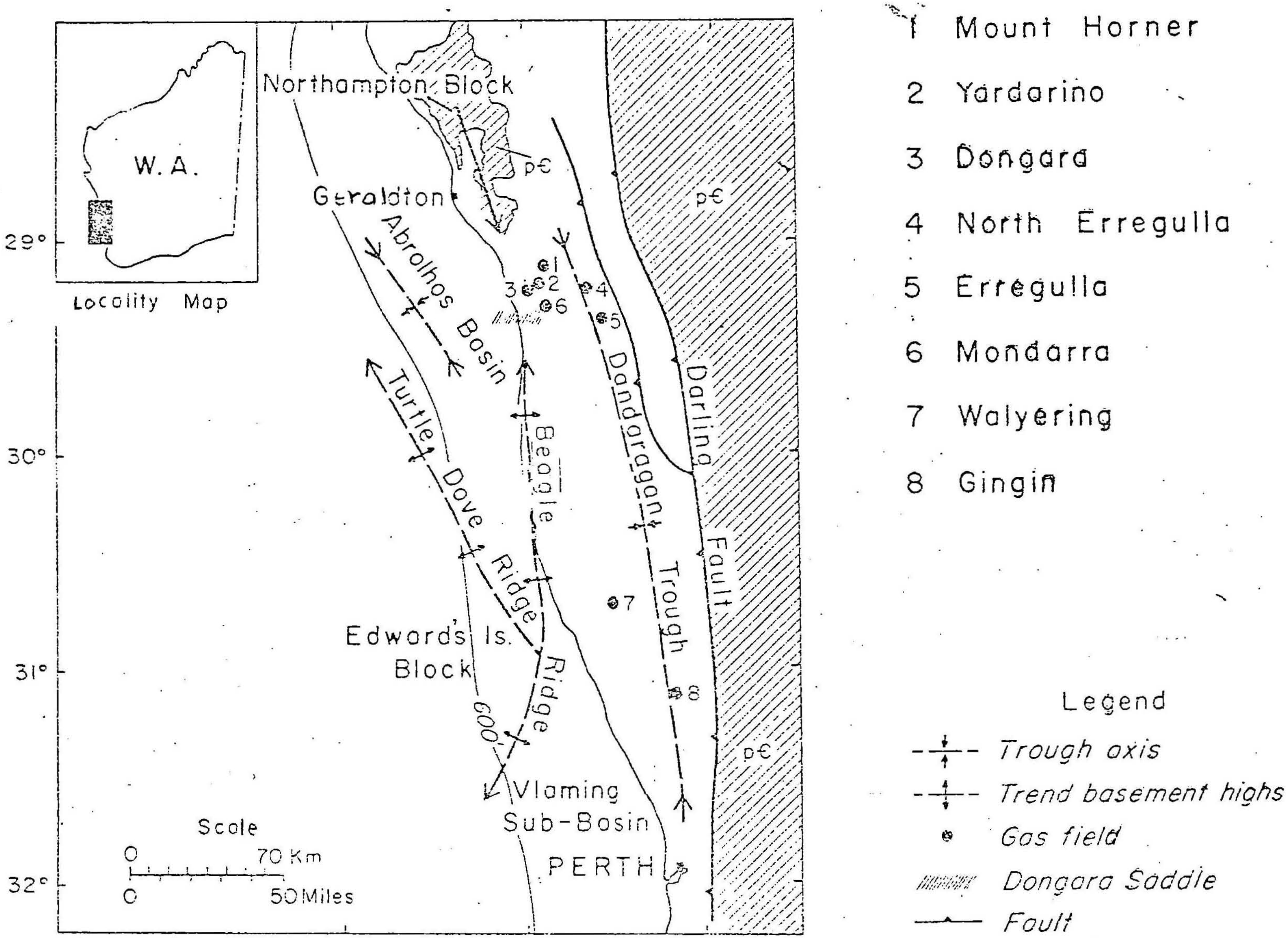

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Fig. 1 Hydrocarbon occurrences in the northern Perth Basin.

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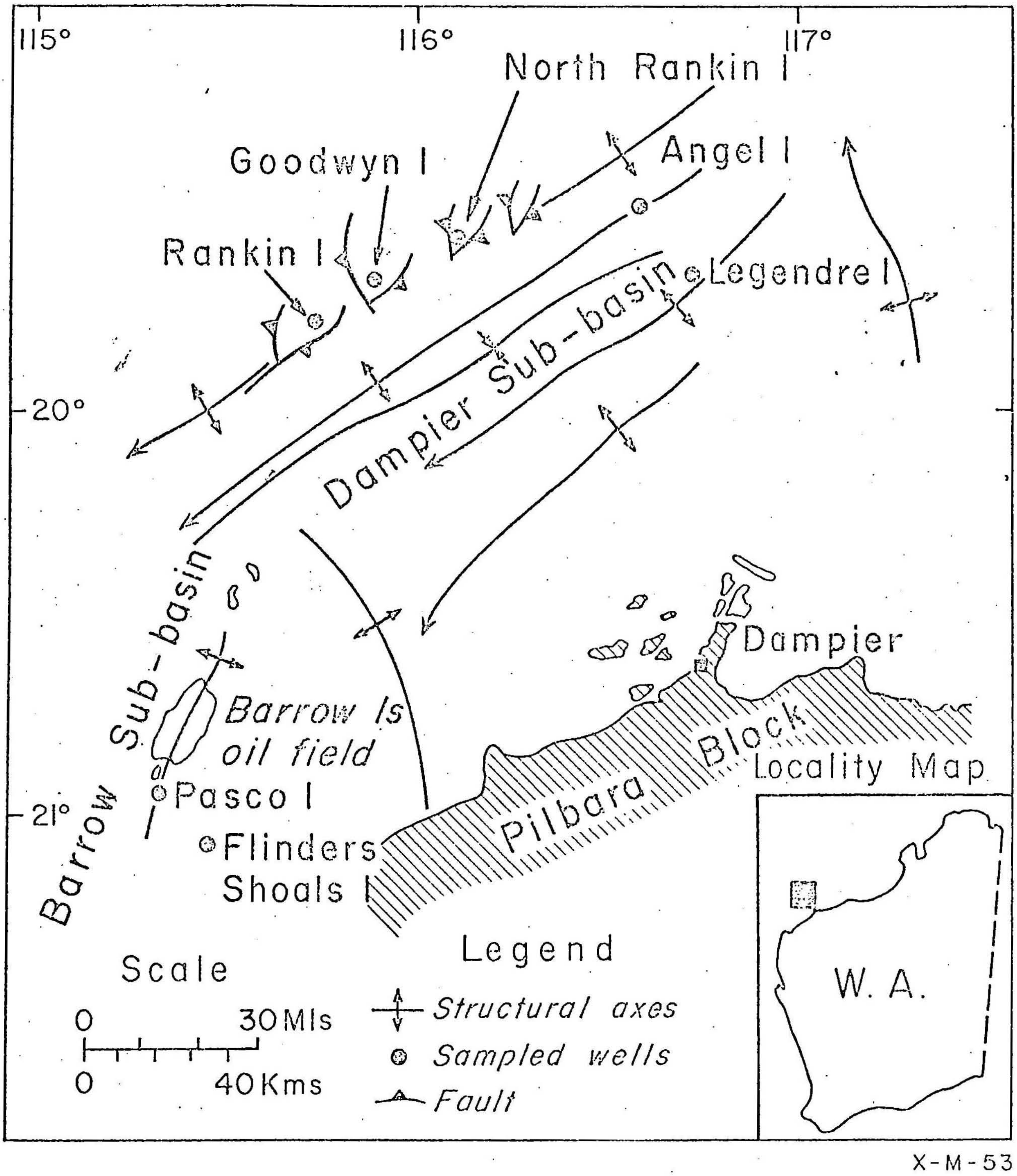

Fig.2 Hydrocarbon occurrences in the Barrow and Dampier Sub-basins of the Carnarvon Basin

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PERIOD	EPOCH	FORMATION	OIL & GAS OCCURRENCES: NORTHERN DANDARAGAN TROUGH	OIL & GAS OCCURRENCES: CENTRAL DANDARAGAN TROUGH
TERTIARY	MIOCENE	Unnamed Formation		
	EOCENE	Kings Park Formation		
	PALEOCENE			
CRETACEOUS	UPPER	Gingin Chalk		
	LOWER	Osborne Formation South Perth Formation		
JURASSIC	UPPER	Yarragadee Formation		
	MIDDLE	Cadda Formation		
	LOWER	Cockleshell Gully Formation	ERREGULLA	GINGIN WALYERING
TRIASSIC	UPPER	Lesueur Sandstone		
	MIDDLE	Woodada Formation		
	LOWER	Kockatea Shale Yardarino Sandstone	N. ERREGULLA MOUNT HORNER DONGARA	
PERMIAN	UPPER	Wagina Sandstone	MONDARRA YARDARINO	
	LOWER	Carynginia Formation Irwin River Coal Measures Holmwood Shale Nangetty Formation		
ORDOVICIAN – SILURIAN		Tumblagooda Sandstone		
PRE CAMBRIAN		Basement		

X-M-56

Fig. 3 Stratigraphic distribution of hydrocarbon occurrences in the Northern Perth Basin

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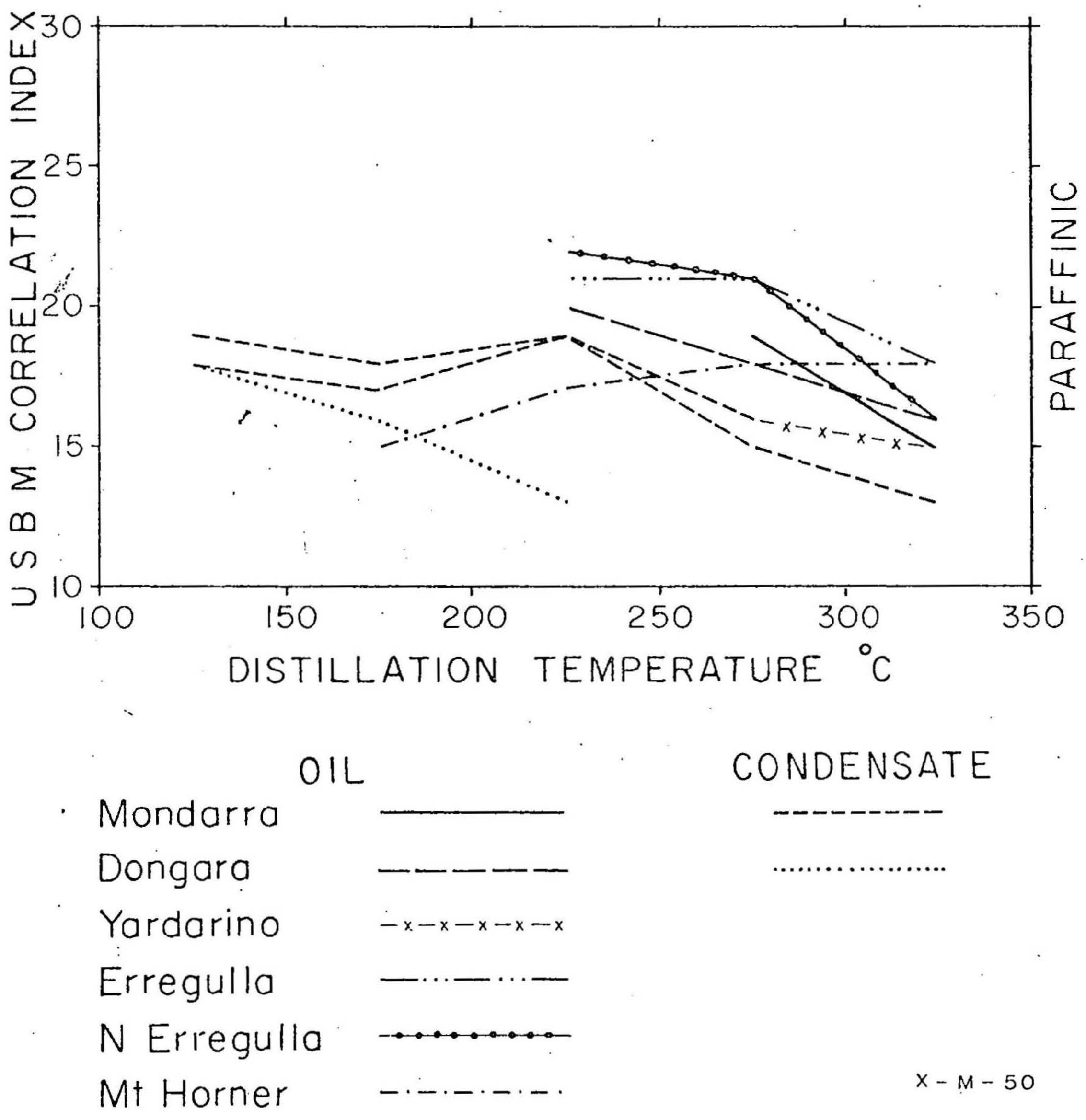

Fig.4 Correlation curves for oils and condensates from the north Dandaragan Trough

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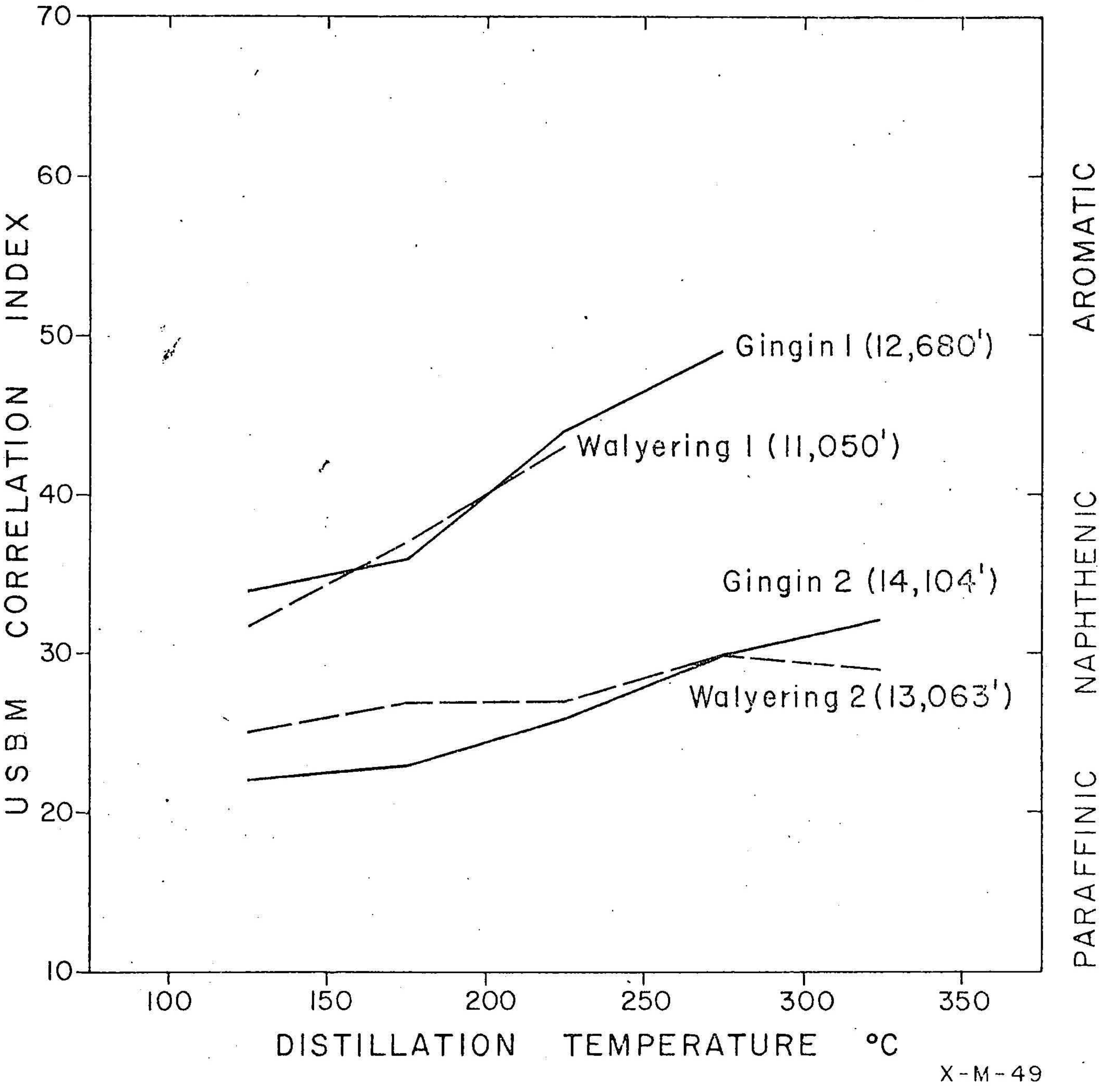

Fig.5 Correlation curves for oils and condensates from the central Dandaragan Trough

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PERIOD	EPOCH	FORMATION	GROUP	OIL & GAS OCCURRENCES Barrow Sub-Basin	OIL & GAS OCCURRENCES Dampier Sub-Basin
QUATERNARY		UNNAMED			
TERTIARY	PLIOCENE	TREALLA			
	MIOCENE	TREALLA			
		CAPE RANGE			
	OLIGOCENE	GIRALIA			
	EOCENE	GIRALIA			
	PALEOCENE	CARDABIA			
CRETACEOUS	UPPER	MIRIA MARL			NORTH RANKIN
		TOOLONGA CALCILUTITE			
		GEARLE SILTSTONE	WINNING GROUP		
		WINDALIA	WINNING GROUP	BARROW	
	LOWER	MUDERONG SHALE	WINNING GROUP		
		MUDERONG GREENSAND	WINNING GROUP	BARROW	
		BIRDRONG SAND	WINNING GROUP	FLINDERS SHOALS	
		BARROW GROUP		BARROW	LEGENDRE
JURASSIC	UPPER	DUPUY SAND MBR.	DINGO GROUP	PASCO	ANGEL
		DAMPIER FORMATION	DINGO GROUP		
	MIDDLE	LEGENDRE FORMATION	DINGO GROUP		
	LOWER	ENDERBY FORMATION	DINGO GROUP		
TRIASSIC	UPPER	MUNGAROO BEDS			NORTH RANKIN GOODWYN RANKIN
	MIDDLE	MUNGAROO BEDS / LOCKER SHALE			
	LOWER	LOCKER SHALE			
PERMIAN	UPPER	UNNAMED			
	LOWER	UNNAMED			

X-M-55

Fig 6 Stratigraphic distribution of hydrocarbon occurrences in the Carnarvon Basin

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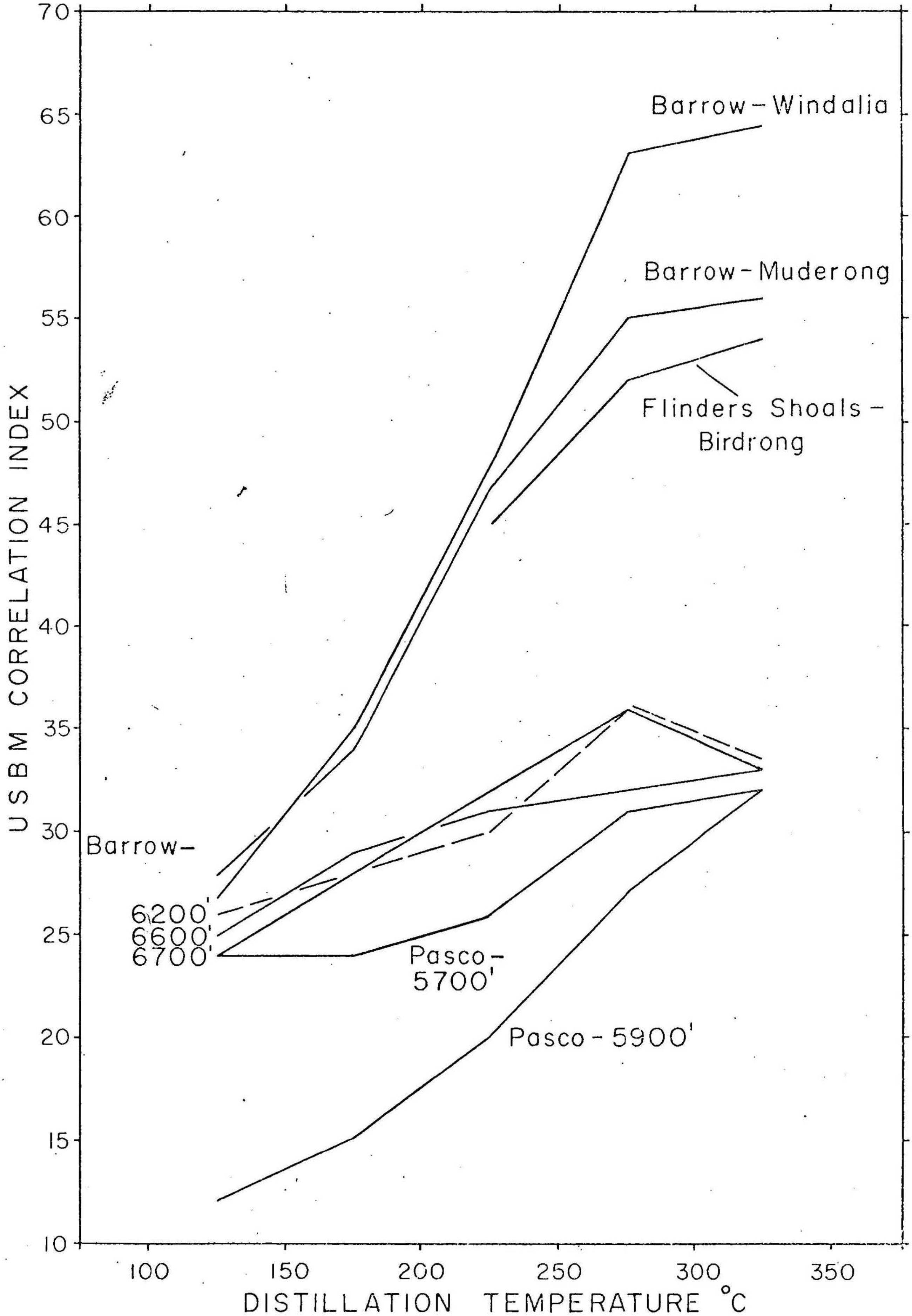

Fig. 7 Correlation curves for oils from the Barrow Sub-basin

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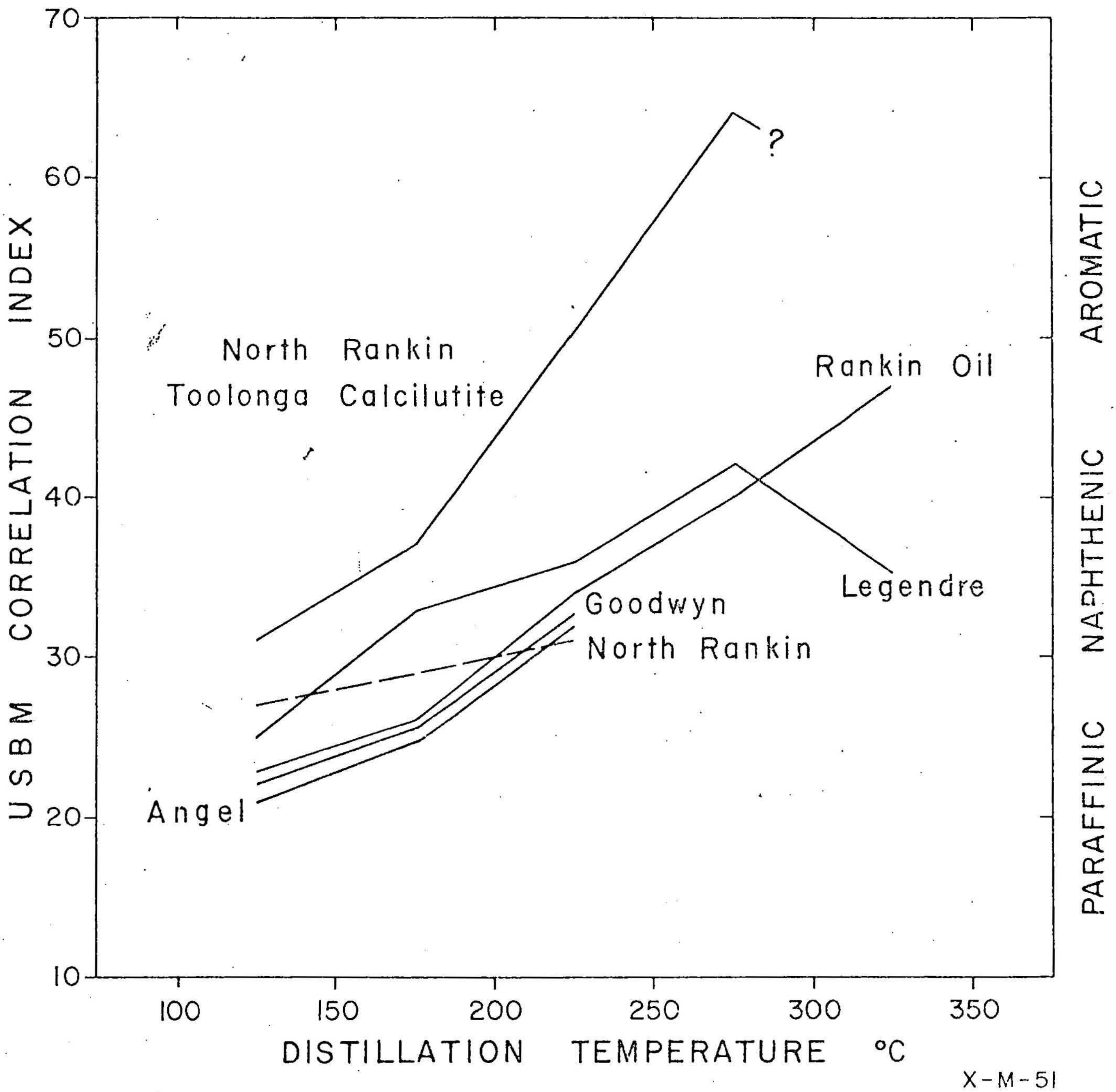

Fig. 8 Correlation curves for oils and condensates from the Dampier Sub-basin

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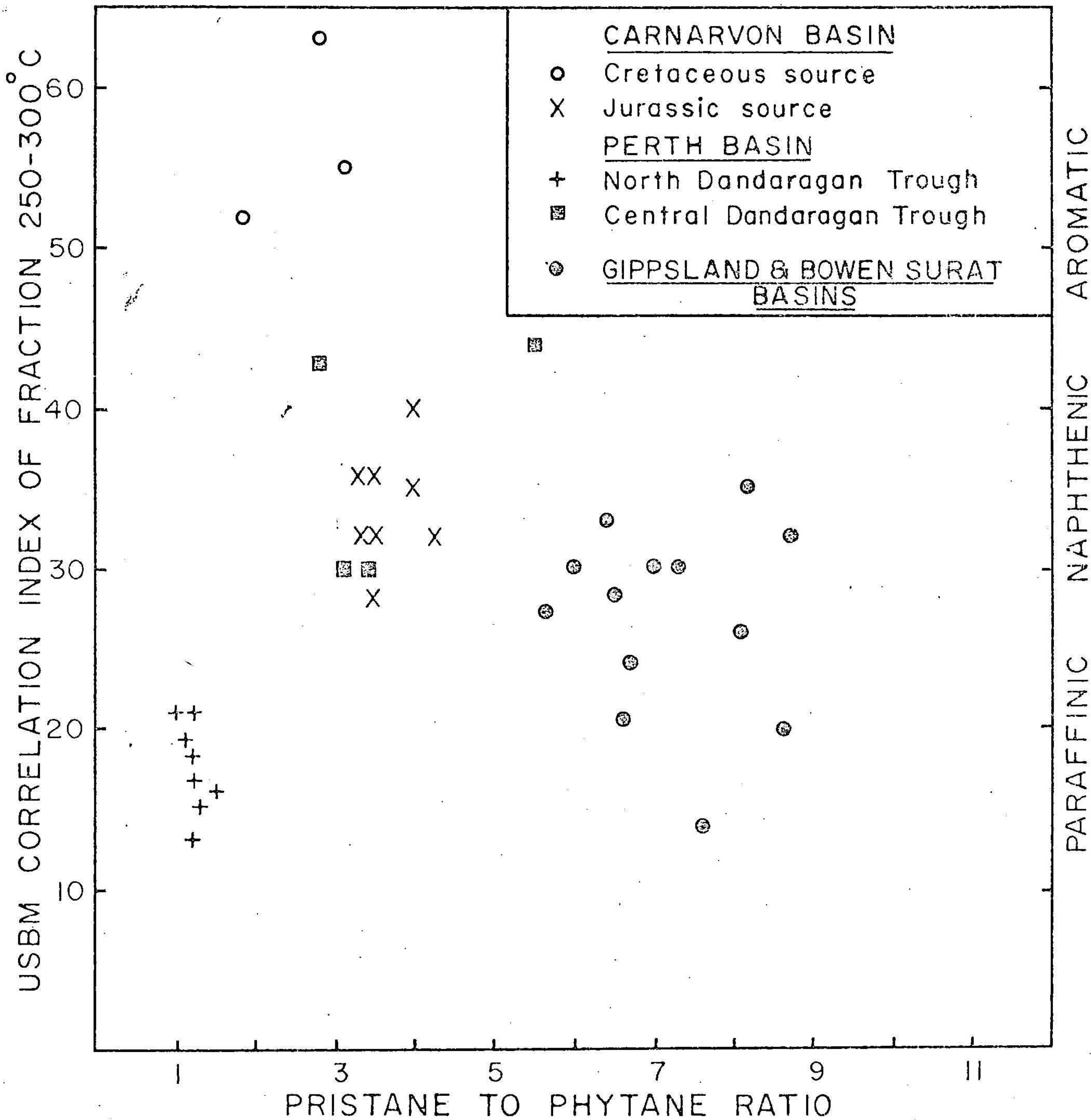

Fig.9 Relationship between pristane to phytane ratio and crude oil composition in the Perth and Carnarvon Basins

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