The North West Shelf, Australia — An Introduction.

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Abstract

The North West Shelf of Australia extends c2400 km along the northwest margin of the continent. It is a geographic province rather than a physiographic feature *sensu stricto*, and includes the continental shelf proper and the marginal platforms and plateaus, out to about the 2000 m isobath.

Four major sedimentary basins occur along the shelf: Carnarvon, Offshore Canning, Browse and Bonaparte, from south to north respectively. These basins contain a thick Phanerozoic section, ranging to 17,000 m or more, and made up of several superimposed basin sequences. The development of these basins can be related to successive cycles of rifting and break-up of the Gondwana supercontinent.

The undiscovered reserves in the North West Shelf basins are estimated at 1500 million barrels of oil and 20 TCF of gas. Major gas and oil accumulations have been discovered in the Carnarvon, Browse and Bonaparte basins; commercial oil production has been established in the Carnarvon and Bonaparte basins. Discovery and development of the hydrocarbon resources of the North West Shelf is vital to Australia's future. In the short term, the oil production will contribute to the nation's dwindling supplies, and LNG exports will help offset oil import costs. In the longer term, the development of the North is essential for Australia's security and welfare in the 21st Century.

Introduction

In the early 1950s, as Australians tried to seize the mood of post-war optimism, the discovery of oil at Rough Range was a momentous event. The dreams of rich Australian oilfields seemed finally true and, for the first time perhaps, Australians saw the nation's future security in the vast North West.

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It was not to be of course; but, for the mood and the moment, it didn't matter. The message to the sceptics was clear: Australia had oil to find; and there were men and companies keen to find it.

As it transpired, the security of domestic oil flowed from the giant Gippsland Basin fields in the late 1960s, and for nearly two decades Australia has been virtually self-sufficient in petroleum. That era has passed. The Gippsland fields are declining and self sufficiency will slide from 95% in 1986 to a projected 65% in 1995, and perhaps only 35% by the year 2000. Import bills will be enormous, and will affect national growth and living standards.

Figure 1: Location Map, North West Shelf.

Australia is again in need of oil. Again, the hope of the future is tending north west. Gas from Woodside's North Rankin Field has already replaced fuel oil in Western Australian homes and factories. By the mid-1990s, LNG exports to Japan will be helping offset the oil import bill. Production from existing- and newly discovered- fields will contribute significantly to the nation's oil supplies, but the gap between supply and demand will still be growing. The basins of the North West Shelf (Figure 1) contain an estimated 1500 million

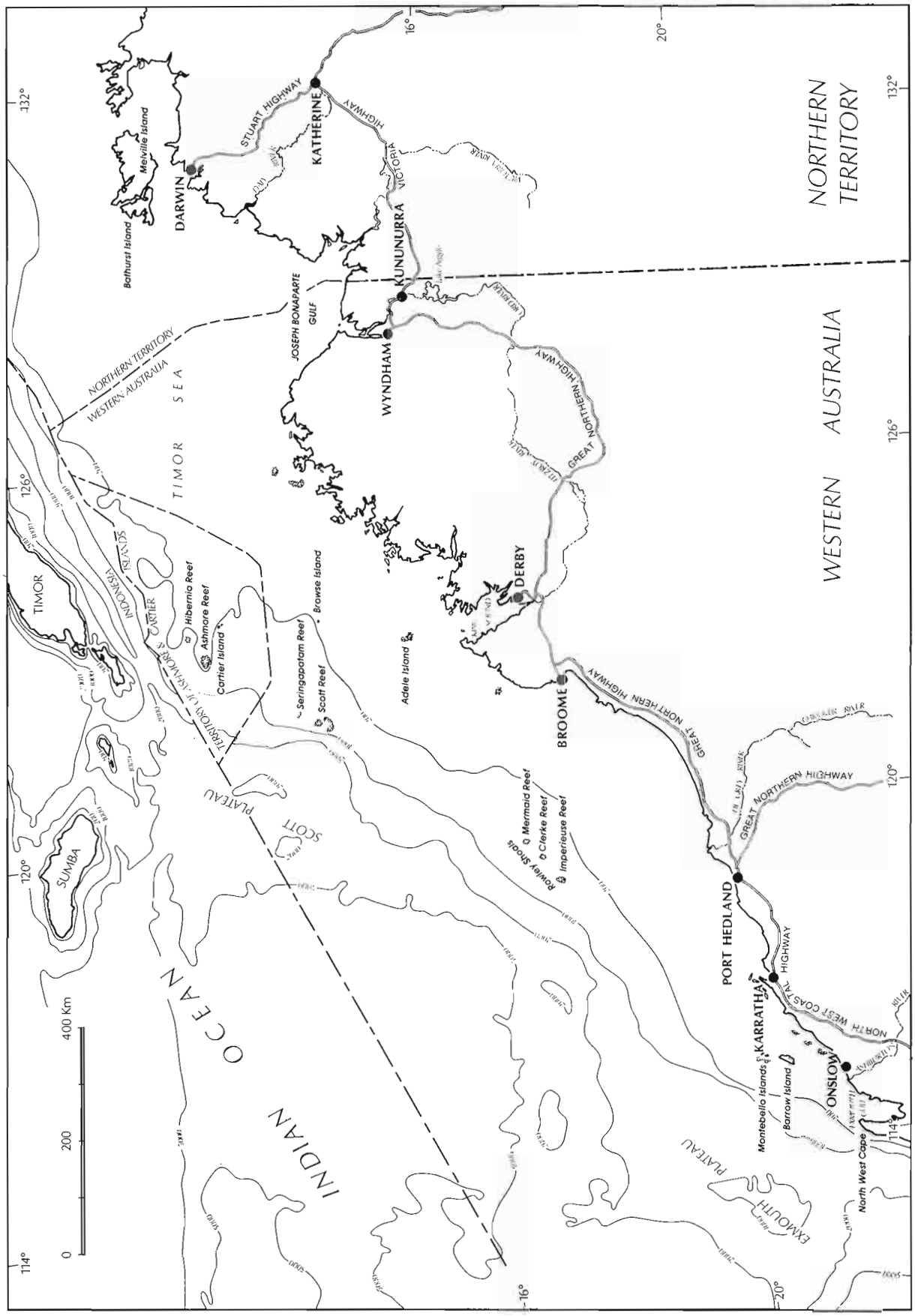


Figure 2: Geography and Physiography, North West Shelf.

barrels of oil and 20 TCF of gas, more than two thirds of the nation's estimated undiscovered reserves (Bureau of Mineral Resources, 1988). The discovery and development of those resources is vital to the nation's future.

This volume of papers on the geology and petroleum potential of the North West Shelf is dedicated to achieving that future. This paper presents a general introduction to the North West Shelf, its geography, geology and exploration history.

Nomenclature

G.W. Earl, Commissioner for Crown Lands, Northern Territory, in the 1840s was the first person to identify the shelf off northern Australia as a "major earth feature", the "Great Australian bank" (Earl, 1845). Krummel (1897) subdivided this area into the Arafura Shelf, between Australia and New Guinea, and a North-West Australian Shelf, extending from the North West Cape to Melville Island. Fairbridge (1953) subdivided the North-West Australian Shelf into the Sahul Shelf and the Rowley Shelf.

Popular usage of the geographic term, North West, has evolved as a matter of convenience. Early BOC/ Woodside publications (e.g., Mollan et al., 1969) and government reports (e.g., Jones, 1973) identified the Rowley and Sahul shelves, but for permits and surveys covering both, the more general term was convenient. Over the years, it has been used variously as North-west, North-West, Northwest and North West. Woodside's naming of their North West Shelf Project has served to establish "North West" as the preferred term.

The nomenclature for the sedimentary basins of the North West Shelf is reviewed in detail by Bradshaw et al. (this volume). Early studies of the geology of the North West shelf were based on correlations of sea floor topography with the onshore basins and basement provinces. This was reflected in the terminology: the Offshore Canning Basin; the Northern Carnarvon Basin. The terminology which developed for various sub-basins and structural elements is also imprecise in some areas. The need for review of the terminology is discussed elsewhere in this volume (Bradshaw et al.; Mory).

Geography

The North West Shelf extends over 2400 kms from the Exmouth Gulf in the south to Melville Island in the north (Figure 2). It lies mainly offshore Western Australia but extends into Northern Territory waters at the northern end. Built by a prograding wedge of Tertiary to Holocene carbonates, it is a physiographic feature, but is not rigorously defined as such. Indeed, in popular usage, it is as much a geographic province i.e., it is not simply the continental shelf *sensu stricto*, but includes the outer shelf and marginal plateaus.

The North West Shelf has an average width of c300 kms and covers an area of over 720,000 sq km. The size of the area (Figure 3), and the distance from major population centres and facilities, has hindered exploration and development. This was especially true in the early years but remains true today. For its remoteness, Woodside's North Rankin Field was dubbed "the loneliest gas in the world".

Figure 3: Size comparison — North West Shelf, Texas and

At its southern end, the North West Shelf is c1200 kms north of Perth, the state capital of Western Australia and the administrative centre for most exploration activity in the area. The very northern end of the region lies offshore from Darwin, the capital city of the Northern Territory. The region is connected to Perth by two highways, which meet at Port Hedland: the Northwest Coastal Highway and the inland Great Northern Highway. The latter then continues along the coast to Broome, inland across the Kimberley, and onto Darwin via the connecting Victoria and Stuart highways.

The main towns along the coast include Onslow, Dampier, Karratha, Broome and Derby. Onslow has been an important staging point for the exploration of the Barrow Island region. Karratha is the centre for the development of Woodside's North West Shelf Project; Dampier is the nearby port. These towns have daily air services from Perth and all are on regular shipping routes.

The entire region lies within the tropics. The weather pattern is influenced by southeast trade winds during the winter months and the northwest monsoon during the summer. This establishes a general sub-division of

the year into the "wet" monsoon season and the "dry" season. These influences, and the pattern they control, are less pronounced in the south: the average rainfall at Broome is 580 mm, double that at Port Hedland (277 mm); Temperatures throughout the region remain relatively high during the year, but do show a marked winter low. The average daily mean temperature at Broome ranges from a low of 20.8°C in July to a high of 30.2°C in December.

The major weather threat to petroleum operations in the area are the cyclones of the summer months. These occur regularly each year and cause damage whenever they track across population centres. The planning of offshore operations and production facilities on the North West Shelf has to provide for the possibility of a major cyclone.

Physiography

The North West Shelf consists of a continental shelf proper, extending from the shoreline to the break in slope at 120-180 m depth; a marginal platform or terrace (Jones, 1973), extending down to 500-600 m; and an outer continental margin which includes the continental slope and the Exmouth Plateau (Figure 2). The continent/ocean boundary is generally located near the 4-5000 m isobaths. Bradshaw et al. (this volume) restrict the North West Shelf to the continental shelf *sensu stricto* (i.e., within the 200 m isobath), but this is not the popular usage of the term.

The continental shelf proper (i.e., less than 200 m depth) varies in width from a narrow 15 kms near Cape Range to over 200 kms nearly Rowley Shoals and c400 kms across the Bonaparte Gulf and Timor Sea. The main sedimentary processes on the shelf are winnowing and sediment transport, rather than deposition; over large areas the surface is very flat and smooth. However, the sea bed is rough and uneven in some areas, particularly off the Kimberley coast where numerous islands and shoals occur.

A break in slope near the 600 m isobath marks the edge of the platform which borders the continental shelf, and is called the Rowley Shoals/Scott Reef Platform (Jones, 1973) or the Rowley Terrace, with the Ashmore Terrace further north (Bradshaw et al., this volume). A chain of atolls extends along this edge and includes, from north to south, Sahul Bank, Ashmore Reef, Cartier Island, Seringapatam Reef, Scott Reef, and the Mermaid, Clerke and Imperieuse reefs of the Rowley Shoals. Other drowned reefs occur along this trend. These atolls have grown on the subsiding margin and rise nearly vertically 350-450 m from the sea floor.

Numerous islands also occur in the southern area. The largest, Barrow Island, is the surface expression of a broad, faulted dome which contains the Barrow Island Oilfield. Miocene limestones outcrop on Barrow Island; most other islands are formed of Pleistocene to Holocene sands and limestones. Several of these islands are being used in the development of nearby offshore fields (Carr, this volume).

Two large marginal plateaus separate the shelf proper from the deep Indian Ocean basin: the Exmouth Plateau in the south and the Scott Plateau in the north. Both are considered to be foundered continental blocks (Falvey & Mutter, 1981). The Exmouth Plateau extends c450 km westward into the Indian Ocean from Barrow Island, rising from c1100 m depth on the inner continental slope to a minimum c800 m. Exploration drilling found a large gas accumulation here in the early 1980s, uncommercial in these water-depths (Barber, this volume). Water depths on the Scott Plateau are greater than 2000 m.

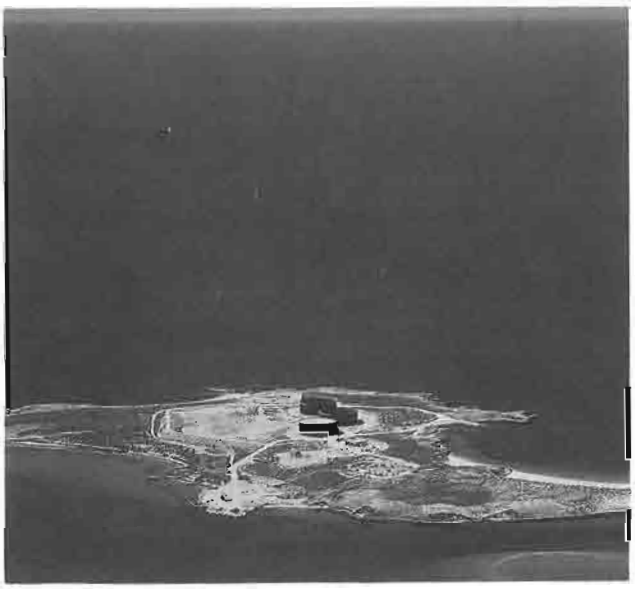


Figure 4: Varanus Island, with storage tanks, and the Harriet Platform in the distance. (Photograph courtesy of Bond Corporation.)

Petroleum Legislation

The North West Shelf region is administered and controlled by State, Territory and Commonwealth authorities and agencies. For the purposes of petroleum exploration activity, the area is subdivided into onshore and offshore domains; with the offshore domain subdivided into inland (W.A. only), territorial and open seas. The dividing line between onshore and offshore areas is usually the coastline but in Western Australia extends across embayments (e.g., Exmouth Gulf) and shallower water areas such as near Barrow Island. Petroleum exploration in these so-called inland waters has been administered under the W.A. Petroleum (Submerged Lands) Act 1982, and predecessors, but is being moved under the administration of the W.A. Petroleum Act 1967.

The area within three nautical miles coastline/boundary is referred to as the Territorial Sea. Responsibility for this area is with the State/Territory Governments. In Western Australia the Territorial Sea is administered under the W.A. Petroleum (Submerged Lands) Act 1982; in the Northern Territory, under the N.T. Petroleum (Submerged Lands) Act 1982.

Petroleum operations in the offshore area beyond the

Territorial Sea are the responsibility of the Commonwealth Government and are administered under the Petroleum (Submerged Lands) Act 1967. This Act is administered under a co-operative arrangement between the Commonwealth and State/Territory Governments. Responsibility is vested in the so-called Joint Authority, a Statutory Body comprising the Commonwealth Minister for Energy and the State/Territory Minister for Mines. In the Territory of Ashmore and Cartier Islands, also administered under the Commonwealth Act, the designated authority is the Federal Minister, but responsibility and authority for day-to-day administration has been delegated to the N.T. Minister for Energy.

This legislation is seen by Government to provide for orderly exploration and development of the petroleum resources of the region by way of stipulating a basic framework of rights, entitlements and responsibilities of Governments and industry.

Exploration Permits within the North West Shelf region are issued under either a work programme system or, in selected areas which are considered highly prospective, a cash bidding system.

Basin Framework

The North West Shelf covers areas of four sedimentary basins, the Northern Carnarvon, the Offshore Canning, the Browse, and the Bonaparte basins, from south to north respectively. These basins contain up to 17,000 m of sediments, ranging in age from Palaeozoic to Holocene. In most areas, the sequence involves several superimposed basins: a north-northwest trending Palaeozoic-Early Mesozoic intracratonic basin; a northeast trending Mesozoic rift basin; and a Late Cretaceous — Holocene open margin basin. This superposition of the basins is a main cause of dissatisfaction with some of the current basin definitions and nomenclature.

The development of the basin complex of the North West Shelf can be related to the pattern and history of the rupturing of the Gondwana super-continent. Through the Palaeozoic and Mesozoic eras, the northwestern margin of that continent was progressively ruptured by earth forces, and continental blocks and slivers were rafted away, leaving a younger ocean in their wake. In this way, Tethys was consumed and recreated several times: Ur-, Palaeo- and Neo-Tethys, Veevers (this volume) has called them.

Initial break-up occurred in the Cambrian after extensive rifting across the Proterozoic super-continent (Bond et al., 1984), branching into the interior to form the Bonaparte, Canning and Carnarvon basins. A second period of rifting and continental fragmentation commenced in the Late Carboniferous, and a continental "sliver", now identified as Sibumasu (China-Burma-Malaya-Sumatra) by Sengor (1987), was trimmed from the Gondwana margin. Uplift and rifting commenced again in the Triassic, intensified in the Early Jurassic, and seafloor spreading commenced in the Oxfordian, forming the early Indian Ocean. Finally, India and Australia separated in the Early Cretaceous.

The northwest Australian margin subsided through the Cretaceous and Tertiary and carbonate sediments accumulated, slowly building the North West Shelf. In the Miocene, the margin began to impinge on the Eurasia plate along the Banda Arc, causing extensive folding, faulting and igneous activity. Some major reefs, growing initially in the Miocene, kept pace with subsidence to form the reefs and shoals near the modern shelf edge.

Superimposed on this complex structural evolution, and inter-related with it, have been changing patterns of climate and sea level. The constantly changing "mosaic of environments" in the basins of the North West Shelf is described in detail by Bradshaw et al. (1988) in this volume.

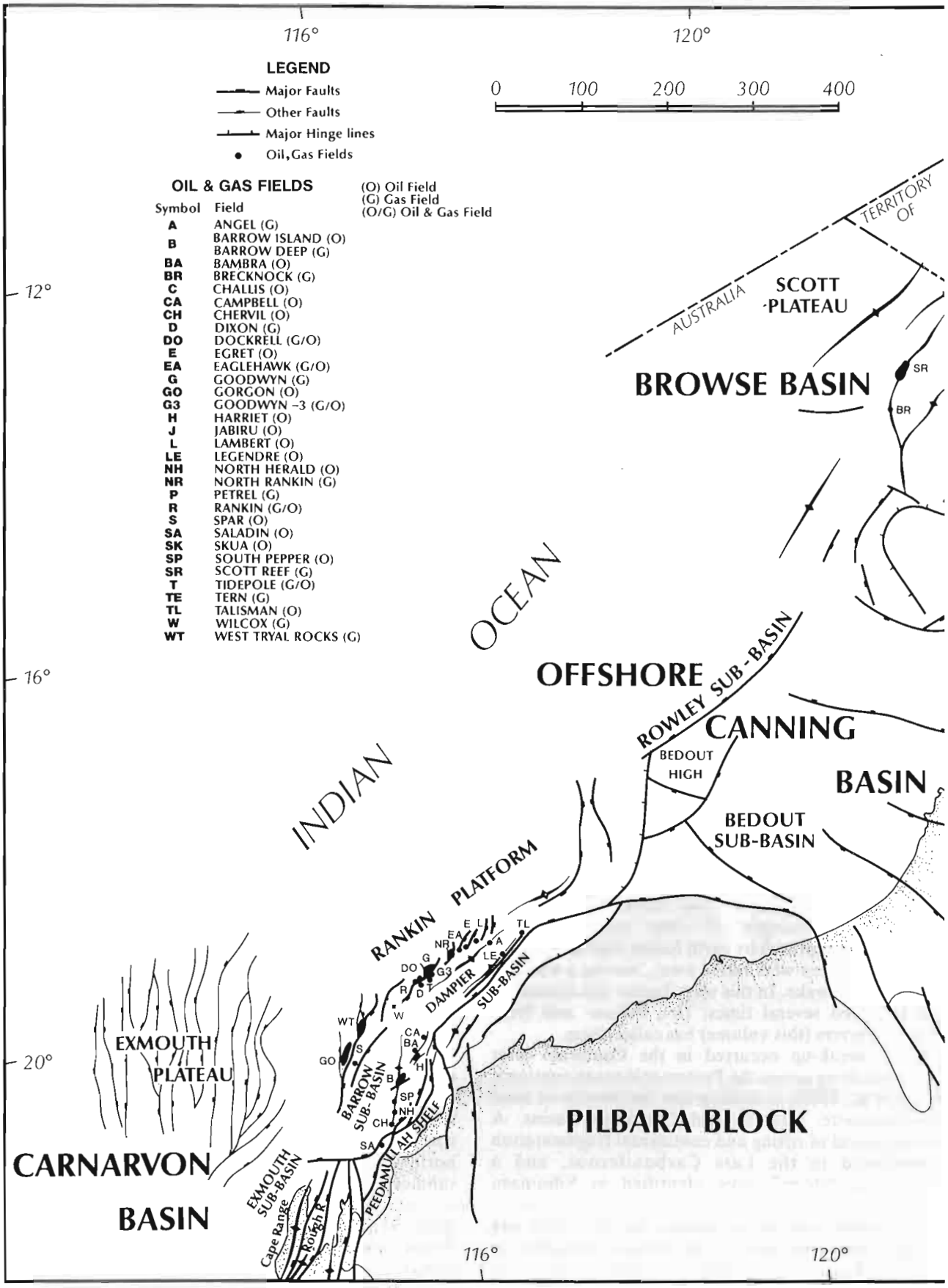
There have been many geological articles published about these basins, both in general terms and in detail. Veevers (1984) and Forrest and Horstmann (1986) are a useful starting point for geologists new to the region. Important papers on individual basins include: for the Bonaparte Basin, Laws and Kraus (1974) and Lee and Gunn (1988); for the Browse Basin, Bhattia et al. (1984) and Allen et al. (1978); for the Timor Sea, MacDaniel (1988); for the Exmouth Plateau Exon and Willcox (1980) and Exon et al. (1982); for the Exmouth, Barrow and Dampier sub-basins of the Northern Carnarvon Basin, Kopsen and McGann (1985), Veenstra (1985), Osborne and Howell (1987), Parry and Smith (1988) and Woodside Offshore Petroleum (1988). A comprehensive list of references for the North West Shelf basins can be found in Bradshaw et al. (1988; this volume).

This volume contains papers on the geology and hydrocarbon potential of all the basins.

Early Geological Concepts

Earlier geological interpretations saw the Banda Arc as a tensional domain, a chain of horst blocks — rising and falling land bridges across which the elephant-like Stegadon walked to Timor, and the monotremes, ancestors of the platypus and echidna, came to Australia. The discovery of low-angle overthrusting on Timor (Molengraaff, 1914) demanded a compressional explanation. Wegener (1924) foresaw current concepts — an Australia plate drifting north and colliding with Asia in the Tertiary — but his was not the popular view.

Most geologists preferred the "undation" concept, as proposed for this region by the Dutch geologist, van Bemmelen (1949) and others. The East Indian arcs were seen as a geosynclinal downwarp in an Australian continent which had originally extended much further north. Early geophysical data seemed to support this: submarine gravity readings across the Timor Trough, for instance, revealed anomalies typical of a continental shelf (Vening Meinesz et al., 1934). The geology of Timor was interpreted in terms of Permo-Triassic geosynclinal activity with the main orogenic phase in the Miocene.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EXMOUTH PLATEAU
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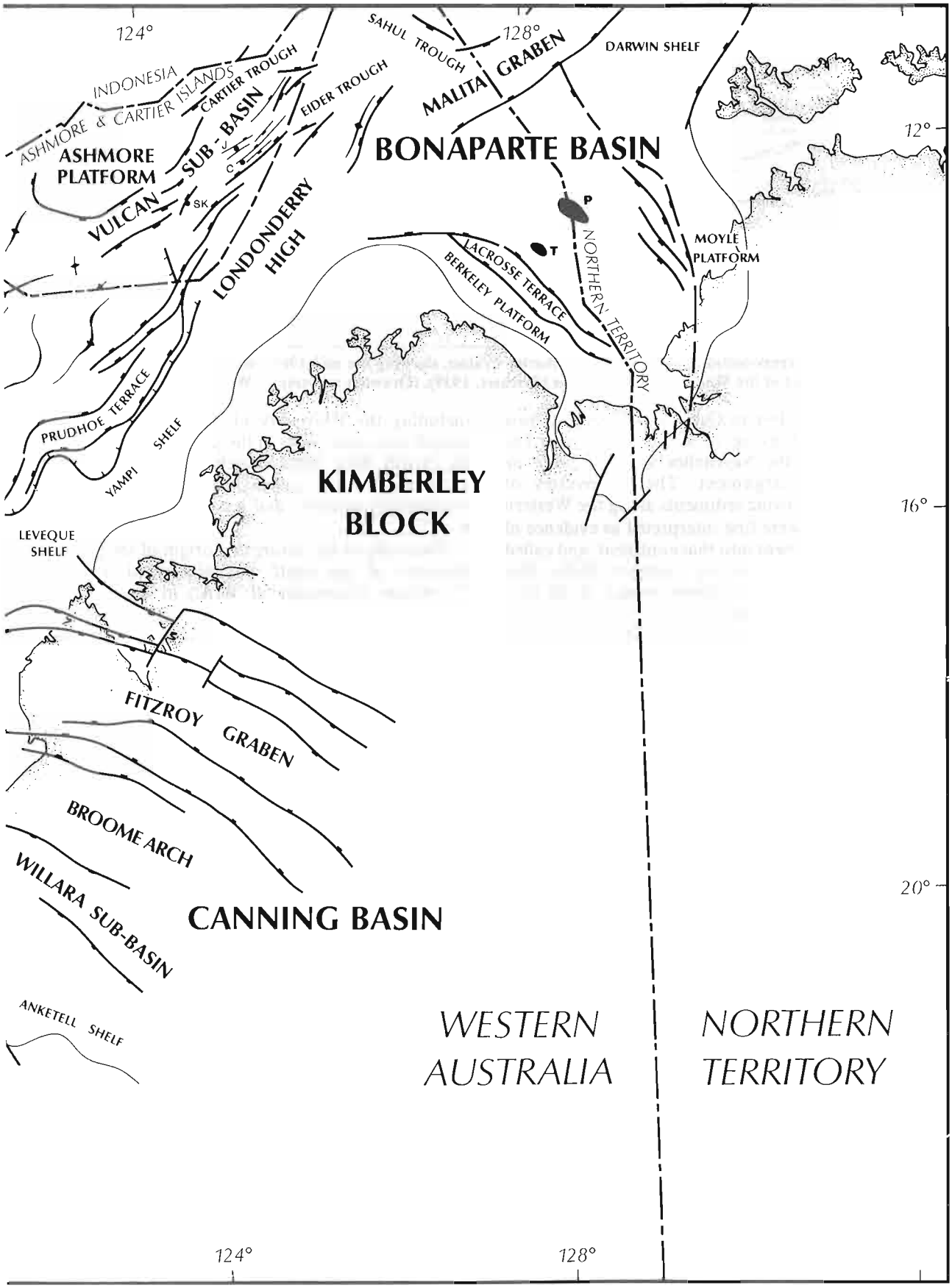

Figure 5: North West Shelf, Australia showing Main Tectonic Elements and Oil and Gas Fields.

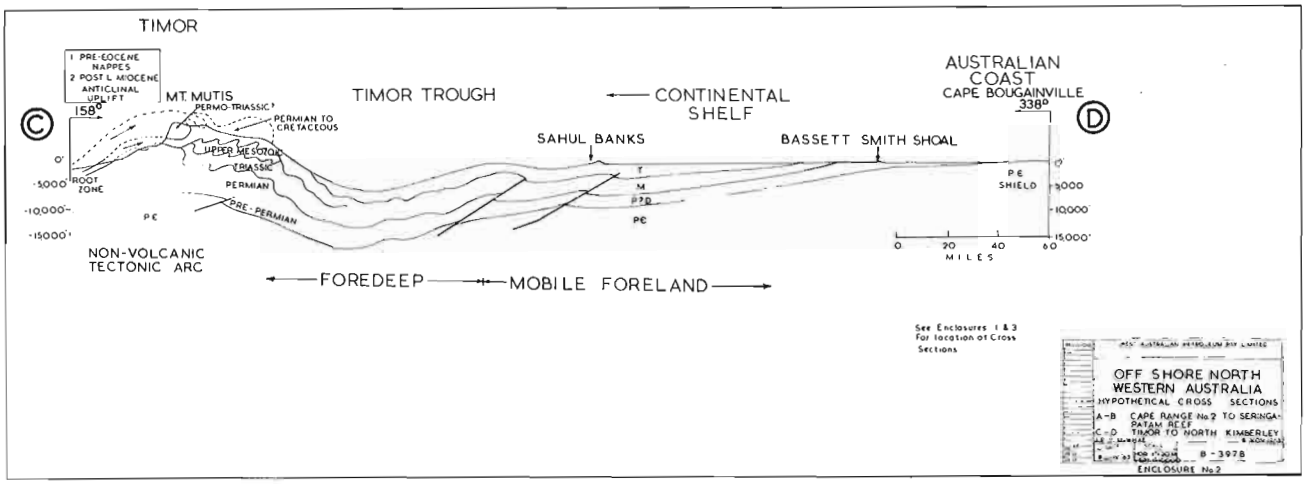

Figure 6: Geological cross-section, Timor to the Kimberley Craton, showing the mid-1960s interpretation of the North West Shelf as part of the Westralian Geosyncline (Teichert, 1939). (Drawing courtesy of Wapet).

At that time, the Indian Ocean was seen as a new ocean, formed by sinking of a vast continent. The granitic nature of the Seychelles was the *piece de resistance* of this argument. The discoveries of Palaeozoic and Mesozoic sediments along the Western Australian margin were first interpreted as evidence of an extensive embayment into that continent, and called the Westralian Geosyncline by Teichert (1939). This geosyncline was seen as a southern branch of the East Indian geosynclinal complex.

The pioneering geology studies of the North West Shelf by Fairbridge (1953, 1955) and others (Carrigy & Fairbridge, 1954), seemed to provide further support for "fixist" concepts. Newly-obtained bathymetric data showed that the continental shelf was broadest and deepest opposite the mainland basins, but narrow and shallow opposite the Precambrian blocks. The connection seemed precise even at a local geomorphological scale: rocky shores and islands offshore from the Precambrian; sandy shores and coral reefs offshore from the basin. Moreoever, these trends seemed to continue far into the Indian Ocean, with deep-sea basins opposite the broad shelves, and the deep sea ridges "in the same trends as the Pre-cambrian structural grain of the mainland" (Fairbridge, 1955). With the features of the continent and ocean so "intimately related", there seemed little room for doubt about structural continuity between the two domains.

These ideas were overthrown, like many other dictates, by the geological revolution of global tectonics in the 1960s. It should be acknowledged, however, that it was these older ideas — naive though they may seem to the new generation — which led explorers to the North West Shelf, and guided their early efforts.

Some of today's geological wisdom may find itself similarly regarded in the 21st Century!

Geological Exploration

Earth scientists from State and Commonwealth Government agencies, and from the universities, including the University of Western Australia, have played important roles in the geological exploration of the North West Shelf. Much of this work has been conducted in co-operation with the petroleum exploration industry, and has been of great benefit to it.

The study of the nature and origin of the geographic features of the shelf was pioneered by Rhodes Fairbridge (University of W.A.) in the early 1950s,

Figure 7: Doug Smith, plane-tabling on Barrow Island, 1962. (Photography courtesy of D.N. Smith).

using soundings by the Royal Australian Navy's Hydrographic Office. Curt Teichert's (University of Tasmania) palaeontological studies of onshore basins led him to predict that Permian and Mesozoic sediments would be present beneath the North West Shelf.

Most work by the Geological Survey of Western Australia has been in the onshore basins adjacent to the North West Shelf, but the 1:250,000 geological mapping programme extended to the offshore islands, including Barrow Island and the Dampier Archipelago (Kriewaldt, 1964). The results of petroleum exploration were summarised to 1975 in Memoir 2 (GSWA, 1975); this is currently being updated in Memoir 3 "The Geology and Mineral Resources of Western Australia", to be published during 1988.

More recently, a number of regional syntheses of the geology of the North West Shelf have been undertaken. The onshore Carnarvon Basin has been reviewed, with the assistance of oil company geologists (Hocking et al., 1987), and a Depth-to-Basement map of the State covers the shelf out to the continent-ocean boundary (Middleton, 1987). Detailed studies of the stratigraphy and sedimentology of the Barrow-Dampier sub-basins (with Curtin University of Technology and MERIWA), and the offshore Bonaparte Basin (with petroleum companies) are being conducted, and are presented in this volume (Hocking et al.; Eriyagama et. al.; Mory).

Figure 8: Jim Parry surveying on Cape Range, 1954. (Photograph courtesy of J. Parry).

The Bureau of Mineral Resources has been the leading Government agency in the study of the North West Shelf. The Bureau's involvement can be traced from its founder, Dr Harold Raggatt, who directed the early mapping of sedimentary basins in Western Australia adjoining the North West Shelf. His perception of the prospectivity of the Exmouth area was instrumental in the formation of Western Australian Petroleum Pty Ltd (Wapet).

The first regional study of the continental shelf by the BMR (1960/1) involved a survey of sediments and morphology of the Sahul Shelf and Timor Trough (van Andel and Veevers, 1967). During the late 1960s and early 1970s, the BMR made numerous geophysical and geological research cruises on the North West Shelf and adjacent deep ocean basins (Whitworth, 1969). Results of the geological reconnaissance of the shelf between Barrow Island and Scott Reef were summarised in Bulletin 136: Marine Geology of the North West Australian Continental Shelf (Jones, 1973).

In 1972 the Bureau conducted a 12,000 km reflection seismic survey in the Exmouth Plateau region, as part of the extensive Continental Margin Survey (CGG, 1975). Integrated with available exploration survey data, the results were presented as Bulletin 199: The Exmouth Plateau: Stratigraphy, Structure and Petroleum Potential (Exon and Willcox, 1980). Along with the earlier publications (e.g., Exon and Willcox, 1978) this work was a major contribution to the exploration for petroleum in the deep water on the Exmouth Plateau.

This tradition of work, in co-operation with the petroleum exploration industry, has been continued in the recently completed palaeogeographic study of Australia. This project was a co-operative effort between the BMR and the Australian Petroleum Research Association (APIRA) and involved over 20 man-years work; the results from the North West Shelf area are summarised in Bradshaw et al. (this volume).

Petroleum Exploration

Petroleum exploration on the North West Shelf commenced in the 1950s, with geological mapping on Barrow Island. The main activity began in the early 1960s, and was dominated for many years by three groups, Wapet, Woodside and ARCO/Aquitaine. Several generations of geologists and geophysicists served an apprenticeship with these companies; many hold senior positions in industry and government today.

Wapet and Woodside owe their beginnings to the determination and foresight of their founders. Both owe their involvement with the North West Shelf to geologists from government agencies; both were strongly influenced in the early years by the concepts developed in Australian universities; specifically, Teichert's Westralian Geosyncline and Fairbridge's structural interpretations of the seafloor topography.

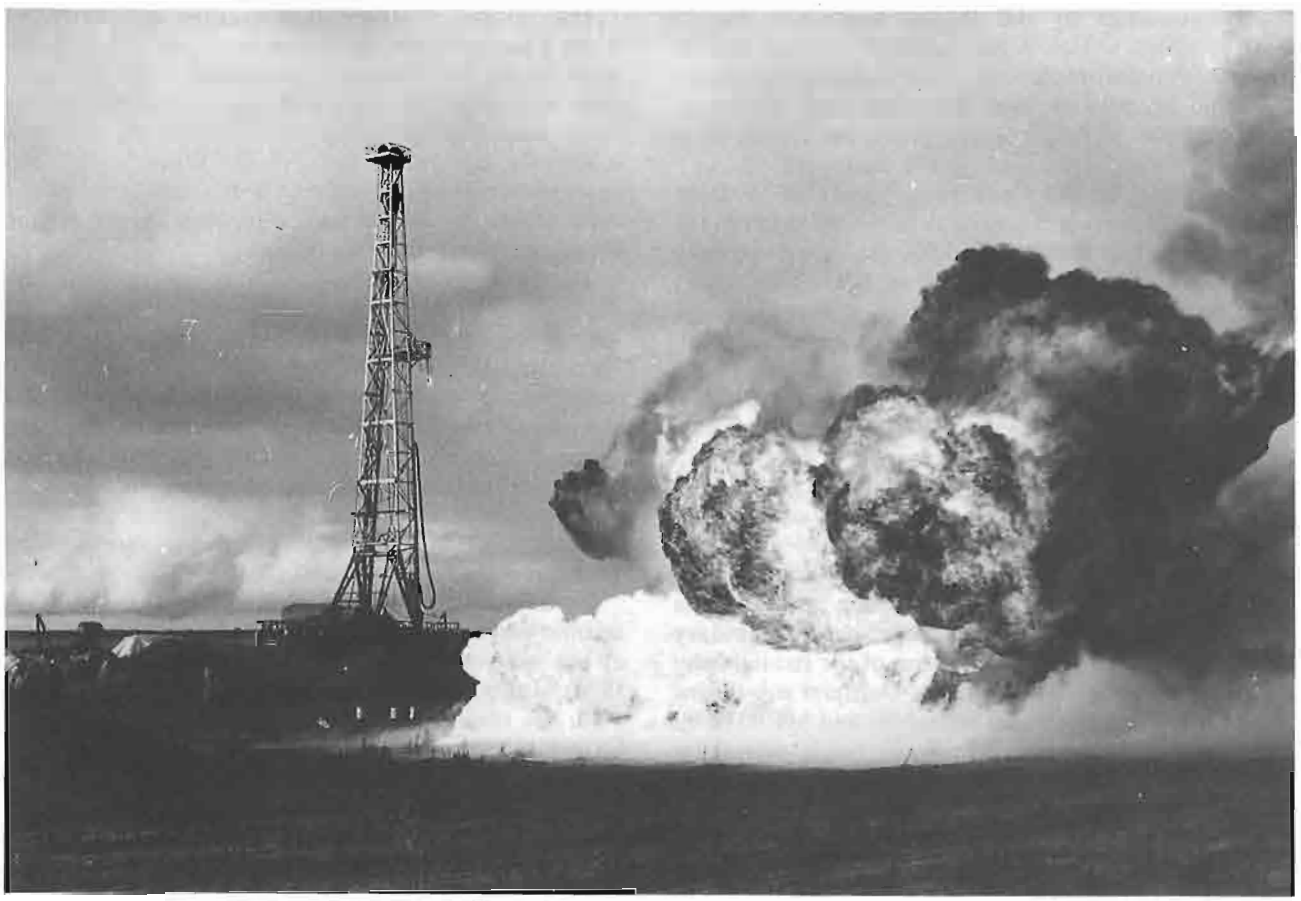

Figure 9: First oil flow in Australia's North West — Rough Range No. 1. (Photograph courtesy of Wapet).

In 1946, William Walkley, of the Australian Motorists Petrol Company (later Ampol) asked Harold Raggatt, then Director of the Australian Bureau of Mineral Resources, about Australia's most prospective areas. Raggatt sent him to explore the so-called North-west Basin, especially the area around Exmouth, where large surface structures had been seen. During the following years, as Walkley tried to obtain funding for the exploration venture, a joint BMR-Ampol field party prepared early maps of the Cape Range, Giralia and Rough Range structures. Logistics and geophysics then came into play: the Giralia anticline offered a less rugged terrain for a first well, but a BMR seismic profile across the structure showed a syncline at depth. Wapet management decreed that the first well had to be located on a seismically-confirmed structure and, with the enormous Cape Range anticline too rugged, attention shifted to Rough Range.

The rest is history. That "most fantastic hole-in-one in the history of oil exploration" (Wilkinson, 1983) boomed across the nation's boardrooms and bourses, and is seen today as a pivotal event in the history of exploration in Australia.

Aware that the islands within their permit might be caused by underlying structures, Wapet geologists went to Barrow Island in 1954 and 1956. They mapped a north-plunging anticline but further work was delayed until 1962 because of the security zone around the Atomic Bomb test-site on the Montebellos Islands. Seismic refraction profiles confirmed the structure, Barrow-1 was drilled in 1963, and the North West Shelf had its first oil discovery.

Wapet went on to drill other islands in the Barrow Sub-basin. None contained hydrocarbons but all provided valuable stratigraphic information. Wapet discovered several gas fields during the 1970s and have continued their success to the present.

Aquitaine commenced exploration in the Bonaparte Basin in 1962, expanding into the offshore with ARCO (operator) in 1964, and later, independently. The second ARCO/Aquitaine well, Petrel-1, blew out after encountering a major gas deposit. The Tern-1 well in 1971 found a second gasfield.

Woodside's involvement with the North West Shelf was, like Wapet's, linked to Cape Range. The Dutch geologist, Dr Nicholas Boutakoff, then Deputy Director of the Geological Survey of Victoria had visited there in 1954, and, looking at the islands to the north, concluded that water depth maps should reveal the location of major structures on the North West Shelf. Over several years, using Admiralty Chart No. 475, "North West Coast of Australia with the off lying islands and reefs" as a base, Boutakoff prepared a relatively detailed water-depth map of the shelf.

Figure 10: The "Glomar Tasman" drilled many of Woodside's early wells. (Photograph courtesy of Woodside Offshore Petroleum Pty. Ltd).

This work "revealed the existence of a number of offshore ridges along the outer edge of the Australian Continental Shelf" (Boutakoff, 1963); these were interpreted as "largely submerged and complex folded ranges, of which considerable parts are accessible to exploration". Situated between the intensely folded "alpine nappes" of Timor, with its numerous oil seeps, and the gently warped sediments of continental Australia, these geanticlinal ridges were judged "to be suitable for considerable accumulation of petroleum".

In 1962, Boutakoff was hired as a Chief Geologist of the Victoria-based Woodside Petroleum by company Directors, Rees Withers and Geoff Donaldson. His brief was to direct them into promising offshore areas. It is not suprising that he recommended the North West Shelf — though it was his third choice, behind the Great Barrier Reef and the Gulf of Carpentaria. Woodside's application for the offshore areas beyond Wapet's leases was approved in 1963 — by which time Boutakoff and Woodside had parted company, less than happily, over his commitment to publish his appraisal of the North West Shelf geology and potential (Boutakoff, 1963).

Aeromagnetics proved a thick sedimentary section in the area and seismic work commenced in 1966 after Woodside entered a joint venture with Shell and Burmah Oil Company, who became operator. The first well (1967), Ashmore-1, 350 km from the coast, and considered at the time to be the most remote drilling location in the world, was dry. The next well, Legendre-1, about 180 km northeast of Barrow Island found oil — too small to be commercial but large enough to sustain the spirit and calm the nerves, then rather frayed from corporate difficulties.

In 1971 the Scott Reef-1 well, on the remote Scott Reef atolls, found a major gas field. It was further proof of the region's potential but cold comfort otherwise: gas was uncommercial in that setting. Only a few months later, in May 1971, the North Rankin-1 well discovered a giant gas and condensate field in the Dampier Sub-basin, about 160 km offshore from Dampier. The Angel field was discovered a few months later; Goodwyn field was discovered early in 1972.

It must have seemed, for a moment at least, that development of these fields, and the future, would follow automatically. That is history too. In such a remote location, the development costs were going to be enormous, and could only be covered by exports. Discussions had barely commenced when the Labor Party won the 1972 Federal election. The new Minister for Energy, Rex Conner, declared an embargo on hydrocarbon exports, and announced plans to buy the North West Shelf gas at the wellhead and ship it to the eastern States.

Whatever the motivations and merits of it all may have been — and this is not the place to debate them

— the effect on Australia's petroleum exploration industry was devastating. Exploration on the North West Shelf, as elsewhere in Australia, ground to a near-halt.

The Decade Past

The past ten years have seen a resurgence of exploration on the North West Shelf, the involvement of many new companies, the discovery of significant commercial oil and gas fields, and the completion of the first stage of Woodside's development of the North Rankin Gasfield. With this has come international recognition that the North West Shelf is one of the future hydrocarbon provinces of the world.

The Federal Government's announcement of World Parity Pricing and the Iran oil crisis helped drive the resurgence in the late 1970s and, by the end of the decade, almost the entire North West Shelf was again under licence.

Great hopes attended the drilling of wells on the Exmouth Plateau in 1979/80 but the results were disappointing. Scarborough-1 found a large gas accumulation, but there were no significant oil shows (Barber, this volume).

Elsewhere on the shelf, the story has been very different.

In the offshore Carnarvon Basin, Wapet discovered the Gorgon and North Gorgon gasfields and the Saladin Oilfield. Woodside discovered the Goodwyn-3 oil and gas field, and the gas deposits at Dixon and Wilcox. The Mesa group (now operated by Western Mining) discovered the South Pepper, North Herald and Chervil oilfields. The Occidental group discovered the Bambra and Harriet fields in 1983; Bond, the new Operator, found Rosette in 1987. Marathon discovered Talisman in 1984. Detailed information on these fields is provided in this volume (McLure et al.; Vincent and Tilbury).

In the Browse Basin, Woodside's North Scott Reef-1 showed that the Scott Reef Gasfield is a giant accumulation, possibly larger than North Rankin (Forrest & Horstman, 1984). The Brecknock-1 well (1979) found a large gas/condensate accumulation c65 kms southeast of Scott Reef (Bint, 1988; this volume). Development of these fields in the last 1990s or beyond is a possibility.

In the Bonaparte Basin, Aquitaine's appraisal drilling has confirmed the Tern and Petrel gasfields. BHP's 1983 Jabiru-1 in the Vulcan Sub-basin flowed nearly 10,000 b/d (cumulative) from two reservoirs (MacDaniel, 1988) and started a major new play in the Timor Sea. Production commenced in 1986, at over 16,000 b/d. A string of oil discoveries has followed, and this area is currently the most active in Australia. The Challis field, discovered in 1984, has been confirmed by four wells (Wormald, this volume). Oil discoveries have also been made at Skua-2, Oliver-1 and Montara-1.

While this exploration has proceeded, Woodside's North West Shelf Project has become the largest resource development project in Australia. Agreement was reached with State and Commonwealth governments in the late 1970s for the project, involving a Domestic Gas Phase (the supply of gas to W.A.) and the Liquid Natural Gas (LNG) Phase (for domestic supply and export). Agreements were signed with Japanese power and gas companies in 1981. The Domestic Gas Phase commenced production in 1984, with the gas piped 1500 kms to Perth. Exports of LNG are scheduled to commence in the early 1990s.

Production commenced from Bond's Harriet Field in 1986, using nearby Varanus Island for storage and support facilities. Western Mining commenced production at North Herald and South Pepper fields in late 1987, also making use of a nearby island. Wapet is continuing with appraisal drilling at Saladin, and proposes to use Thevenard Island as a base. The environmental impact of these projects is discussed by Carr (this volume).

The Decade Ahead

In the 1950s, the North West Shelf of Australia was still "one of the least known regions of the world" (Fairbridge, 1953). Nautical charts carried a warning: "Caution — the whole of the coasts of North-western Australia are as yet very imperfectly examined". The geology of the region was speculation, based on a structural interpretation of sparse bathymetric data.

Today, it is the site of the largest and most expensive development project in Australian history. The facilities and infrastructure required for that project have helped establish the Karratha/Dampier region as a major population and industrial centre in the Australian North. Oil production has commenced from several fields nearby, with storage and development facilities on nearby islands. Oil production has also been established in the Timor Sea area further north, and other fields will be developed in the next few years. This work has been conducted with careful attention to the environment, both as to the natural setting and as a work-place.

Australian petroleum explorers have come to terms with the North. There is a new confidence about its potential, and the prospects of success there. That is essential for the short term and long term future of this country. In the short term, over the coming decade, until synfuels and other energy sources are available, the discovery of oil and gas reserves on the North West Shelf are imperative. Beyond that, the development of the North, with all its resources, is vital to this nation's security and welfare in the 21st Century.

References

Allen, G.A., Pearce, L.G.G. & Gardner, W.E., 1978, A Regional Interpretation of the Browse Basin: The APEA Journal, 18(1), 23-33.

Barber, P.M., 1982, Palaeotectonic Evolution and Hydrocarbon Genesis of the Central Exmouth Plateau: The APEA Journal, 22(1), 131-144.

Barber, P.M., 1988, The Exmouth Plateau Deep Water Frontier: A Case History: this volume.

Bhatia, M.R., Thomas, M. & Boirie, J.M., 1984, Depositional Framework and Diagenesis of the Late Permian Gas Reservoirs of the Bonaparte Basin: The APEA Journal, 24(1), 299-313.

Bint, A.N., 1988, Gas Fields of the Browse Basin: this volume.

Bond, G.C., Nickerson, P.A. & Kominz, M.A., 1984, Breakup of a supercontinent between 625 Ma and 555 Ma: New evidence and implications for continental histories: Earth and Planetary Science Letters, 70, 325-45.

Boutakoff, N., 1963, Geology of the offshore areas of North-western Australia: Australian Petroleum Exploration Association Journal, 3, 10-18.

Bradshaw, M.T., Yeates, A.N., Beynon, R.M., Brakel, A.T., Langford, R.P., Totterdell, J.M. & Yeung, M., 1988, Palaeogeographic Evolution of the North West Shelf Region: this volume.

Bureau of Mineral Resources, 1988, Australia's Petroleum Potential: Petroleum in Australia, The First Century, Australian Petroleum Exploration Association Publication, 48-90.

Carr, W., 1988, Environmental Impact Assessments of Three Offshore Oilfields, Western Australia: this volume.

Carrigy, M.A. & Fairbridge, R.W., 1954, Recent Sedimentation, Physiography and Structures of the Continental Shelves of Western Australia: Royal Society of Western Australia, Journal 38.

CGG (Compagnie Generale De Geophysique), 1975, Geophysical Surveys of the Continental Margins of Australia, Gulf of Papua and the Bismarck Sea, October 1970 to January 1975, Operations and Techniques, a Report by Compagnie Generale de Geophysique for the Bureau of Mineral Resources: Bureau Minereral Resources Australia Record, 1975/151 (unpubl.).

Earl, G.W., 1845, On the Physical Structure and Arrangements of the Islands of the Indian Archipelago: Journal Royal Geographical Society (London),15, 358-365.

Eriyagama, S.C., Collins, L.B. & Hocking, R.M., 1988, Depositional Framework and Major Lithostratigraphic Variations of the Barrow Group: this volume.

Exon, N.F., von Rad, U. & von Stackelberg, U., 1982, The geological development of the passive margins of the Exmouth Plateau off northwest Australia: Marine Geology, 47, 131-152.

Exon, N.F. & Willcox, J.B., 1978, Geology and Petroleum Potential of the Exmouth Plateau area off Western Australia: AAPG, Bulletin 62, 40-72.

Exon, N.F. & Willcox, J.B., 1980, The Exmouth Plateau: Bureau of Mineral Resources, Australia, Bulletin 199.

Fairbridge, R.W., 1953, The Sahul Shelf, Northern Australia, its Structure and Geological Relationships: Royal Society of Western Australia, Journal 37, 1-33.

Fairbridge, R.W., 1955, Some bathymetric and geotectonic features of the eastern part of the Indian Ocean: Deep-Sea Research, 2, 161-171.

Falvey, D.A. & Mutter, J.C., 1981, Regional Plate Tectonics and the Evolution of Australia's Passive Continental Margins: BMR Journal of Australian Geology and Geophysics, 6, 1-29.

Forrest, J.T. & Horstman, E.L., 1984, Australia's Northwest Shelf Booms: AAPG Explorer, April 1984, 22-24.

Forrest, J.T. & Horstman, E.L., 1986, The Northwest Shelf of Australia - Geologic Review of a Potential Major Petroleum Province of the Future: AAPG, Memoir 40, 457-486.

Geological Survey of Western Australia, 1975, Geology of Western Australia: Western Australia Geological Survey Memoir 2, 541p.

Hocking, R.M., Moors, H.T. & van de Graaf, W.J.E., 1987, Geology of the Carnarvon Basin, Western Australia: Geological Survey of Western Australia, Bulletin 133.

Hocking, R.M., 1988, Regional Geology of the Northern Carnarvon Basin: this volume.

Jones, H.A., 1973, Marine Geology of the Northwest Australian Continental Shelf: Bureau of Mineral Resources, Australia, Bulletin 136.

Kopsen, E. & McGann, G., 1985, A Review of the Hydrocarbon Habitat of the Eastern and Central Barrow-Dampier Sub-basin, Western Austrlalia: The APEA Journal, 25(1), 154-176.

Kriewaldt, M.J.B., 1964, Dampier and Barrow Island: Western Australia Geological Survey 1:250,000 Geological Series Explanatory Notes.

Krummel, O., 1897, Handbuch der Ozeanographie: Stuttgart, 2 volumes.

Laws, R.A. & Kraus, G.P., 1974, The Regional Geology of the Bonaparte Gulf - Timor Sea area: The APEA Journal, 14(1), 77-84.

Lee, R.J. & Gunn, P.J., 1988, Bonaparte Basin, in Petroleum in Australia: The First Century: Australian Petroleum Exploration Association Limited publication, 252-269.

MacDaniel, R.P., 1988, The Geological Evolution and Hydrocarbon Potential of the Western Timor Sea Region, in Petroleum in Australia: The First Century: Australian Petroleum Exploration Association Limited publication, 270-284.

McClure, I.M., Smith, D.N., Williams, A.F., Clegg, L.J. & Ford C.C., 1988, Oil and Gas Fields of the Barrow Sub-basin: this volume.

Middleton, M.F., 1987, Depth to Basement, 1:2,500,000: Western Australia Geological Survey.

Molengraaff, G.A.F., 1914, Folded Mountain Chains, Overthrust Sheets and Block Faulted Mountains in the East Indian Archipelago: Compte-Rendu Congr. Geol. Internat., XII Session Canada, 1913 (Ottawa), 689-702.

Mollan, R.G., Craig, R.W. & Lofting, M.J.W., 1969, Geological Framework of the Continental Shelf off Northwest Australia: The APEA Journal, 9(2), 49-59.

Mory, A.J., 1988, Regional Geology of the Offshore Bonaparte Basin: this volume.

Osborne, D.G. & Howell, E.A., 1987, The Geology of the Harriet Oilfield, Offshore Western Australia: The APEA Journal, 27(1), 152-163.

Parry, J.C. & Smith, D.N., 1988, The Barrow and Exmouth Sub-basins in Petroleum in Australia: The First Century: Australian Petroleum Exploration Association Limited publication, 191-212.

Sengor, A.M.C., 1987, Tectonics of the Tethysides: Orogenic Collage Development in a Collisional Setting: Annual Reviews of Earth and Planetary Science, 15, 213-244.

Teichert, C., 1939, The Mesozoic Transgression in Western Australia: Australian Journal of Science, 2, 84-86.

van Andel, Tj. H. & Veevers, J.J., 1967, Morphology and Sediments of the Timor Sea: Bureau Mineral Resources Australia Bulletin 83.

van Bemmelen, R.W., 1949, The Geology of Indonesia: The Hague (Govt. Printing Office), 2 volumes.

Veenstra, E., 1985, Rift and Drift in the Dampier Sub-basin, a Seismic and Structural Interpretation: The APEA Journal 18(1), 177-189.

Veevers, J.J. (Ed.), 1984, Phanerozic Earth History of Australia: Clarendon Press, Oxford.

Vening Meinesz, F.A., Umbgrove, J.H.F. & Kuenen, Ph. H., 1934, Gravity Expeditions at Sea, 1923-32: Waltman, Delft, 2.

Veevers, J.J., 1988, Morphotectonics of Australia's Northwestern Margin — A Review: this volume.

Vincent, P. & Tilbury, L., 1988, Gas and Oil Fields of the Rankin Trend and Northern Barrow-Dampier Sub-basin: this volume.

Wegener, A., 1924, The Origin of Continents and Oceans: Methuen and Company, London.

Whitworth, R., 1969, Marine Geophysical Survey of the North-west Continental Shelf, 1968: Bureau Mineral Resources Australia Record 1969/99 (unpubl.).

Wilkinson, R., 1983, A Thirst for Burning: David Ell Press, Sydney, 383p.

Woodside Offshore Petroleum, 1988, Petroleum Geology and Hydrocarbon Potential of the Barrow-Dampier Sub-basin and Environs, in Petroleum in Australia: The First Century: Australian Petroleum Exploration Association Limited publication, 213-231.

Wormald, G., 1988, The Geology of the Challis Oilfield — Timor Sea, Australia: this volume.