The Sedimentary Basins of Western Australia: An Introduction.

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Abstract

Western Australia is one of six federated sovereign States within the Commonwealth of Australia. It covers an onshore area of over 2 500 000 km², almost one-third of the Australian mainland, and is one of the largest political units in the world. The Phanerozoic sedimentary basins of Western Australia cover about one million square kilometres of the land area and underlie most of the continental shelf and slope. There are five main basins for petroleum exploration — the Bonaparte, Canning, Carnarvon, Officer and Perth. Oil and gas have been discovered in all except the Officer Basin. Smaller basins, including the Eucla Basin, are not considered prospective for petroleum. The small Collie Basin contains inportant coal deposits.

West Australia's first commercial oil production was in 1967 from the Barrow Island Oil Field in the offshore Carnarvon Basin. Several giant gas fields, including North Rankin, were discovered in the Carnarvon and Browse basins in the early 1970s. Exploration in the 1980s led to major oil and gas discoveries in the Carnarvon and Bonaparte basins, and smaller discoveries in the Perth and Canning basins.

Western Australia is poised to become Australia's premier hydrocarbon-producing State. By the mid 1990s, production will reach 350 000 BOPD and surpass output from Victoria's Gippsland Basin. Western Australia's sedimentary basins contain an estimated 45 percent of the nation's current oil reserves, 78 percent of the condensate reserves, and 80 percent of the gas reserves. Current gas reserves can sustain current production levels for 150 years, and will be a major component of the State's welfare and development in the 21st century. Oil production rates will decline markedly after about 1996 and future discoveries are an imperative for the nation's self-sufficiency. The best hope for those discoveries are in the Western Australian basins, particularly on the North West Shelf.

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Introduction

Dreams of rich Western Australian oil fields were born with Statehood nearly a century ago, when oil seeps were reported on the southwest coast. Those dreams soared in the 1920s and 1950s, but it was at Barrow Island in 1964, and at North Rankin and elsewhere in the early 1970s, that the coming-true began.

Today, on the brink of a new century, Western Australia (Fig. 1) is poised to become Australia's premier hydrocarbon-producing State. Western Australia's sedimentary basins contain an estimated 45 percent of the nation's current oil reserves, 78 percent of the condensate reserves, and 80 percent of the gas reserves. By the mid-1990s, production will reach 350 000 BOPD and surpass output from Victoria's Gippsland Basin. Gas from the giant North West Shelf fields will be earning about $1 700 000 000 annually.

This modern achievement is part of an ancient tradition: since man first came to what is now Western Australia, the rocks and mineral resources of the land have been fundamental to the local culture and welfare, and have determined many of the major social and historical developments.

Figure 1: Location map, Western Australia.

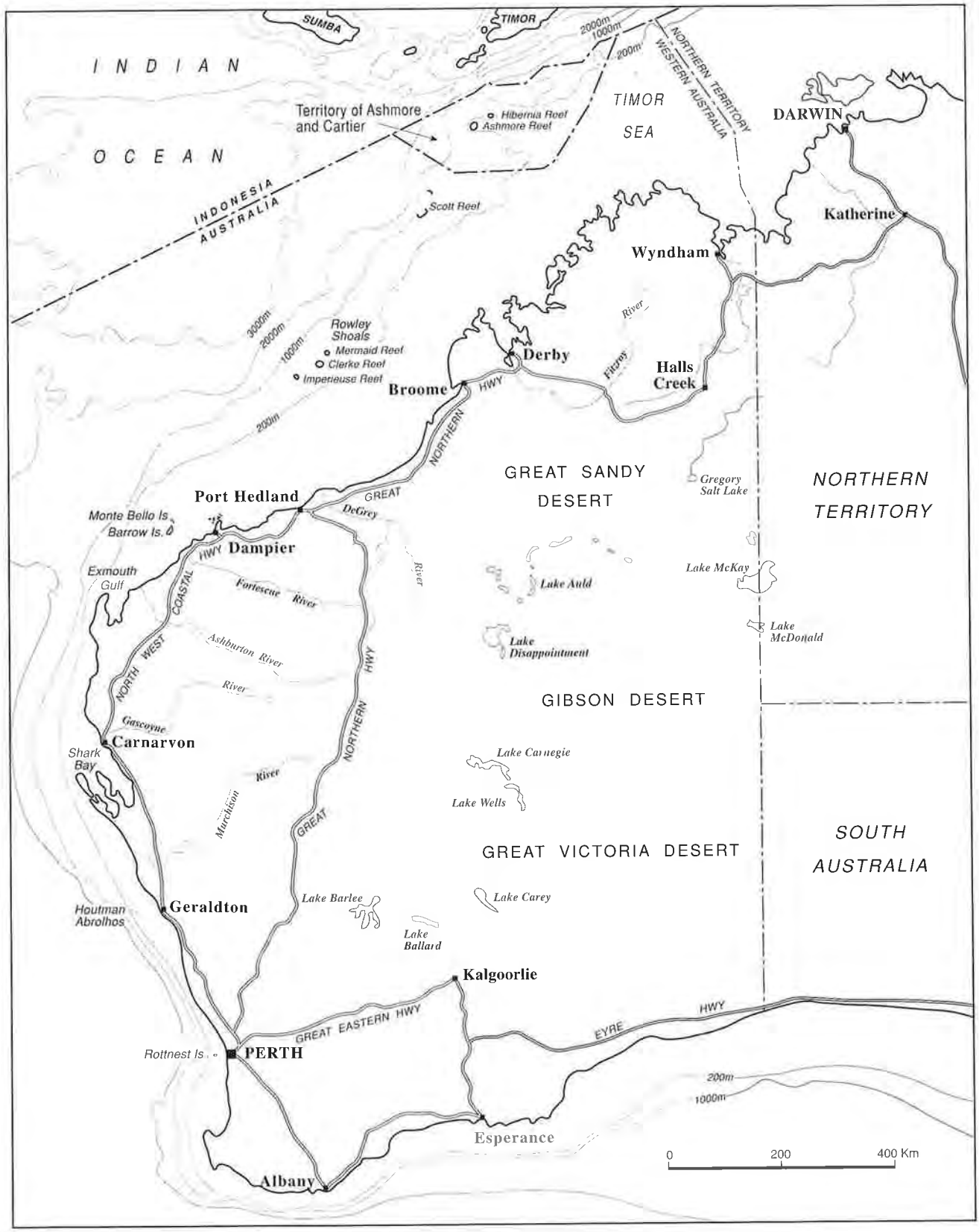


Figure 2: Geography map, Western Australia.

The petroleum resources of Western Australia are now essential components of the State's and nation's future. Australia's hydrocarbon self-sufficiency, having peaked at 96 percent in 1986, has declined to near 78 percent this year, and is falling towards 60% at the end of the decade (ABARE, 1993). Recent oil discoveries on the North West Shelf have slowed the decline, but cannot halt it for more than a few more years. Further discoveries and developments of both oil and gas are imperative: the oil, to replace declining reserves and increased demand; the gas, for export income to offset the rising oil import bill.

The Bureau of Resource Sciences (BRS) estimates that two billion barrels of oil must be discovered over the next decade if a 60–70 percent oil self-sufficiency is to be maintained. The best hope for those discoveries is in the sedimentary basins of Western Australia, particularly on the North West Shelf. Over 1000 MMBBL of Australia's undiscovered oil resources, 50 percent of the national total, and over two-thirds of the undiscovered gas resources are thought to occur in these basins (le Poidevin & Lowden, this volume)

This volume of papers is dedicated to the further successful search for oil and gas in the sedimentary basins of Western Australia and the adjacent areas of the Northern Territory and the Territory of the Ashmore and Cartier Islands. This paper provides an introduction to the geography and geology of Western Australia, and to the history and results of petroleum exploration here. It offers an historic perspective on those resources and our utilization of them, and urges industry pride in the prize of their discovery, and the wealth it has accorded this nation, and will accord in the century ahead.

Geography

Western Australia covers an onshore area of over 2 500 000 km^2, almost one-third of the Australian mainland (Fig. 2). It is one of the largest political states on earth; only the USA, China, Canada and Brazil are significantly larger (Fig. 3).

The State has approximately 7000 km of coastline, extending from the Timor Sea in the north to the Southern Ocean in the south, with most of the coastline bordering the Indian Ocean. State jurisdiction over the adjacent offshore areas extends only three miles seaward from the designated coastline; beyond that, is subject to Federal jurisdiction but administered jointly with the State authorities. The area around the Ashmore and Cartier islands is a Federal territory.

The capital city of Perth is located on the southwest coast, along the Swan River, with the port of Fremantle at the river mouth. Over two-thirds of the State's 1.7 million people live in the Perth metropolitan area. The rest of the population is concentrated along the coast, particularly in the southwest corner of the State.

Most of the State's larger towns are located on the coast; many have played significant roles in the petroleum exploration and production history. Onslow has been the staging point for exploration in the Barrow Island region; Broome and Derby, for the Canning Basin: Geraldton, for the northern Perth Basin. Karratha is the centre for Woodside's North West Shelf Project. These northern towns are connected

Figure 3: Size comparison: Western Australia, Texas and Great Britian.

to Perth by the inland Great Northern Highway and North West Coastal Highway. These highways meet at Port Hedland; the Great Northern Highway continues along the coast to Broome, then inland across the Kimberley and onto Darwin. These towns are all serviced daily by flights from Perth or Darwin. The coastal towns are on regular domestic shipping routes and many have significant international traffic. The ports of Dampier and Port Hedland have the largest international cargo volumes in Western Australia, though almost entirely outbound mineral and petroleum shipments.

Western Australia spans several different climatic zones, ranging from the tropical north to the semi-arid interior and the mediterranean coastal climate of Perth and the southwest. The distinctive feature of the northern climate is the 'wet' (monsoon) and the 'dry' (winter) seasons; the southern region has winter rain and hot summers. The effect of the monsoon is most marked in the northern Kimberley, and decreases from north to south, with the impact less marked in the Pilbara region. The average rainfall at Broome is 580 mm, double that of Port Hedland (277 mm). Maximum temperatures in excess of 40 degrees Celsius are common throughout the State in summer, except in the southwest coastal region. The maximum temperatures in the north occur in November and December prior to the monsoon; in the south, in January and February. Average summer maximum temperatures in Perth is about 31 degrees; at Port Hedland, 36 degrees, at Broome, 33 degrees Celsius.

The weather is controlled mainly by the belt of high pressure systems which separate the southeast trade winds, in the north, from the westerlies, in the south. In winter the highs move north, allowing moist westerly winds across the

southern region, causing most of the annual rainfall; dry southeasterlies predominate in the north, with sporadic rains coming from the northwest. In summer the highs migrate south; most of the State receives hot dry easterly winds from the interior, while the monsoon develops in the north, causing extensive thunderstorm activity and occasional cyclones. The cyclones occur each year and can cause damage whenever they 'track' across population centres.

The climate patterns determine field seasons for exploration in most onshore basins; in the northern Canning Basin, for example, the 'dry' season extends from about March through November. The cyclones are the major weather threat to petroleum operations in the offshore region. One of the most susceptible areas is the offshore and coastal region around Port Hedland, the site of extensive offshore Carnarvon Basin exploration. The planning of offshore exploration and production activity on the North West Shelf has to provide for the possibility of a major cyclone.

Physiography

The physiographic mosaic of Western Australia has been determined mainly by the nature of the surface rocks, and the impact of climatic conditions over the recent geological past. Prolonged exposure and erosion throughout the Tertiary, and even longer, established a relatively low relief landscape and defined most of the major physiographic provinces. Quaternary fluvial, aeolian and littoral processes have shaped some major provinces (the interior dune fields, for example) and formed many local features.

Subdivision of the Western Australian landscape into natural provinces has, from the earliest efforts, been greatly influenced by the surface geology and its regional geomorphological expression (Gentilli, 1979). Hydrology, botany, climate and soils have also been incorporated into some classifications. The subdivisions do vary somewhat, depending on the criteria and the scale of classification, but most are variations on the Jennings and Marbutt (1977) subdivision shown on Figure 4.

The **Nullarbor Plain** is a remarkably flat, mainly karst region that covers most of the Eucla Basin. The Tertiary limestones form cliffs along the coastline, but dune-covered coastal plains occur locally. Rainfall is low (130 – 200 mm annually) and erratic.

Sandland is the largest of the physiographic provinces and covers almost all of the Officer, Savory and Canning basins. It is characterised by seif dunes and sand or stony laterite plains, and incorporates the major Great Sandy, Gibson and the Great Victoria deserts. The sand dunes, with an average length of 80 km and an average height of 12 m, trend generally west to northwest. Remnants of the pre-existing river systems are evident in the landscape as networks of ephemeral lakes, swamps and internal drainage systems. The dunes are vegetated with spinifex and desert gums.

The **Lander-Barkly Plains**, an area of sandplains with scattered low granitic hills and tablelands, and basaltic plains with large claypans also extends into Western Australia.

The diverse **Kimberley Province** is commonly subdivided into northern, western and eastern divisions. The **northern Kimberley** block is essentially a very flat deeply incised dome of Proterozoic sandstones, with basaltic plains and hills in the north. The highest point at Mt Hann is c. 840 m above sea level. Steeply dipping quartzites and granitic hills and plains rim the plateau to the east and southwest. The coastline is rugged and inaccessible, with deep indentations and cliffs rising over 200 m. Extensive mud flats characterise the mouths of the major rivers. The **west Kimberley** province is located between the north Kimberley block and the Sandland province, and corresponds to the geological provinces of the Lennard Shelf and Fitzroy Trough. The main landforms are the limestone ranges and the extensive Fitzroy River flood plain (Fig. 5). Dune fields and sand plains occur in the west over the Dampierland Peninsula. Many Western Australian physiographic schemes recognise an East Kimberley province, corresponding to the drainage basin of the Ord River. Jennings and Mabbutt (1970) include this on the western edge of their broader North Australian Plateaus.

The **Pilbara division** is an elevated, dissected region of Archaean and Proterozoic rocks, bounded north and south by the De Grey and Ashburton rivers respectively. The Hamersley Plateau, south of the Fortescue River, is the highest area of land within Western Australia, and is well known for its scenic gorges. To the northeast, the topography is more subdued with low domes of Archaean granite and gneiss and elongate greenstone ridges.

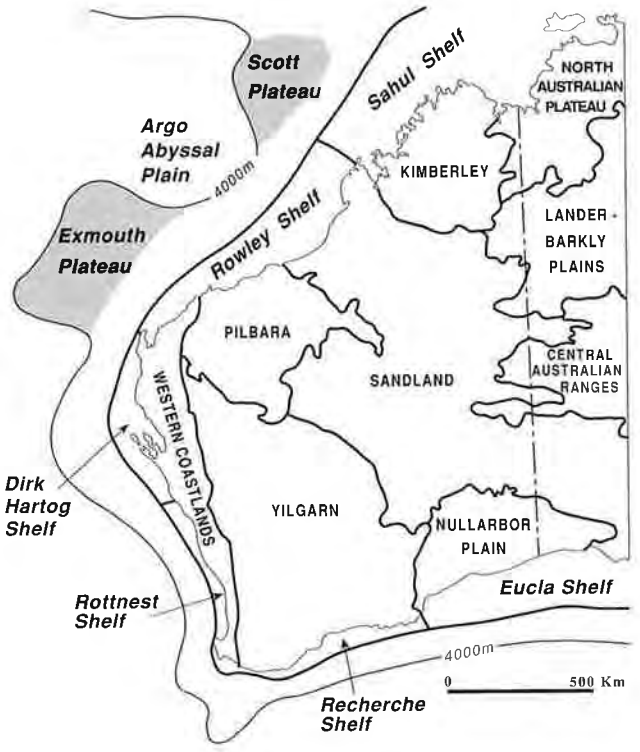


Figure 4: Simplified physiography map, Western Australia.

Figure 5: BMR geological mapping crew watching bush-fire in spinifex country, Fitzroy River plains. (Photograph courtesy of T. Yeates.)

Figure 6: Cape Range-1, the first well to encounter Jurassic sediments in Western Australia, in Shot-hole Canyon, Cape Range. (Photograph courtesy of M. Johnstone.)

The **Western Coastlands** province extends from near Dampier in the north to the south coast, and corresponds closely with the outcropping Palaeozoic to Recent sediments of the Perth and Carnarvon basins. In the north, the north-trending dunes of the Carnarvon Dunefield separate the dissected low folded structures of the North West Cape Ridges sub-province (Fig. 6) from the dissected sandstone plateau of the inland Kennedy Ranges (see page 347, this volume). Indurated calcareous dunes form the bordering peninsulas to Shark Bay.

The most distinct topographic feature in the southern region is the Darling Scarp, separating the granitic rocks of the Yilgarn Block, to the east, from the Perth Basin. Laterised Cretaceous rocks occur on the Dandaragan Plateau between the Darling and Hill River scarps, and the Greenough Block is characterised by a gently undulating sand plain with flat-topped hills of Jurassic and younger sediments (see page 779, this volume), and rounded outcrops of laterized Precambrian rocks. Most of the Swan Plain is covered by calcareous dunes, with lakes common, especially along the boundaries between the different dune systems. In the extreme south, the Donnybrook Lowlands occur between the Darling Scarp and the uplifted Leeuwin basement block.

The **Yilgarn Plateau** is a low relief landscape over a large area of the Precambrian Yilgarn Block. It is also known as the Salt Lake Division because of the extensive salt lakes and broad alluvium-filled valleys. The salt lakes, which range to over 100 km long, are the remnants of a Tertiary river system and are still inter-connected by ground water movement and rare stream flow.

The **Central Australian Ranges,** distinguished by granitic and dissected sandstone ranges and intervening low sand plains and salt lakes, extend into extreme west-central Western Australia.

The Western Australian offshore region is characterised by a continental shelf extending from the shoreline to a break in slope between 100–200 m, a marginal platform or terrace usually extending down to 500–600 m, and an outer continental margin. The continent/ocean boundary is generally located at water depths of 4000–5000 m. The continental shelf varies in width from a narrow 15 km near Cape Range to over 200 km near Rowley Shoals and 400 km across the Bonaparte Gulf and Timor Sea. Subdivions of the shelf are shown on Figure 4. In general, the shelf is narrower and the shelf-break shallower along the Dirk Hartog, Rottnest and Recherche shelves.

Two large marginal plateaus, both foundered continental blocks, occur along the northwest margin: the Exmouth Plateau extends about 450 km westward into the Indian Ocean from Barrow Island, with a minimum water depth of about 800 m; the Scott Plateau, further north, is deeper, at over 2000 m.

In the northwest, a chain of atolls extends along the edge of the platform, near the slope-break at about 600 m depth; these include, from north to south, Sahul Bank, Ashmore Reef, Cartier Island, Seringapatam Reef, Scott Reef, and Rowley Shoals (Fig. 2; see page 313, this volume). These atolls have grown since the Miocene on the subsiding margin, and rise nearly vertically 350–450 m from the sea floor. Numerous islands occur further south. The largest, Barrow Island, is the surface expression of a broad dome. Most of the more southern islands are part of several major reef systems: the Dampier Archipelago and adjacent reefs of the Pilbara coast; the Ningaloo reef tract and adjacent reefs; the Houtman Abrolhos and adjacent banks. Minor reef systems also occur along the western islands of Shark Bay and at Rottnest Island. The development of these reefs is a geologically recent event, associated with the transgression that followed the peak of the last glacial event c. 18 000 years ago. Their growth is sustained by the Leeuwin Current, a body of warmer tropical water which flows south down the Western Australian coast, causing elevated sea temperatures and reduced nutrient and particulate concentrations, and allowing reef-building communities to colonise further south than usual (Lenanton et al., 1991).

Government

Western Australia is one of six federated sovereign States which, together with the various territories, including the Northern Territory and the Australian Capital Territory, constitute the Commonwealth of Australia. Western Australia has its own Parliament and executive government, and is also represented in the Federal legislature.

The modern state began with British annexation in 1827 and became the Swan River Colony in 1829. Responsible government was granted in 1890 and, on 1 January 1901 the Colony became a State and part of the Commonwealth of Australia. The distribution of powers between the Federal and State Parliaments, as specified in the Constitution, has been and remains a source of conflict between the two authorities, and a point of passion for many Western Australians.

Legislative authority over land areas is constitutionally vested in the State and for many decades was taken to extend to the adjacent waters. In 1967 the Commonwealth laid claim to any offshore petroleum resources through the *Petroleum (Submerged Lands) Act 1967*, and State protests were over-ruled by the High Court of Australia. The Offshore Constitutional Settlement of 1979 saw a semi-formal splitting of powers relating to offshore petroleum matters, with the Commonwealth responsible for fiscal and overall policy, and the State responsible for day-to-day administration of the various Acts. The introduction of Resource Rent Tax by the Federal Government in the 1980s further reduced direct State earnings from future offshore petroleum production.

The 'State's rights' conflict is currently manifest in Federal efforts to exercise authority over land administration, by way of the *Native Titles Act 1993*, enacted in response to the High Court's controversial Mabo decision of 1992. A challenge to this legislation by the State of Western Australia is currently before the High Court of Australia.

Petroleum Legislation

All petroleum resources of Western Australia and its adjacent submerged lands are owned by the Crown. The State holds authority over all onshore areas, and the adjacent three miles of ocean; the dividing line between onshore and offshore is usually the coastline but locally extends across embayments such as Exmouth Gulf, and encompasses shallow- water areas such as the Barrow Island region. These offshore 'onshore' areas are known as 'inland seas'; the area within three nautical miles of the boundary is the territorial sea.

Exploration for, and production of, petroleum is permitted under the provisions of State and Commonwealth legislation: the Western Australian *Petroleum Act 1967* covers all onshore areas of the State, including its islands and internal waters; the Western Australian *Petroleum (Submerged Lands) Act 1982* applies to Western Australia's territorial sea; and the Commonwealth *Petroleum (Submerged Lands) Act 1967* applies to marine areas beyond the territorial sea. The WA Petroleum Act and the WA Petroleum (Submerged Lands) Act are administered solely by Western Australia, while the Commonwealth Petroleum (Submerged Lands) Act in respect to the Western Australia adjacent area is administered by a Joint Authority comprising the Commonwealth and Western Australian ministers responsible for petroleum matters.

The prime title for exploration is the Exploration Permit. Areas are released regularly, both onshore and offshore, on a work-based, competitive bid system. Permits are awarded on the basis of a six-year work program system, with a firm program for the first two or three years, and the remaining work program subject to renegotiation. At each renewal, 50 percent of the permit area must be relinquished. Permits are defined in terms of graticular blocks, five minutes square and covering an average area of about 80 km^2. Onshore permits may be up to 400 blocks, an area of over 32 000 km^2 (c. 8 million acres). Over recent years the WA Government has introduced incentives to stimulate exploration in the remote areas; these include the Drilling Reservation title (prospect-size blocks with a well-per-year renewable program), regular quarterly gazettal of all onshore acreage, and other administrative changes.

Production licences are issued for 21 years and may be renewed for further periods of 21 years. When required a pipeline licence will be granted for the same period. If a discovery is expected to become commercial within the next 15 years a Retention Lease, rather than a Production Licence, can be awarded for five years, with renewal periods of five years.

Royalty is payable at a rate of 10 percent to 12.5 percent of the post-wellhead value of petroleum recovered at the wellhead(s). The Australian company tax rate is 39 percent of taxable income.

Basin Framework and Evolution

The Phanerozoic sedimentary basins of Western Australia cover about one million square kilometres of the land area and underlie most of the continental shelf and slope. The Neoproterozoic basins cover an area of 60 000 km^2 onshore and underlie extensive areas of the Palaeozoic basins in the east central region. The location of these basins is shown on Figure 7.

The Phanerozoic basins were originally recognised late last century and, by the 1920s, were known as the Gulf Basin (now the Bonaparte Basin), the Desert Basin (Canning), the North West Basin (Carnarvon), the Coastal Plain Basin (Perth), and the Eucla Basin. The current names were introduced in the 1940s and 1950s, and were extended into the offshore domain when exploration began there in the 1960s. This has been reasonably appropriate in instances such as the Perth Basin, but less satisfactory in basins such as the Canning where there are significant geological differences between the onshore and offshore provinces. The review of basin nomenclature and classification by Hocking et al. (this volume) is a welcome step.

The Neoproterozoic basins of Western Australia were initially part of a vast basin within the super-continent Rodinia. During the assembling of Rodinia about 1300 Ma,

Figure 7: Sedimentary basins of Western Australia. (O, Ord Basin; MS, Money Shoal Basin; N, Ngalia Basin; S, Savory Basin; K, Karara Basin; C, Collie Basin; W, Wiso Basin.)

northern and western Australian cratons had collided along the line of the Paterson Orogen, and a vast epicontinental sag-basin developed over large areas of western and central Australia. This basin persisted until about 540 Ma during the latest Precambrian when transcontinental shear reactivated the Paterson Zone, and established foreland basins in the Savory (Wells Foreland Basin) and Officer basins (Yowalga and Waigen sub-basins). The subsequent history of basin formation in Western Australia is linked to the breakup of Rodinia and the progressive dismemberment of Gondwana through the Phanerozoic (Veevers, 1988; Baillie et al., this volume).

Continental breakup along the Rodinian margin in the latest Precambrian was far north of the present margin, but it was accompanied by rifts that branched into the continent interior, and the extensive basaltic volcanism in the Ord, Bonaparte and Officer basins. Renewed extension in the Early Ordovician led to the formation of the Canning Basin, along trend from the Amadeus Basin, and the development of an extensive seaway across the Australian continent. A major marine gulf extended south into the southern Carnarvon Basin by this time, either as a rift or an intercontinental sag, revealing the zone of weakness along which Australia and India would later separate. Further rifting occurred in the Middle Devonian in the Bonaparte, Canning and Carnarvon basins but, in the continent interior, coincident with major compressional uplift in the Amadeus Basin, caused by collision of the eastern Australian margin with a volcanic arc.

A second period of rifting and continental fragmentation commenced in the Carboniferous as the continental sliver of Sibumasu (Sengor, 1987) was trimmed from the northwestern Australian margin. The southeast-trending rift system along the incipient Australian/India margin was reactivated and a northeasterly-trending trough formed along what is now the North West Shelf. The northwestern basins were within a shallow marginal embayment on the northern shores of Gondwana. Australia had drifted into high latitudes by this mid-Carboniferous time, remaining there through the Early Permian, and vast ice sheets covered much of the continent.

In the Late Permian, the tensional forces dismembering Gondwana intensified, and the Australia plate began to drift into lower latitudes. The Mesozoic history of the western Australian basins is a record of the interplay of this complex structural development and the changing pattern of climate and sea level. The product of that interaction was what Bradshaw et al. (1988) called a 'constantly changing mosaic of environments' in the Western Australian basins.

Late Jurassic sea-floor spreading formed the Argo Abyssal Plain (the adjacent continental margin is Australia's oldest) and sea-floor spreading commenced between Australia and India in the Early Cretaceous. Currents began to circulate in the widening Indian Ocean and carbonate shoals flourished on the subsiding northwestern margin. A major sea-level rise flooded across northern Australia, and along the rift valleys of the southern margin and northward into the continent interior. Sea level rose and fell through the Cainozoic, flooding into the Eucla Basin and locally on the western coast. The climate was wetter and humid, and vast river systems flowed from the interior into the Indian and Southern oceans. Ice ages and drier conditions led to duricrusts over much of Western Australia and the northern margin collided with the Sunda Arc.

Carbonate sedimentation continued to build the North West Shelf. Reefs commenced growing in the Miocene, kept pace with subsidence and now form shoals near the modern shelf edge. Sea level changes saw the coast advance and retreat and, as drier conditions became established, the rivers dried to lake-ribbons and westerly winds blew dunefields across the land.

Geology and Culture

This long and complex evolution has endowed the Western Australia region with a vast and rugged landscape and rich mineral resources. From the beginning, the use of those resources has been fundamental to man's survival and prosperity here. Radiocarbon dating of sites in Northern Australia show that the area was occupied at least 30–40 000 years ago, probably by negrito people who used the stones for tools and weapons, and etched the caves and cliffs with delicate art work. A new people came about 6000 years ago, bringing with them the dingo and a new technology of stone work and weaponry. They made the billowing monsoon clouds their rain gods, the Wanjina,

and found their shapes reflected in the eroded Permian hills inland. Their art and technology over-stepped the older culture, and their dingo companion decimated the continent's pre-existing megafauna.

From the earliest days of the Swan River colony, when the poor quality of the soil was recognised, the need for mineral resources to sustain the economy was clear. The State's first mineral boom occurred in the early 1840s, driven by rumours of rich coal deposits on the Murray River. Famed Western Australian explorers, the Gregory brothers, did find good coal deposits in the Irwin River area in 1846. The coal deposits in the Collie Basin were discovered in 1883 and production commenced in 1898. These coal deposits have been the main source of electrical power in the State for decades, being used as fuel in power stations in the southwest.

In the early 1890s, the discovery of gold in large quantities dramatically improved the colony's economy, and the population increased four-fold. By 1900, gold dominated export earnings and the network of railways built to mine sites facilitated the establishing of the wheat industry. Export earnings from gold funded the construction of the Fremantle inner harbour, the Mundaring Weir and the water pipeline to Kalgoorlie.

The importance of the mineral resources of this State was very clear in the public mind in the early years of Statehood. When the University of Western Australia opened in 1913, seven faculties were to be established. Mining was one of the first chosen; the choice for the last Chair came down to either Geology or the Classics: Geology was chosen (Lord, 1979). It seems there was a better appreciation of the importance of geology's value then, than is usually evident today.

The value of gold exports soared in the 1930s in response to sharply higher gold prices, and sustained the State and national economies when wheat and wool exports declined. The development of iron ore mining in the Pilbara during the 1960s offset another economic downturn in the agricultural industries. The discovery of nickel in the late 1960s brought further wealth and revitalised the Eastern Goldfields region. All periods of major economic growth in Western Australia are related to mineral discoveries.

Early petroleum discoveries, though they fell short of expectations, stimulated work elsewhere, and raised the spirit (Figs 8 & 9). The Rough Range oil discovery offered hope in that lean post-war decade, and showed that there was oil to be found. The move to develop the North Rankin gas field, in the largest development project in Australian history, cast aside the negative connotations of gas, and gave to many a renewed sense of purpose in building the State's future. The past decade has seen numerous discoveries of oil and gas, and their importance and impact will grow in the future.

Few Australians are aware that Western Australia is now one of the world's leading mineral producers. The State produces 35 percent of the world's mineral sands, 33 percent of the diamonds, 30 percent of the ilmenite, rutile and zircon, 25 percent of the salt, 20 percent of the alumina, 12 percent of the iron ore, 9 percent of the gold, and 8 percent of the nickel. Mining and petroleum production in WA in 1992 provided 70 percent of our exports and earned over $12 billion; $413 million came to Western Australia. This is the highest single wealth-generating industry in the State and provides livelihood to one in six people.

The next few decades will see gas emerge as the most important 'mineral' in this State. LNG and condensate export earnings in 1992/3 were valued at more than $2.6 billion. The growth in earnings from Western Australian petroleum production is shown in Figure 10.

By the end of this decade, export earnings from gas will surpass those from gold and iron. Asian markets will allow development of a third and fourth gas facility by the year 2010. Even greater social and economic impact will follow the establishment of the Gas Goldfields Transmission pipeline, designed to move North West Shelf gas to the Kalgoorlie goldfields region. The pipeline will pass through the State's rich mineral provinces, stimulating exploration, development and, ultimately, processing in these remote areas.

OIL

IT'S OFFICIAL!

STRIKE IN WESTERN AUSTRALIA

Oil has been found at Exmouth Gulf on the West Australian coast about 650 miles north of Perth.

This sensational news was confirmed by the Prime Minister's Department this afternoon.

A well is flowing at the rate of 500 barrels a day.

As soon as the news hit the Sydney Stock Exchange brokers bid furiously.

"Great bearing on economy"

Figure 8: The *Daily Mirror*, 4 December 1953 headlines the Rough Range-1 discovery. (Clipping courtesy of S. Summerhayes, Ampolex Ltd.)

Figure 9: Seven dry holes later, divine intervention was sought at Rough Range-9! (Photograph courtesy of M. Johnstone.)

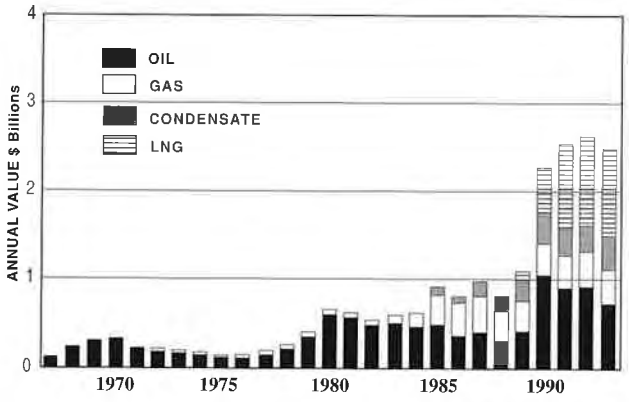


Figure 10: Value of sales of Western Australian petroleum production, 1967–1993. (Data courtesy of Petroleum Division, WADOME.)

Creationism and Early Geological Concepts

The origin of the rocks and landscape of Western Australia has always challenged the people who lived here. In prehistoric times, Aboriginal man believed the earth was given form in the distant past, now popularly called the Dreaming: mythical creatures, human and animal, or both at once, crossed the landscape and shaped it with their lives and deaths. What later people would see as glacial debris, were the eggs of the goanna Looma; the folded rocks of St George Ranges was the body of the snake Galyidjida.

The arrival of different peoples and different cults always provided different explanations. Inland migrations, probably forced by new arrivals and rising sea levels, sponsored myths about wandering mobs: the Dingari, Wadi Gudgara (the Two-men), Malu (Kangaroo-man), and others. The Rainbow Snake, in its myriad manifestations, dominates another creation belief system.

The European migration brought new beliefs, but with many similarities, notably of a sacred creative epoch and the formative impact, both moral and geomorphological, of great floods and cataclysmic upheavals. The more 'scientific' approach to the geology of Western Australia is not much more than a century old, and currently accepted views have only a few decades standing.

Early this century, the Banda Arc was seen as a chain of horst blocks: rising and falling land bridges across which the elephant-like Stegadon walked to Timor, and the ancestral platypus and echidna came to Western Australia. The discovery of low-angle thrusting 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.

There was also considerable support in Western Australia for the so-called tetrahedral theory, which interpreted the folded mountain chains as evidence of the earth's contraction (Cockbain, 1983). A tetrahedron has the smallest volume for a given surface and was seen as the form towards which the world was shrinking. The four faces of the global tetrahedron were the Arctic, Pacific, Atlantic, and Indian oceans; the edges and corners were the land masses. A principal supporter of this concept was W.G. Woolnough, the Professor of Geology at the University of Western Australia.

The Indian Ocean was seen as a new ocean, formed by the sinking of a vast continent. The discoveries of Palaeozoic and Mesozoic sediments along the Western Australian margin were interpreted as evidence of an extensive embayment into that continent, and called the Westralian Geosyncline by Teichert (1949).

The pioneering geology studies of the North West Shelf by Fairbridge (1955) and others (Carrigy & Fairbridge, 1954) seemed to provide further support for 'fixist' concepts. Bathymetric data showed that the continental shelf was broadest and deepest opposite the mainland basins, but narrow and shallow opposite the Precambrian blocks. With the features of the continent and ocean so 'intimately related', there was little room for doubt about structural continuity between the two domains.

These ideas were overthrown by the geological revolution of global tectonics in the 1960s and are now held by new generations of geologists to be almost unbelievable in their naivity and flaws. There may be wisdom in accepting that some of today's views will be similarly derided in the 21st century.

Several papers in this volume challenge today's dogma. Stagg and Colwell (this volume) argue that deep-seismic profiles show the Carnarvon Basin to be a major sag basin, with little indication of Mesozoic extension, and call into question the ubiquitous descriptions of the Dampier and other sub-basins as rifts. Labutis (this volume) and Apthorpe (this volume), arguing from geophysical and palaeontological perspectives respectively, raise doubts about commonly accepted Mesozoic marine environments on the North West Shelf. Logan (this volume) offers a challenging new perspective on the Devonian limestones of the Canning Basin.

Geology in Western Australia

Dr F. Von Sommer, retained by the Government in the late 1840s to examine the reported coal find in the north Perth Basin was the first professional geologist to work in Western Australia and the first employed by the Government. His drawings constitute the first known geological maps of Western Australia. The first published geological map of the colony was, fittingly enough, by the Gregory brothers in 1860 (Archbold, 1981).

A Government geologist was employed intermittently through the latter part of the 19th century, whenever funds allowed; all contributed significantly to scientific knowledge of the State's sedimentary basins. A.G. Maitland was appointed as Government Geologist in charge of the newly formed State Geological Survey in 1896. It is surprising that the survey remained a relatively small organisation until 1961 when it was expanded, with renewed emphasis on geological mapping of the whole State at 1/250 000 scale. This expansion coincided with, and drew motivation from,

the rapid development of the State's mineral resources, after discovery of economic deposits of bauxite, iron ore, oil, gas and nickel (Lord, 1979).

The Commonwealth Government became involved in the geology of Western Australia when the Northern Territory Survey Act 1934 established the Areal Geological and Geophysical Survey of Northern Australia (AGGSNA). The Bureau of Mineral Resources (BMR) was established immediately after World War II and played a major role in geological mapping of the State, both independently and, after 1961, in association with the Geological Survey of Western Australia (GSWA) (Fig. 11).

Earth scientists from these agencies, and from the University of Western Australia (UWA), have played important roles in the geological exploration of Western Australia's sedimentary basins. Much of this work has been conducted in co-operation with the petroleum exploration industry, and has been of great benefit to it. This is true of the offshore area as well as the onshore basins, and is evidenced by the many papers in this volume by scientists from the Australian Geological Survey Organisation (AGSO), GSWA, UWA and other agencies.

The study of nature and origin of the Western Australian shelf was pioneered by Rhodes Fairbridge (UWA) in the early 1950s, but the BMR has been the leading Government agency in the study of the offshore basins. The first regional study in 1960/1 involved a survey of sediments and morphology of the Sahul Shelf and Timor Trough (van Andel & Veevers, 1967). The Bureau's 1972 reflection seismic survey in the Exmouth Plateau region was a first step towards the exploration of that deep-water province.

The establishing of the Division of Marine Geoscience and Petroleum Geology, and the instigating of the Continental Margins Program, led to increased BMR work on the offshore basins, both directly and by way of analysis of data collected by petroleum exploration companies. The Bureau's R/V *Rig Seismic* made its first survey in Western Australia in 1986, on the Exmouth Plateau and offshore north Perth Basin. During 1990--1991, cruises were undertaken over large areas of the North West Shelf, and included deep-seismic profiling. Data from the Carnarvon, Offshore Canning and Browse basins are presented in this volume, and offer new insights into basin formation (AGSO North West Shelf Study Group, this volume).

BMR scientists have been involved with various legs of the Ocean Drilling Project (ODP) in areas adjacent to Australia over the period 1987 to 1991. This work has attracted significant international research expenditure and scientific expertise to Western Australia. A summary of this work and its related studies is given by Exon and von Rad (this volume).

Oil company scientists have contributed greatly to geological knowledge in Western Australia, particularly over the last fifty years. Much of the pioneering mapping in many sedimentary basins was done by oil company geologists. Early surveys and compilations by Government agencies made use of the sparse subsurface and geophysical control available from early petroleum exploration work.

This tradition of co-operation between industry, government and academic geo-scientists is continued today in many projects, including co-authorship of several papers in this volume.

Figure 11: Joint GSWA/BMR geological mapping expedition departing from Halls Creek, 1972. (Photograph courtesy of T. Yeates.)

Petroleum Exploration

The search for petroleum in Western Australia began at the turn of the century when oil shows were reported near the Warren River on the southwest coast. The reports caused great excitement in the new State but four shallow holes yielded no encouragement. Interest waned until after World War I when Western Australia was caught up in the world-wide oil 'fever' (Fig. 12).

Perhaps the first person to 'explore' for petroleum in Western Australia was Walter Okes who had heard about seeps and oil fields from American soldiers he met in France. Okes went prospecting in the Eastern Kimberley in 1919 and found his seep, near the junction of the Ord and Negri rivers, on a station called Texas! A bore drilled near the seep by the Okes Durack Kimberley Oil Company NL in 1923 encountered basalt at 365 m (1196 ft).

The first confirmed oil shows in Western Australia were discovered by a water driller, Harry Price, in a water well near Fitzroy Crossing in the Canning Basin. The Freney-Kimberley Oil Company Limited was formed to explore this area; their mapping of structures in the Fitzroy Trough by the geologist Arthur Wade constitutes the first scientific exploration for petroleum in WA. The first exploratory well based on geological mapping was Freney's Mount Wynne-1 in June 1922.

It is difficult now to appreciate the great excitement and expectation of that time. Newspaper reports on the 'Kimberley Oilfields' were common, with much speculation on the size of the fields and fortunes to come. There was no doubt that oil would be found. This enthusiasm found a serious critic in American consulting geologist Frederick Clapp, brought to Western Australia to advise some companies holding exploration permits over the State. 'Seldom in (my) experience', Clapp wrote, 'has any more discouraging set of conditions been found. Expenditure in drilling for oil is useless and should be discouraged' (Clapp, 1926).

Figure 12: Locke Oil Expedition, 1922. (Photograph courtesy of the Battye Library, Perth, No. 3772B.)

Discourage, it did! Apart from Freney's efforts, there was little exploration in the State until the 1940s, when several companies acquired permits and conducted geological investigations; no wells were drilled.

Systematic exploration for petroleum in Western Australia commenced onshore in the 1950s and offshore in the early 1960s. It was dominated for many years by two groups, West Australian Petrolem Pty Ltd (WAPET) and Woodside Offshore Petroleum Pty Ltd.

WAPET's origin was with William Walkley of the Australian Motorists Petrol Company (later Ampol), and is the subject of many retellings (Purcell, 1988: Wilkinson, 1991). A joint BMR--Ampol field party prepared early maps of the Cape Range, Giralia and Rough Range structures. Texaco, Chevron and Shell joined Ampol to form West Australian Petroleum Pty Ltd; their first well was Rough Range-1. The rest is history.

WAPET geologists had mapped a north-plunging anticline on Barrow Island in 1954--56 (see page 433, this volume), but drilling was delayed until 1963 because of the security zone around the atomic bomb test-site on the Montebello Islands. Barrow-1 gave Western Australia its first oil discovery. Production commenced in 1967. In 1966, WAPET discovered a large gas field at Dongara in the Perth Basin, and commenced production in 1971. Extensive exploration programs elsewhere were unsuccessful but WAPET progressively relinquished most of its permits by the mid 1970s.

Woodside's involvement with the North West Shelf began with Dr Nicholas Boutakoff, one of the few internationally experienced petroleum geologists in Australia in the early 1950s. While Deputy Director of the Geological Survey of Victoria in 1954, he visited the Rough Range discovery and concluded that water depth maps should reveal the location of major structures on the North West Shelf. His 'detailed' bathymetric map, prepared privately from Admiralty Chart No. 475, revealed a number of 'offshore ridges' which Boutakoff interpreted as 'submerged and complex folded structures' and which he judged 'to be suitable for considerable accumulation of petroleum' (Boutakoff, 1963). After trying unsuccessfully to obtain a licence over the North West Shelf in 1955, Boutakoff took his ideas and maps with him to Woodside in 1962 when he was hired as Chief Geologist. Woodside's application was approved in 1963; Shell and Burmah joined them in 1964, and seismic work commenced. The first well was dry; the second, Legendre-1, found a non-commercial oil field; the third, Scott Reef-1, found a major gas field; the fourth, North Rankin-1, discovered a giant gas and condensate field in the Dampier Sub-basin. The Angel field was discovered a few months later; Goodwyn, a few months after that. (Boutakoff had no joy from all this. He resigned in protest in 1963, and maintained bitterly until his death in 1977, that Woodside had not honoured a 'gentlemen's agreement' regarding bonus payments in exchange for his ideas.)

Several other companies conducted major exploration programs during this period. Aquitaine commenced exploration in the Bonaparte Basin in 1962, expanding offshore with ARCO as operator in 1964. Their second well, Petrel-1, blew-out after encountering a major gas deposit; Tern-1 in 1971 found a second gas field. Continental Oil Company explored in the Carnarvon and Canning basins under farm-out from WAPET. Hunt Oil Company explored the remote Officer Basin.

None of this work yielded any real encouragement regarding the oil potential, and exploration declined markedly in the early 1970s, as shown on Figure 13. The gas discoveries on the North West Shelf, though enormous, were seen by many as evidence that the region was gas-prone, and served to discourage exploration. Plans to develop the gas fields were set back by the Labour Party victory in the 1972 Federal election: the new Minister for Energy, Rex Conner, declared an embargo on hyrdrocarbon exports, and announced plans to buy the North West Shelf gas at the wellhead and ship it to the eastern States.

A new round of exploration began towards the end of the 1970s, stimulated by escalating oil prices and a change in government policy. Large areas of onshore and offshore basins were under permit and major exploration programs were proceeding. Deep-water exploration on the Exmouth Plateau led to Esso's Scarborough-1 gas discovery but was disappointing relative to pre-drilling expectations of oil potential. However, drilling in the Carnarvon and Bonaparte basins in the early 1980s led to a string of discoveries, including Gorgon, Dixon, Harriet, South Pepper, Jabiru and Challis. That pattern of discoveries has continued, as shown on Figure 14.

In 1973 Western Australia had one giant and one minor oil field; today, there is still only the one giant oil field (Barrow Island) but there are four major oil fields and 43 minor fields. In 1973, there were two super giant gas fields, three giants, one major and four minor gas fields. Today, there are six super giant fields, four giants, five major and 24 minor fields.

It is this past decade of exploration that has established Western Australia as an important petroleum-producing region. The success has been built on the work of the decades before. An important stimulus and guide was the vast data-base available from that earlier work, much of it available on open-file courtesy of the *Petroleum Search Subsidy Act 1957*. The success of future decades will depend, among other things, on the availability to future explorers

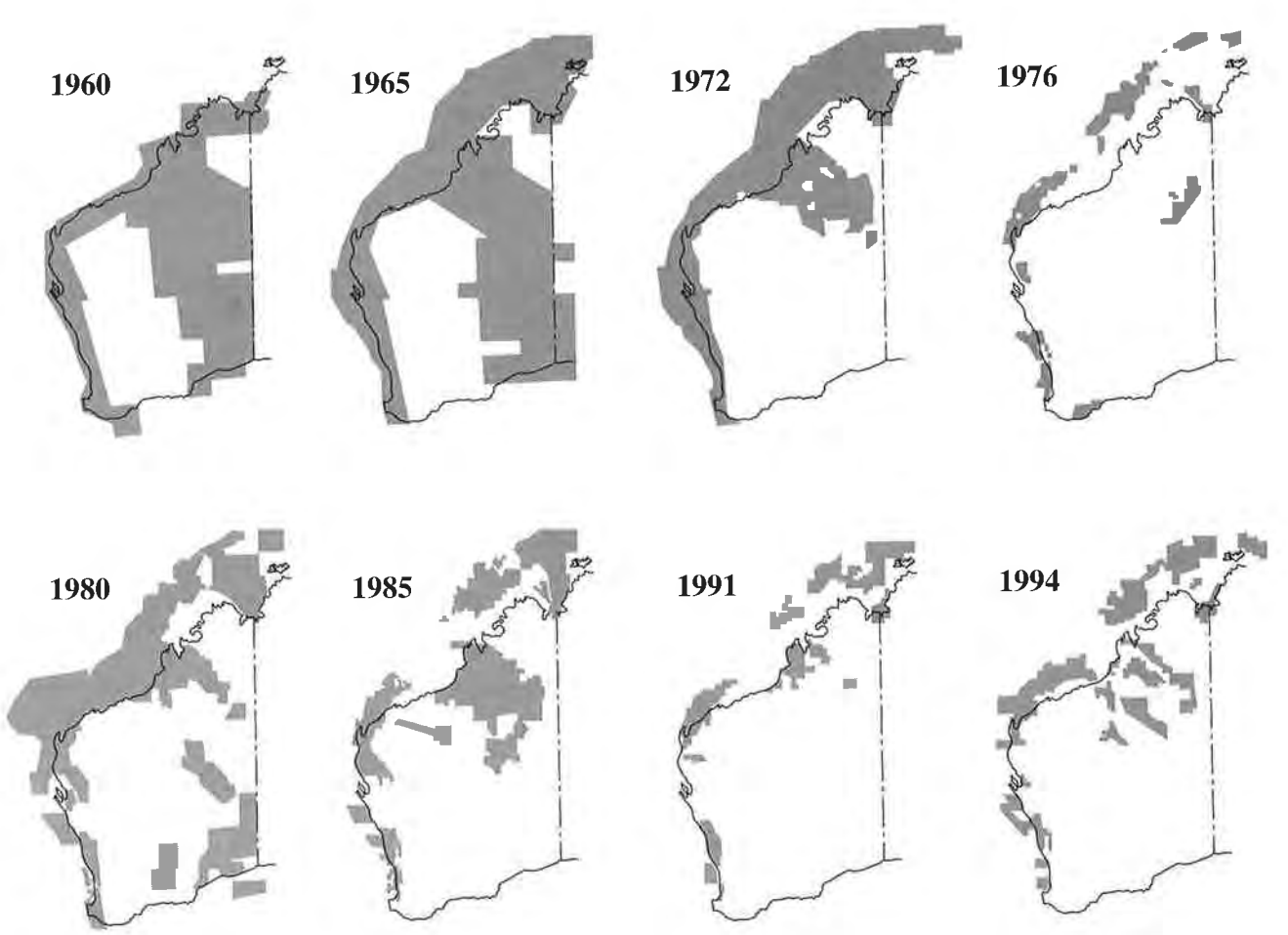


Figure 13: Simplified petroleum tenement maps of Western Australia, 1960–1994. (Maps for 1960–1980 are redrawn from Blumer, 1982.) Note the reduction in permits onshore by 1972; the dramatic collapse in activity in the mid-1970s; the 1980 'boom' onshore and offshore, including the Exmouth Plateau; the contraction through the 1980s, except for the mid-decade peak of activity in the Canning Basin; and the expansion of recent years.

of the results of today's exploration. Recent initiatives by the Western Australian Department of Minerals and Energy in releasing 'interpretive data' from past surveys and wells are welcome and could usefully be expanded to provide for immediate release of all data, basic and interpretive, from relinquished acreage.

Oil and Gas Production, Reserves and Resources

The location of producing fields within Western Australia and adjacent territories is shown in Figure 15. A detailed summary of petroleum production and resources in these basins is given by le Poidevin and Lowden (this volume).

West Australia's first commercial oil production was in 1967 from the Barrow Island Oil Field in the offshore Carnarvon Basin. The annual production of oil, gas and condensate from that first production to 1993 is shown on Figure 16. The dramatic increase in production levels during the late 1980s is very clear and is set to be repeated over the next few years as Wanaea, Wandoo and other field come onto production.

Barrow Island field remains the largest Western Australian field. Production rates are now declining but total roduction had reached 256 MMBBL by the end of 1993. There are now 17 other producing fields in the Carnarvon Basin; total production from these fields to end 1993 was approximately 125 MMBBL. Condensate production to end 1993 from Carnarvon Basin fields was 76 MMBBL.

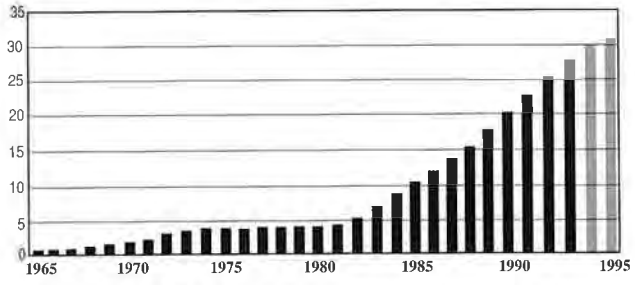
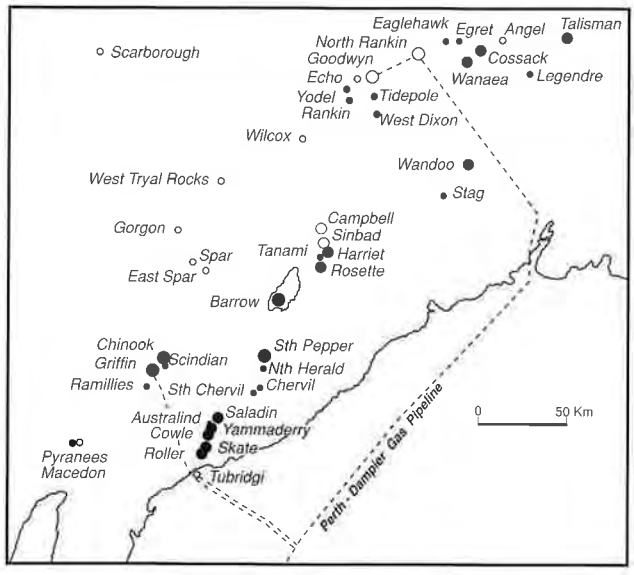


Figure 14: Number of Western Australian producing fields, 1965–1993, and projected to 1995. (Data courtesy of Petroleum Division, WADOME.)



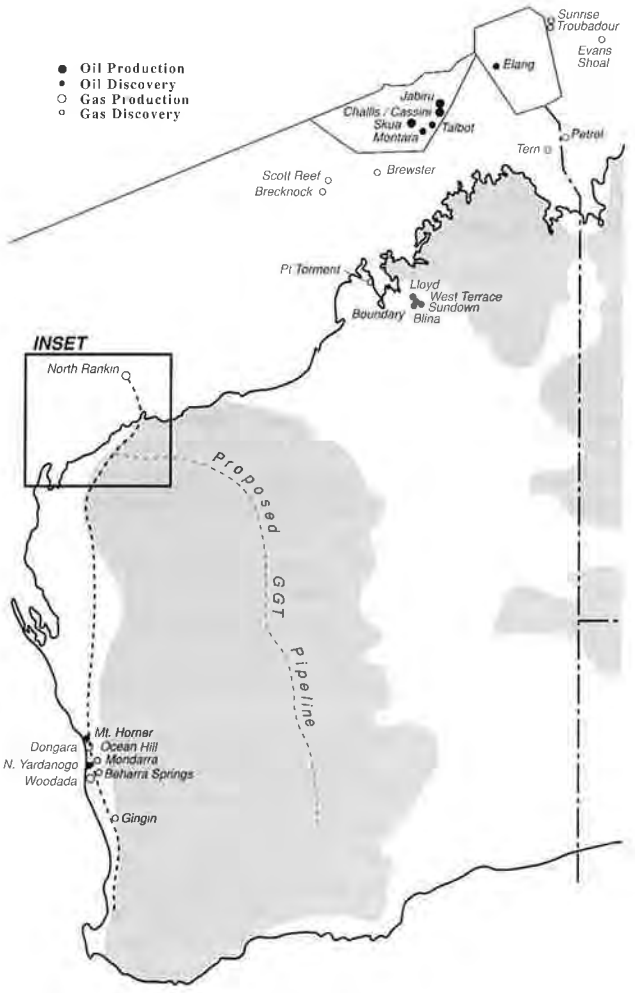


Figure 15: Oil and gas producing fields and discoveries, Western Australia.

In the Perth Basin, oil production commenced from Dongara in 1971. Total production from Dongara, Mount Horner and other small fields was approximately 2 MMBBL by end 1993. A similar production level has been achieved in the Canning Basin where production commenced in 1983 from Blina and nearby fields

Production commenced in the Bonaparte Basin at Jabiru in 1986. By end 1993, Jabiru Challis, Cassini, and Skua fields, all located in the Ashmore/Cartier and Northern territories had produced 129 MMBBL.

Gas production from West Australian basins is about 1 BCFD, approximately 50 percent of the national total. This gas comes mainly from the North Rankin Field in the Carnarvon Basin and is mostly exported as LNG. Some of the gas is used in the domestic WA market, as is gas from Tubridgi, Griffin and the Harriet Gas Gathering Project. Total production to end 1993 from these fields was over 2100 BCF. Perth Basin gas fields contribute to the domestic market at a 1993 rate of 0.03 BCFD.

The Bureau of Resource Sciences (BRS) estimates that Western Australian basins contain 45 percent of the current estimated reserves of oil, 78 percent of the condensate reserves and 80 percent of the gas reserves. Western Australian reserves are set at 770 MMBBL of oil, 885 MMBBL of condensate and 57 TCF of gas. They also estimate that Western Australian basins contain about 50 percent of Australia's undiscovered oil resources (1000 MMBBL) and over two-thirds (14 TCF) of the undiscovered gas resources (le Poidevin & Lowden, this volume).

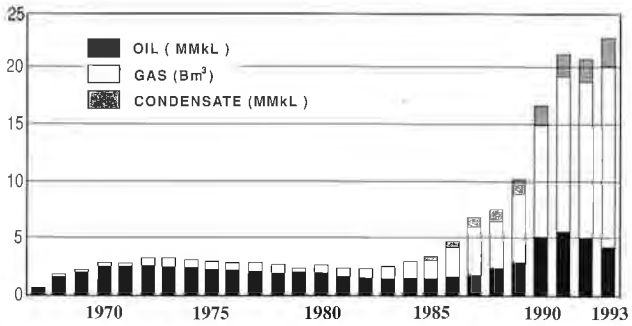


Figure 16: Western Australian petroleum production, 1967–1993. (Data courtesy of Petroleum Division, WADOME.)

The Decades Ahead

It does seem like oil-boom times in the West again.

WAPET's Roller and Skate oil fields and BHP Petroleum's Griffin Oil Field will come onstream this year. Ampolex's Wandoo Oil Field should be commissioned in mid-1995. Woodside has given the go-ahead for the $1 billion Wanaea-Cossack development and LPG facility, with production by early 1996. A joint venture of Australian companies is making a feasibility study for a $400 million pipeline from the North West Shelf gas fields over 1400 km south to Western Australia's rich gold fields. BHP Minerals has announced plans for a $300 million pipeline from the gas fields to Port Hedland to fuel a gas-fired power station.

Exploration programs are proceeding with renewed pace. The Australian Petroleum Exploration Association (APEA) recently announced that offshore exploration expenditure in Australia will increase by 100 per cent in 1994, with the larger proportion to be spent in Western Australia. The main activity remains in the Carnarvon Basin but other offshore basins are not being neglected. Much of the offshore Perth and Browse basins are covered by permits again. There has also been a resurgence of interest and activity in Western Australia's vast onshore basins. The WA Department of Minerals and Energy believes these basins hold some of the State's most highly prospective acreage, and have backed this conviction with initiatives to stimulate exploration.

Perth is fast becoming one of the leading oil and gas administration centres in the Asia- Pacific region. In recent years there has been a constant stream of companies moving operational and corporate headquarters from Southeast Asia, or increasing their presence here. The Government's Locate to Western Australia Program actively promotes the State's strategic location and economic and physical advantages, and provides incentives to encourage national and international companies to locate their Australasian headquarters in Western Australia.

Local petroleum industry expertise is now being exported very successfully, especially to Southeast Asia. A number of major contracts have been awarded to West Australian companies, including Worley Engineering (UNOCAL's Jakrawan development project in Thailand) and Clough Engineering (design and construction of a gas plant in Pakistan).

Research and academic programs are developing in pace with this activity. A Masters course in oil and gas development is to be established at the University of WA under the sponsorship of Woodside Offshore Petroleum, and will be marketed throughout Southeast Asia. A centre for research and development in oil and gas disciplines will be developed alongside the Masters course.

There is bad news, however. Western Australia's oil production rate may be soaring to new heights but the peak is sharp and short (Fig 17): oil production will peak in 1996 and decline very rapidly thereafter unless further discoveries are made. Those discoveries are a national imperative.

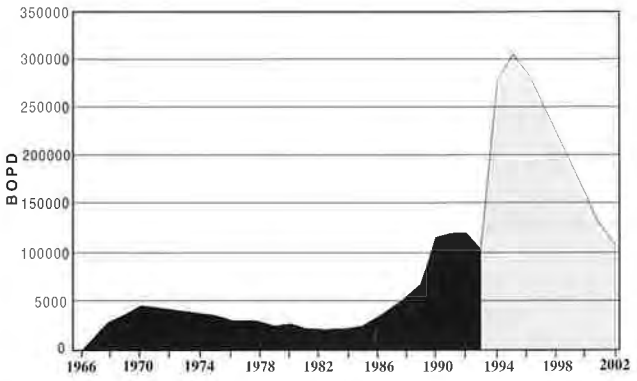


Figure 17: Western Australian oil production, 1967–1993, showing projected 1996 peak and decline to the year 2002. (Data courtesy of Petroleum Division, WADOME.)

Figure 18: Producing wells on Barrow Island, with offshore drilling rigs in distance. (Photograph courtesy of R. Lagdon, WAPET.)

The recent discovery of oil in Petroz's Elang-1 in the Timor Sea region is a good sign. This discovery lies within the Zone of Co-operation (ZOCA) between Australia and Indonesia and is viewed hopefully by many as an omen of future good fortune in that area. The Nebo oil discovery in the Beagle Sub-basin may point to new potential there. The Canning Basin activity is at the highest levels since the mid 1980s.

Petroleum and the Western Australian Environment

The successful search for, and production of, the petroleum resources of Western Australia has been conducted in accord with the natural environment. Our industry must be aware and proud of that.

Environmentalists' opposition to the petroleum exploration and production industry finds its best Western Australia symbol today in the perceived threat to Ningaloo Reef adjacent to North West Cape. That this wonderful locality, like many others, deserves care and preservation is undeniable and, to the extent they encourage that, media and other groups do us all a service for the education and the reminder. We need to remember for our own comfort and to remind them and the public generally, for their more balanced understanding, that our industry's care and concern matches their own — and is usually more soundly based and practiced.

The coral reefs that abound north of Ningaloo and stretch along the Pilbara coast are part of the same ecosystem. The most active area of petroleum exploration and production in Western Australia is within that area, with its complex environment of coral reefs, sea grass beds, sandy bays and mangrove swamps. These provide nursery areas for prawns and fish, turtles and dugong, as well as rookery habitats for many seabirds. The delicate reef enviroment around Thevenard and Muiron islands exist unaltered by the petroleum exploration and production activity there. Exploration in this region has led to the discovery and development of large oil and gas deposits, to the greater benefit of the State and nation. Indeed, the detailed studies

Figure 19: Production of Saladin Field proceeds in harmony with the local environment. (Photograph courtesy of WAPET.)

conducted in these areas by the petroleum industry is the main source of our knowledge and better understanding of their ecology (Figs 18 & 19).

The World Bank's 1992 *World Development Report* offered a reminder that environmental care is linked to peoples' standard of living and, that, to the availability of cheap energy supplies. Oil and gas currently provide 62 percent of the world's power supplies; 88 percent of Australia's fuel and energy needs. Alternative energy sources will emerge in the next century but, for the foreseeable future, the wealth and well-being of this nation and the world will depend on petroleum.

The petroleum industry was working to establish sustainable harmony with the environment long before it was a popular idea. WAPET's work with Harry Butler on Barrow Island, for instance, is decades old. Similar efforts by many companies over the past decade have been exemplary — but are not well known enough or understood by the public.

Our industry is belatedly coming to the public arena. The contest must be won. Hadson's recent efforts in public education about its Exmouth Gulf program show that victory is possible. This education must continue, both by individual companies in the area of their operations, and by the industry generally through programs such as being run in local schools by the Petroleum Society.

After air and water, petroleum is one of the most essential products for human life. It is a prize, not a pariah, to modern society, and we must challenge all who would argue otherwise. The world we offer to future generations depends on our wise use of this resource, as it does on our use of all the resources around us and within us.

Concluding Remarks

Western Australia's gas supplies will underwrite the growth of this State over the coming decades and contribute more than any other source to the wealth and well-being of all people here, and elsewhere in Australia. The reserves-to-annual production ratio for natural gas resources in Western Australian basins is 16 years, based on currently producing fields. When currently non-producing fields are included, the ratio is closer to 150 years. That is a sustaining asset for the 21st century. Developing those fields, in remote locations and deeper waters, will be a challenge to the petroleum production industry.

The discovery of new oil fields is an imperative. Gas exports will help offset the cost of oil import bills but that is no substitute for the highest possible oil self-sufficiency. Discovering two billion barrels of recoverable oil reserves during the next decade, and preserving Australia's self-sufficiency at 60–70 percent, is the challenge for explorationists.

These challenges must be met. So, too, must the challenge of re-establishing public perception of the importance of petroleum in their daily lives and in the national economy.

The petroleum resouces of Western Australia are a gift of nature. The discovery and development of those resources is a prize our industry has won and shared with the nation, and must now win again and share anew in the 21st century.

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