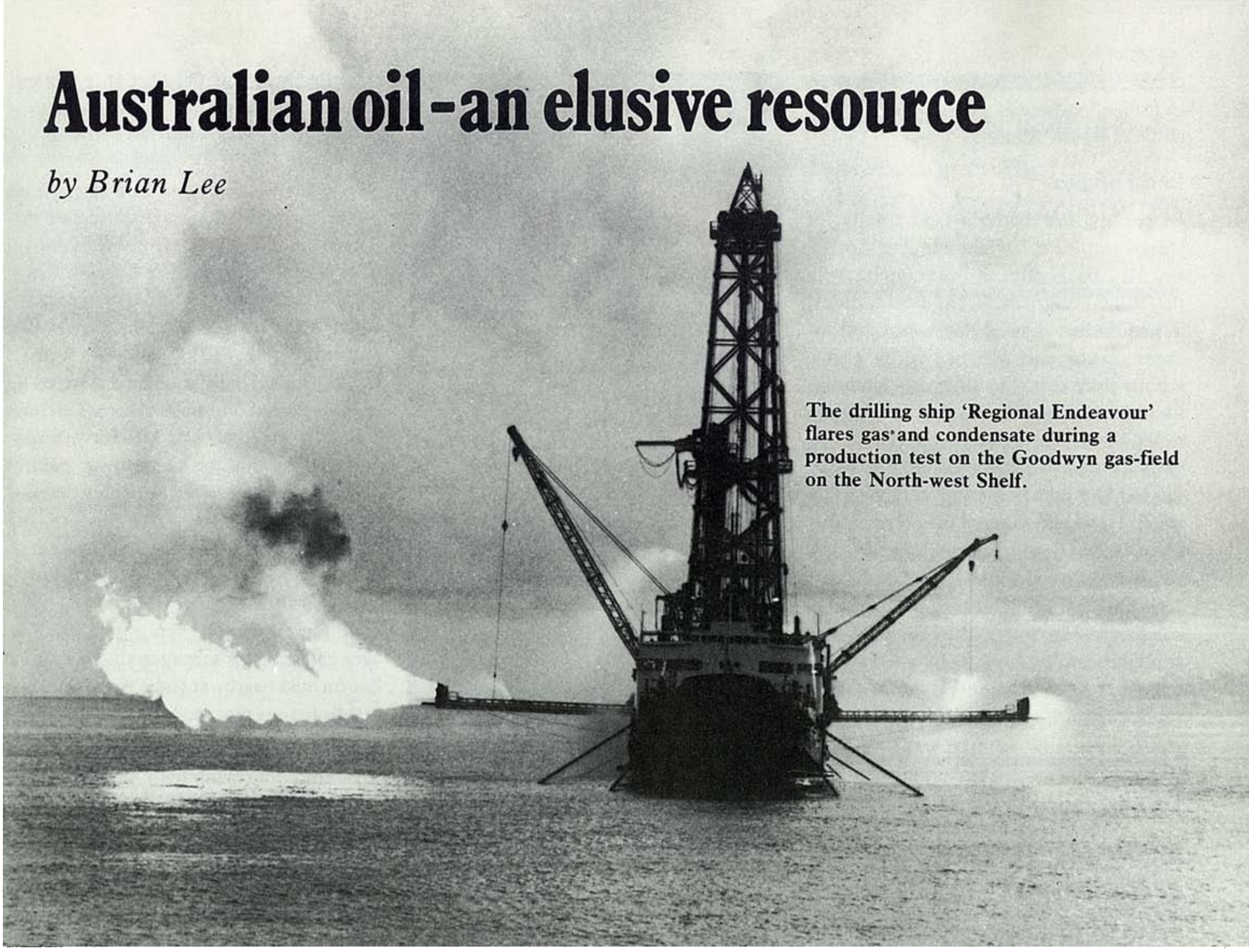
Australian oil - an elusive resource

by Brian Lee



The drilling ship 'Regional Endeavour' flares gas and condensate during a production test on the Goodwyn gas-field on the North-west Shelf.

Oil-fouled beaches: most people think of them as a sign of our time. We hear so much about accidents involving supertankers — and about captains who wash out their tanks at sea — that they, naturally, get the blame.

Each year beaches along the southern Australian coastline receive their share of fouling, and it's only human to jump to the conclusion that tankers, other ships, or the oil-production operations in the Bass Strait oil-fields should bear the blame.

But closer investigations reveal that some beaches are much more pollution-prone than others, and although oil washes up from Cape Leeuwin, W.A., to South West Cape, Tas., most seems to land on the eastern coast of South Australia and on the western coast of Victoria.

In fact the first records of 'coastal bitumen' being washed up in Victoria date back to 1869, and fishermen, farmers, and other local residents of these coastlines have frequently reported fresh discoveries of fouling ever since. Obviously, such historical oil strandings can hardly be a by-product of our modern industrial society. We have to look elsewhere for the source.

Two facts about the southern coastal oil strandings stand out — they occur mainly after violent winter storms and they are commoner after the occasional earthquakes that affect the area. For reasons that will be gone into later, both of these facts suggest that the oil sources are natural rather than man-made. Indeed, local people have known for many years of places along the eastern South Australian coastline where, from time to time, black sticky oil exudes out of the ground; and there are plenty of reports of sightings of oil rising from the sea-bed in shallow water just off shore.

Sodom and Gomorrah

Such natural seepages, which are known as 'seeps' by the oil industry, are hardly a new phenomenon. Indeed they have been known on land since time immemorial. 'Now the valley of Siddim was full of bitumen pits; and when the kings of Sodom and Gomorrah fled, they fell into them' (*Genesis* 14:10). At the end of the 13th Century, Marco Polo described one seep in the Baku area of the Soviet Union as 'a fountain from which oil springs in great abundance'. Perhaps the best-known modern ones are the Great Pitch Lake, Trinidad, the Pitch Lake of Guanoco in eastern Venezuela, and the La Brea tar pits, Los Angeles, California. In the Dead Sea, also, massive lumps of bitumen weighing several tonnes float to the shore at times.

Australia does not have many records of seeps other than those mentioned already off the southern Australian coast. Bitumen has been found washed up on the Northern Territory coast at Melville and Bathurst Islands, and on nearby Cobourg Peninsula. Oil slicks have been reported off the New South Wales coast from time to time.

Scientists first took an interest in the reports of oil strandings on the southern Australian coast after World War I. However, nobody investigating at that time actually witnessed oil exuding from the ground or from the shallow sea bottom. These investigators usually doubted the testimony of the locals. Instead, scientific opinion generally held that the oil washed in from elsewhere — possibly from as far away as South America.

Local origins

Incredibly, the matter wasn't finally resolved until 1962 when Mr Reg Sprigg and Mr J.B. Woolley showed conclusively that the oil originated from local sources. Their studies showed that waves and inshore rip currents whipped up by winter storms were scouring oil from accumulations located on the bottom in shallow water along the coast. These accumulations develop when oil seeping through the sea-bed comes into contact with the water. However, some of the oil had a different chemical composition, which suggested that it came from somewhere else. Later experiments using drift bottles convinced Mr Sprigg that some of this could be coming from as far away as the edge of the continental shelf to the south-east of Kangaroo Island.

Practically all the world's major oil-fields were found around known seepages of oil or gas.

In 1976, Dr David McKirdy and Mr Zoltan Horvath, at the Bureau of Mineral Resources in Canberra, analysed oil stranded on both the southern Australian and the Northern Territory coasts. The southern Australian samples came from beaches at six localities between Bridgewater Bay near Port Campbell, Vic., in the east, and Sleaford Bay near Port Lincoln, S.A., in the west. They were compared with others from oil wells drilled in the area.

Of the samples taken from the southern Australian beaches, only one did not appear to be a natural crude oil. This one sample was definitely fuel oil that had been subjected to weathering for quite some time. It was clear that the samples of natural crude came from two different sources — they had different chemical make-ups.

Geltwood Beach near Beachport, S.A., has a reputation for being particularly badly affected by oil, and the researchers' analyses confirmed that much of the oil stranded there had come from nearby. Some, however, had also come from much further away, as it was extensively weathered, and it had a completely different chemical make-up. Oil similar to this second type was also washing up as far away as Sleaford Bay, some 480 km to the north-west.

The chemical composition of the bitumens certainly supported the belief that they came from natural seepages of oil from the sea-bed, and the distribution of the two different types added weight to the belief that some came from quite a distance off shore.

After analysing the chemical make-up of oil stranded on the Northern Territory coast, Dr McKirdy and Mr Horvath concluded that this too came from natural seepages. These were probably located somewhere to the north-east of the Cobourg Peninsula, in what's known as the Money Shoal Basin.

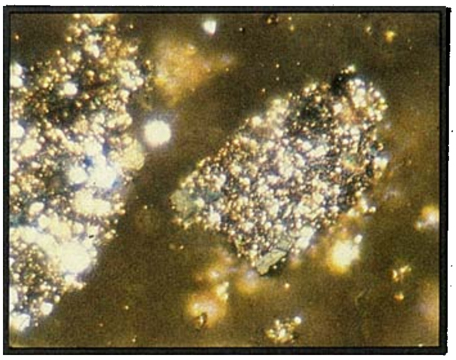
Why do the seepages occur, and what does their existence really tell us? The very existence of seepages shows that oil has formed nearby at some time. So there is the obvious place to look for oil. Indeed practically all the world's major oil-fields were found around known seepages of oil or gas. Yet the presence of a natural seepage of oil or gas does not necessarily mean that a large resource of hydrocarbons lies waiting to be discovered. So Australia's salvation, as oil becomes scarcer, does not necessarily lie in drilling off the coasts of South Australia and the Northern Territory. A look at how oil and gas form will show why.

Oil formation

Like coal, oil has formed from the remains of living things. Much of the natural gas (predominantly methane) did so also, but there is dispute about whether some may have derived from other sources. Conditions have to be just right before the fossilized plant and animal remains will change into oil or gas.

While coal formed in the ancient swamps as thick layers of almost purely organic material, oil did not. Oil comes from rocks that formed originally as sediments accumulating at the bottom of mostly shallow seas. These source rocks, the commonest of which are the oil shales, may contain as little as 1% of carbon-containing material sandwiched between mineral grains. This carbon-containing material, which is a mixture of many organic compounds, is usually known as 'kerogen'.

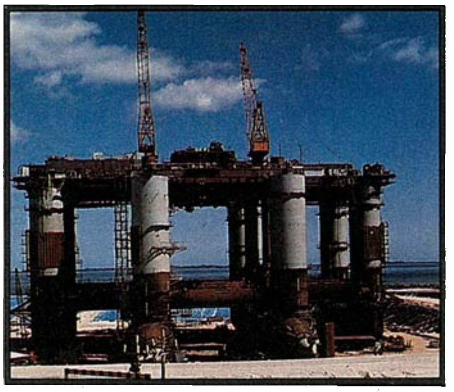
For the source rock to have any hope of yielding oil, the kerogen it contains must have been derived from the right sort of living things. Wood, for example, contains a major proportion of lignin, which



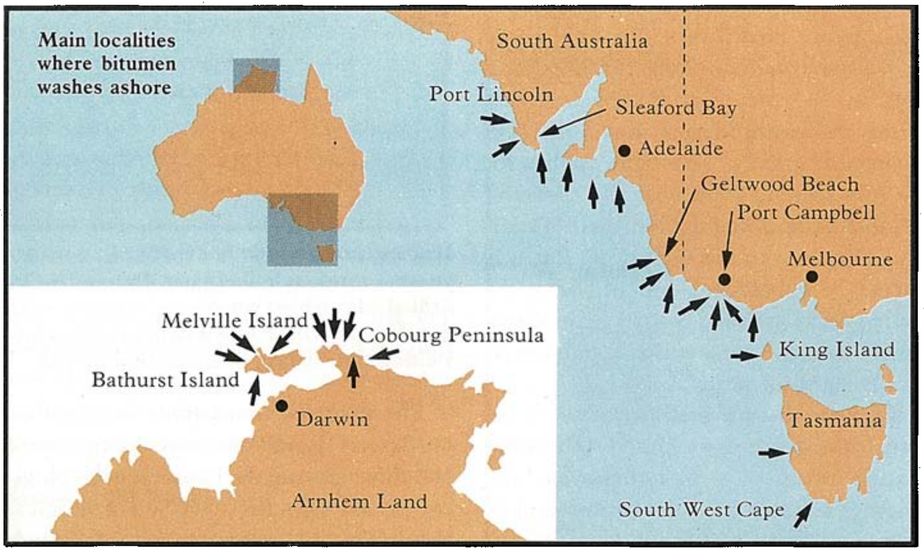
Lumps of demineralized kerogen, mounted in a polished resin block, glitter when viewed through the microscope. The black blobs are the material most likely to yield oil.

Fossilized resin bodies appear yellow beneath a microscope as light shines through them. Oil may form from plant remains such as these.

The 'easy' oil that keeps Australia's refineries running has already been found. The search now is for the more elusive deposits.



The drilling rig 'Ocean Endeavour', shown here during construction, has been used for drilling on the North Rankin gas-field.



Bitumen from natural seepages located off shore not infrequently fouls parts of the southern and northern coastlines of Australia.

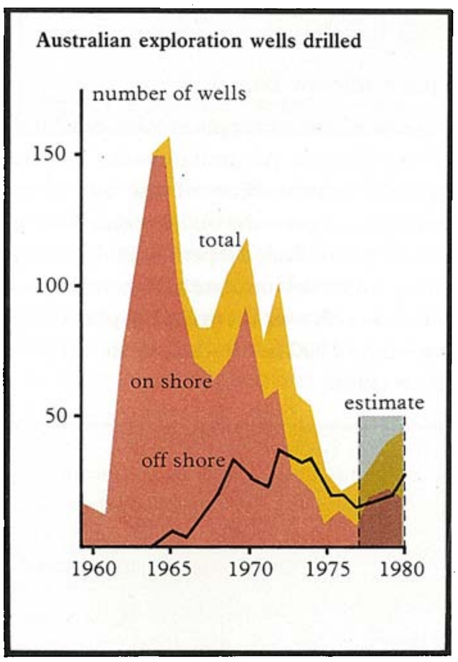
in its turn yields coaly material with a chemical structure that predisposes it to form gas rather than oil when the right conditions occur. On the other hand, the residues left by marine animals and plants yield kerogen with the right chemical structure for forming oil.

Within CSIRO, a group led by Dr John Saxby in the Organization's Fuel Geoscience Unit has been studying Australian source rocks by analysing drilling cores provided by the Bureau of Mineral Resources and by oil companies. Their studies have shown that Australia's petroleum resources are unusual. While most of the world's oil came originally from marine organisms, much of that so far discovered in Australia has come from the spores, leaf cuticles, resins, and other non-woody materials from plants that grew on land.

Where to search

Since many of the most suitable source rocks accumulate as sediments in shallow seas, the sedimentary rocks most likely to yield oil in Australia seem to be ones that would have formed in shallow basins located close enough to the coast of that time to have allowed accumulation of debris from plants growing on the shore. These rocks would have had to have been laid down and covered quickly, otherwise bacteria would have converted all the organic material to carbon dioxide and water. The conditions most conducive to sediments forming rapidly occur when the sea floor is subsiding. Thus the best places to look for oil in Australia seem to be sedimentary basins, the floors of which were subsiding as the rocks were forming, and which were located not far off shore at that time.

These seepages undoubtedly show that oil has formed off the South Australian coast.



The number of wells drilled each year fell from a peak in the mid 1960s to a low level a decade later. It seems to have increased again during the last 3 years.

Once the source rocks have formed, appreciable amounts of hydrocarbons will not be generated unless the temperature rises to about 130°–150°C and remains there for a long period of geological time. Then the large kerogen molecules will 'crack', and oil will form in low concentrations in the spaces between the mineral particles that make up the rock.

Dr Saxby concludes that oil exploration is most likely to succeed where oil generation is still going on.

The most usual way this can happen is if the rock becomes buried several thousand metres down. Then heat from the earth's interior will raise the rocks to the temperatures needed. If the temperature becomes too high (in other words if the rock is buried too deep), then gas rather than oil will form.

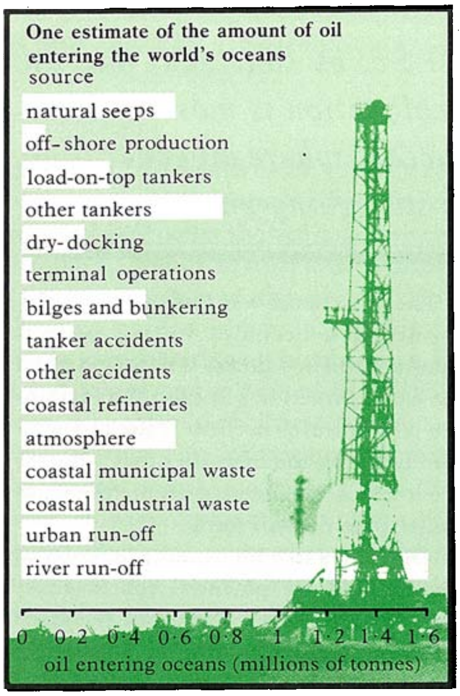
(Oil shales like the Rundle deposits in Queensland are potential source rocks that have not been subjected to raised temperatures. Extracting oil from these will involve heating them for extended periods to high temperatures to crack the kerogen they contain — in other words, doing in a few minutes what takes many years naturally.)

Migration to reservoirs

If the surrounding rock is relatively porous, or if it contains faults, the newly formed oil or gas will emigrate from the source rock, usually upwards. If they encounter structures in the rock layers that will serve as reservoirs, the hydrocarbons may accumulate and form concentrations that are sufficiently large for them to be of interest to exploration geologists and petroleum engineers.

A reservoir usually consists of a layer of porous rock, such as limestone or sandstone, that has a more or less impervious cap-rock above it to prevent the hydrocarbons from escaping. But if movements of the earth's crust crack the cap-rocks, the accumulated oil or gas may move up through any faults that develop to emerge at the surface as seepages.

The South Australian seepages are located along an earthquake-prone belt that passes north-westwards across the continental shelf, along the coast of the eastern part of South Australia, and then inland east of Adelaide. Submarine earthquakes with epicentres close to the South Australian coastal town of Beachport (which is only a few kilometres from Geltwood Beach) occurred in 1898, 1915, and 1948. The amounts of oil stranded on nearby beaches increased temporarily after each shock — presumably because the earthquakes opened faults in the region, thus allowing movement of crude oil to the surface.



Natural seepages may contribute nearly 10% of the oil that enters the world's oceans.

These seepages undoubtedly show that oil has formed off the South Australian coast in the Otway and possibly the Duntroon Basins, but all wells drilled to date have proved disappointing. The oil does not seem to have been able to accumulate in large quantities. So far, wells drilled off the Northern Territory in the Money Shoal Basin have fared no better. Probably neither region has been explored in sufficient detail to show for sure whether suitable reservoirs really exist.

Age important

If accumulated oil or gas is going to remain in a reservoir for epochs of geological time, the cap-rock will have to be very impermeable indeed. In practice, no reservoir is completely oil- or gas-proof, so the accumulated hydrocarbons will very slowly leak away. Thus the oil prospector needs to know how long any oil accumulation may have actually existed. If his studies suggest that it formed too long ago, then the chances that large quantities still remain are much reduced, even though suitable reservoirs may exist.

In addition, as Dr Saxby has pointed out, bacteria and other microorganisms attack petroleum in the ground and convert it into a heavier oil that is less useful and more difficult to recover. Some bacteria may also increase the sulphur content of the oil. Dr Saxby concludes that oil exploration is most likely to succeed where oil generation is still going on.

Almost certainly oil is still being formed in the rocks at depths between 3500 and 5000 metres in the Gippsland Basin below Bass Strait. The light crude from here contains many straight-chain paraffins — a sure sign that bacteria and other microorganisms have not yet changed it greatly. The same applies for the oils seeping from near the coasts of South Australia and the Northern Territory. The floor of the Gippsland Basin is currently subsiding, and unconverted source rocks are thus being carried down slowly into the zone where the temperature is right for oil production.

What an oil man needs to know, therefore, is the depth at which the right temperature occurs for oil generation, and whether any suitable source rock actually exists at that depth. That may sound easy, but it isn't. He rarely has the benefit of samples of rock from these depths — they are too far down. It's doubtful, for example, whether anybody has yet drilled down deeply enough in the Gippsland Basin to reach the rocks from which the Bass Strait oil has come. Certainly the deepest holes bored in the area have reached carbon-containing rocks, but at 4000 metres depth these still seem to be too young and too cool to have been able to have produced the oil.

Under Barrow Island

The same seems to apply at Barrow Island off the Western Australian coast. There, CSIRO's examination of the evidence available suggests the oil has come from a zone a great deal deeper than the level where it has accumulated. Recent exploration has shown that natural gas exists more than 1000 metres below the deepest oil reservoir.

Average drilling costs in 1975

	Australia ($ per metre)	U.S.A. ($ per metre)
on-shore	609	274
off-shore	1015	305

Drilling in Australia is expensive, and the success rate is relatively low. One well in 36 drilled has yielded petroleum, and one in 12 gas. For the world, one well in 11 drilled has yielded petroleum, and one in nine gas.

The main accumulations of crude oil on Barrow Island are in rocks that were laid down during the Cretaceous geological period (see the chart on geological time). These occur at the relatively shallow depth of about 1000 metres. The accumulations contain a considerable proportion of aromatic hydrocarbons. They contain very little in the way of straight-chain paraffins, which means that they have been broken down by bacteria. Yet 1000 metres deeper are rocks laid down some 45 million years earlier, during the Jurassic period. These yield a waxy paraffin-containing crude — a sign perhaps that this deeper oil is much less altered.

Presumably, the shallower but more altered oil has migrated from much lower down some time in the past. The only sure way to find out where it came from is to drill right down to the original source rock.

But to do that is prohibitively expensive, which goes part of the way to explain why drilling for oil is such an unpredictable business. Australia in particular has not been a very encouraging place to drill

Geological time

era	period	epoch	age (millions of years)
Cainozoic	Quaternary	Recent	0·01
		Pleistocene	2
	Tertiary	Pliocene	7
		Miocene	25
		Oligocene	40
		Eocene	60
		Paleocene	70
Mesozoic	Cretaceous		135
	Jurassic		180
	Triassic		225
Palaeozoic	Permian		270
	Carboniferous		350
	Devonian		400
	Silurian		440
	Ordovician		500
	Cambrian		600
Precambrian			3500

— the success rate here has been one well yielding oil for every 36 drilled (compared with a world average of one for every 11 drilled). The ratio for natural gas has been rather better — a success rate of about 1 in 12 holes drilled compared with a world average of about 1 in 9.

Usually, not knowing where any oil may have come from, oil prospectors have to rely on any leads that their petroleum geologists can give them. But the evidence will be circumstantial, and the only way that the company will really be able to find out whether oil is present is by drilling very expensive holes.

Geological wager

A quick look at what the petroleum geologist can find out shows how much of a bet drilling any well will be. For oil or gas to be present, the following conditions must exist. There must be:

- a source of hydrocarbons (source rocks)
- a suitable increase of the temperature with depth (temperature gradient)
- evidence that the rocks remained warm enough for sufficiently long for oil to have formed
- rock formations that can serve as reservoirs
- routes by which the hydrocarbons can migrate to the reservoirs

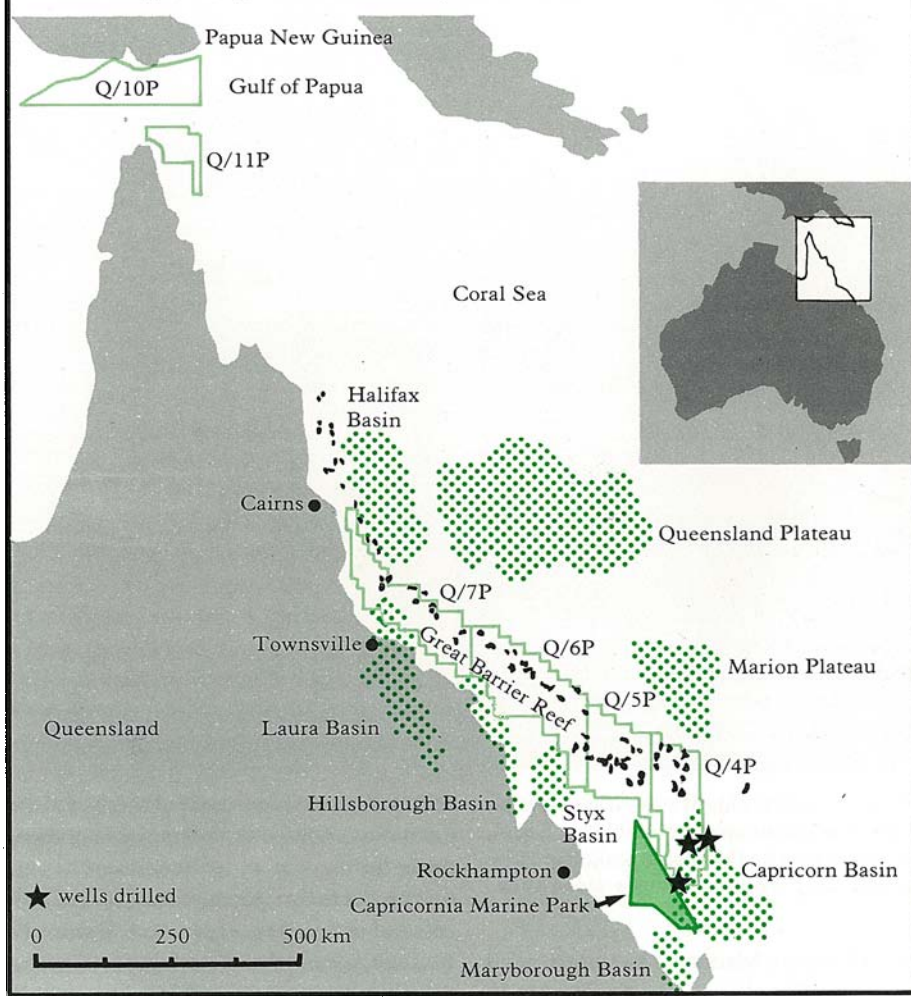
Seismic surveys, perhaps the best-known of the petroleum exploration techniques, can reveal the presence of faulting and rock layers of different types. They can thus suggest the presence of migration routes, and can also indicate that suitable rock structures exist for reservoirs to be present. They cannot yet reliably show that these structures have oil in them.

There's a 90% chance that at least another 1550 million barrels remain to be discovered.

Armed with the information gained from seismic surveys and background knowledge gained from similar areas, the petroleum geologist can estimate the likelihood of each of the five above conditions being present at any particular site.

Usually he decides on percentage chances for each of the necessary conditions being present. By combining these probabilities he arrives at a figure that roughly indicates the likelihood of hydrocarbons being present. However, even if most indications are favourable and there appears to be a good chance that oil and gas are present in quantities large enough to make obtaining them a commercial proposition, drilling will yield nothing if, for example, what are assumed to be source rocks contain no kerogen.

Petroleum exploration permits held off the Queensland coast

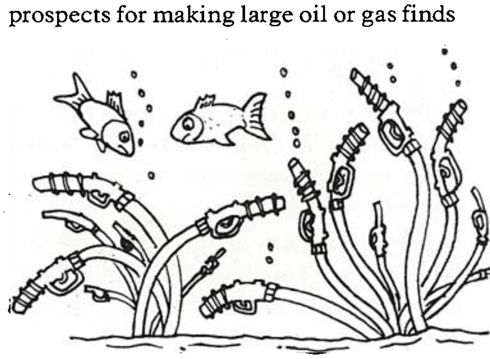


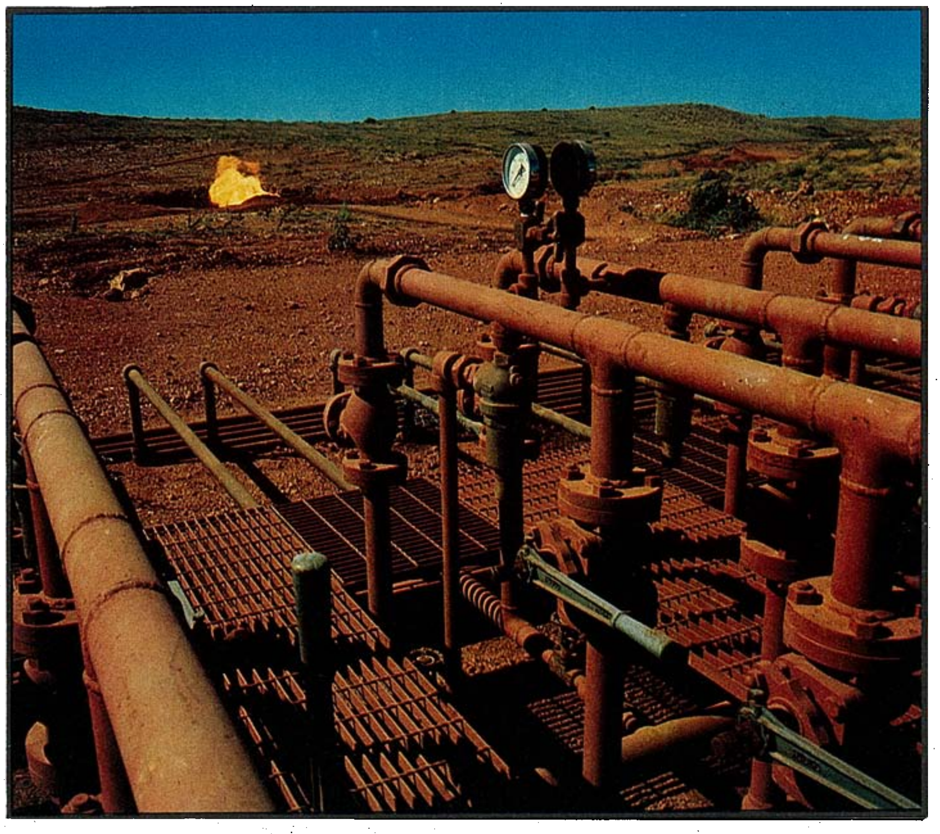
Australian oil prospects

So, bearing these thoughts in mind, what prospects does Australia have of finding much more oil? Obviously, nobody knows for sure. Recently the Commonwealth Government's National Energy Advisory Committee published a report entitled 'Exploration for Oil and Gas in Australia'. According to this report, the best estimate available of our crude oil resources suggests that there's a 90% chance that at least another 1550 million barrels remain to be discovered. There's a 10% chance that the actual amount will be as high as 6500 million barrels. Our identified economic reserves currently stand at about 1870 million barrels.

The report hastens to add that these estimates must be treated with caution. They were arrived at by making assumptions on how Australian sedimentary basins compare with those in other parts of the world. Thus these figures merely provide a rough guide. The true situation, as the report also states, can only be discovered by geophysical surveys followed by drilling on and off shore. Australian sedimentary basins are not well surveyed when compared with those in many other countries.

While much of Australia is covered by sedimentary basins, those most likely to yield oil or gas occur mainly off shore on the continental shelf. According to the National Energy Advisory Committee, prospects for making large oil or gas finds





Production manifolds at a separator station on Barrow Island on the North-west Shelf. Oil production on the island peaked in 1970 and has been declining slowly since then.

in the off-shore basins are currently rated as follows: Bass Strait, North-west Shelf, and Exmouth Plateau offer the best prospects, while Bonaparte Gulf and the Browse, Carnarvon, and Perth Basins offer reasonable ones. The basins off the Queensland coast (including the Barrier Reef) have not been sufficiently explored for even a guess to be hazarded. Even so, the chances of oil or gas occurring there don't look particularly great.

Barrier Reef: any oil?

Only three exploration wells have ever been drilled off the Queensland coast. All were located in the Capricorn Basin, a small part of which will be included in the Capricornia Marine Park. None yielded oil or gas. From the little that is known about the geology of the basins in the region, it appears that in many places the thickness of the sediments may not be sufficient for there to be much chance of oil having formed.

With a depth of about 3000 metres, the sediments of the Capricorn Basin — apparently the second-thickest among the basins off the Queensland coast — seem rather thin for any source rocks to have become warm enough for much oil or gas to have formed. The fact that there are no known signs of natural oil or gas seepages off the Queensland coast also gives little encouragement that the region contains much in the way of hydrocarbons.

The National Energy Advisory Committee considered that the Exmouth Plateau offers the best bet for finding giant new oil-fields. This submarine plateau lies some 400 km north-west of Dampier beyond the North-west Shelf, of which it is a north-westerly extension. Oil has been found on the North-west Shelf at Barrow Island, and gas appears plentiful on the Rankin Platform, which lies under about 200 metres of water. Drilling the Exmouth Plateau is a very different operation that is stretching exploration technology to its limits.

The sediments of the Capricorn Basin seem rather thin for any source rocks to have become warm enough for much oil or gas to have formed.

The Exmouth Plateau Arch is the shallowest part. It is also the one where hydrocarbons seem most likely to be found. It lies under more than 1000 metres of cyclone-prone sea.

The main reason for optimism that the area will yield hydrocarbons is that its geology is not dissimilar to that of the Rankin Platform. (It's one of the maxims of oil exploration that hydrocarbons are most likely to be found in areas close to where others have already been found, rather than in apparently more favourable locations in regions where no oil or gas have been found before.)

Interpretation of seismic surveys suggests that source rocks exist on the Exmouth Plateau at suitable depths for large-scale hydrocarbon generation to have occurred. Sandstones nearer to the surface also seem to provide reservoirs.

At the time of writing at least two exploration wells had been completed. One, on the Kangaroo Syncline, which is a shallow trough that divides the Exmouth Plateau from the North-west Shelf, apparently yielded neither oil nor gas.

Even if the first wells don't yield oil or gas, they will provide information on the actual temperatures of the sediments through which the holes have been drilled. They will also show whether the picture built up from seismic surveys is really correct. Even with today's technology it is still easy to be misled by such surveys — as Shell Development (Australia) Pty Ltd found to its cost between 1966 and 1977.

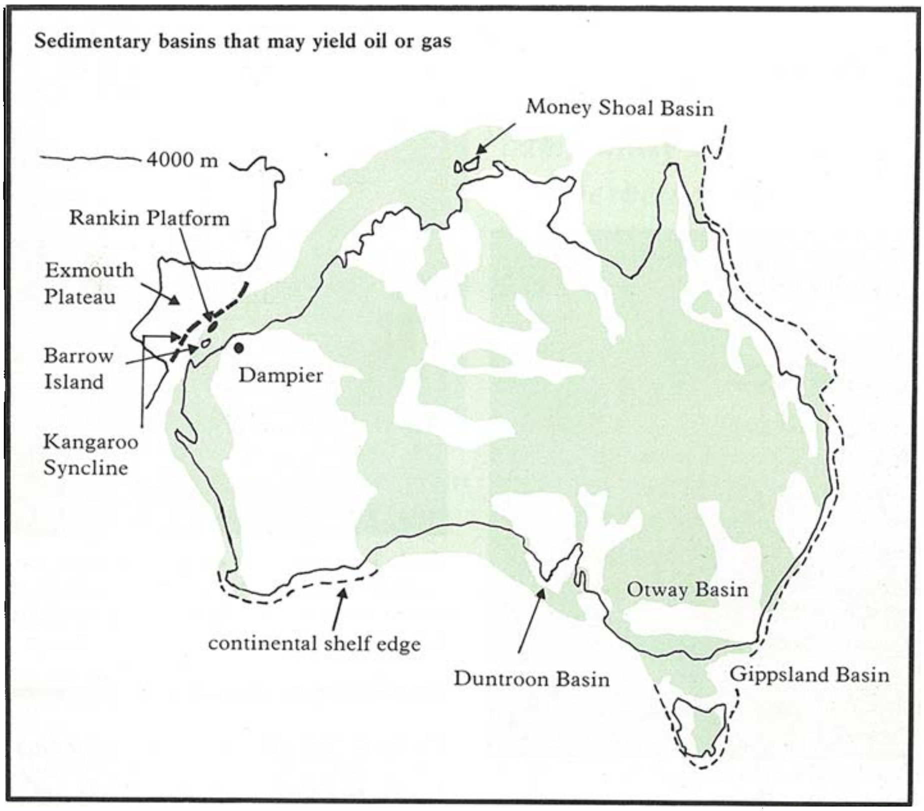
Frustrating business

During this period the company carried out a prospecting and drilling program in the Duntroon Basin off the South Australian coast — an area that seemed to hold considerable promise. Indeed, some of the

Depths of basins off Queensland

basin name	maximum thickness (metres)
Capricorn	2750
Queensland Plateau	1500?
Halifax	5000?
Laura	1000
Marion Plateau	?
Maryborough	4500
Hillsborough	3000
Styx	400
Papuan (Queensland Portion)	2750

According to Dr Saxby, most of the sedimentary basins and plateaux located off Queensland seem rather thin for much oil or gas to have formed.



While much of Australia consists of sedimentary basins, the National Energy Advisory Committee considered that the Exmouth Plateau offers the most hope for finding large amounts of oil.

seepages that foul the State's beaches may well be located within the zone covered by the company's original exploration permits.

By the time the company surrendered the last of its permits in 1977, it had recorded 24 546 km of seismic data, and drilled three dry wells. It had spent $15 837 000 in the process.

Early exploration, using seismic and other methods, yielded encouraging results. But two wells drilled in 1971 both failed to produce significant indications of hydrocarbons. What's more, examination of the drilling cores showed that some of the seismic data had been misinterpreted. However, the most bitter disappointment came in 1976, when studies using more accurate seismic methods showed that a huge feature known as the Rosella–Jabiru Trend did not have the structure indicated by the earlier surveys. The apparent form of the Rosella–Jabiru Trend had been the main incentive during the previous 5 years for deep-water exploration to continue.

Thus the company found that it had continued exploration for 5 years because of seismic interpretation that ultimately proved incorrect — which just goes to show what a frustrating business oil and gas exploration can be.

Such debacles reflect how little anybody knows about our sedimentary basins, But then this lack isn't surprising, since much of Australia both on and off shore has yet to be explored. Combining what's known about surface seepages and geology with geophysical and geochemical information about the sedimentary basins as it accumulates will help reduce the risk of drilling dry wells. However, the 'easy oil' has already been found, and the hunt now is for the more elusive deposits.

More about the topic

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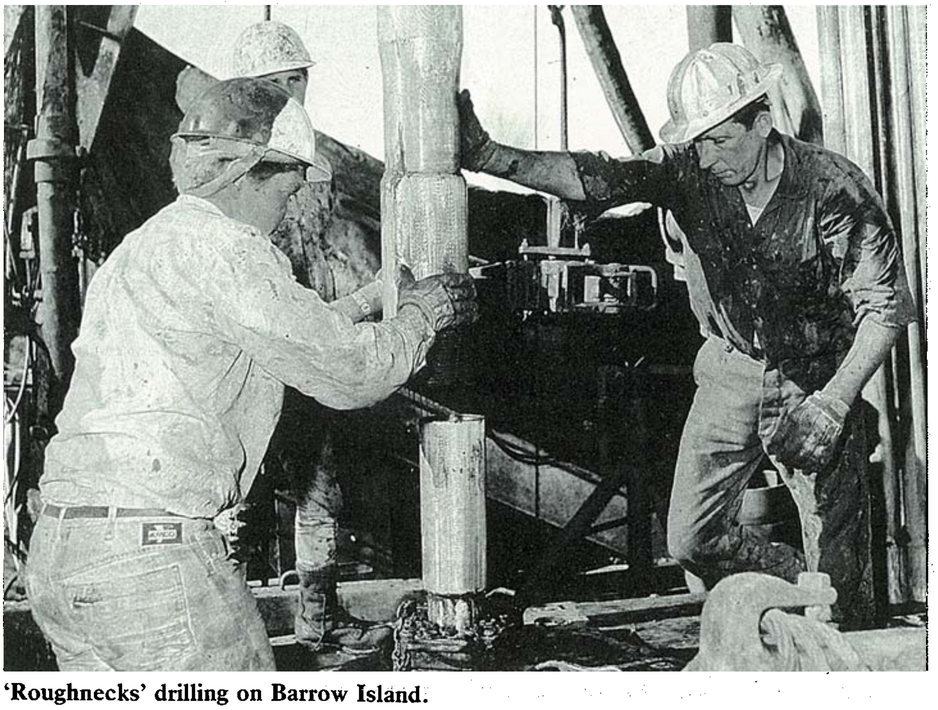

'Roughnecks' drilling on Barrow Island.