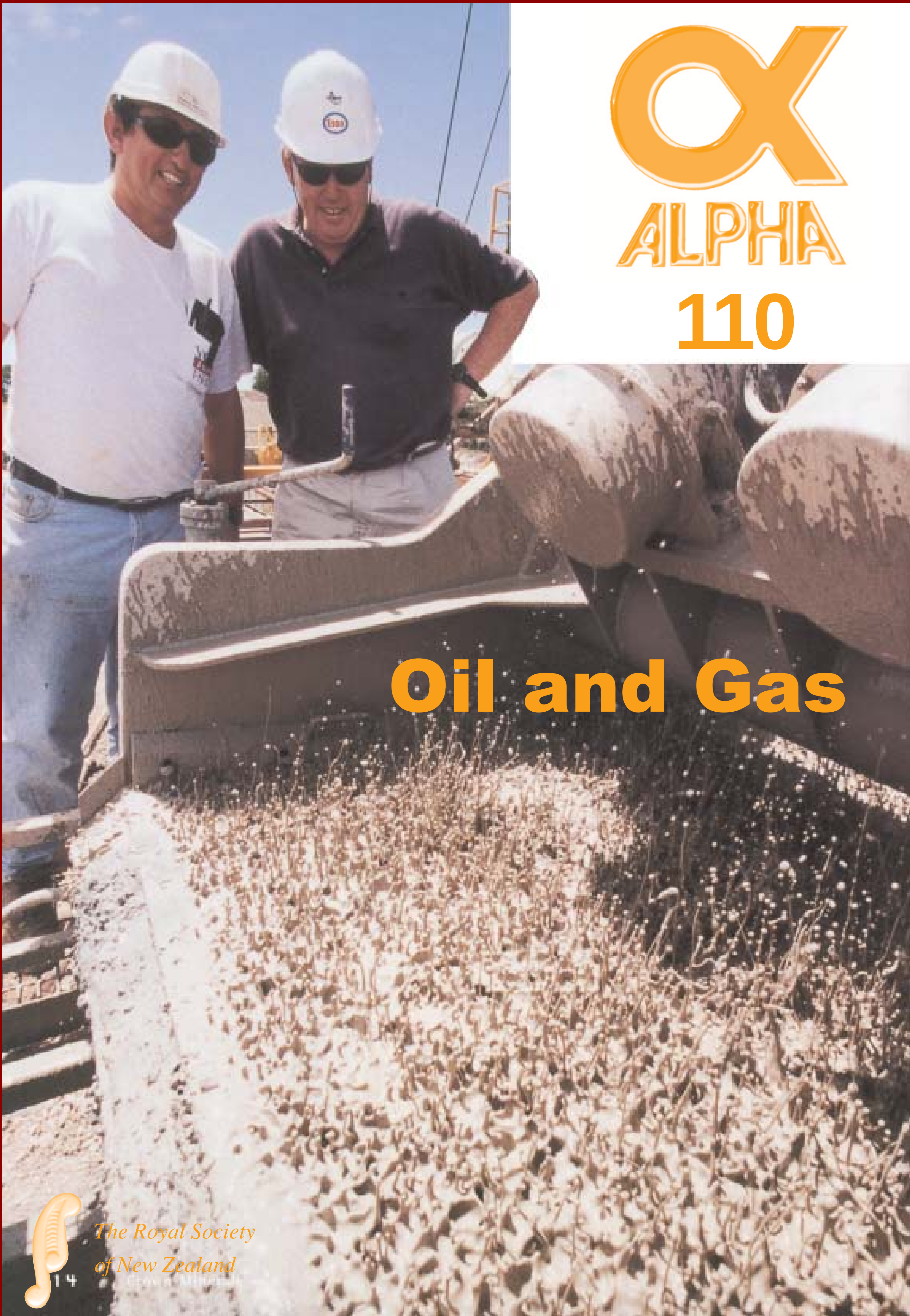
ALPHA 110

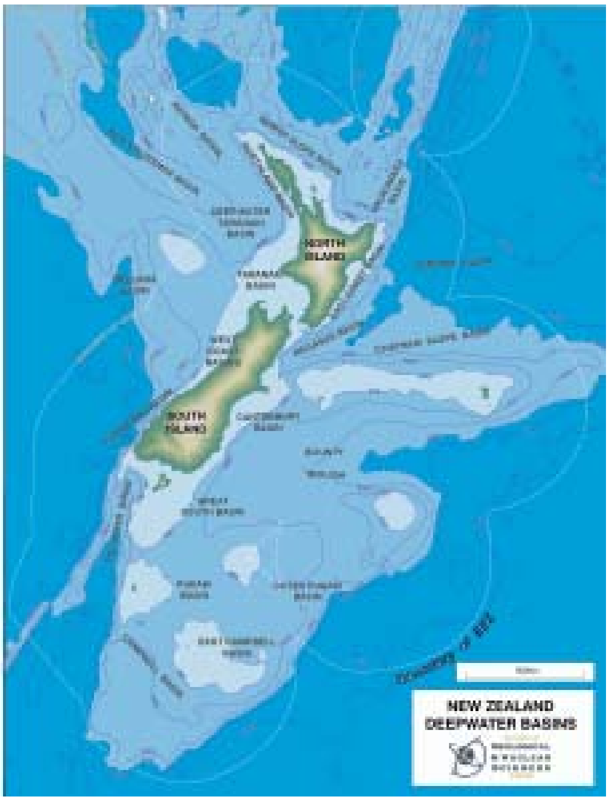
Oil and Gas



The Royal Society of New Zealand

Investing in oil prospecting

Imagine if you were the chairperson of an oil exploration company. Each well your firm drills costs many millions of dollars and you know you will be unlikely to get a return on your investment for at least ten years. Would you pick New Zealand over other places in the world where oil can be found? You'd need to think about:



Institute of Geological and Nuclear Sciences

Politics

Oil exploration is a long-term business. In New Zealand the 'Crown' (that is the government of the day on behalf of all the people) owns the rights to all mineral resources including oil and natural gas. However we need the expertise and financial support of private firms to find the places where they are buried. This means we also need to work out how to share the profits when the search is successful. Investors need to be confident that they are dealing with a government that will keep its side of the bargain. They need to assess us in terms of our so-called sovereign risk. (In New Zealand a department called The *Crown Minerals Group* within *The Ministry of Economic Development* looks after all oil exploration activity, both on land and in the very large coastal waters area that is under our control. New Zealand is seen as stable – and 'low risk' – by international oil exploration companies.)

Economics

Since it costs a lot of money to find and recover oil and gas, you'd need to be sure you could make a lot of money from a successful find. There is international concern over the rate at which humans are using Earth's oil and gas reserves, and about the atmospheric changes that are related to the burning of these fossil fuels. However, if you pause and consider what our life would be like if suddenly there was no more oil or gas, you'll realise that this is not quite such a simple decision. We live in an 'oil age'. Without fossil fuels, the current transport industry would grind to a halt – then, just for starters, many people in cities would begin to starve as food supplies were used up. Until we find more environmentally friendly alternatives, we have no option but to continue using oil, and companies can be reasonably certain of a good return from its sale. It also makes sense to find and use our own oil and gas supplies where we can. It costs a lot of money to import oil. We are at risk of large fluctuations in the balance between our import accounts and export earnings if oil prices are very volatile. The oil price shocks of the 1970s showed how our economy can suffer when we are too reliant on imported oil.

Geology

Oil and gas aren't found just anywhere. Particular geological processes, taking place over millions of years, have led to their formation. In the last thirty or so years, it has become increasingly evident that the sedimentary basins under New Zealand's coastal waters are just the sort of places where important new oil reserves could be found. Our geology makes New Zealand a place of great interest for exploration. However, companies still need to know a lot more before they decide exactly where to drill their wells. This helps to explain why there has not been lot of oil and gas exploration until recent years. This Alpha is the story of the science and technology behind that search.

Photos: Colin Walker

An inter-related sequence of events

1816 Coal gas is used for first public street lighting in a Western nation – in Baltimore, USA (NB: The Chinese used oil drilling technologies centuries before the West)

1821 A water well in New York state explodes, leading to the discovery of 'natural gas' which is then drawn off through wooden pipes for street lighting

1847 First commercial sale of bottled 'rock oil' in USA (as a lubricant for machines)

1852 Canadian chemists discover how to refine kerosene from oil, for use in lamps

1859 First true oil well begins pumping in Pennsylvania, USA

1865 First NZ oil well drilled near oil seeps on New Plymouth beach

1876 First successful four-stroke internal combustion engine is designed in Germany

1906 First steel oil rig blows out oil and gas near New Plymouth, leading to a speculative boom

1920s Small oil refinery built in New Plymouth

1959 First major discovery of gas and condensate on land at Kapuni in Taranaki (commercial development of the field begins in 1970)

1964 Marsden Point oil refinery opens

1968 First New Zealand offshore oil well sunk

1969 Discovery of the first Maui gas field off the coast of Taranaki

1972 Beachfront oil wells in New Plymouth closed

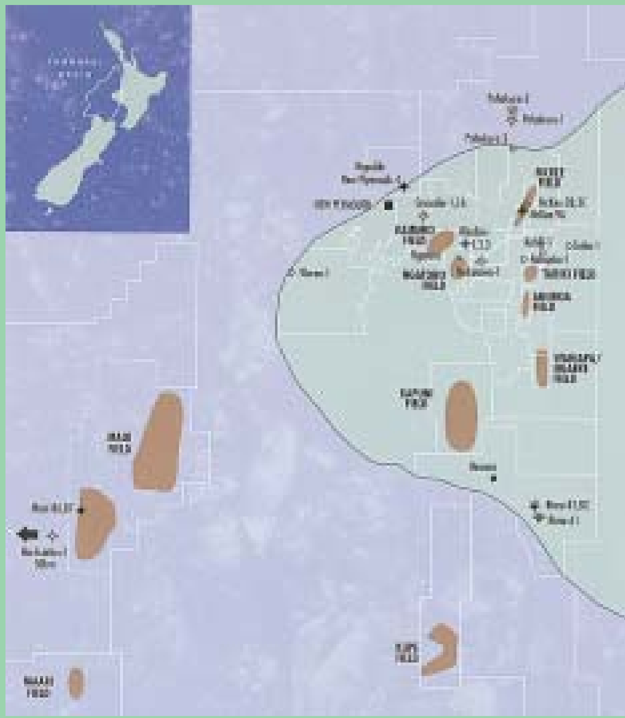
1973 Arab-Israeli war disrupts world oil supplies and prices rise steeply – New Zealand's oil debt soars and car-less days are introduced, along with an 80kph open road speed restriction

1976 Exploratory drilling begins in the Great South Basin. Traces of hydrocarbons suggest this could be a promising source of oil, although there has been little further exploration since the mid 1980s

1979 Iranian revolution leads to second world wide oil price shock, leading to increased exploration in New Zealand and the "think big" projects to help make NZ more self-sufficient in gas and liquid fuels

1980 McKee No. 2 well in North Taranaki strikes oil as well as gas, the beginning of the McKee field and production station

1981 1985 Gas and condensate found in exploratory wells in the off-shore Canterbury basin. Like the Great South Basin, this field has yet to be further explored/ developed



Taranaki Basin

1986 Kupe gas field offshore in South Taranaki discovered

1991 Two ships from the North Sea are used in a large scale 3D seismic survey of the whole Maui field – oil discovered below the gas fields of Maui B

1998 First commercial scale gas find offshore on the East Coast of the North Island near Wairoa: discovery of the Maari oil field in an off-shore Taranaki basin

1999 Conoco's drilling ship, *Deepwater Frontier*, is the first to sink a well in very deep water (1500m+) in New Zealand, using revolutionary technology that keeps the ship positioned over the well, even when the waves are quite high

1999–2001 Pohokura and Mangahewa (gas/condensate) and Rimu (oil) fields discovered in Taranaki

2001 Seismic survey of the deep water basin off Taranaki begins – it is an international collaboration to survey an area that has never been prospected before

Hit and miss

Early wells were often sunk near **oil seeps**, where oil bearing formations have been exposed by fault activity and/or erosion, allowing the oil to leak out of the ground. Sometimes oil was found quite by accident when water wells were being sunk.

In New Plymouth, wells were sunk near oil seeps on the beachfront as early as the mid-nineteenth century. These wells were amongst the very first to be sunk in the world. Oil was taken out of the first of these wells by a simple bailing method. A container with a valve in the bottom was dropped into the well. With the valve open, the oil seeped in. When it was full, the valve was closed and the container pulled up by rope or wire.

New theories, new searches

Faced with increasing demand, oil exploration companies began to widen their search for oil. One early idea was that oil would collect in the bottom of valleys. However the lack of success when drilling according to this theory forced the geologists to think again.

The Kotuku oil seep, West Coast

They needed to understand the actual rock structures where oil had been found before they could get better ideas for searching. Once they knew that oil is associated with sedimentary rocks that typically form in undersea basins they had new ideas about where to look. However, finding those types of basins was still a matter of luck and hard work. Geologists learnt about 150 years ago that they could with some accuracy predict what might be underneath the sedimentary rocks they found on the surface. Much later new technology enabled them to drill deep exploratory holes to "see" beneath the surface..

OIL AND GAS IN THE MAKING AND ON THE MOVE

For oil or gas to have been made AND trapped where we can find it, a whole chain of co-incidental events, stretching over many millions of years, must have occurred in the right places and in the right sequences. The flow chart shows how 'hit and miss' this natural process is:

Pathway to oil and/or gas | **Pathway disrupted – no useable oil or gas**

Remains of plants and animals buried in mud with little oxygen → Oxygen gets into the sediment — plants and animals rot

Sediments buried deeply and begin to form into rock → Disturbance of sediment before rock formation completed (earthquakes, erosion). Organic material rots.

Rock becomes squeezed at depths up to 1000m and heated at temperatures up to 50…C. Organic matter turns into a greasy substance called kerogen → Rock formation not in the critical depth/ temperature range (e.g. if too hot the kerogen will overcook and turn into gases that escape) → Rocks return to the surface via uplift and weathering.

Deeper burial and higher temperatures cook the kerogen into hydrocarbons (oil, gases, coal) → Geologists find an oil kitchen that is immature — burial for another 10 million years could yield results (but only if the temperature is in the critical range)

Hydrocarbons squeezed out of source rocks and migrate towards surface → Gas and oil seeps out and dissipates undetected, or there is a lack of suitable reservoir rock to hold it

Anticlines, fractured faults and/or sealing layers of rock trap pockets of hydrocarbons → Pockets are in places humans can t detect, or˚get to

This is the resource we can use — if we can find it!

If only the oil would stay put!

Oil will only remain in one place as long as it is trapped by very hard non-porous layers of rock above and/or alongside it. Scientists are researching factors that affect the rate of oil movement. Their aim is to create mathematical models that will predict how far oil would be expected to move from its formation site under particular conditions. Such models could be used to refine search areas, making the hunt more efficient.

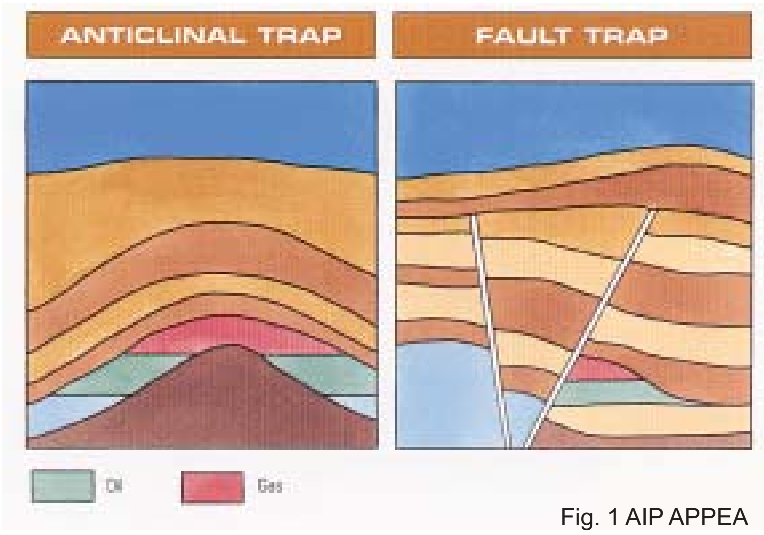


Fig. 1 AIP APPEA
Two types of rock structures that can trap oil and gas

SEEING INSIDE THE EARTH

Trucks used for seismic testing

Lessons from earthquakes

Imagine if you could look inside the earth without first drilling into it – this ability would mean that test drilling for oil could be done with much more likelihood of success. Relatively early in the twentieth century geologists worked out a way to achieve this goal. They began to realise that they could use the travel pathways of earthquake shock waves like a sort of giant CAT-scan of the inside of the earth. By timing the arrival of waves from one earthquake in different places, they could **infer** what sort of structures the waves had passed through along the way.

In the oil industry **seismic surveying** uses exactly this principle. Now that scientists also have the techniques to generate computerized patterns from their scan data, they can detect much more subtle patterns in the earth under our feet. Seismic surveying is a very powerful tool for increasing the odds of locating possible oil bearing structures. (The geologists call it 'shooting seismic'.)

Different shocks for different situations

Scientists send artificial 'earthquakes' into the ground in one of three ways.

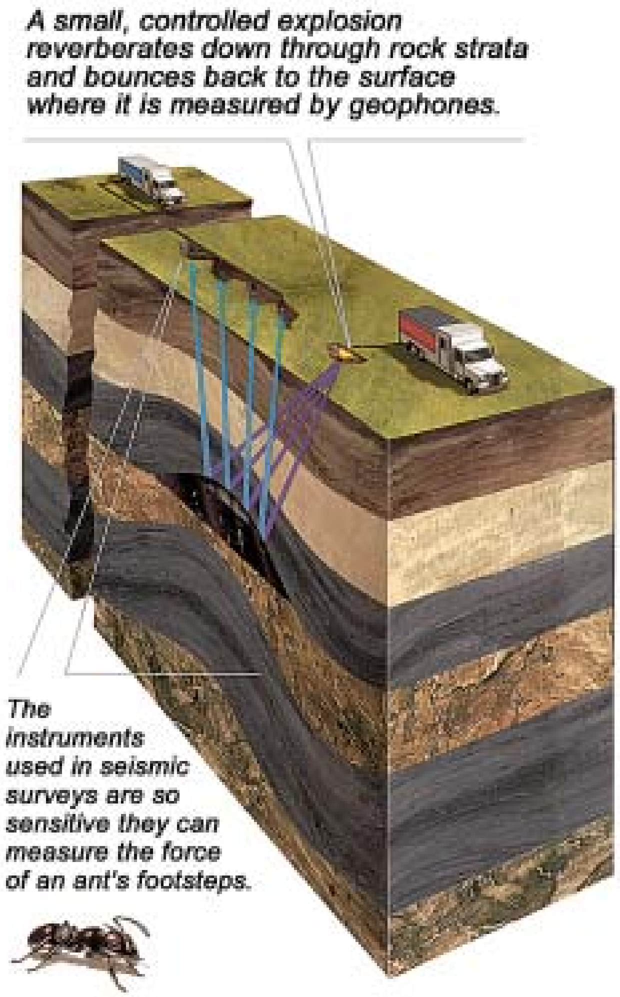
1. In the countryside, they drill shallow holes and explode small dynamite charges.
2. Nearer to urban areas or on beaches, they use vibrating pads under heavy trucks. (Notice how the back wheels are off the ground so that all the vibrations are concentrated into the pad).
3. To survey the sea bottom, they use a special air gun that fires shock waves through the water.

Seismic waves at work

Shock waves spread out from the point of origin. They can change in **speed, frequency** and **direction**, depending on their own initial frequency and the patterns of rock layers they travel through.

Some rock layers will **reflect** (bounce) waves of some frequencies back to the surface.
Some layers will **refract** (bend) waves of some frequencies so that they change direction slightly and slow down.
Some waves will move faster along an **interface** between layers, until they gradually get reflected back to the surface.

To collect the whole pattern for any one shock wave, scientists need to anticipate where, and by which frequency combinations, the wave will come back to the surface at closely spaced times. They need to have special timing detectors in all these places, tuned to the range of likely frequencies. (On land these detectors are called **geo-phones**. At sea they are **hydro-phones**.) This means laying out many kilometers of cable and detectors for each survey. All cables must lead back to the truck or ship and the computer that will collect and store the data. (Cows on farms and sharks at sea have been known to munch up cables that have just been set out for a survey!)



From *The Story of Oil*
Fletcher Challenge Energy

Keeping it complex

The line diagram (fig.2) shows how the test works *in principle*. To keep the diagram clear, only a few of the possible shock-wave pathways can be shown and no frequency information is included at all. Nowadays geologists often run several survey lines simultaneously. This allows them to collect such a complex tangle of wave patterns that the computer can calculate 3D patterns and print out a picture of the likely underground structures which might have trapped oil and gas.

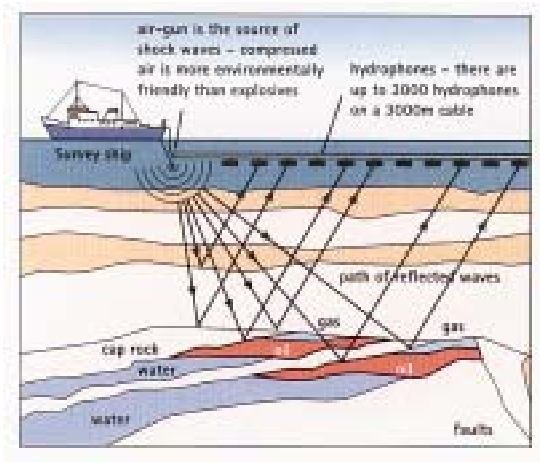


Fig. 2 AIP APPEA

Fig. 3 AIP APPEA

THE ART AND SCIENCE OF WELL DRILLING

From inference to fact

Seismic surveys locate possible oil and/or gas bearing structures. However the only way to find out if there really is oil or gas in a particular spot is to drill a hole and see what is there. Of course it's not quite that simple – many deposits lie very deep underground. If there is also a deep ocean in between, then the challenges multiply still more.

Onshore drilling rigs can usually be transported to the site by truck or helicopter. Generally they can be set up directly above the drilling target. If this is not possible, because of the terrain or land use, then the well can be drilled on an angle. Specialised offshore rigs, "tailor made" to suit the local conditions and the seismic information, are brought to New Zealand waters. These rigs may be supported from the sea floor, floating rigs – or even a specialized drill ship.

Expensive drill bits, often with diamonds attached, are used to cut through the rock. The drill bit is attached to the rig by lengths of drill pipe that are added to as the hole gets deeper. Special drilling mud is pumped in to lubricate the bit. This also reduces the chance of the oil or gas under pressure blowing to the surface as a gusher. Most wells are two to three kilometres deep but they can be drilled to four kilometres (or more).

Turning corners

Now that geologists can use seismic surveys to detect underground structures, they can be much more strategic about how to get to the pockets that look the most promising. If the rock that sits above a pocket is very thick and hard to drill through, they may even choose to attempt to drill side-ways into a target formation, by starting drilling in an easier spot and gradually moving the shaft on an angle. At millions of dollars per well, the drilling engineers have huge responsibilities to get the pathway just right. Even a few metres one way or the other out of line can mean the difference between success and failure.

MAKING THE MOST OF MATERIALS

A separation challenge

The mud used inside the drill string (the number of drill pipes joined together) isn't just any old mud. It is actually a specially mixed material that has to be adjusted constantly by the on-site 'mud doctor'. Some of the more expensive substances mixed into the mud are:

- **Bentonite**: a type of clay used for its lubricating and sealing properties
- **Barite**: a very heavy mineral that helps keep the mud under pressure to help prevent blowouts in the drill string. (Pockets of gas are sealed in their rocky hiding places under pressure – when the space is opened up by drilling the gas can rush to escape as a 'blowout'.) If pressure starts to build, more barite is added to the mix.

From *The Story of Oil* Fletcher Challenge Energy

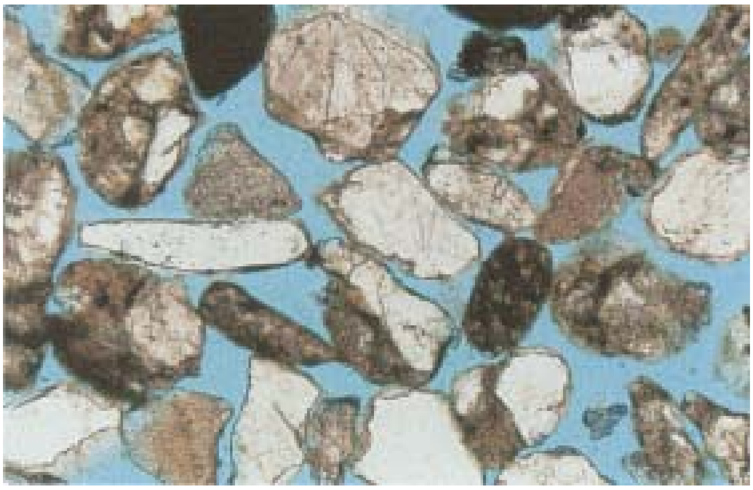
Clean mud is constantly fed down the drill string to keep the drill bits lubricated but it comes back up the outside in a very dirty state. All the scraps of rock (the cuttings) are mixed in. Separating them out to recover the mud for reuse is an engineering challenge. That's when the mud shaker gets to work! (See front cover)

Mud is sticky stuff! One way to separate it into different components is to get it moving vigorously. The *Linear Motion Shaker* has a bed of vibrating mesh screens. The fluid mud that is shaken loose drops down through the screens and is collected for reuse. The cuttings are carried away on the screens for analysis by the project geologists before their disposal.

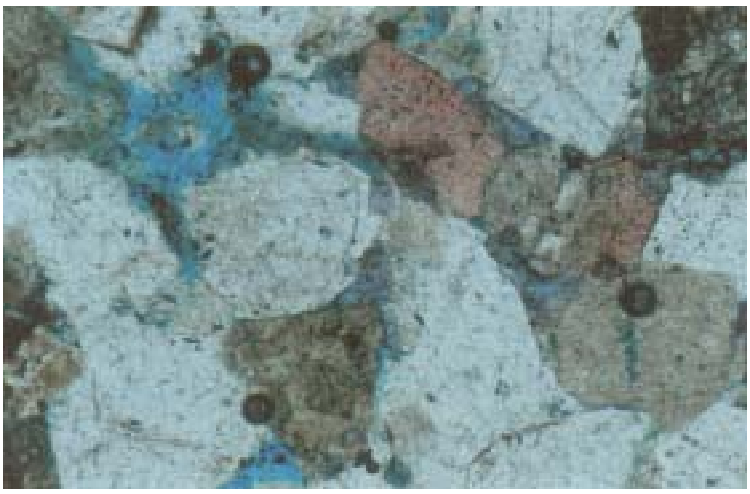
A different sort of separation

'Oil' isn't exactly the same from one well to the next. Mixed in with the hydrocarbons that will be sent to the refinery are other materials that can be used if they are separated out. The whole mixture that comes out of the ground is often gently heated to remove:

- Natural gas: some may be used as fuel for running the small on-site separation plant, or it may be burnt off as a 'flare'. Some may be pumped back down the well. As it slowly bubbles back to the surface it will lift up the oil too. (Often crude oil also contains carbon dioxide – this cannot be used as a fuel but it can be pumped back down the well.)
- Water: oily water is expensive to clean so it too is often pumped back down the well. As it seeps through the underground spaces in the reservoir rocks, the geologists hope it will push more oil towards the well shaft, and so increase the total amount of oil recovered from the well.



Thin-section rock with many porous spaces (the blue area is epoxy resin that has been used to hold the section together.) this would be a good reservoir rock for oil and gas deposits.



Thin section of rock with very few porous spaces (the bright blue sections). Such a rock could only hold natural gas, and would not be a likely source rock for oil.

TELL TALE EARTH

Rocks in close-up

Geologists need to be able to identify and match up the different strata seen in the drill core. Rocks are identified by looking at thin slices (or sections) under a special petrographic microscope. Thin sections are made by cementing a polished slab of the rock under study on to a glass microscope slide, and grinding the slab down until it is about 0.03mm thick, before covering it with a thin glass cover slip.

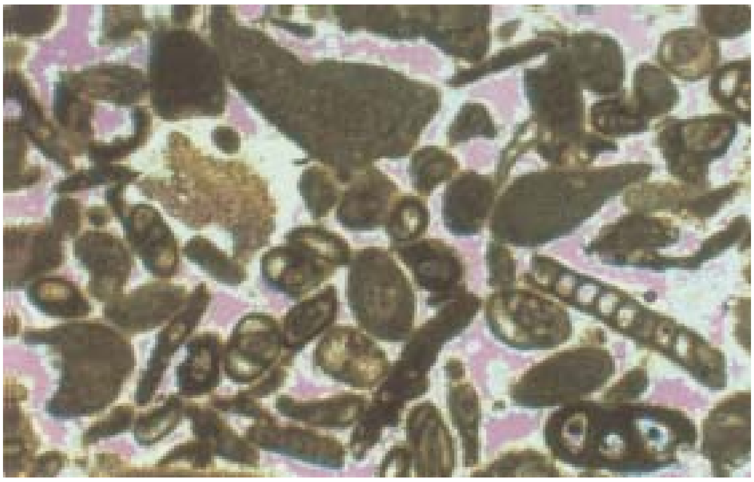
All rocks are made up of one or more minerals that are readily distinguished by colour, shape and other diagnostic properties at high magnification. By examining the drill cutting and core samples taken as the well is drilled, geologists can identify the strata and minerals present at each section of the sample, and they can tell how close they are getting to possible oil-bearing structures.

Invisible Fossils

You might think of fossils as shells and things you can easily see. But some of the ancient traces of life that interest prospecting geologists are invisible to the naked eye. They are **microfossils** and there can be literally millions of them in even a small rock chip . To find microfossils, geologists need to break away the surrounding rock minerals. This can be by softening with water or by the use of chemicals such as dishwashing detergent or sodium carbonate. The remaining soft sludge is then washed through extremely fine screens. The fine silt left on the screens is then viewed it under a powerful microscope and the fossils picked and mounted for detailed study and identification.

The photograph shows what a **paleontologist** can expect to see. Notice the huge diversity of fossil types on just this one slide. Over long periods of geological time the microscopic creatures that lived in the sea or on land gradually change. Some types become extinct and new types appear. Paleontologists have reference lists that detail the types of **micro-fossils,** including pollen, that they can typically expect to find in rocks of different geological ages. They date their rock sample by comparing what they see to the reference data.

A collection of tiny diatoms extracted from many rock samples. Because there are so many shapes and textures, diatoms are very useful microfossils for distinguishing between different rock types.



A microscopic section of 20 million year old limestone. The many microfossils are embededed in calcite (coloured yellow) and the purple patches are pores in the rock.

Fuel for our future

Whether we like it or not, modern life styles are very energy intensive. To maintain things we take for granted in New Zealand (for example), ease of travel, steady supply of electricity) we need good sources of fuels. The less oil we import, the healthier our balance of payments can be. The more electricity we use, the more urgent is our need for diversifying methods of generation. (Think about what happens when our hydro-lakes don't fill as expected because the weather is too dry.) Finding new sources of oil and gas, using all the science and technology outlined in this Alpha, will allow us to meet these needs into the future. Of course, we also need to use our energy supplies as efficiently as possible so we don't waste our precious resources – but that's another story for another Alpha!

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