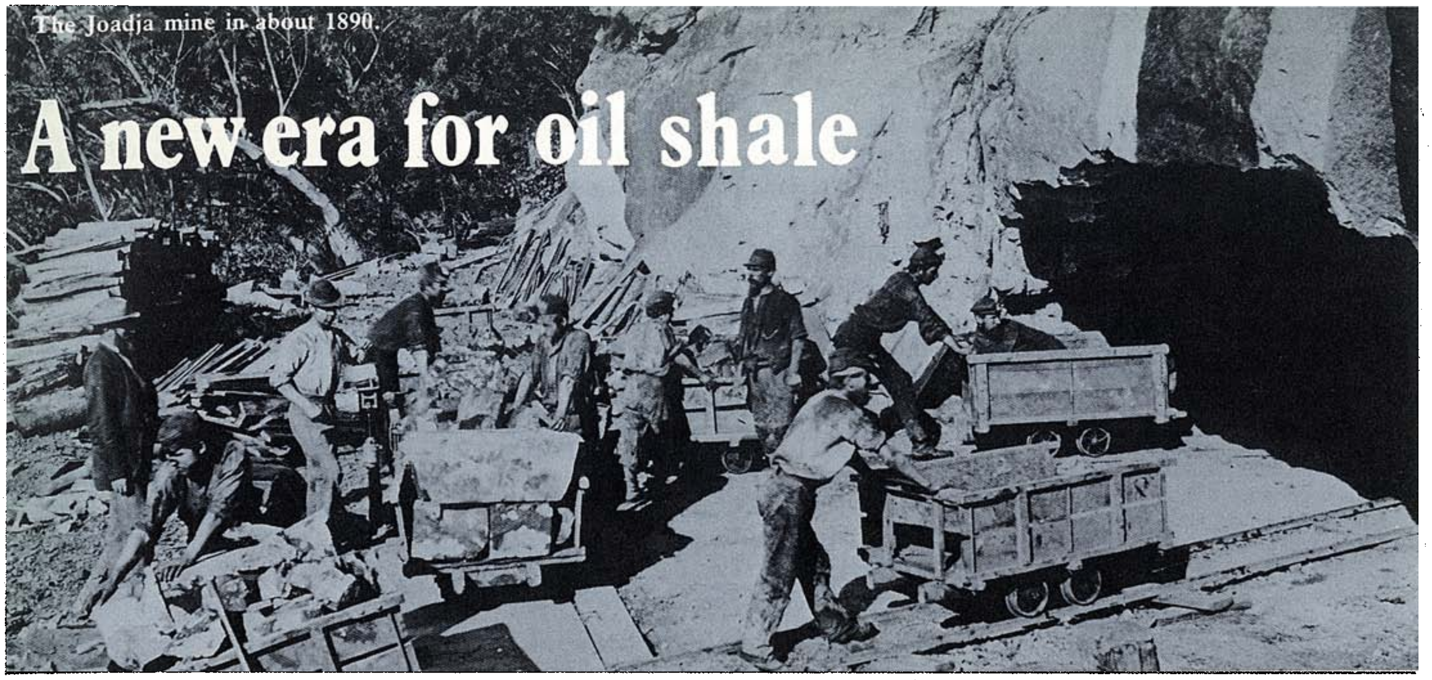


A new era for oil shale

Oil shales don't contain oil and are seldom shales. Geologically, they are usually classified as marlstones or mudstones, and they contain a resinous solid material called kerogen. But semantics aside, the fact is that, when heated, such rocks yield a valuable commodity — an oil that can be readily converted to something akin to crude oil.

As much energy is believed to reside in the world's oil shales as in all its known petroleum reserves. The difficulty lies in the energy's diffuseness: there's plenty of shale for precious little oil.

It's no good mining material that produces less than about 25 litres of oil for each tonne processed. It takes as much energy as those 25 litres contain just to run the retorts used to heat the shale. The Rundle oil shale deposit on Queensland's central coast, so much in the news, offers 77 litres (or about half a barrel) of oil per tonne.

Synthetic crude oils can, of course, be produced from coal. One tonne of coal can give 0·8–0·9 tonne (equivalent to about 4 or 5 barrels) of liquid fuel via a Fischer–Tropsch pathway, or flash pyrolysis may yield 0·2 tonne of tar. A wonder of modern economics, then, is that an oil-shale process yielding approximately 0·1 tonne per tonne of rock looks like being a profitable undertaking. It has something to do with the relative cost of plant, but it also requires that economies of scale be pushed to their limit.

More competitive

One thing that can be said with certainty is that substitute fuels are becoming more competitive each year as the Australian crude-oil price continues to increase. From $2 per barrel in 1960 and $2 in 1970, it rose to $9 in 1975, and $28 in 1980.

In 1865 the first commercial operation commenced at Mt Kembla, south of Sydney.

The cost of producing synthetic crude oil from shale is difficult to pin down. Most estimates fall in the range $10–25 per barrel, although more recent calculations, claiming to take a more realistic account of the effect of inflation on capital and operating costs, give a figure of $30–50 a barrel.

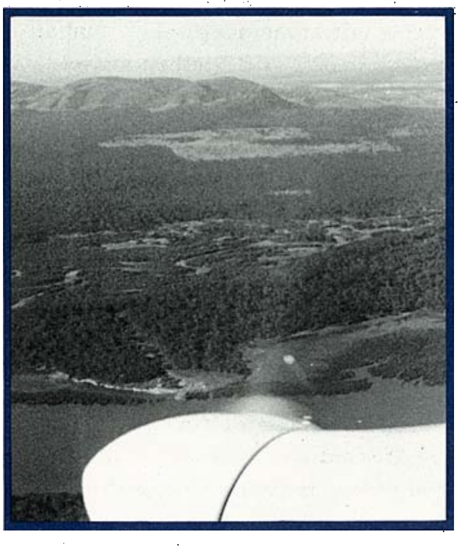
The projected scale of the Rundle scheme is enormous. At full production the mine — it would be an open-cut one — is expected to handle about a million tonnes of shale and waste materials a day to produce some 200 000 barrels of oil. This would make it the biggest mine in Australia and one of the largest in the world.

Immense bucket-wheel excavators, similar to those working the La Trobe Valley brown coal deposits, are being considered for the mining job, which will involve shifting much more material than any other Australian mining enterprise — coal or minerals. It is the soft, moist nature of the Rundle deposits that makes such an operation possible. An outline of the Rundle scheme is given in the box on page 14.

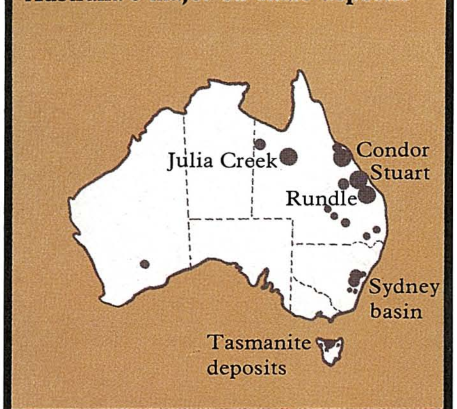
Dr John Saxby of the CSIRO Fuel Geoscience Unit has been studying Australian oil shales for many years. Knowledge of how they were formed may help in locating new deposits of the shale, and of oil itself. Just as heating oil shale in a retort produces oil, so — over geological time — does the heat hundreds of metres below the surface give rise to it. The oil flows from its source rock — sedimentary rock bearing organic matter, in some cases an oil shale — into impervious geological basins from where, if we are lucky, we can recover it.

Dr Saxby has been systematically examining the occurrence and properties of our oil shales, and recently he prepared

From the air, Rundle gives no clue as to the wealth beneath.



Australia's major oil shale deposits



deposit	approximate reserves shale (million tonnes)	oil (million barrels)
Condor	18 000	6 000
Rundle	4 000	2 000
Stuart	5 000	2 000
Julia Creek	4 000	1 500
Sydney basin	50	200
Tasmanite	25	20

Most of our oil shale occurs in Queensland.

a review of what is currently known about them. At present he is testing them to discover how they behave when retorted.

In the beginning

There's nothing new about oil-shale mining in Australia. It began in 1865 when the first commercial operation commenced at Mt Kembla, south of Sydney. A total of 16 mines tried their luck in the ensuing years.

In 1873 mining began at Joadja, near Mittagong, N.S.W., on one of the richest deposits ever exploited. Its 'kerosene shale' mined from underground yielded about 450 litres of oil per tonne. By 1880 the Joadja township had a population of 1000 — quite large when it is remembered that Australia's total population at that time was just one million.

Importation of cheap American kerosene derived from petroleum spelt the end for Joadja and the mine finally closed in 1903, most of its rich seams exhausted. Nearly all the other mines closed down about the same time, although there were exceptions. High-quality road bitumen was produced between 1910 and 1934 from an underground mine in the Mersey River area of northern Tasmania. A deposit at Glen Davis, 150 km north-west of Sydney, was worked during World War II and continued until 1952, when abundant crude oil from the Middle East became available. A similar pattern of events occurred overseas.

However, it is interesting to note that a few schemes utilizing oil shale have begun in the last 10 or 20 years and are operating today. Brazil, a country short of petroleum, extracts about 1000 barrels of oil a day from oil shale. Sparse information suggests that, in China, some 30 million barrels a year are produced this way.

In another two countries, oil shale is burnt for its energy content. Two Russian power stations generate 1600 MW each from shale combustion, with town gas produced on the side. The burnt shale is used as a construction material. In West Germany, power is similarly generated, and the spent shale is used to make cement. However, the burning of oil shale produces copious amounts of fly ash, and all three of these installations cause serious air-pollution control problems.

A turn of the page

Of course, Middle East oil is no longer in cheap supply and it may not remain abundant for many more years. In this context, a renewed interest in oil shale as a source of liquid fuel has arisen.

Oil-shale deposits are widespread in many countries, but they vary greatly in their grade, size, and geological age. Reserves are notoriously difficult to quantify, but we can hazard the following guesses.

Australia has not been extensively explored for these hidden deposits.

In the big league, the United States, China, Russia, Zaire, and Australia probably have recoverable reserves of shale oil greater than 10 thousand million barrels each. The most extensively studied deposit in the world, and probably the largest, is that in the Green River formation of the Rocky Mountains. This could yield 80 thousand million barrels, or even a hundred times more if low-grade material is included.

The Americans are greatly interested in tapping this resource, and a lot of effort has been directed towards this. However, various constraints — environmental, economic, and legislative — have to date stood in the way.

Countries with reserves greater than a thousand million barrels include Burma,

Shales originated from debris accumulated on the bottom of hot, shallow ponds.

Brazil, France, Germany, Luxembourg, Italy (in Sicily), Sweden, Thailand, and the United Kingdom.

Australia has known oil-shale reserves greater than 12 thousand million barrels. The most significant deposits are listed in the table on this page.

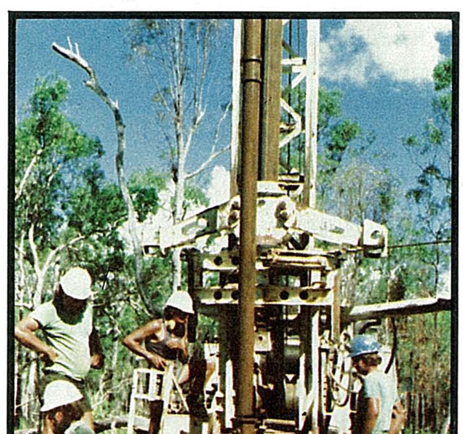
The Rundle deposit, on the coast near Gladstone in Queensland, looks set to host the first of a new wave of oil-shale mining ventures in Australia, and indeed the world. Its 2 thousand million barrels are equivalent to Australia's known crude-oil reserves. The *Rundle Oil Shale Agreement Act* 1980 was passed in April last year by the Queensland parliament, and an arrangement has been made between the holders of the mining rights and Exxon for exploitation of the deposit if, as expected, the results of detailed geological and economic assessments are favourable.

The output of 200 000 barrels a day envisaged by Rundle's backers is equivalent to about one-third of the current Australian consumption of oil. Another measuring stick is the current local production of crude oil — 420 000 barrels a day.

Near the surface

Last century, oil-shale deposits were found simply by observing outcrops on

Test drilling at Rundle.



exposed cliff faces and in river valleys. Pioneers would pick up the rock to fuel camp fires. Miners attacked a seam, typically thin and difficult to mine, from its edges, using underground techniques. Today, to be of any worth, deposits must be massive — thick seams with little overburden, allowing efficient large-scale open-cut mining.

Yet Australia has not been extensively explored for these hidden deposits. Only recently, further discoveries have been made. The Condor deposit, near Proserpine in northern Queensland, is reckoned to hold 6 thousand million barrels — Australia's largest yet. Another deposit next to Rundle, called the Stuart prospect, is estimated to have the potential to produce as much oil as its well-known neighbour.

The Julia Creek deposit in north-central Queensland was only discovered in 1966, during exploration for petroleum. Reserves are put at 1·5 thousand million tonnes, with the oil shale occurring in seams up to 10 m thick. At least part of the deposit could be mined by open-cut methods, and CSR, the holder of the mining rights, is undertaking a feasibility study of this. The company envisages a $2000 million investment in the project.

The high vanadium content of the Julia Creek material (up to 0·5%) intrigues scientists. Dr Saxby's studies have shown the vanadium to be associated with both the kerogen and the clay minerals in the shale, deepening the puzzle of its origin. However, recovery of this element could help make the mining venture profitable.

The oil-shale deposits of the Sydney Basin offer potential production of about 200 million barrels of oil. They occur next to coal seams that surface at the rim of the basin, and include the old Joadja and Glen Davis workings. The deposits are small and numerous, and some that do not form outcrops no doubt remain undiscovered. The seams are often less than one metre thick and must be mined by difficult underground methods. Nevertheless, the shale generally has quite a low mineral content, so particularly high oil yields are possible.

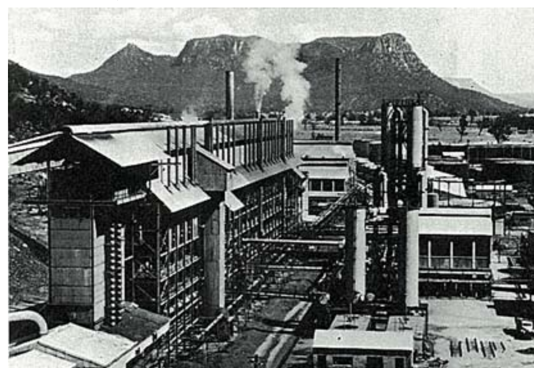
Unlike coal, oil shales contain much mineral matter.

The remaining known significant oil-shale deposit occurs in the Mersey River area of northern Tasmania, and could produce perhaps 20 million barrels of oil from the localized thin seams of shale.

What's in oil shale?

In general, oil shale is more likely to be found in sedimentary basins where crude oil is absent than in oil-bearing basins. Dr Saxby's studies confirmed the widely held

Rundle oil shale — there's a lot more where that came from.



Glen Davis — in 1948 (above) and today.

Rundle and the environment

Named after the nearby mountain range, the Rundle shale-oil deposit lies on the Queensland coast between Rockhampton and Gladstone. In a flat valley — flanked on the west by the Rundle and Mount Larcom Ranges, and on the east by the mangroves and mud-flats of a shallow tidal channel, The Narrows — sit an estimated 4 thousand million tonnes of shale. Each tonne can produce, on average, half a barrel of oil.

The Narrows separates the mainland from Curtis Island, and is the work area for several professional crab-fishermen. The mainland vegetation is mostly medium-density eucalypt forest, with some scrub. To the north, the land is used for forestry and some grazing, while to the south some small areas have been cleared for pasture improvement.

The two Australian companies that plan to change this rural area to an open-cut mine of vast proportions are Southern Pacific Petroleum N.L. and Central Pacific Minerals N.L. They have received approval from the Queensland government to develop a project that in the end could cost $3000 million. Exxon would provide most of the capital, if a recently concluded agreement is followed through.

The deposit, up to 300 m thick in places, is covered by a thin layer of overburden, averaging 15 metres in depth. The ratio of waste to oil shale averages a favourable 1·2 : 1. Obviously it is impossible to mine a million tonnes of material a day, as planned, without environmental impact. Probably 30 square kilometres of native bushland will be removed in the operation.

The disposal of spent shale presents major problems. Not only are the quantities involved massive, but the very act of crushing the shale increases its volume by 10–25%.

The plan is to return the shale to the pits that it came from. However, because of the increase in volume, the new surface will be higher than the old, forming a gentle hill. The companies intend to spread topsoil over it to allow revegetation.

Before the shale goes back into the pit, it will be stored in massive waste dumps. These will have to be kept constantly damp to hold down the dust. The alkalinity of spent shale (pH values of 7·8 to 9·9 have been recorded in America) increases the ease with which some trace metals and other harmful chemicals, possibly including organic carcinogens, could be leached out, creating a risk of water pollution.

Very large volumes of water will be needed for the enterprise; 90 000 megalitres a year is one estimate of the requirements of the full-scale Rundle plant. Substantial amounts of electrical power will also be needed.

Problems of air pollution will have to be guarded against. Gas produced in the retorts will contain oxides of sulphur and nitrogen, and possibly traces of fluorine and some heavy metals. Gas-scrubbers may be necessary. Fortunately, deposits of limestone, which is used to control sulphur emission, are located just to the south of Rundle.

Moisture driven off from the shale (Rundle shale contains 20–27% water) is condensed back with the oil. When separated, the water may carry with it soluble organic carbon, as well as inorganic salts. A number of these organic compounds may be toxic or carcinogenic, and care will be needed in their disposal.

Wastes from up-grading of the oil will also need to be handled carefully. The companies involved believe none of these obstacles is insurmountable. They are continuing to study the region's aquatic and terrestrial ecosystem, air and water quality, meteorological conditions, and the physical and chemical properties of spent shale. The results of these studies will be presented in a forthcoming submission to the Department of Science and the Environment.

The companies propose that the project be undertaken in two stages. The first, costing about $300 million, calls for some 25 000 tonnes of oil shale to be processed each day to produce at least 15 000 barrels of oil. When production is under way the viability of proceeding to stage 2 — production of about 200 000 barrels of oil a day from 400 000 tonnes of oil shale — will be assessed.

If all goes according to plan, by 1985 we will see the first oil flowing from a resource as big as Bass Strait. Spurred on by rising oil prices, Rundle looks set to be the forerunner of modern-day ventures into oil-shale mining.

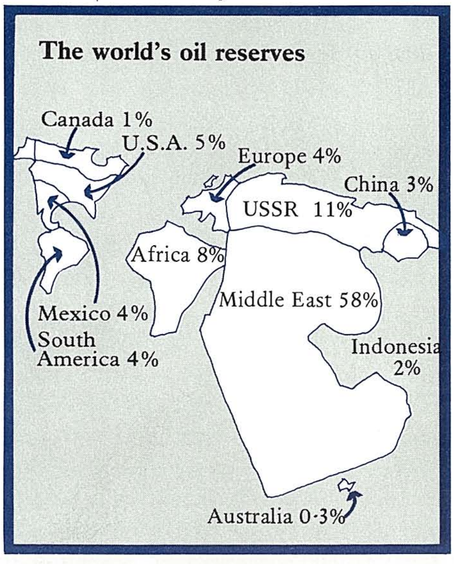
view that the shales originated from debris accumulated on the bottom of hot, shallow ponds. To survive this harsh environment, the organisms responsible had to be fairly tough, and they produced large amounts of kerogen, a substance built up from sugars, amino acids, lignin, and, particularly, lipids. Over time, unsaturated lipids and other components have polymerized to form the hard, cross-linked structure that we find in oil shale today. More than 90% of the organic matter in oil shales is kerogen, and the rest mostly bitumen.

In Rundle oil shale Dr Saxby has found algal debris, together with some woody plant remains. The Julia Creek kerogen is more difficult to define precisely, but fish scales found with it suggest a shallow marine environment. The Sydney Basin deposits show kerogen derived from the ancestors of the present-day green colonial alga *Botryococcus,* leading Dr Saxby to think they have originated from freshwater swamps.

The Tasmanian oil-shale deposits are unique — the material has acquired the name Tasmanite. The kerogen is composed largely of cysts of a large unicellular alga (called *Tasmanites*) that lived in sea shallows. The tough outer sac of the alga was originally spherical, but it was flattened to a disc during formation of the sediment. Because of the large size of the algal kerogen particles, Tasmanite oil shale can be concentrated to more than 50% organic matter by physical methods, such as froth flotation.

But for most oil shales, recovering the kerogen is not so easy. Unlike coal, oil

Drawn on a scale of oil reserves, the Middle East looms large on the world map and Australia is very small.



Getting it out

Underground extraction methods were used in Australia's early shale mines, but today open-cut seems the way to go. Huge bucket-wheel excavators can bite 150 000 cubic metres per day to achieve the economy of scale that seems necessary.

At Rundle, where the overburden is about 15 metres thick, and the material is soft and moist, open-cut methods seem ideal.

Nearly the whole of a deposit can be recovered this way, compared with a maximum of 50–70% from an underground mine. The drawback is the monumental scar on the environment until revegetation takes place.

There is a third way to recover shale oil, called *in situ* processing. It has never been used commercially, but tests being undertaken in America are showing promise. Buried oil shale is first fractured, usually by explosives. Then a portion of the kerogen is burnt to retort the remainder, and the oil is pumped off.

The advantages claimed for the method include the absence of spoil piles, low water requirements, and its suitability for low-grade shales.

Dr Saxby thinks the technique is promising, but much research remains to be done. At present, controlling combustion is difficult, drilling costs are high, rates of recovery are low, and there is a risk of contaminating aquifers in the vicinity. Possible future developments include the use of nuclear devices to fracture the shale, lasers to initiate combustion, and radio-frequency heating to retort the shale.

shales contain much mineral matter, at least 33% and usually 70–80%, depending on the grade. It is sometimes suggested that dissolving the oil out of oil shale with a solvent would be a simple approach.

Unfortunately, kerogen is insoluble in most organic solvents. Solvents would only extract the bitumen fraction; indeed oil can be recovered from tar sands this way. The Syncrude tar-sands operation in Canada, begun 2 years ago, works in such a manner.

Oil shale is more easily converted into useful liquid hydrocarbons than coal.

The standard way of getting the organic material out of the shale is to crush it and heat the pieces to roughly 500°C in a retort. This 'cracks' the kerogen and bitumen molecules into lighter volatile products that are driven off and recovered by condensation.

Adding hydrogen

But why go to the trouble of mining and heat-treating oil shale with perhaps 10% yield when we could make oil from coal with much higher yields?

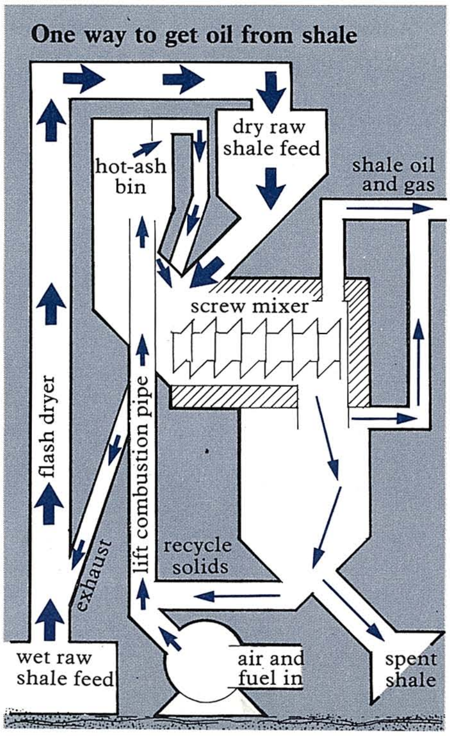
The answer is that oil shale is more easily converted into useful liquid hydrocarbons than coal. Kerogen has a ratio of hydrogen to carbon (about 1·5 : 1) that approaches the values common for petroleum (around 1·9 : 1). Shale oils are heavier and more viscous than petroleum because of their slightly lower hydrogen-to-carbon ratio, but a little hydrogen added during retorting or refining easily makes up the difference.

In coal, by contrast, the ratio is much lower — about 0·8 : 1. This is because of its high lignin content — derived from woody plants. Considerably more hydrogen must therefore be added to coal to make it liquid — a real disadvantage.

Many different types of retort can be used to get oil out of the shale. The resulting oil will, of course, vary depending on the type of shale and the retort used. It could be tailored for use as petrochemical feedstock, fuel oil, or a transportation fuel.

The aim of the Rundle project is to produce a petroleum substitute, and a combination of two types of retorts is planned. Plant to up-grade the oil to the point where it is an acceptable substitute for crude oil will also be necessary. Only after hydrogenation and removal of nitrogen, sulphur, oxygen, and trace metals does the product resemble a top-grade natural crude oil.

One type of retort, the Lurgi, used to heat shale so that the kerogen in it breaks down to oil and gas.



The principal contaminant in most shale oils is nitrogen, at a level of 0·5–1·5%, or even higher in some American samples. Nitrogen quickly poisons most catalysts commonly used in petrochemical plants and must be virtually eliminated from oil feedstocks.

Sulphur also interferes with petrochemistry, and must be removed. Oxygen is found in quantities (up to 3%) sufficient to produce problems in refinery towers.

All shale oils are sure to bear traces of one or other of the metals iron, nickel, vanadium, copper, lead, zinc, selenium, and arsenic. All must be removed for trouble-free refining.

Hydrogenation is the favoured upgrading process. Impurities are removed as hydrogen reacts with them with the help of a metal oxide catalyst. Nitrogen goes to ammonia, sulphur to hydrogen sulphide, and oxygen to water. Hydrogenation also stabilizes the hydrocarbons by converting unsaturated compounds to saturated ones.

Of course, the process requires great quantities of hydrogen, normally an expensive commodity. However, when Rundle oil shale is retorted, it produces a gas stream rich in hydrogen. This would reduce the need for additional supplies.

Hydrogenation tests have been carried out on Rundle shale oil. They indicate that a high-quality synthetic crude, suitable for petrol production, can be obtained.

Andrew Bell

More about the topic

Oil shale in Australia. J. Saxby. *Energy Resources and Technology,* 1980, 2 (5), 30–4.

Technology of oil shale extraction. J. Saxby. *Energy Resources and Technology,* 1980, 2 (7), 24–8.