The age of fossil fuels

Phanerozoic sedimentary basins

At times during the Phanerozoic* large parts of the Australian continent were covered by sedimentary basins which also extended offshore onto the present continental shelf.

Sedimentary rocks ranging in age from Proterozoic to Cainozoic underlie more than half the land area of Australia and nearly all of the continental shelf. Most of the basins are very old, so the likelihood that tectonic processes would have destroyed any initial petroleum reservoirs is increased. Compared with other producing countries, where petroleum resources are usually found in much younger sediments, Australia has only been seriously considered a good prospect for discovering significant oil and gas resources during the last two decades.

Though petroleum formation began in Australia as early as the Proterozoic significant quantities did not develop until the Palaeozoic and, in particular, the Mesozoic and the Cainozoic. Coal was formed from the Permian through to the Tertiary.

Australia's main proven hydrocarbon rocks thus span a wide range of geological time. Large parts of the continent, notably in the central-east, contain basins of differing age which overlie and overlap each other. Some basins even contain hydrocarbon-bearing sequences of different ages within their boundaries.

Coal

The evolution and rapid propagation of land plants in the Devonian was followed world-wide by the deposition of sediments containing plant remains which eventually became coal. Whereas the most extensive and productive coal measures of the Northern Hemisphere are of Carboniferous age, the main coal-forming period in the southern continents (then still joined together as 'Gondwana'), was not until after the Permian Ice Age.

Australia's major black coal deposits were formed in the Permian. Most were deposited in the *BOWEN* and *SYDNEY BASINS* along the newly formed eastern margin of the continent. Variations in the extent and quality of coal across the basins result from local differences in structural and stratigraphic history, and the kind of vegetable matter from which the coal formed.

Favourable coal-forming conditions persisted locally throughout the Mesozoic and Cainozoic, giving rise to deposits in the small, isolated *LEIGH CREEK, IPSWICH* and *CALLIDE BASINS* in the Triassic; then widespread coal measures of Jurassic–Cretaceous age in the *EROMANGA* and *CLARENCE–MORETON BASINS*; and huge brown coal deposits of Tertiary age in Victoria and, to a lesser extent, South Australia.

Permian

SYDNEY and *GUNNEDAH BASINS*. There were at least two periods of widespread coal formation. In the early Permian the Greta Coal Measures were formed, followed, late in the Permian, by the Illawarra, Newcastle, Tomago and Singleton Coal Measures. At up to 1450 m, the Singleton Coal Measures are the thickest in New South Wales and contain 28 significant coal seams.

Deposits occur in five major regions:

- Hunter (**Singleton–Muswellbrook**) has the largest resources and currently produces soft coking and thermal coal.
- Newcastle (**Newcastle–Lake Macquarie**, **Cessnock**) contains substantial resources of soft coking and thermal coal.
- Western (**Ulan**, **Lithgow area**, **Kandos**) contains mainly high energy thermal coal.
- Southern (**South Coast area**, **Burragorang Valley**, **Tahmoor**, **Berrima**) is known for its premium quality hard coking coals.
- Gunnedah (**Boggabri**, **Gunnedah**) contains large resources of thermal coal and some soft coking coal.

BOWEN BASIN. This basin is a major source of high quality coking coal which ranges in age from early to late Permian, the latter being the most extensive. The principal deposits are mined at **Newlands**, **Goonyella**, **Riverside**, **Peak Downs**, **Saraji**, **Norwich Park**, **German Creek**, **Oaky Creek**, **Gregory**, **Blackwater** and **Moura–Kianga**. Igneous intrusions have metamorphosed large parts of some coal seams, mainly in the north (e.g. at **Collinsville**), to high ash, natural coke.

Aggregate coal thickness is greatest in the Blair Athol Coal Measures (**Blair Athol**), at 40 m, with one seam alone measuring 33.5 m. A similar aggregate coal thickness exists in the small Wolfang Basin (**Wolfang**) nearby.

Less extensive Permian coal measures, generally of low rank, are preserved in the *GALILEE, OAKLANDS, ARCKARINGA, TASMANIA, BONAPARTE, PERTH, COLLIE and CANNING BASINS*.

Triassic

The *IPSWICH BASIN*, parts of the *CLARENCE–MORETON BASIN* and the **Fingal** area of the *TASMANIA BASIN* contain medium rank coals suitable for steam generation. The *TARONG* and *CALLIDE BASINS* contain bituminous coal amenable to opencut extraction for power generation. Up to 18 seams of low rank coal occur in four small basins at **Leigh Creek** (S.A.).

Jurassic

Jurassic coal deposits occur in the *CLARENCE–MORETON, SURAT, POLDA* and *PERTH BASINS*. The coals are mostly sub-bituminous, occurring in thin, lenticular seams.

Tertiary

Australia has about 8% of the world's economic demonstrated resources of brown coal, mainly in *GIPPSLAND BASIN* (**Yallourn–Morwell**, **Loy Yang**) east of Melbourne. With large reserves at shallow depth the deposits can be mined economically on a large scale for power generation.

Brown coal deposits are widespread across the south of the continent near the margins of Tertiary basins and in depressions on adjacent cratonic blocks, for example **Esperance** (W.A.), **Wakefield–Lochiel**, **Mannum** and **Kingston** (S.A.), and **Anglesea** (Vic.).

Petroleum

In proportion to the extent of its sedimentary rocks, Australia is not particularly well-endowed with liquid hydrocarbons although it does have large deposits of natural gas. The main commercial hydrocarbon fields are offshore in the *GIPPSLAND, BONAPARTE* and *CARNARVON BASINS* and onshore in the *COOPER/EROMANGA, AMADEUS* and *BOWEN/SURAT BASINS*. Most deposits are in anticlinal traps in Tertiary or Mesozoic sandstone reservoirs overlain by shale caprocks.

Precambrian

Any oil or gas formed in rocks of this age is now generally considered to have long since been destroyed or squeezed out into other strata. However, what is believed to be the world's oldest oil was discovered in 1985 in Precambrian rocks of the *McARTHUR BASIN* though there are no commercial fields in rocks of this age in Australia.

The first well drilled in the AMADEUS BASIN recorded a small flow of gas from Precambrian limestone.

Cambrian/Ordovician

In the *AMADEUS BASIN* the **Palm Valley** (gas) and **Mereenie** (oil and gas) fields produce from sandstone reservoirs sourced from an adjacent thick marine shale.

Devonian

Commercial hydrocarbon accumulations have been identified in Devonian reservoirs only recently. In the *CANNING BASIN* (**Blina**) they are in and adjacent to fossil coral reefs built up along an ancient coastline.

Plans have been announced to develop the **Gilmore** field in the *ADAVALE BASIN*, where gas is trapped in continental to shallow marine sandstones.

Carboniferous/Permian

Hydrocarbons dating from this time are trapped in reservoirs formed in a variety of depositional environments. Currently the most important fields are in the *COOPER BASIN* (**Moomba area**, **Tirrawarra area**). Here, hydrocarbons have been generated from plant matter in carbonaceous shales and coals interbedded with the reservoir sandstones formed in fluvial to lacustrine environments.

Hydrocarbons have been discovered in the *BOWEN BASIN* and significant gas fields are known in the **Denison Trough area**. Gas has been found in Permian marine limestones of the *PERTH BASIN* (**Woodada**) and in deltaic to marginal marine sandstones of the offshore *BONAPARTE BASIN* (**Tern**, **Petrel**). The *CANNING BASIN* has proven reservoirs (**Sundown**) lying on top of the Devonian reef sequences referred to above.

Mesozoic

Like the Carboniferous and Permian, the Mesozoic was a time of extensive source, reservoir and caprock deposition within thick layers of sediments in shallow seas and inland lakes. Much of the eastern half of the continent as well as parts of its western margins were covered in this way, giving rise to the **Jackson area** and **Dullingari area** fields in the *EROMANGA BASIN*; to various fields including **Barrow Island** and **Harriet** (oil) and **North Rankin**, **Goodwyn**, **Angel**, **Scarborough**, **Gorgon** and **West Tryal Rocks** (gas) in the *CARNARVON BASIN*; to the **Jabiru** and **Challis** fields in the *BONAPARTE BASIN*; to **Scott Reef** and Brecknock (gas) fields in the *BROWSE BASIN*; to the **Dongara** area fields in the *PERTH BASIN*; and to the **Kincora area**, **Boxleigh area**, **Moonie** and **Alton** fields in the *SURAT BASIN*.

Much of the petroleum in the *SURAT BASIN* fields is thought to have been derived from underlying coal and shale sediments in the *BOWEN BASIN*.

Along the Rankin Trend in the offshore *CARNARVON BASIN* gas is trapped in Early Mesozoic reservoirs in fault blocks sealed by younger Mesozoic shales. In the *BONAPARTE BASIN* oil is trapped in Mesozoic sandstones which overlie Jurassic source rocks.

Tertiary

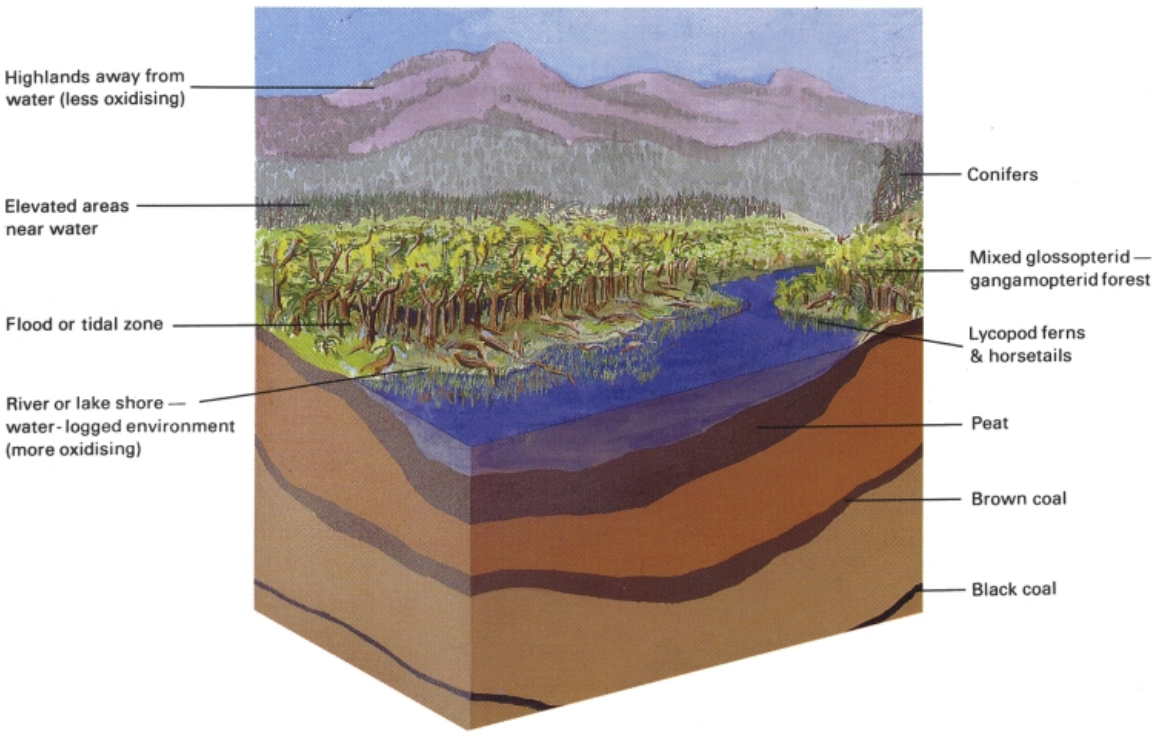
Once again, this was a time of luxuriant plant growth and abundant animal life. The huge brown coal deposits of Victoria laid down in this period are widely accepted as the source of the Bass Strait oil and gas fields. The *GIPPSLAND BASIN* contains the bulk of Australia's oil resources, the fields occurring in moderately folded, capped sandstones. Liquid hydrocarbons are probably still being generated there today.

* The eon covering the Palaeozoic, Mesozoic and Cainozoic Eras—see geological time-scale diagram on page 7.

The hydrocarbons

Coal, petroleum and oil shale are fossil fuels formed predominantly during the Phanerozoic. Their energy is derived from the process of photosynthesis, in which plants and, indirectly, animals have stored solar energy in the form of complex carbon compounds. The organic remains of plants and animals were preserved in sedimentary sequences and under certain conditions then chemically altered into hydrocarbons.

How coal is formed



Coal is a readily combustible rock, consisting mainly of carbonaceous material derived from the compaction and alteration of plant remains similar to those found in present-day peat bogs.

Coal has formed from the accumulation of abundant plant debris over long time intervals in a variety of landscape environments. These sites varied from dry land through to swamps and shoreline lagoons. Each had a distinct plant assemblage and water and oxidation levels which influenced the way the plant debris decayed. As a result coals with a wide range of properties have developed; they are classified on the basis of flora (coal type), degree of alteration (coal rank) and contained impurities (coal grade).

Formation of the first substantial coal deposits commenced about 360 m.y. ago. The actual climatic conditions existing at the various times of coal formation are a matter of debate, although the cycles of climatic and sea-level fluctuation associated with ice-ages of the time were important.

A commonly held concept is that subtropical conditions were necessary to support a diversity of rapidly growing vegetation. However, in the case of some Australian coal deposits there is strong evidence to suggest that at times the climate prevailing during the accumulation of major deposits was cool–temperate, particularly as the associated sediments sometimes show the influence of glacial activity.

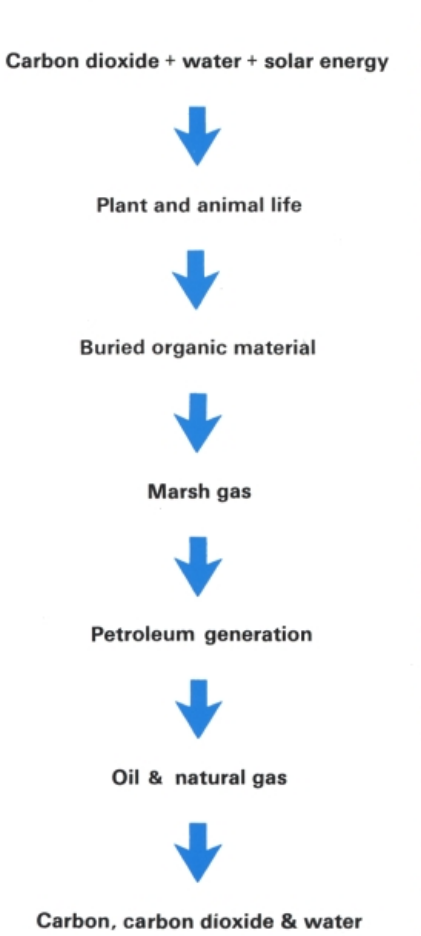
Coal formation begins with the accumulation of enormous volumes of plant debris, commonly in stagnant swamps. Here, poor circulation minimises the influx of contaminating sediments and in combination with bacterial activity reduces the supply of oxygen, thus slowing oxidation of the accumulating organic material.

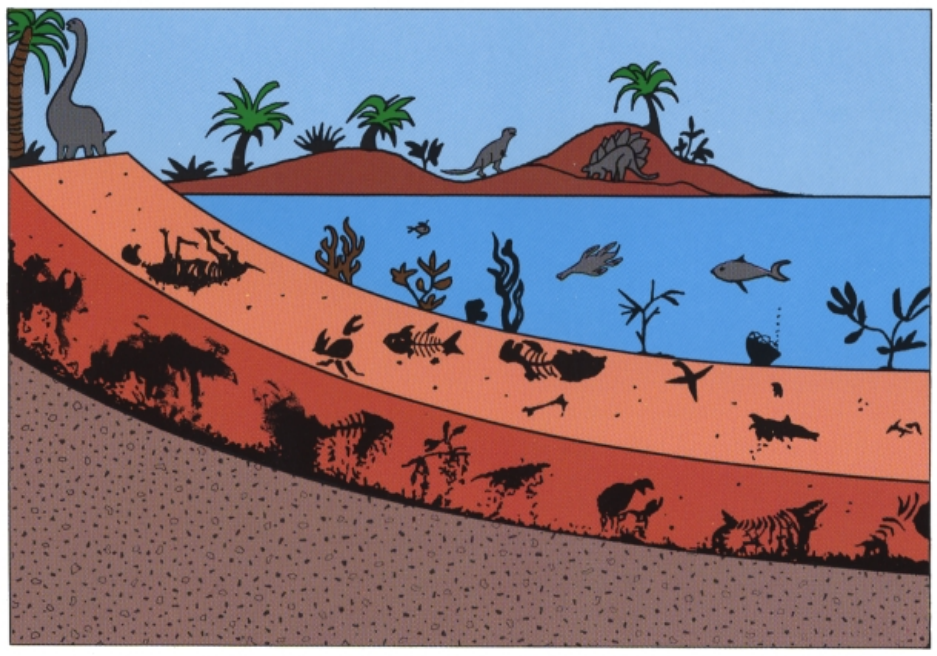
Partial decay transforms the accumulated plant material initially into peat. Subsequent burial by overlying sediments compresses and hardens the peat through increasing temperature and pressure. It has been estimated that a 120 metre-thick layer of plant debris is transformed over about 1.5 m.y. into a coal seam of only one metre in thickness.

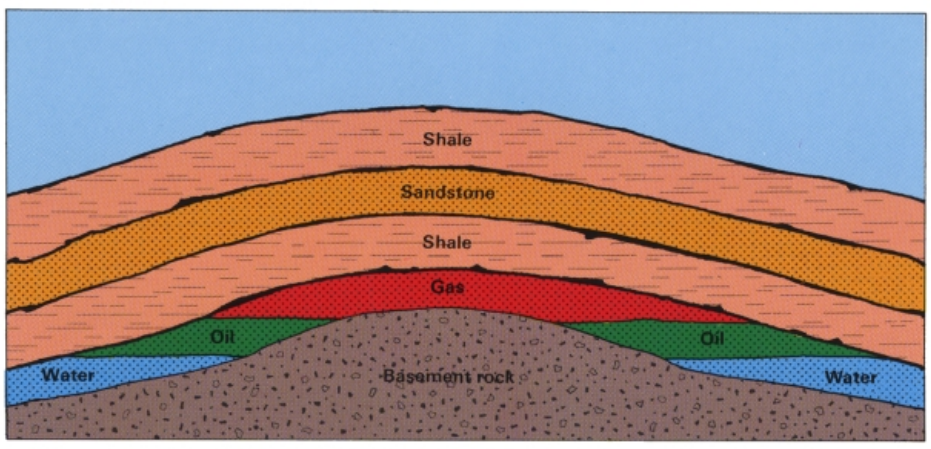
This process of coalification yields coals of successively higher rank, the highest rank coals having the greatest carbon content and calorific value and the lowest degree of moisture and volatile matter. The five broad ranks are peat, brown coal (lignite), subbituminous black coal, bituminous black coal and anthracite.

The use to which coal is put depends on its rank, type and grade. Particular kinds of bituminous coal are reduced to coke for use in the smelting of iron ore. 'Hard' coking coals can be converted directly to coke. In contrast, 'soft' coking coals are of lower rank and have greater volatility. They are usually mixed with hard coking coal to form a blend suitable for charging coke ovens. Lower rank sub-bituminous and brown coals are mainly burnt as 'thermal' or 'steaming' coal, particularly in the generation of electricity.

How petroleum is formed







Crude oil and **natural gas** are the liquid and gaseous fractions of **petroleum.** They are generated from source rocks—fine-grained, organic-rich sediments—which are often shales but also coals and some carbonates. The organic matter is derived largely from land plants, and lacustrine and marine plankton. These may be altered by bacterial action, and deposited and preserved in the sediments under low oxygen conditions. Various factors in this process will determine if the source rocks are capable of generating primarily oil or gas.

As the source rocks are buried under further layers of sediments, their temperature rises and they enter the critical temperature range in which the organic matter breaks down to yield petroleum. Most gas is formed at a slightly higher temperature range than oil.

In general the liquid petroleum initially consists of complex compounds. At higher temperatures these break down to simpler oils that are lighter and more mobile, and eventually to gas. Further heating causes the breakdown of the hydrocarbons to methane (dry gas) and as the sediments enter the early stages of metamorphism only a carbon residue is left. Thus with too shallow burial petroleum is not generated, but with too deep burial it is destroyed.

Petroleum expelled from source rocks moves upwards due to buoyancy through minute, interconnected pore spaces (which are generally water-bearing) in coarser grained rocks or along rock fracture planes. These migration routes may lead to traps which prevent the escape of petroleum at the earth's surface. Traps generally consist of porous and permeable reservoir rocks (such as sandstones) sealed by overlying impermeable cap rocks (such as shales) to form a kind of subsurface structure which prevents further migration. Here the petroleum collects in the pores of the reservoir rock to form 'pools'. Oil can occur alone (sometimes with gas dissolved in it) or with an overlying gas cap. Natural gas commonly contains components which are gaseous under reservoir conditions but revert to liquid form (condensate) when temperature and pressure fall during extraction.

The whole process of source rock formation, petroleum generation, migration and accumulation is complicated and economic reserves of petroleum will not be found in an area unless suitable conditions have existed at the right times for each part of the process. Australia's petroleum deposits, formed mostly in a terrestrial environment, are dominated by gas, with the notable exception of the oil and gas fields of the Gippsland Basin.