U3A Geology

Fossil fuels

Introduction

- Fossil fuels are carbon compounds or hydrocarbon-containing materials such as coal, oil, and natural gas
- they formed naturally in the Earth's crust from burial and decomposition of prehistoric organisms (animals, plants and plankta)
- conversion from these materials to high-carbon fossil fuels typically requires a geological process of millions of years
- coal, petroleum and natural gas are the primary fuels of our modern industrial society
- most of the energy we consume originates from these basic fossil fuels although other forms are becoming more accessible*

Coal

- Coal is a sedimentary rock found interbedded with sandstones and shale
- coal is a versatile material → used as fuel, transformed into coke* for steel production, processed into liquid and gaseous fuels
- coal is composed of large and small fragments of plant material
- microscopic studies of coal often show the cell structure of wood, spores and other plant tissues
- most of the world's coal deposits are Carboniferous or younger
- before this time, plants were not abundant → not possible for coal to form

Conditions of coal formation

- For coal to form an environment where plants grow rapidly is essential*
- plant material must be deposited in an environment that receives little inorganic sedimentation e.g. sand, clay
- vegetation must be preserved from decomposition by oxidation
- stagnant swamp waters are ideal for accumulation of plant material
- any dissolved oxygen in the water is quickly used by bacteria
  → little decomposition occurs

Carboniferous swamp environment

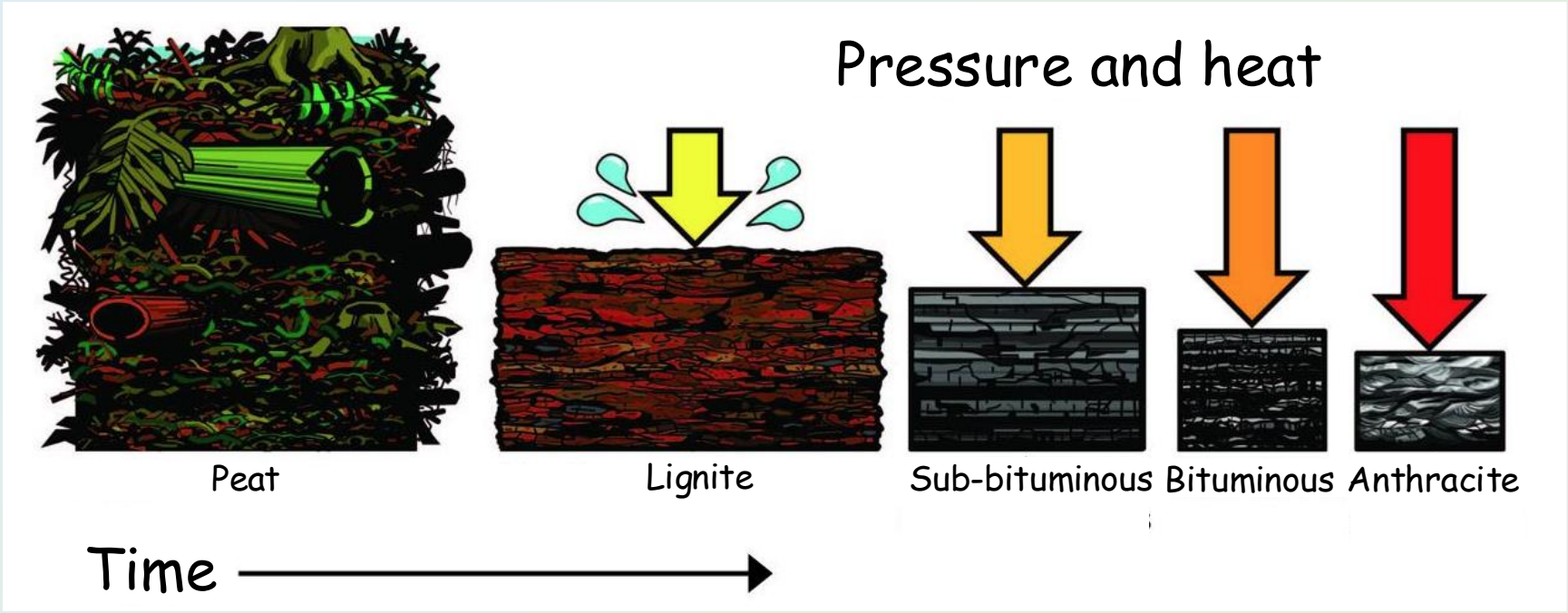
Changes after deposition

- Accumulation of vegetable matter in a swampy environment is the first step in formation of coal
- changes take place in density of material, water content, volatile and non-volatile matter and fixed carbon content
- effects of compaction and temperature increase as the material is deposited under other strata forming various coal types*
- coal is assigned to several ranks with increasing rank:
  peat → lignite → sub-bituminous → bituminous → semianthracite → anthracite
- process is called rank advance and degree that organic material is affected → expressed as rank of coal

Coal rank advance

Coal is assigned to several ranks with increasing rank:

peat → lignite → sub-bituminous → bituminous → semianthracite → anthracite



Peat

- Peat → lowest rank coal, formed by plant material in original swamp
- soft, spongy mass generally containing plant fragments and high water content
- when dry, used as low-grade fuel

peat

Bog peat, southern Ireland

Brown coal (lignite)

- Lignite → stronger than peat but still contains plant remains including tree trunks and woody fragments
- contains about 70% water
- lignite deposits are located in East Gippsland, Vic and eastern parts of South Australia

lignite

Sub-bituminous coal

- Dull, dark brown to black, soft and crumbly
- carbon content → 35-45%; moisture content as high as 25%
- occurs in several places in Australia e.g. Leigh Creek in South Aust, Collie in WA

Sub-bituminous coal

Bituminous coal

- Bituminous coal – dull black coal
- evidence of plant tissue lost due to increased temperature and pressure
- moisture content mostly less than 10%
- widespread throughout Australia, mainly in rocks of Permian and Mesozoic age

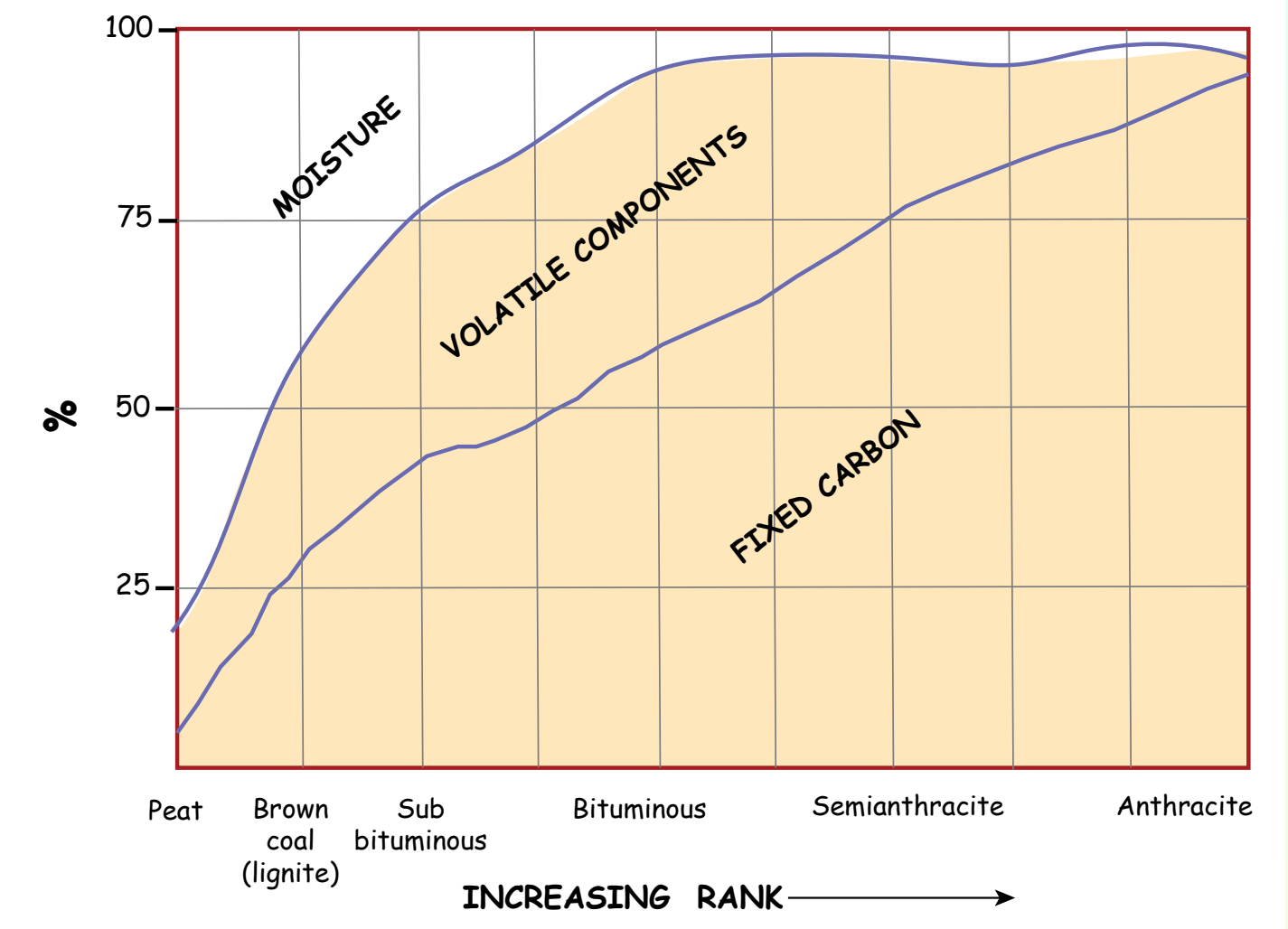
Bituminous coal with vitrine bands, Kentucky, USA

Anthracite

- Anthracite – shiny, hard, black coal formed under conditions of extremely deep burial (metamorphosed), conchoidal fracture
- contains almost no moisture and more carbon and less hydrogen than that of equally pure bituminous coals
- rare in Australia but semianthracite occurs in deformed Permian strata at Barolaba and Yarrabee in central Queensland and Mittagong in NSW

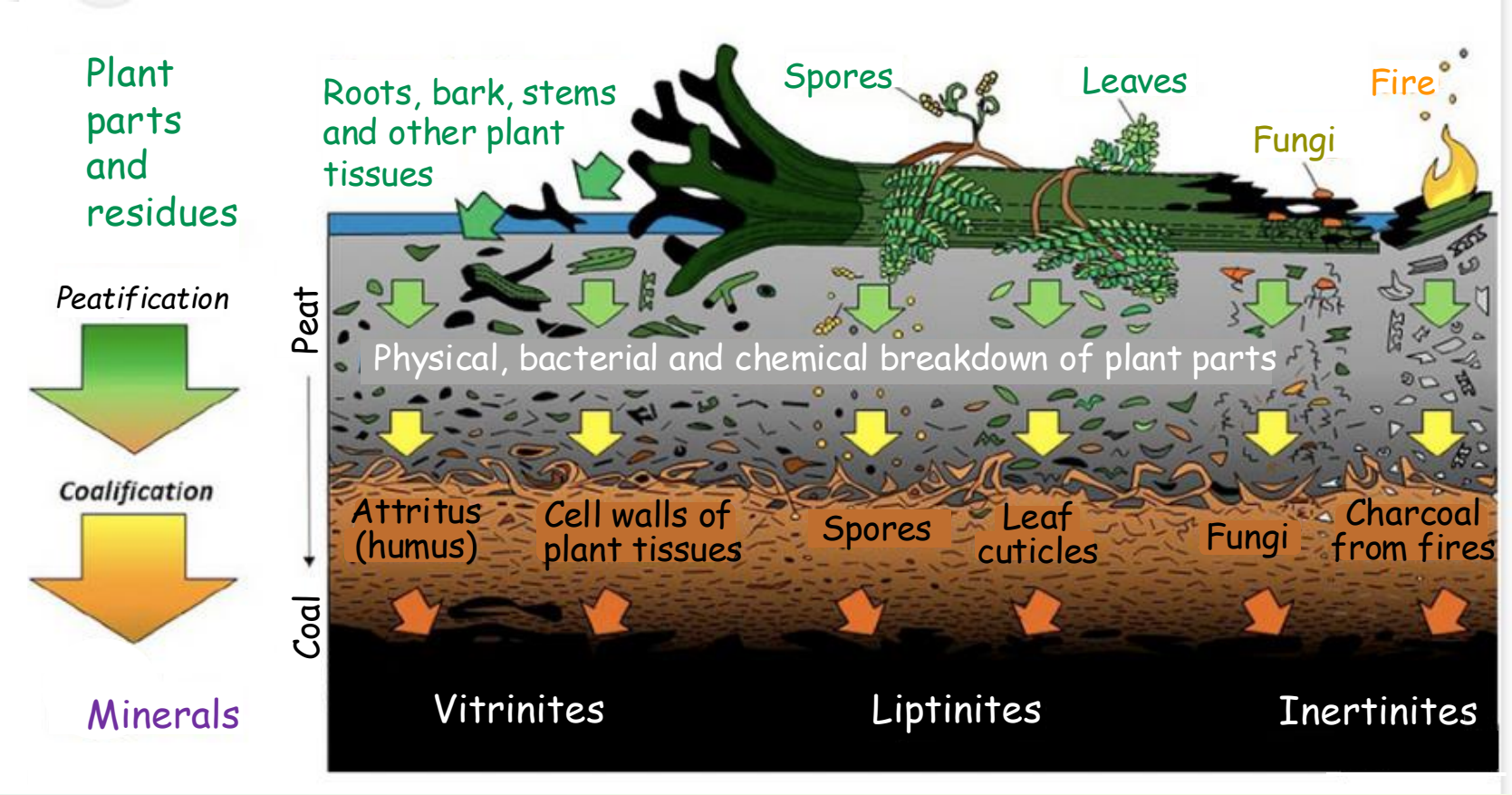
anthracite

Coal Rank


100
75
50
25
%
MOISTURE
VOLATILE COMPONENTS
FIXED CARBON
Peat
Brown coal (lignite)
Sub bituminous
Bituminous
Semianthracite
Anthracite
INCREASING RANK

Coal macerals (Jovanoski et al 2023)

Maceral → altered remain and byproduct of the original plant materials from which the coal-forming peat originated. Three groups of macerals are recognized vitrinites, liptinites, inertinites



Coal maceral composition

- Individual components in coal are called macerals
- Three groups of macerals are recognized:

(1) Vitrinite – homogenous material that appears glassy → derived mainly from woody tissue. Thick bands are visible in most banded bituminous coals

(2) Liptinite – group of relatively small plant components consisting of the outer skin of various plant components (leaf cuticles, spores, resin and algae). Coals mostly dull

(3) Inertinite – group of macerals derived from woody tissue that was partly oxidized in the original swamp. They contain more carbon and less hydrogen than other groups

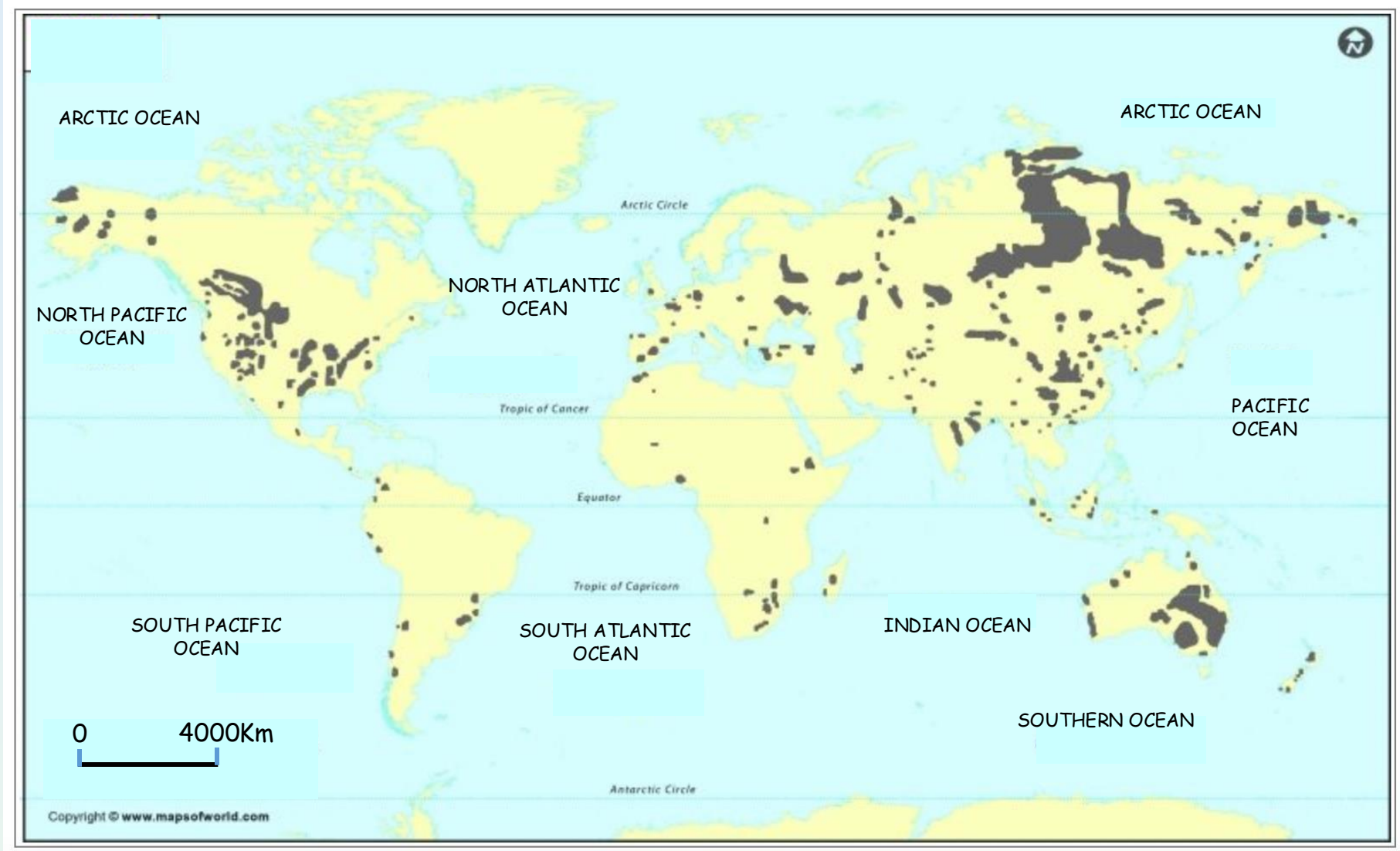
Coal uses

- Brown and black coal → mainly used as a source of fuel for power stations and heating in some parts of the world
- by 2017, coal was used to produce 60% of Australia's electricity
- there has been a gradual decrease in amount of coal used with increase of natural gas, wind and solar
- certain types of bituminous coal (coke) are used in raw steel production
- it is an important source of light aromatic hydrocarbons in the chemical industry

World coal resources

- World's coal resources → not distributed uniformly
- China is the largest producer of coal and coal power in the world → over half of the world's total
- major other known reserves are located in Russia, Ukraine and the USA
- other countries with significant coal reserves include Australia, Germany, UK and Canada

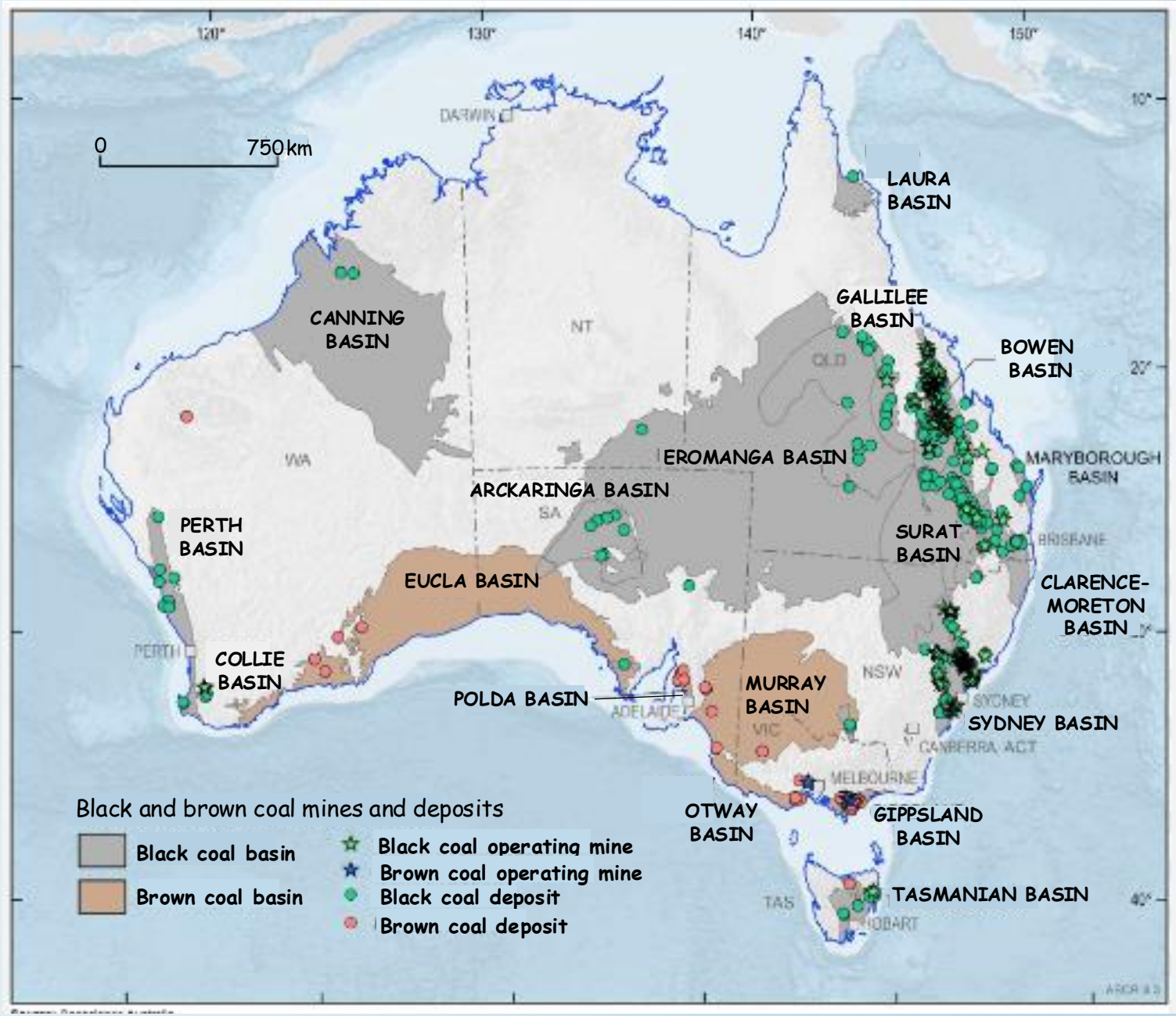
World coal resources



Australian coal resources

- Australia has the fifth largest share of the world's coal resources
- since the late 1700s, more than 9 billion tonnes of black coal and over 2.3 billion tonnes of brown coal → mined in Australia
- major black coal resources occur in NSW, Qld and SA
- locally important black coal also occurs in Collie, WA and Fingal, Tas.
- large brown coal deposits occur in Victoria

Australian coal resources



Coal mining in Australia

- In Australia, nearly 80% of coal is produced from open-cut mines → coal seams close to surface
- open-cut mining cheaper than underground mining → enables recovery of ~90% of resource
- many brown coal beds lie close to the surface and can be 100s of metres thick*

Australian coal mines

Premier coal mine, Collie Basin, WA

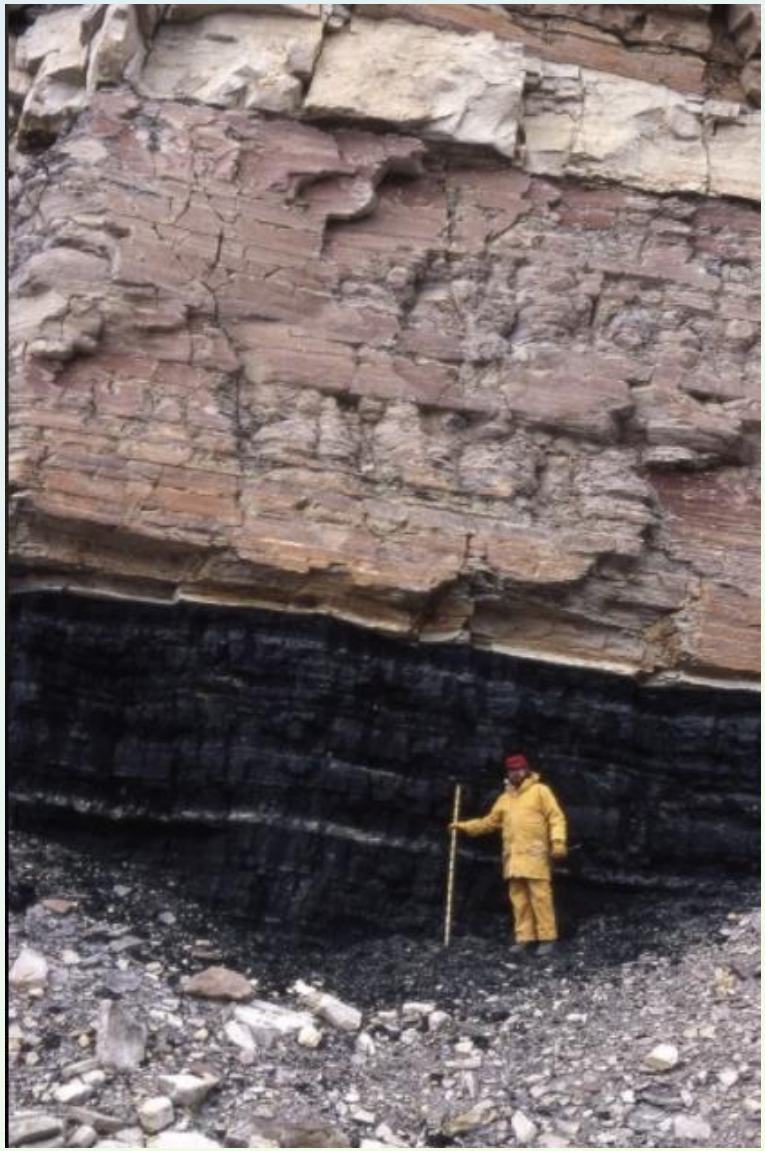
Open cut coal mine,

Hunter Valley NSW

Coals of Gondwana

- Coal-bearing strata of Permian and Mesozoic age are found in South America, India, Antarctica and Australia
- most of the coal formed when these land masses formed the super continent Gondwana
- these coals are different to Northern Hemisphere coals* partly due to climate and different plant communities
- Carboniferous coals commonly contain more pyrite formed by bacteria acting with seawater encroaching into peat swamps
- most Gondwanan coals were deposited in terrestrial conditions and are largely free of pyrite

Coals of Gondwana



Coal seam in Antarctica

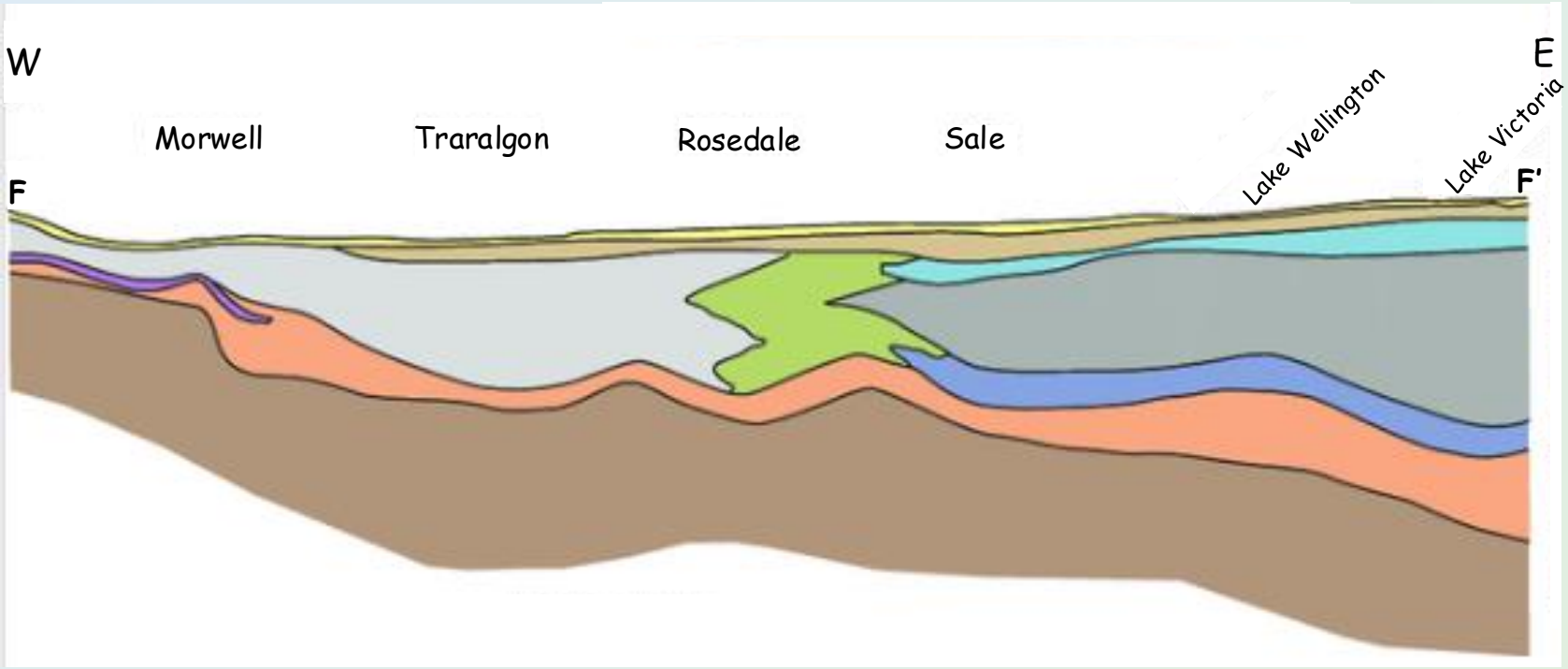
Geology of the Gippsland Basin

- Large brown coal deposits occur in the LaTrobe Valley within the Gippsland Basin
- the Gippsland Basin started to form in Late Jurassic when rifts opened between mainland Australia, Tasmania and Antarctica
- the first sediments deposited were non-marine Strzelecki Group (sandstones and mudstones) → no petroleum potential
- LaTrobe Group consisting of non-marine and marginal sediments, provide both source and reservoir for coal and Gippsland oil

LaTrobe Valley stratigraphy

- Basal strata are pre-Tertiary rocks overlain by the LaTrobe Group
- the LaTrobe Valley Group contains the Latrobe Valley coal measures within the Traralgon Formation and comprises sands, clays and basaltic rocks
- overlying the LaTrobe Valley Group coal measures is the Boisdale Formation that is a terrestrial (fluviatile) sequence that primarily comprises sand, silt and clay and lignite lenses
- the surface rocks are Haunted Hills gravels that comprise cross-bedded coarse sands, gravels and minor silt and sand capping

LaTrobe Valley stratigraphy



LEGEND

- Haunted Hills Gravel
- Boisdale formation
- Jemmys Point, Tambo R. L. Wellington Fms.
- Gippsland Limestone
- LaTrobe Valley Coal measures
- Balook Formation
- Lakes Entrance Fm.
- LaTrobe Valley Group
- Older volcanics
- Pre-Tertiary

Kerogen

- Kerogen → waxy, insoluble organic material in sedimentary rocks*
- consists of a variety of organic materials including dead plants algae and other microorganisms heated and compressed
- kerogen does not have a specific chemical formula
- there are various types of kerogen depending on original material present
- type of kerogen also depends on degree of heat and pressure it has been subjected to and over what length of time
- a complex mixture of organic compounds reside in sedimentary rocks serving as precursors for hydrocarbons

Formation of kerogen

- Kerogen formed during sedimentary diagenesis* from degradation of once living matter
- burial of kerogen with increasing temperature and pressure due to progressive burial of overburden further changes composition with loss of H, O, N and S and associated chemical compounds
- during process of thermal maturation → kerogen breaks down to form bitumen, oil and gas
- these products are partly expelled from kerogen-rich source rocks → may flow into reservoir rocks

Crude oil

- Crude oil → raw material resource extracted from the Earth and refined into products such as petroleum, jet fuel and other petroleum products
- characterised by the type of hydrocarbon compound that is most prevalent in them → paraffins, napthenes and aromatics
- paraffins → most common hydrocarbons in crude oil
- because crude oil is a mixture of varying constituents it ranges in appearance from colourless to black

Hydrocarbons in crude oil

- paraffins → large group of hydrocarbons constituents of natural gas and petroleum → contain fewer than 5 C atoms per molecule → gaseous at room temperature e.g. methane, propane
- napthenes → hydrocarbons that have at least one ring of C atoms → present in heavier parts of crude oil e.g. cyclohexane, methylcyclohexane
- aromatics → cyclic hydrocarbons that contain a benzene ring in their structure e.g. benzene, toluene

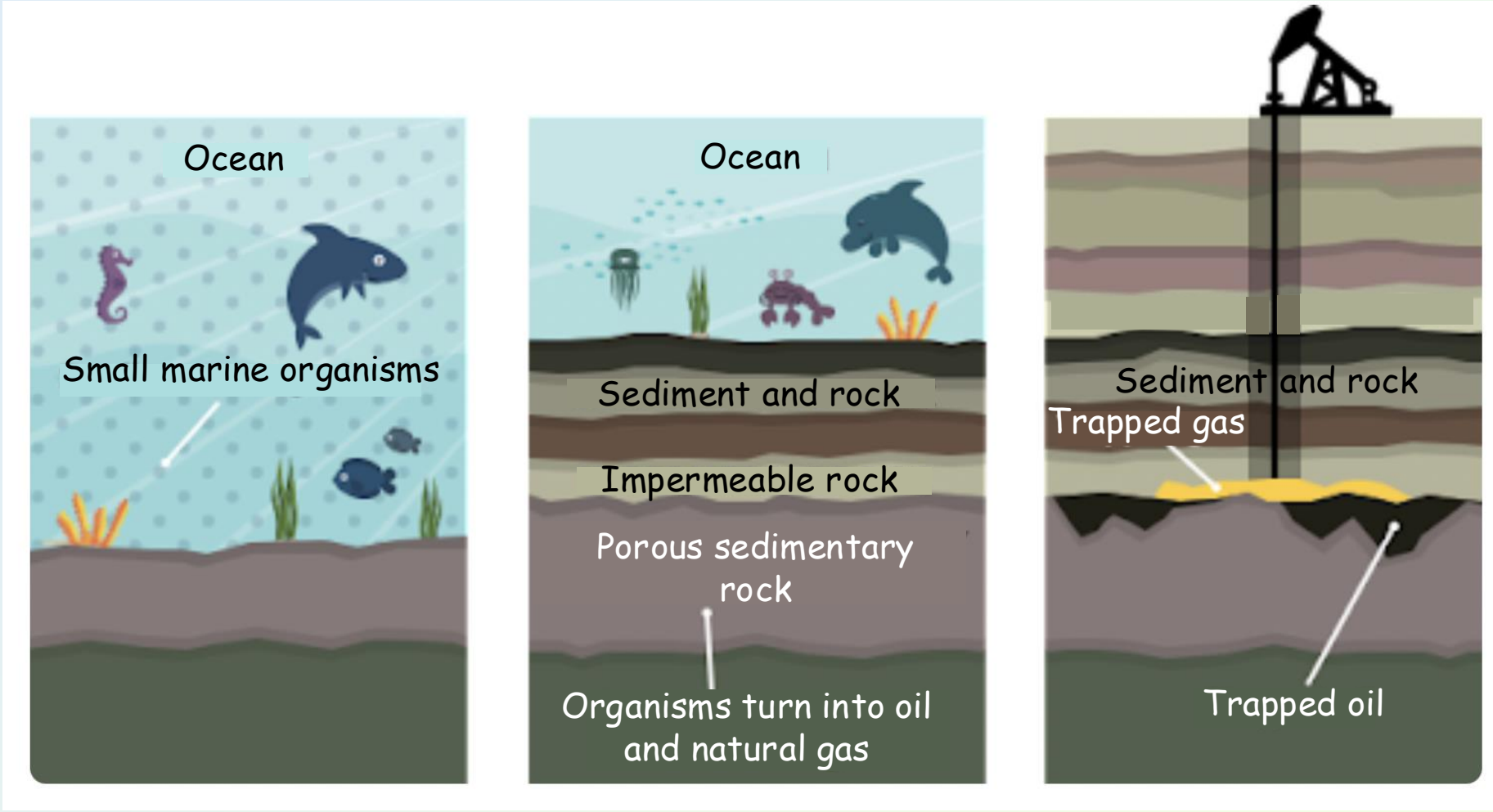
Petroleum

- Crude oil and natural gas are liquid and gaseous parts of petroleum*
- they are composed of hydrocarbons → compounds of hydrogen and carbon
- petroleum is formed in sedimentary rocks and forms in both marine and freshwater environments with high a degree of organic matter
- when petroleum forms, it goes through a number of stages, earliest formed compounds are more complex → produce very viscous oils
- when complex hydrocarbons are subject to higher temperatures they change into simpler hydrocarbons → process called cracking

Origin of petroleum

- Petroleum generally begins to form in marine basins in tropical environments with a rich diversity of microscopic plants and animals
- layers of sediment and additional organic material may bury organic remains → prevent their subsequent decay
- as sediments accumulate, pressure and heat convert organic molecules into a substance called kerogen a solid, waxy, organic compound
- kerogen becomes converted to various liquid and gaseous hydrocarbons at temperatures between 50-200°C and depths 2-10km

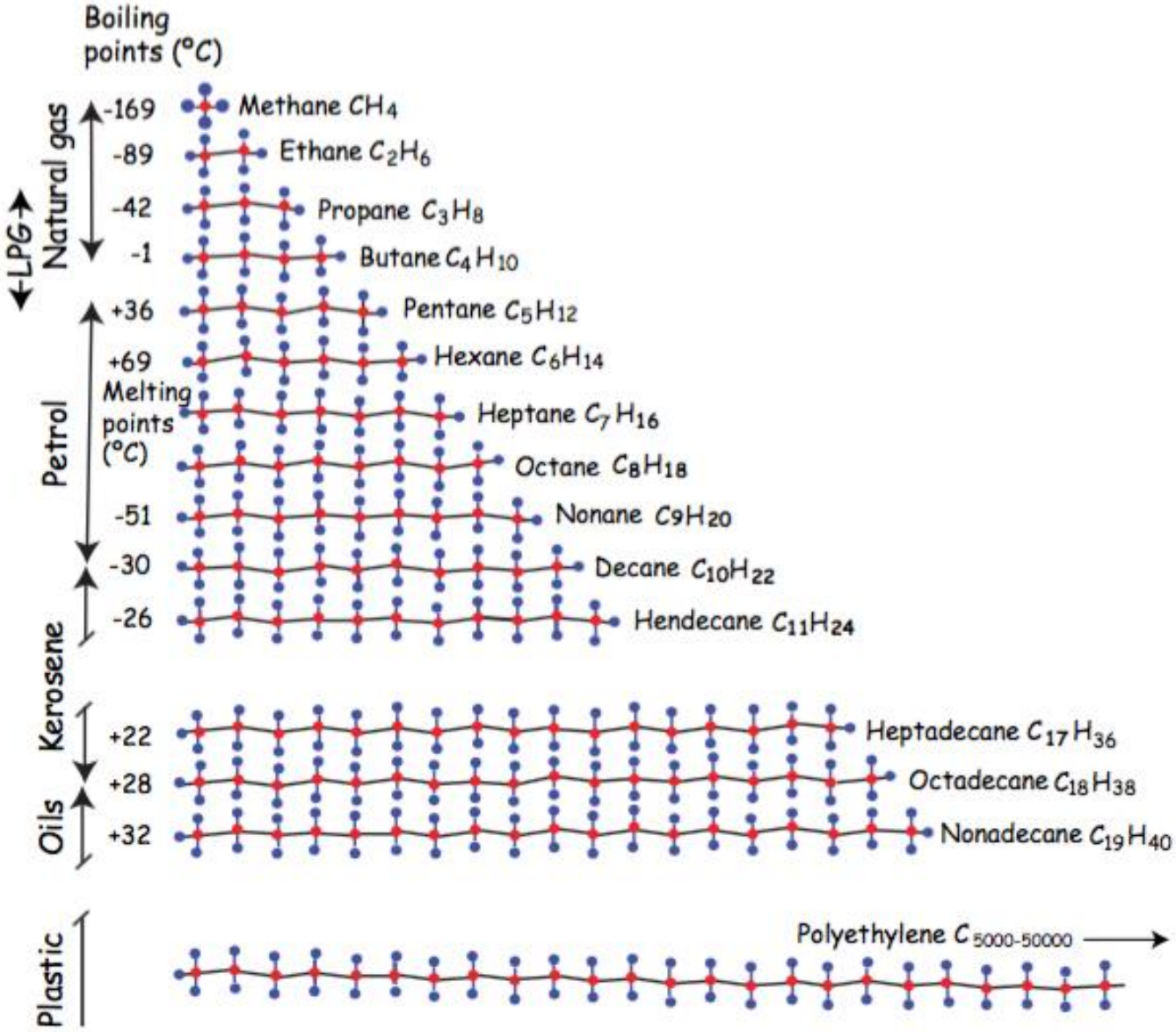
Stages in oil and gas formation



Origin of petroleum

- At the start of increase in temperature and pressure, kerogen's large complex organic molecules form highly viscous hydrocarbons such as tar
- with increasing heat, molecules break down to form smaller, simpler, less complex ones such as those found in diesel, kerosene and petrol
- at temperatures above 100°C liquid petroleum becomes converted into a variety of natural gases from relatively complex molecules such as butane to the simple lightest gases e.g. propane, ethane, methane
- at depths >7km, methane the lightest gas breaks down completely
  → rocks no longer contain hydrocarbons

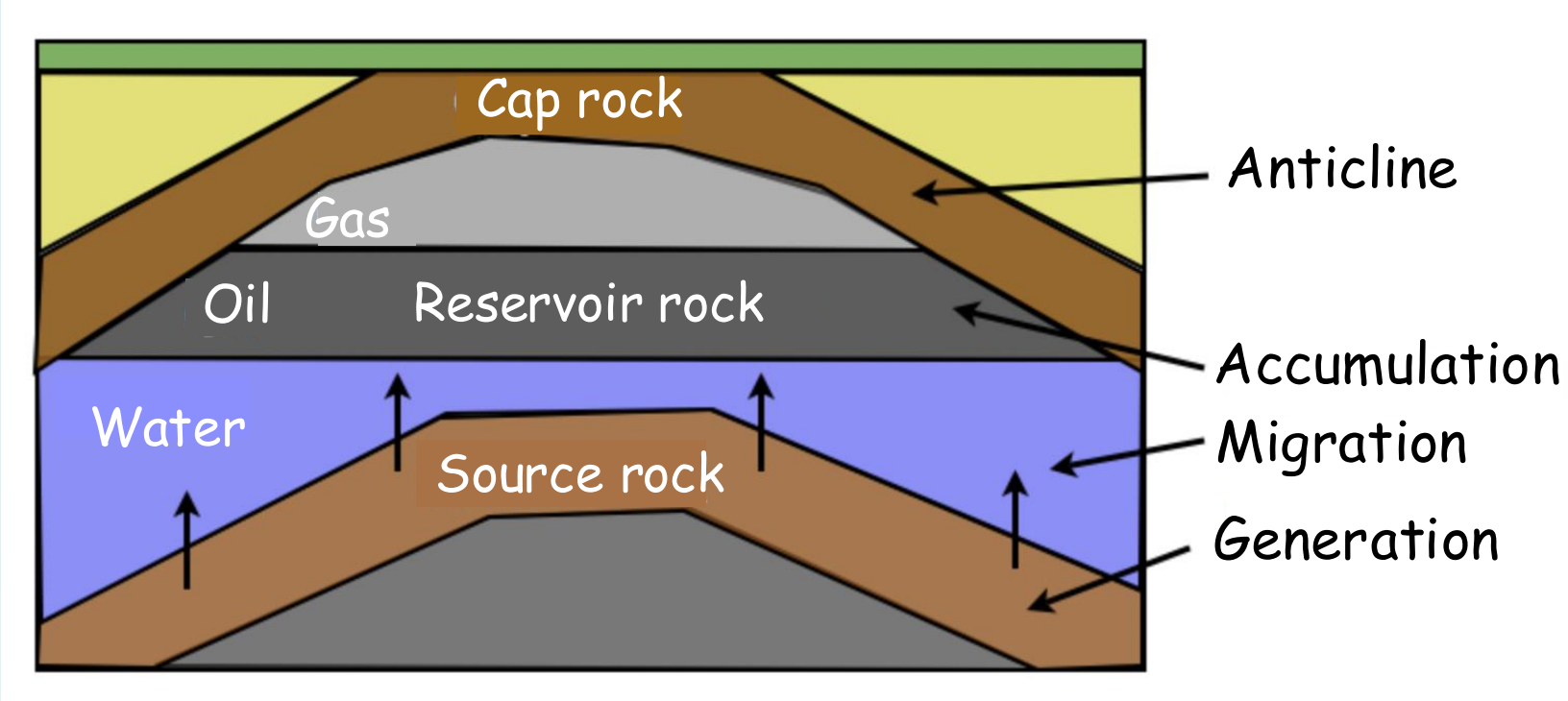
Hydrocarbon molecular species



Source rocks

- Hydrocarbons typically form in shales and siltstones lithified under reducing conditions (O poor) from fine-grained organic mud
- oil and gas are rarely found in source rocks because most liquid and gaseous hydrocarbons are readily expelled from their compacting source muds
- oil and gas tend to migrate upwards into adjacent permeable rocks such as well-sorted sandstones and highly fractured or porous limestone
- they continue to migrate upward until they are trapped by impermeable caprock

Oil migration



Metamorphism of organic matter

- At greater depth in Earth, rocks become hotter, more sediments accumulate on organic-rich rocks → sink deeper into crust → enter temperature zone where contained organic matter converted into hydrocarbons → oil forms
- if source rocks are at temperatures that greatly exceed 200°C → all lower temperature hydrocarbons may be burned off
- source rocks not buried deep enough to enter generation zone → no organic matter will be converted into liquid hydrocarbons
- if rocks buried too deeply → organic matter may have been destroyed

Generation and migration of hydrocarbons

- Source rocks must be buried under sufficient cover of overlying strata so conditions are right for conversion of organic matter in source rocks to hydrocarbons
- when hydrocarbons are generated they must migrate into permeable and porous rocks that allow rapid flow of large volumes of fluid
- once molecules of hydrocarbon flow through pores they combine with others → form oil droplets
- since most crudes are lighter than water → migrate to highest part of sandstone body
- if no impermeable barriers to upward migration of oil, hydrocarbons will follow sandstone to surface → form oil seep

Hydrocarbon traps

- Sedimentary rocks that prevent the flow of water or hydrocarbons are called cap rocks
- cap rocks include dense impervious rocks e.g. dense limestone, strongly cemented sandstone or quartzite or rocks where pores are too small to allow fluid flow
- one of the most effective rocks is clay or shale*
- this is the rock type in which the oil originally formed

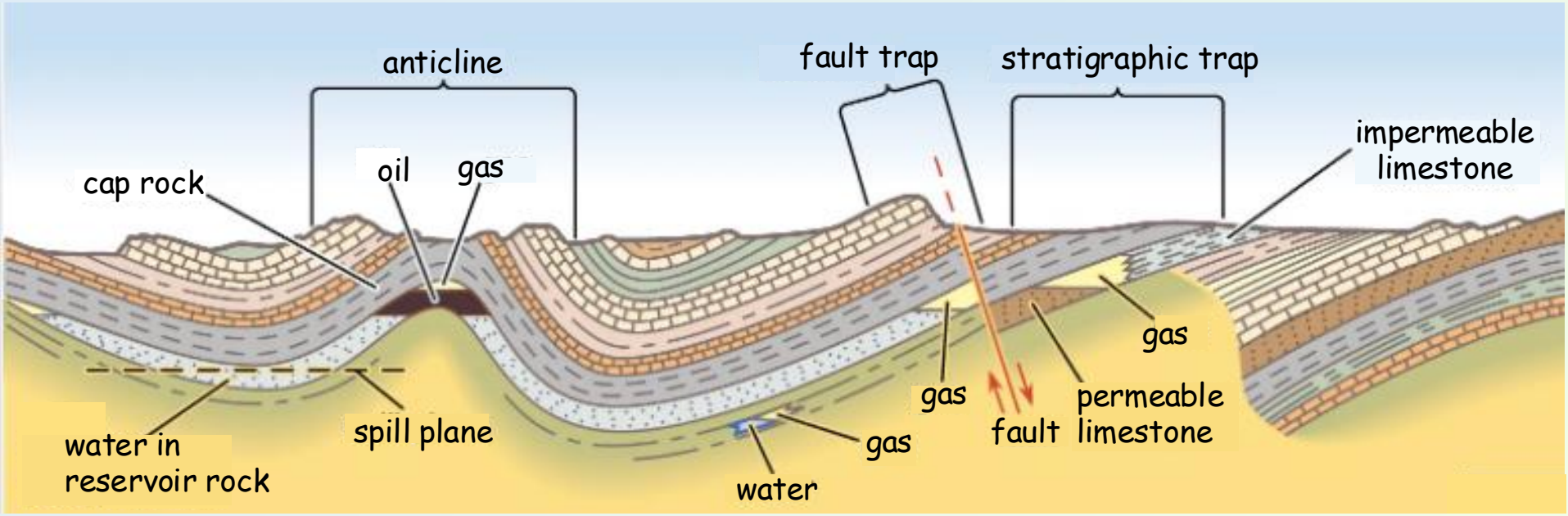
Hydrocarbon traps

- Hydrocarbon trap → underground rock formation that blocks the movement of oil resulting in it being trapped in a reservoir
- oil is always accompanied by water and often by natural gas all of which are confined in a porous, permeable reservoir
- reservoir rocks are usually sandstones, arkoses and fissured limestones and dolomites
- natural gas being the lightest, occupies the top of the trap and is underlain by oil then water

Types of hydrocarbon traps

- Hydrocarbon traps can be either structural or stratigraphic
- the most common trap is an anticline caused by deformation of reservoir rock and overlying impermeable rock
- a fault trap may be caused by fracture and slippage of rock along a fault plane may bring impermeable stratum in contact with a layer of permeable reservoir rock
- change in character of rock type along strike may form impermeable barrier

Hydrocarbon Structural traps



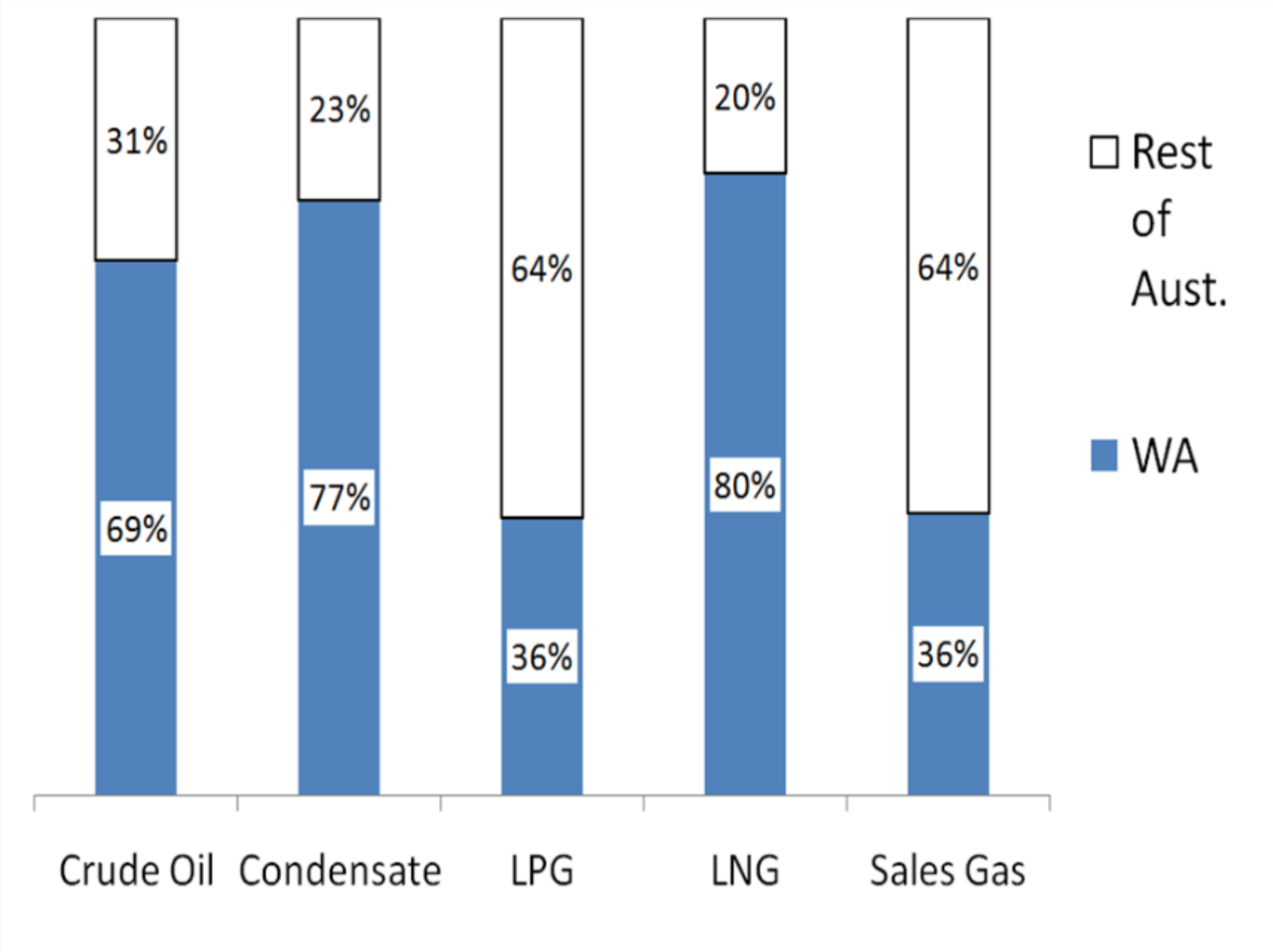
Reservoir rocks

- Reservoir rocks → rocks that contain interconnected pore spaces between grains → fluids in pore spaces move under pressure
- gas being lightest tends to migrate to zones of lowest pressure (highest part of reservoir)
- oil droplets accumulate in pore spaces of rocks immediately below gas-saturated zone, water fills remainder of ore space
- to form a trap for hydrocarbons, porous bed must be covered by effective cap rock
- cap rock must have configuration creating barrier preventing hydrocarbons escaping to surface

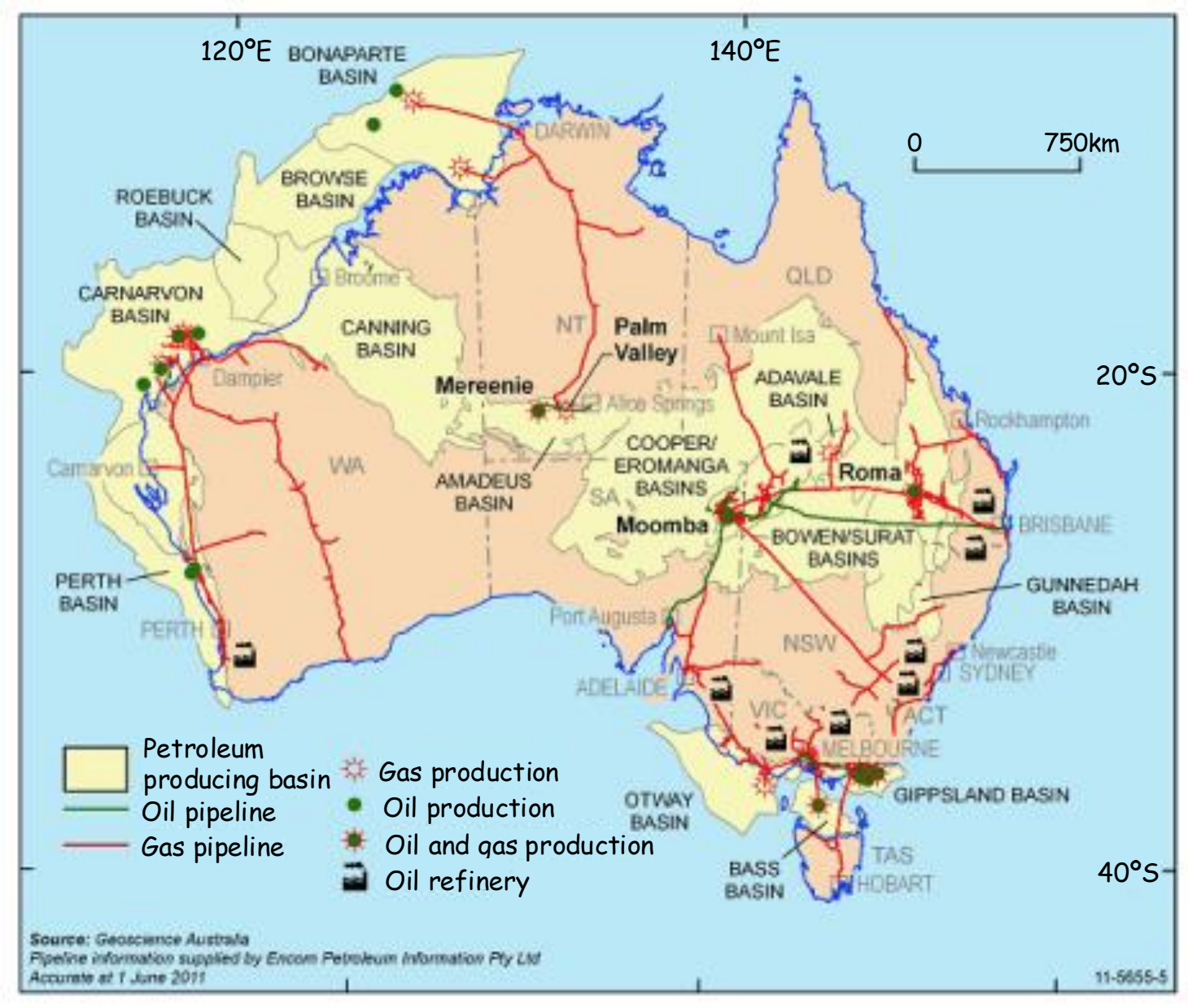
Australian hydrocarbon deposits

- WA is the largest producer of gas → ~90% of Australia's estimated recoverable reserves of conventional gas are in Carnarvon Basin on Western Australian NW shelf
- WA has gas production from the northern Perth Basin and a sizeable field on Barrow Island
- major gas production comes from the Cooper Basin in northern South Aust. and small fields in Qld
- production of hydrocarbons has also occurred from giant fields in the Gippsland Basin

National petroleum production



Australian oil and gas resources



Bass Strait oil and gas

- Bass Strait was Australia's first major offshore development → began 1969
- Bass Strait oil and gas fields are in the Gippsland Basin
- 80% of total area of basin is at eastern end of Bass Strait
- basin has supplied 40% of Australia's east coast domestic gas demand
- also produced crude oil and concentrate, LPG and ethane