SACE Stage 2: Earth and Environmental Science

Topic 2: Earth's Resources

Earth at night showing Africa, Europe and western Asia (https://earthobservatory.nasa.gov/NaturalHazards/view.php?id=79793)

What can be interpreted from this image?

Version 1 notes by Bernd Michaelsen

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Topic 2: Earth's Resources

Students study how, for thousands of years, humans have made use of Earth's resources to sustain life and provide infrastructure for living. They consider how new technologies have made possible the discovery of the larger quantities of resources needed in a technological society and have led to new extraction processes.

Students extend their personal and social capability and ethical understanding through discussing the environmental consequences of the extraction, processing, and use of non-renewable mineral and energy resources. They recognise how sustainability of resources is now a topic for public debate — a debate that can be informed by the work of scientists.

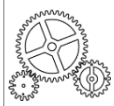
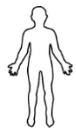
Students investigate the formation of non-renewable mineral and energy resources; techniques used for their discovery; identification and extraction, and effects of the extraction; and use of these resources on ecosystems. They use skills in selection, graphing, analysis, and evaluation of data to draw conclusions about the environmental impacts associated with the use of non-renewable resources and current extraction and processing practices.

NOTE TO TEACHERS:

These notes have been designed to elaborate on the ***Possible Contexts*** *provided in the* *Earth and Environmental Science* *subject outline. They are intended to provide further ideas and links to teaching and learning resources that address the* ***Science Understanding.*** *It is important to remember that you are not expected to cover all of the material included. Rather, these notes should be regarded as a 'smorgasbord' from which individual teachers might pick and choose, according to the needs and abilities of their students and according to the context of their externally assessed 'Earth Systems Study'.*

Science Understanding	Possible Contexts	
People use the geological resources of the Earth to help satisfy their needs and wants. • Compare the use of geological resources in various lifestyles. • Discuss, using examples from a variety of cultures, ways in which geological resources are used.	Compile a list of all the resources that one person uses in a day. Explore ways in which Indigenous Australians, or Indigenous peoples in other countries, used geological resources before colonisation.	
Non-renewable mineral and energy resources are formed in various ways over geological time-scales, so are not readily replenished. • Discuss the sustainability of reserves of fossil fuels, and metallic and non-metallic resources.	Collect data on global consumption and the rate of new discoveries of conventional petroleum during the 20th and early 21st centuries (e.g. 'peak oil'). Construct graphs to illustrate the findings. Construct a table to display non-renewable fuel resources, including uranium and unconventional petroleum, and the approximate known global reserves of each resource, and critically evaluate this information in terms of sustainability. Collect and graph data on global reserves and current rate of use of a range of metallic resources, and critically evaluate this information in terms of sustainability.	
The formation of non-renewable energy resources, including fossil fuels and unconventional gas, is related to their geological setting. • Explain the processes by which coal is formed. • Describe the processes by which petroleum and coal-seam gas are formed and are trapped. • Describe structures within which petroleum may be trapped.	Explore the benefits and risks of the extraction and use of unconventional gas. www.csiro.au/en/Research/Energy/Hydraulic-fracturing/What-is-unconventional-gas Use diagrams to explain the formation of a placer deposit in a stream bed. Draw labelled diagrams of common petroleum traps to help explain how petroleum and coal-seam gas are formed and are trapped.	
	Identify hand specimens of various ranks of coal.	
The formation of non-renewable metallic mineral resources is related to their geological setting. • Explain how metallic ores may be concentrated by gravity-settling and hydrothermal processes.	Use step-by-step diagrams to explore the formation of ore bodies by the processes of gravity-settling in a magma chamber, and by hydrothermal vein formation associated with igneous activity.	

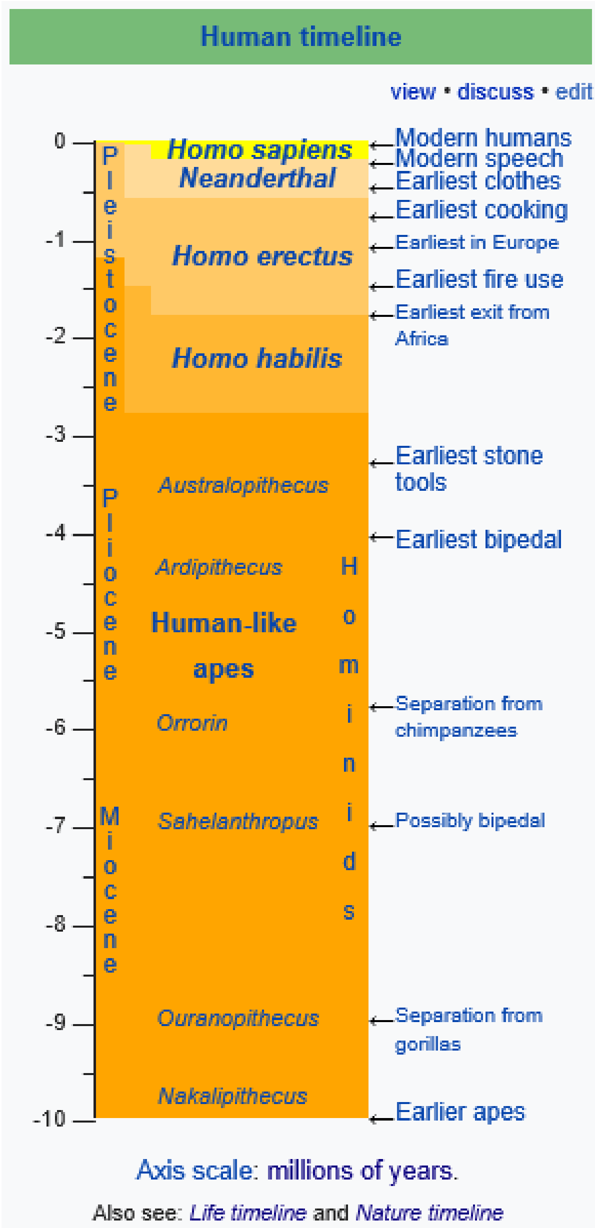
Scientific Understanding	Possible Contexts	
• Explain how the processes of weathering, erosion, and deposition may concentrate metallic ores. • Explain how the formation of iron ore (banded iron formations) occurred in an anaerobic environment. • Identify metallic ores, using their physical and chemical properties.	Identify minerals such as chalcopyrite, haematite, magnetite, galena, sphalerite, rutile, gold, bauxite, graphite, and copper and uranium minerals.	
	Evaluate discovery techniques such as satellite imaging, and geochemical and geophysical sampling to collect datasets, and direct sampling techniques such as drilling, and core, soil, and rock sampling. www.earthsciencewa.com.au/mod/resource/view.php?id=1149	
A variety of techniques can be used to discover deposits of mineral and energy resources and identify the extent and quality of these resources. • Discuss techniques for finding mineral resources, using magnetic and electromagnetic surveys, geochemical sampling, and drilling. • Explain how seismic and gravity surveys are used in petroleum exploration. • Discuss how the presence of a resource can affect the surrounding physical and chemical environment.	Use a magnetometer (or a metal detector) over a measured grid to locate and map buried metal objects.	
	Investigate the impacts of various steps used in mineral exploration on the environment: www.earthsciencewa.com.au/mod/resource/view.php?id=1155 www.earthsciencewa.com.au/mod/resource/view.php?id=1154	
The depth, extent, and location of mineral and energy resources determine the method of extraction. • Describe the essential features of underground, open-cut, and in-situ leaching methods of extraction of mineral resources. • Explain how the size, shape, and depth of a mineral deposit influence the choice of extraction method. • Explain how petroleum, shale oil, coal, and coal-seam gas are extracted from the Earth in different locations.	Draw and label diagrams showing the essential features and environmental impact of each mining and extraction method. Discuss reasons for using underground mining or open-cut mining in different scenarios. Explore the life cycle of a mine: www.minerals.org.au/resources/gold/life_cycle_of_a_mine	

Scientific Understanding	Possible Contexts	
The extraction and use of mineral and energy resources influences interactions between the abiotic and biotic components of ecosystems, including hydrologic systems. • Describe potential environmental impacts that can be associated with the extraction, use, and processing of mineral and energy resources.	Compare the environmental impacts associated with the extraction and use of coal and uranium for electricity generation.	
	Investigate sources of methane (including natural sources such as bacterial action and methane hydrates, and anthropogenic sources such as livestock and fugitive emissions from coal-seam gas extraction), its use as a fuel, and its action as a greenhouse gas.	
	Investigate how the processing of sulfide minerals can lead to the formation of acid rain or acid mine drainage, and the environmental impact of this. Use case histories and news reports to evaluate environmental impacts of mining. Examples include uranium and bauxite mining at Poços de Caldas in Brazil, and pyrite mining at Brukunga in South Australia. Create a poster explaining the benefits of generating electricity from a floating solar power station.	

People use the geological resources of the Earth to help satisfy their needs and wants.

- ***Compare the use of geological resources in various lifestyles.***

Human timeline



The earliest humans and pre-human-like apes have been using **non-renewable** and **renewable** resource since about 3.5 Ma.

Human timeline (https://en.wikipedia.org/wiki/Prehistory)

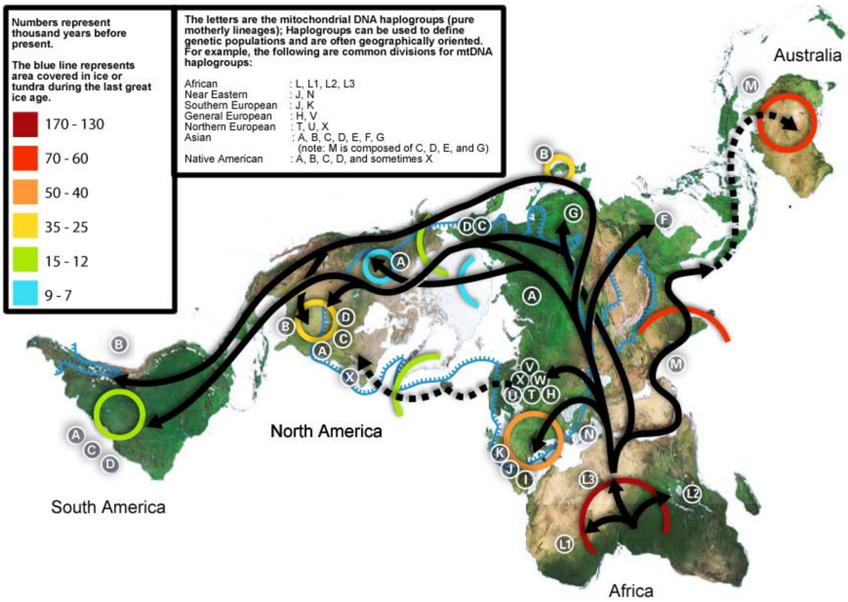
Prior to the smelting of ore minerals, prehistoric humans mined, traded and used **flint**.

What is flint?

What properties does flint have that made it important to prehistoric humans?

What other mineral commodities did (or still do) "Stone Age" peoples value and how were (are) they used?

Prehistoric spread of modern humans (Homo sapiens)



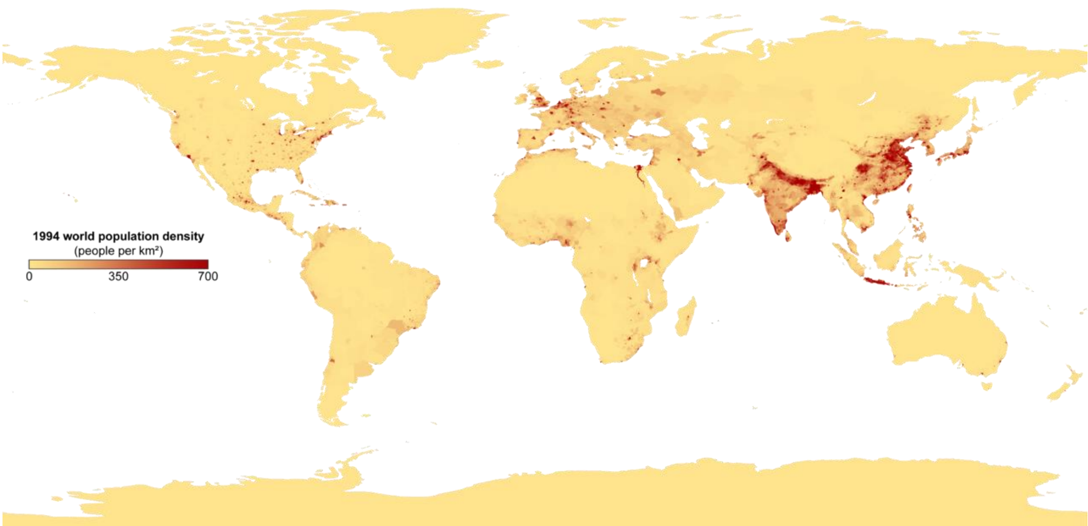
World map of human migrations based on genetic studies (https://commons.wikimedia.org/wiki/File:Map-of-human-migrations.svg). The blue saw-tooth line indicates the area of ice and tundra during the last great ice age (glacial maximum at ~21 ka).

- ***Discuss, using examples from a variety of cultures, ways in which geological resources are used.***

As mankind left Africa and spread across the globe he encountered different challenges and needed to adapt to new environments. Over millennia his appetite to consume resources has dramatically increased.

In the figure above, how does the blue saw-tooth line representing the extent of ice and tundra at ~21 ka compare to other interpretations for the extent of the glacial maximum? (we shall revisit this matter in Topic 4)

World population



World population map by NASA, originally uploaded by Keenan Pepper, legend added by SG (en.wiki). - Image:Population density.png from NASA.gov, Public Domain, (https://commons.wikimedia.org/w/index.php?curid=2871394https://en.wikipedia.org/wiki/Population_density#/media/File:Population_density_with_key.png)

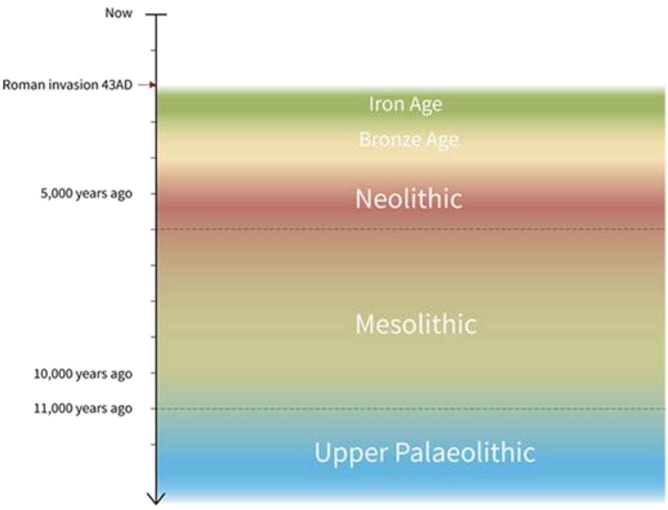
What is Earth's present human population? And how has it increased since the Stone Age?

Prehistoric Age

The **Prehistoric Age** refers to the period of human history prior to the invention writing (~5.5 ka).


Left: Stencils of hands on rock (13–9 ka), Cueva de las Manos, Argentina (https://en.wikipedia.org/wiki/Cueva_de_las_Manos)

Right: Large black stag on rock (~17 ka), Lascaux Caves, France (http://www.macroevolution.net/lascaux-cave.html)



European anthropologists, archeologist and historians have divided European archeological history into three periods: the Stone Age, Bronze Age and Iron Age ages. The Iron Age ended around 450 to 500 CE (1450 ka). Collectively, the Stone, Bronze and Iron ages are known as Antiquity.

Are these subdivisions applicable to other parts of the world and other cultures other than to Europe and the Mediterranean basin?

Europeans are still using iron: What cultural and geo-political developments in Europe defines the close of the Iron Age and the beginning of the Middle Ages? (When answering this question consider in particular the mass movement of people across Europe and the Mediterranean Basin)

Stone age in Europe

When was the Stone Age?

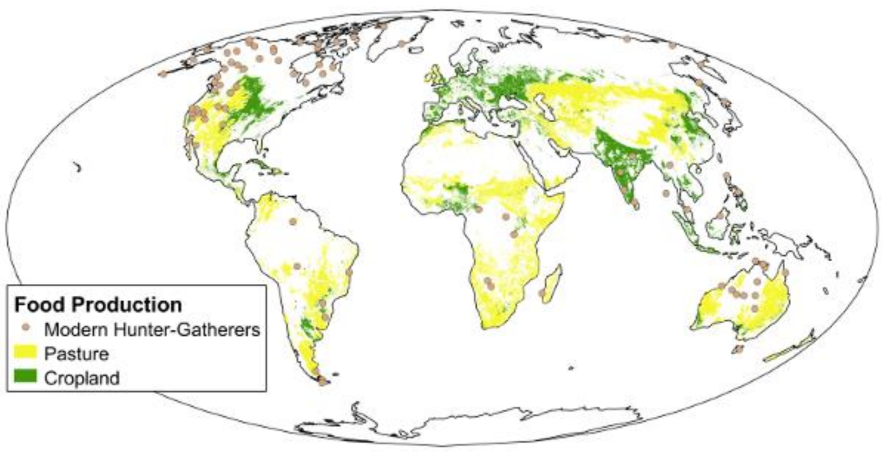
Did the Stone Age end because humanity ran out of stones?

What other rock-type can be used as a substitute for flint and why?

What is a fire-striker?

What is carbon steel? When was it invented? And by what society?

Hunter-gatherer societies



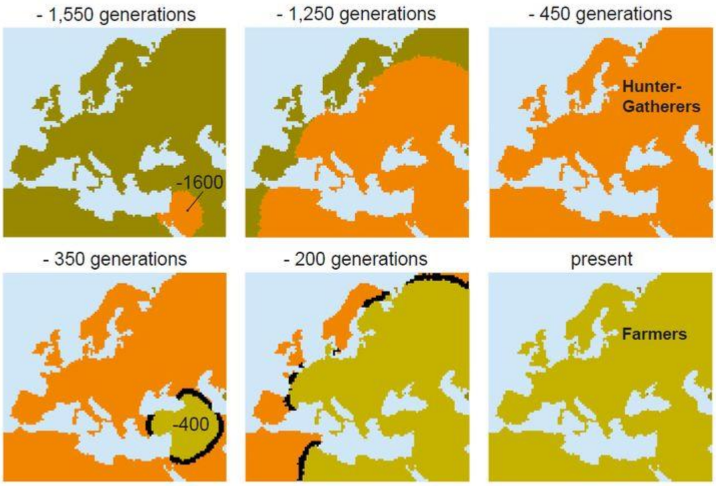
*Areas of modern agriculture (**pasture** and **cropland**) and the locations of societies that depend significantly on huntering and gathering. Data from Navin Ramankutty and Ohio State University Hunter-Gatherer Wiki (http://debitage.net/humangeography/agriculture.html)*

Critically evaluate the above figure. Is it a good or misleading representation?

When and where did agriculture begin? And how did it spread world-wide?

On the figure above, what do the white areas of land represent?

What implications did agriculture have for mankind's use of geological and non-resources?



The above image is found at https://au.pinterest.com/pin/189432728056166224 and purports to describe how hunter-gather culture spread from the Middle East, northern Africa and Europe was, over the course of 1550 generations, replaced by agrarian culture. However, taken at face-value, the maps imply that Europe and northern Africa were unpopulated 1550 generations ago.

What kind of (primary) data may have been used to construct this cultural time-line? How accurate might the interpretations summarized by these maps be?

If one generation is taken as representing 25 years, then 1250 generations ago equates to 31,250 ka. However, if one generation is assumed at being only 20 years, then 1250 generations represents 25,000 ka.

Now reconsider the time-line represented by the six images, using data/interpretations from the internet. What are your findings?

Ötzi the Iceman *in situ* within icy sludge on the Austrian-Italian border (http://www.crystalinks.com/otzi.html)

Mummified remains of "Ötzi the Iceman" were found on the Austrian-Italian border in 1991. Carbon dating indicates that he died around 5300 ka – this makes him the oldest known human mummy. With Ötzi were discovered his clothes, tools and weapons.

Using the internet, carefully assemble a list of the artifacts found with Ötzi and what information do they provide about the "resources" used by Chalcolithic Europeans? Indeed, what does chalcolithic mean?

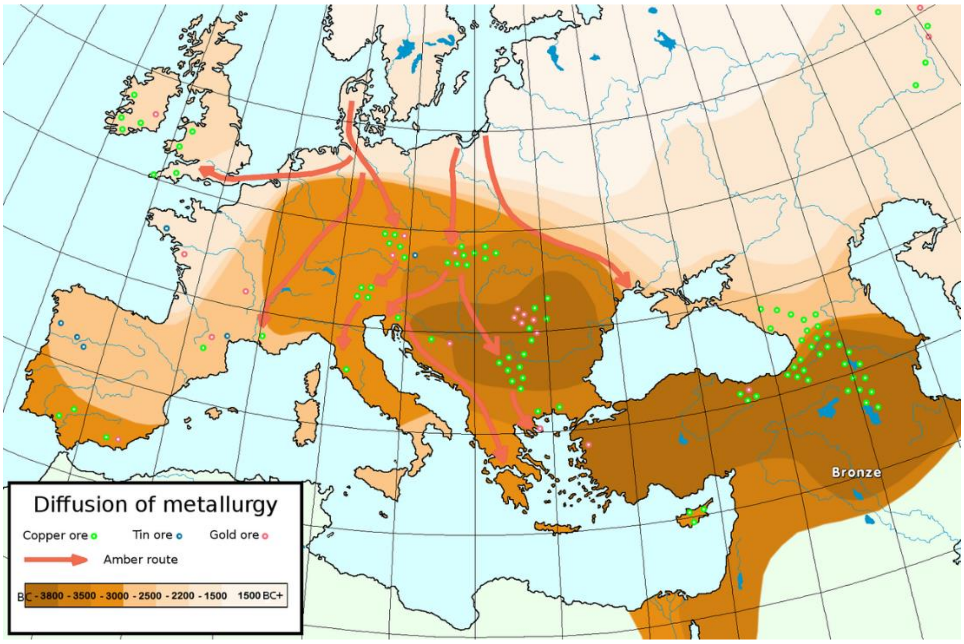
Use Google Earth to visit the site where Ötzi was discovered. Suggest a reason why Ötzi was found in the <u>summer of 1991</u>? Why not 20 or 200 years earlier?

Mineral and energy resources

Bronze age in Europe

What is bronze, and when was the "Bronze Age"?

Did the duration and beginning of the Bronze Age vary across Europe and is the term relevant in a world-wide context?



Spread of metallurgy in Europe and Asia Minor (https://en.wikipedia.org/wiki/Bronze_Age#/media/File:Metallurgical_diffusion.png)

Iron age in Europe

What is iron?

Why did the Iron Age supplant the Bronze Age?

Map of the world in the late Bronze Age, by Thomas Lessman
(https://en.wikipedia.org/wiki/List_of_Bronze_Age_states#/media/File:East-Hem_1300bc.jpg)

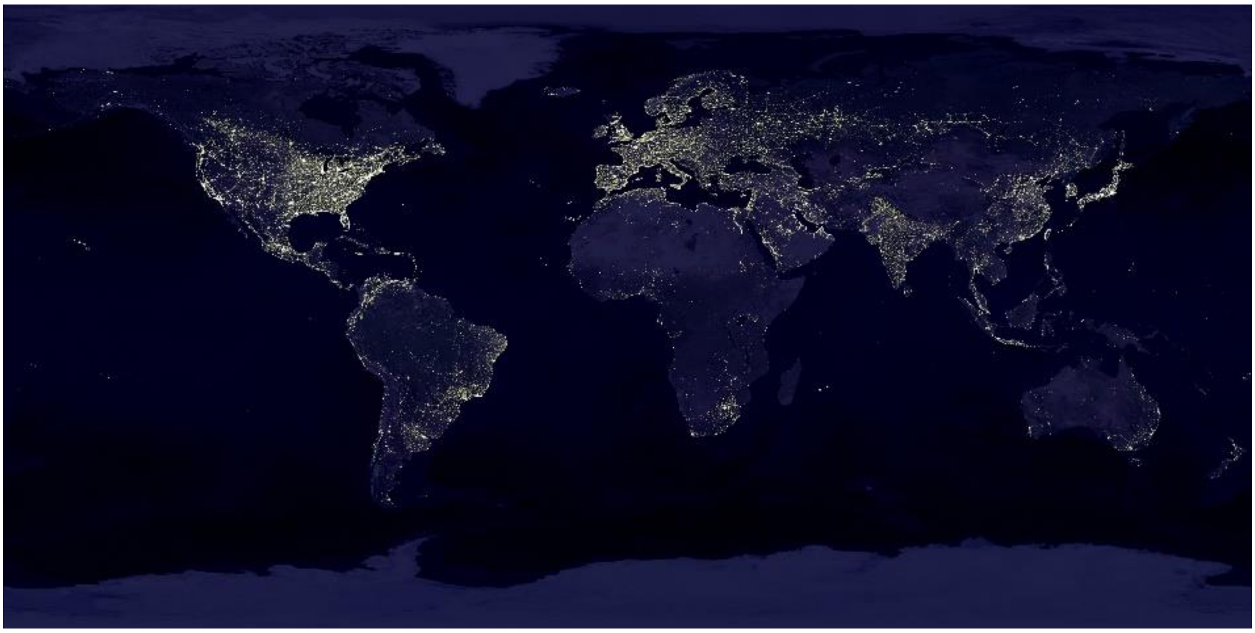
The map of the world shown above, is one interpretation of mankind's "geo-political" sub-divisions in the "late" (European) Bronze Age (~ 4000 ka).

Did the Iron Age end because we ran out of iron?

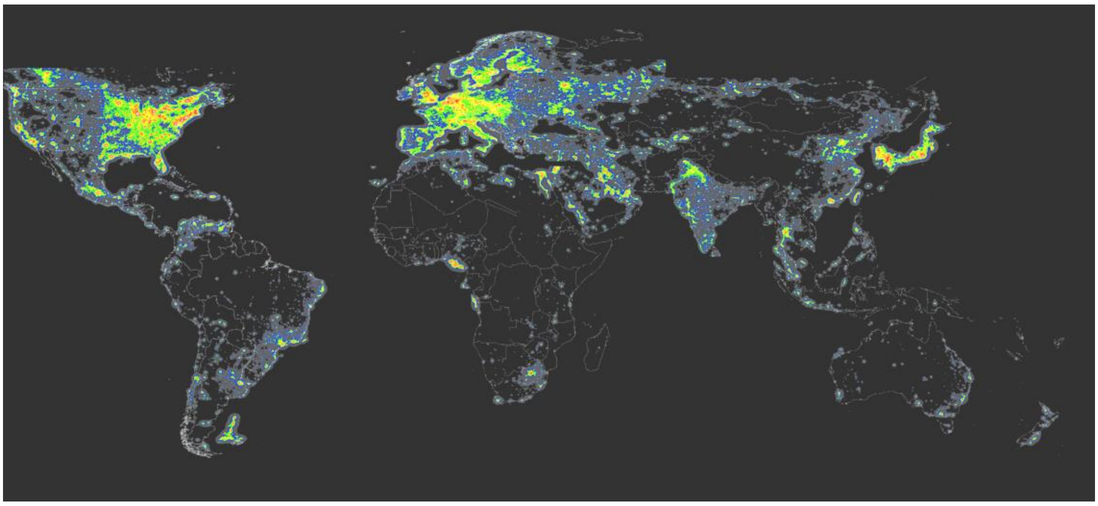
Technologically and time-wise, how did the "Iron Age" differ in sub-Saharan Africa?

Electricity consumption

If all of humanity were living a similarly affluent (Australian-like) lifestyle, electricity consumption might be considered as a proxy for mapping the global human population. But that is not the case.



Earth's city lights, Visible earth, NASA (https://visibleearth.nasa.gov/view.php?id=55167)



World atlas of the artificial night sky brightness (http://www.lightpollution.it/download/mondo_ridotto0p25.gif)

It would be folly to assume that all the lights on "night-time" Earth are entirely from electrical lighting. What alternative "light sources" may be represented in these images?

Satellite imagery gives us a means to compare energy use (electricity consumption) across the globe. By comparison with world population maps it is clear that, access to electricity use is considerably greater in wealthy industrialised counties like Japan, central Europe and North America.

See https://djlorenz.github.io/astronomy/lp2006/overlay/dark.html to night sky illumination in GoogleMaps

Satellite image of the Korean Peninsula at night with the border between North Korea and South Korea clearly demarcated. (https://phys.org/news/2015-02-war-borders-space.html). The border between North Korea and South Korea is clearly demarcated.

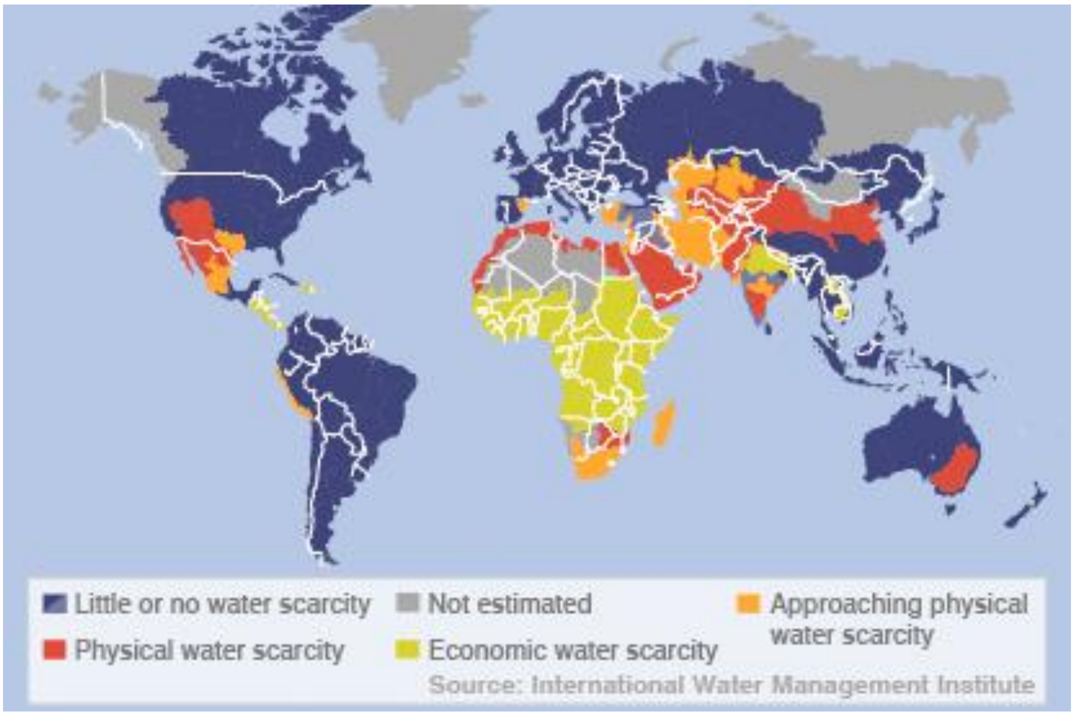
Bearing in mind Korea's total population distribution, what does the night-time image of the Korean Peninsula reveal about access to energy and mineral resources in the two Koreas? Where is the China-North Korea border?

What does the satellite image reveal about electricity consumption in rural China versus rural North Korea?

Some interesting numbers: Estimated per capita GDP (Gross Domestic Product) of the three countries in the image are indicated in parenthesis: North Korea ($1800, 2014), South Korea ($29,000, est 2017), China ($8500, est 2017) and Japan ($38,300, est 2017).

Lies, damned lies and statistics: Water resources

Critically evaluate the map (below) of Earth' water resources.



Wikipedia (By BBC NEWS – (http://news.bbc.co.uk/2/hi/science/nature/5269296.stm, CC BY-SA 1.0, https://commons.wikimedia.org/w/index.php?curid=25387034)

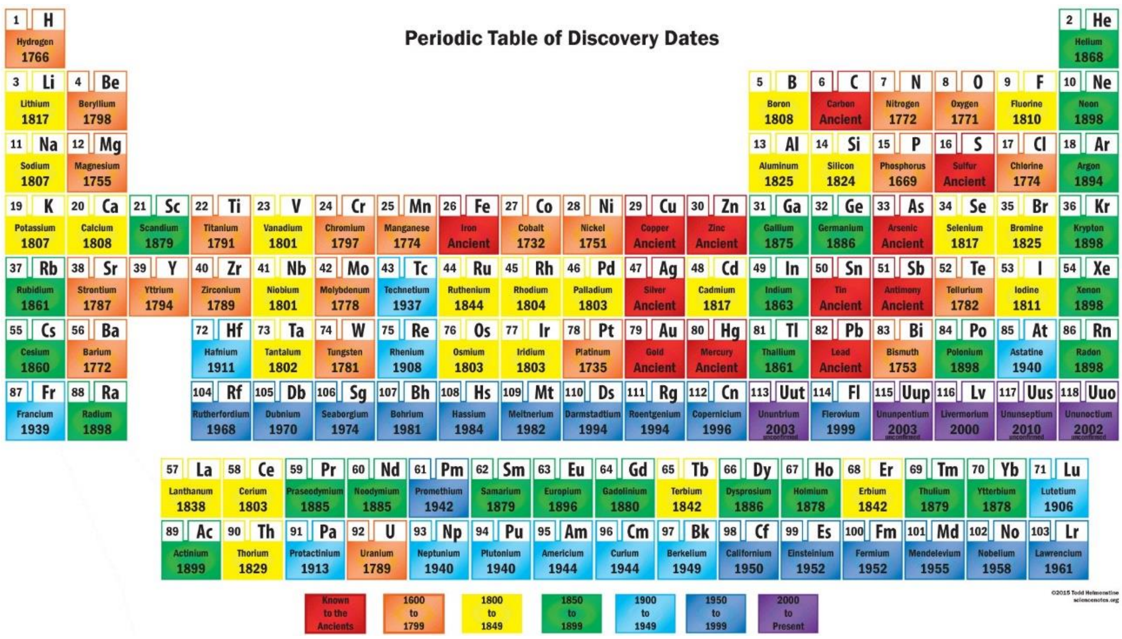
Have you ever heard that "South Australia is the driest state on the driest continent"? How does that fit in with the (derived) data summarised in this figure?

What does the data say about water resources in Turkey, Iraq and Syria? How do you judge the data? You may need to research some countries and their respective water resources

*Use Google Earth to study land use in the drainage basin (**watershed**) of the Congo River, and also the Amazon River watershed. What observations can you make?*

And finally, what improvements might the International Water Management Institute make when drafting a new release of this type of map?

The Periodic Table of Element, discovery dates



Periodic table of elements indicating discovery dates (https://sciencenotes.org/periodic-table-discovery-dates/)

Twelve elements were known to the "Ancients" – C, S, Fe, Cu, Zn, As, Ag, Sn, Sb, Au, Hg and Pb.

What were the 12 elements used for by the "ancients"?

Are there any "hunter-gatherer" or "iron-age" societies that still use these elements in similar ways to the "Ancients"?

Excluding elements where $Z \geq 95$, the most recently discovered naturally occurring elements are At ($Z = 85$), Np ($Z = 93$) and Pu ($Z = 94$).

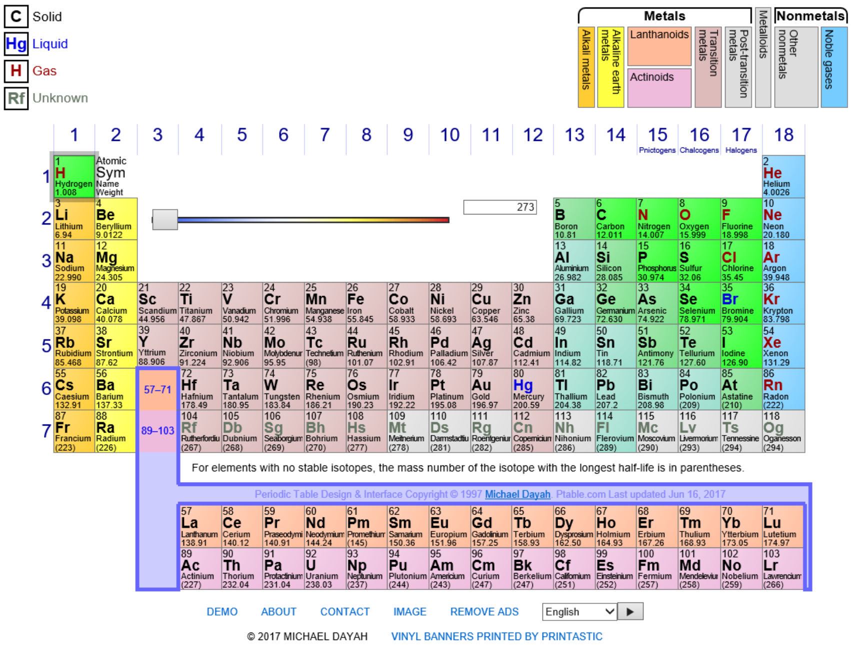
Do these 12 elements still have utility in the modern 21st Century? If so, how are they used?

Compile a list of resources that a typical person in Australia uses in a day.

The Periodic Table

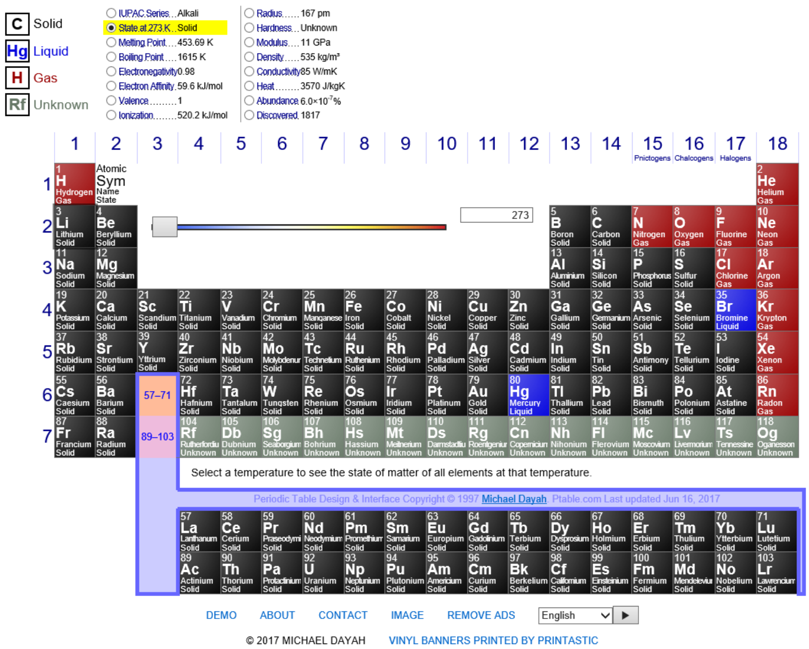
The modern economy requires access to nearly all the naturally-occurring chemical elements (Z = 1 – 92); there are a few exceptions (e.g. technetium: Tc, Z=43).

Most of the elements on the Periodic Table are metals.



Michael Dayah's interactive periodic table indicating the grouping of elements (https://www.ptable.com/#Writeup/Wikipedia)

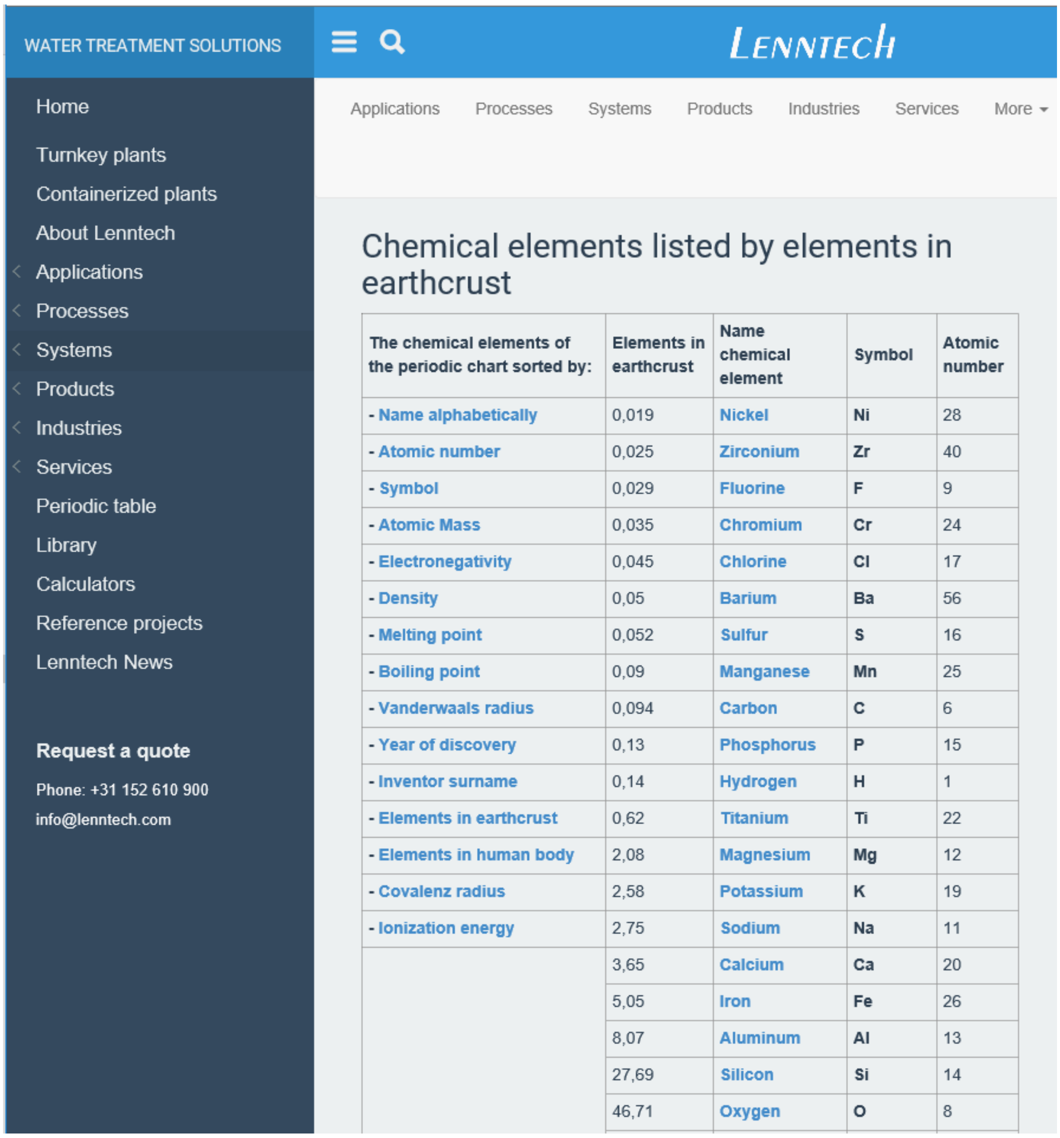
Interactive periodic table (showing states at 273 K)



Michael Dayah's interactive periodic table and their states at 273 K (0 °C) (https://www.ptable.com/#Property/State)

Chemical elements in Earth's crust

Lenntech BV, a consulting firm based in the Netherlands, offers engineering, chemical and environmental services with respect to water treatment and water quality; it has an excellent website concerned with the periodic table and related matters (http://www.lenntech.com/periodic/name/alphabetic.htm).



Chemical elements listed by elements in earthcrust

The chemical elements of the periodic chart sorted by:	Elements in earthcrust	Name chemical element	Symbol	Atomic number
- Name alphabetically	0,019	Nickel	Ni	28
- Atomic number	0,025	Zirconium	Zr	40
- Symbol	0,029	Fluorine	F	9
- Atomic Mass	0,035	Chromium	Cr	24
- Electronegativity	0,045	Chlorine	Cl	17
- Density	0,05	Barium	Ba	56
- Melting point	0,052	Sulfur	S	16
- Boiling point	0,09	Manganese	Mn	25
- Vanderwaals radius	0,094	Carbon	C	6
- Year of discovery	0,13	Phosphorus	P	15
- Inventor surname	0,14	Hydrogen	H	1
- Elements in earthcrust	0,62	Titanium	Ti	22
- Elements in human body	2,08	Magnesium	Mg	12
- Covalenz radius	2,58	Potassium	K	19
- Ionization energy	2,75	Sodium	Na	11
	3,65	Calcium	Ca	20
	5,05	Iron	Fe	26
	8,07	Aluminum	Al	13
	27,69	Silicon	Si	14
	46,71	Oxygen	O	8

The 20 most abundant elements in Earth's crust (http://www.lenntech.com/periodic-chart-elements/earthcrust.htm). Note that oxygen (O) alone accounts for nearly 47% (by mass = weight %) of Earth's crust, and that the 10 most abundant elements (O, Si, Al, Fe, Ca, Na, K, Mn, Ti, H) constitute >99% of the Crust (by mass).

http://hyperphysics.phy-astr.gsu.edu/hbase/Tables/elabund.html provides an interesting comparison of the abundances of chemical elements in Earth's crust with the solar system and living organisms.

See also http://www.worldatlas.com/articles/the-most-abundant-elements-in-the-earth-s-crust.html.

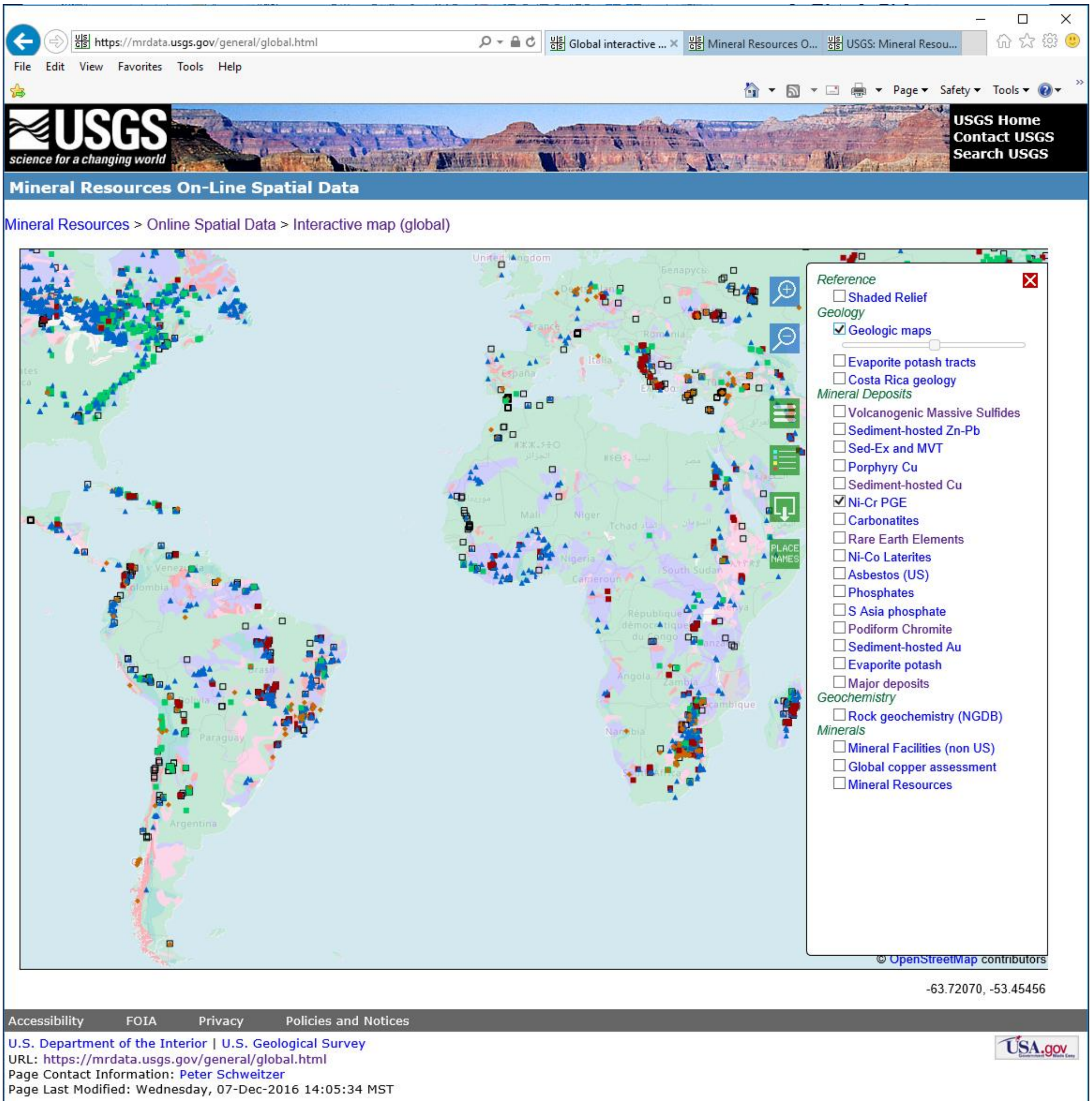
Mineral Commodity Summaries 2016

An excellent and up-to-date mineral commodity summary is provided by the USGS (United States Geological Survey) and available at https://minerals.usgs.gov/minerals/pubs/mcs/2016/mcs2016.pdf

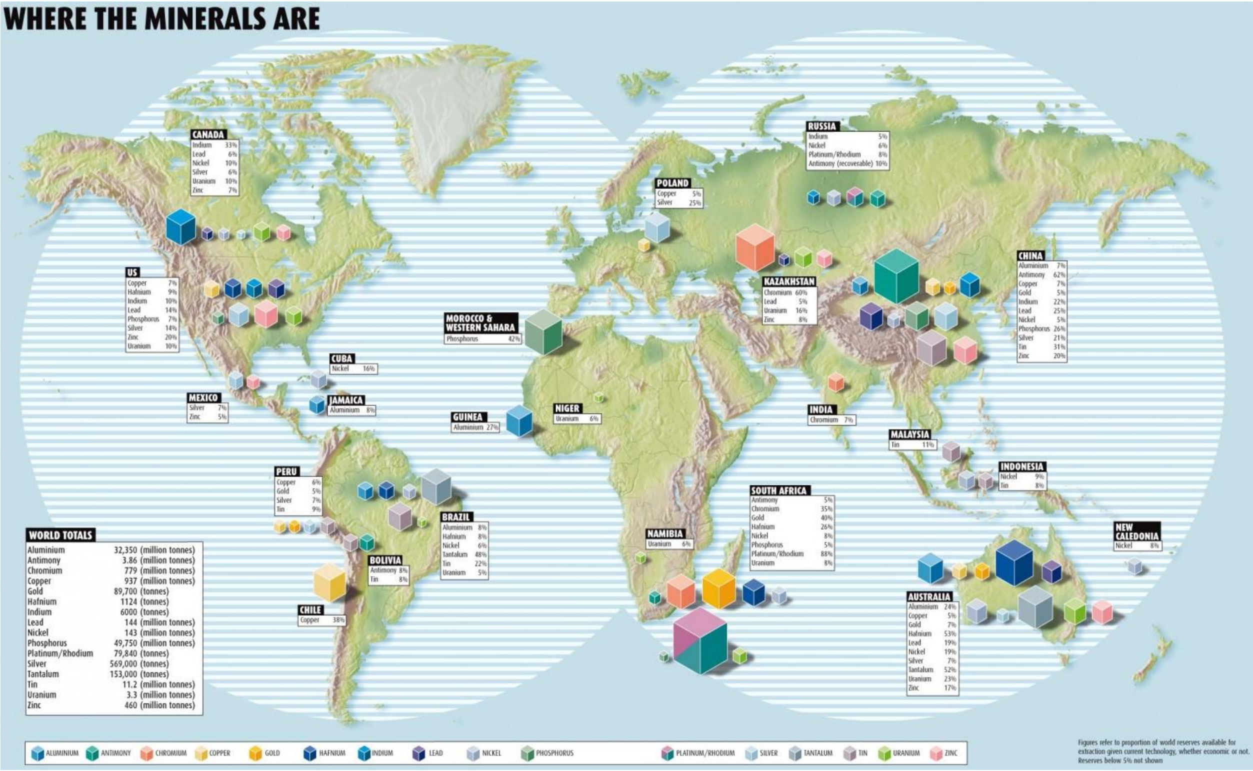
Although the data from the USGS refer to the United States (the world's largest economy representing 25% of the world's GDP at US$19 trillion), the mineral commodity data are indicative of other industrialised western economies, and in many ways the Australian economy.

Interactive global map of mineral deposits

Explore the mineral deposits of the world at:
https://mrdata.usgs.gov/general/global.html



Mineral deposits of the world



Metal resources of the world (http://www.mining.com/infographic-where-the-minerals-are-82638/)

Mineral resources

In the geological and metallurgical industries **base metals** include the non-ferrous/non-precious metals: Cu, Pb, Ni, Sn and Zn.

What are base metals used for? What countries have the most demonstrated resources of base metals?

"Rare" metals can include cobalt, mercury, tungsten, beryllium, bismuth, cerium, cadmium, niobium, indium, gallium, germanium, lithium, selenium, tantalum, tellurium, vanadium, and zirconium.

What are "rare" metals used for? What countries have the most demonstrated resources of "rare" metals?

Precious metals include Au, Ag and Pt, palladium (Pd) and rhodium (Rh).

What are precious metals used for? What countries have the most demonstrated resources of precious metals?

The USGS lists 84 so-called mineral commodities. Indeed, the list includes "Rare Earths" as a single category – these are also known as **rare earth elements (REE)**, although that name is somewhat misleading in that some RRE are arguably not that rare!

Rare-earth elements are cerium (Ce), dysprosium (Dy), erbium (Er), europium (Eu), gadolinium (Gd), holmium (Ho), lanthanum (La), lutetium (Lu), neodymium (Nd), praseodymium (Pr), promethium (Pm), samarium (Sm), scandium (Sc), terbium (Tb), thulium (Tm), ytterbium (Yb) and yttrium (Y).

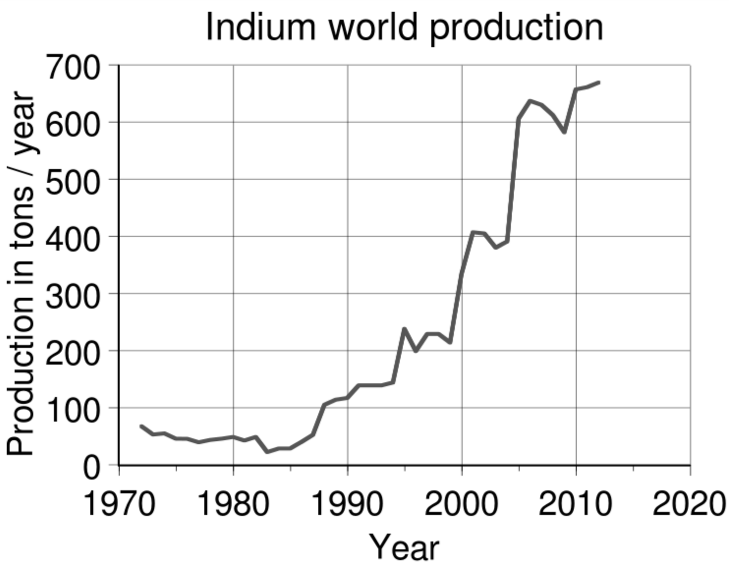
What are REE used for in a <u>modern</u> economy?

Which countries have the largest resources of REE?

Case study: A relatively unknown element – Indium (In)

An element that is rarely mentioned is indium (In) and, whilst ***not*** defined as a REE, is indeed very rare! Indium is an element, of particular importance to the modern economy.

There are probably no mines built solely for the recovery of indium; however, it is recovered from the ores of other metals, notably zinc-bearing ore (e.g. sphalerite).



World indium production between 1972 and 2012, by U.S. Geological Survey, 2013, http://minerals.usgs.gov/ds/2005/140Template to indicate the source: <ref>U.S. Geological Survey, [http://minerals.usgs.gov/ds/2005/140]</ref>, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=27802059

The above graph indicates that from about 1985 onwards, the production of indium increased significantly. In fact, it is more than likely that from 1985 onwards, increased effort was made to ***recover*** indium from waste rock derived from the mining of zinc ore (world production of zinc has increased steadily from 1945).

What modern technology requires indium?

Non-metals (mineral resources)

Non-metallic resources include:

- marble, slate and other building and paving stones

- limestone and gypsum
- chemical and fertiliser minerals
- salt
- clay
- sand and gravel

Arguably, prior to sophisticated metallurgical knowledge used at an industrial scale during the 19th and 20th Centuries, non-metallic resources were more important to human society than they now are.

Modern society has become highly dependent on metals and synthetic materials like plastic (a petroleum product) and polymers. The human population's appetite for e.g. high quality (pure) sand for glass manufacturing continues to grow.

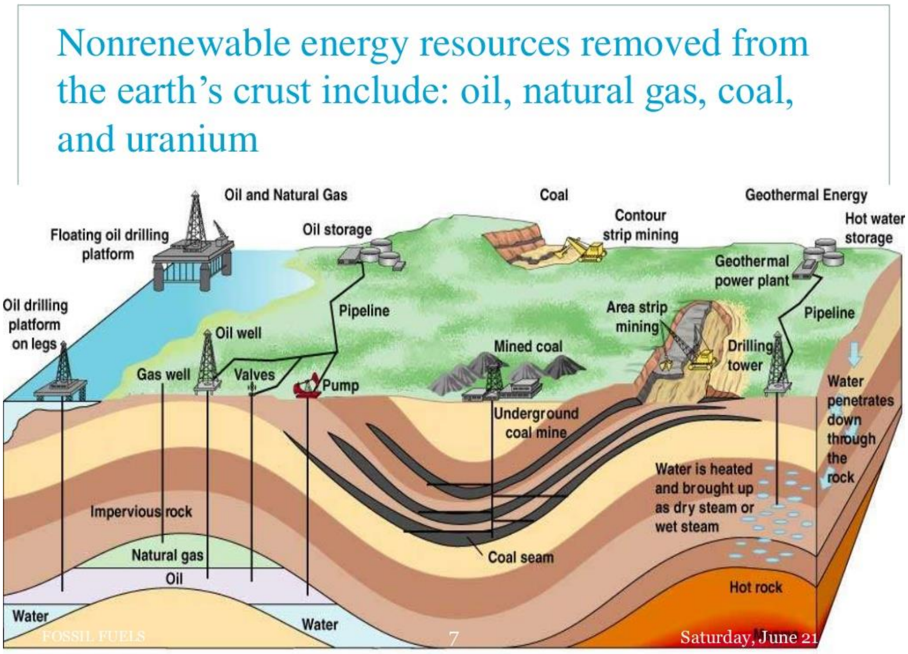
The image below shows a forest of apartment blocks, somewhere in China – the reality is that many of these buildings will never be occupied.

Ghost city in the making?: A modern "village" of high-rise apartments in China (https://pacificlegal.org/the-one-plan-to-rule-them-all-or-the-chinafication-of-the-bay-area/)

Concrete required to build modern cities requires several ingredients – dry cement powder is only one of them.

The chemistry of modern cement "science" is complex; however, the environmental consequences of cement production is the liberation of CO_2 from limestone that is heated to temperatures around 1450 °C. This also requires a large amount of energy, further contributing to increases in CO_2 emissions. We shall study CO_2 emissions in greater detail in Topic 3 (Climate Change).

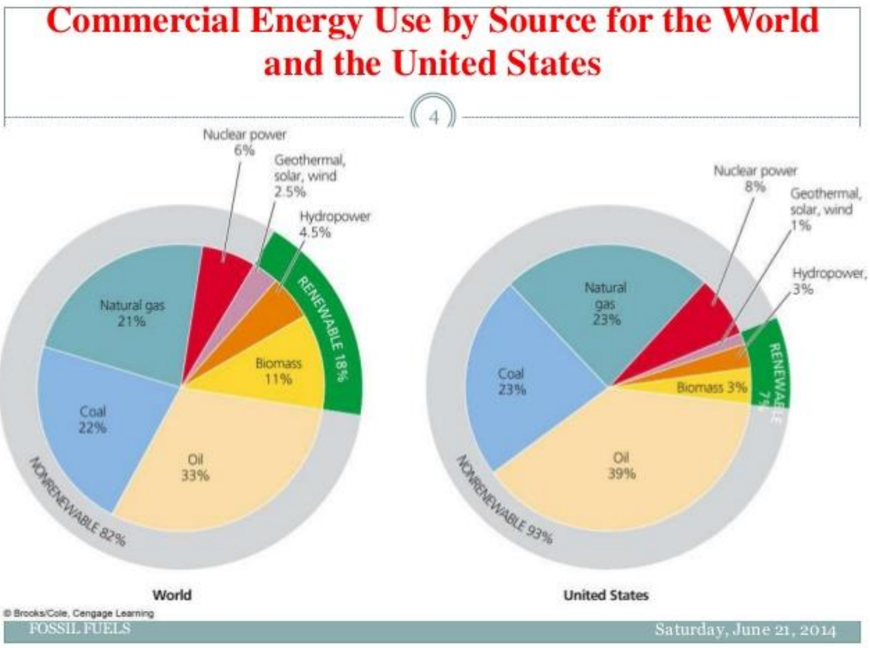
Non-renewable mineral and energy resources are formed in various ways over geological time-scales, so are not readily replenished



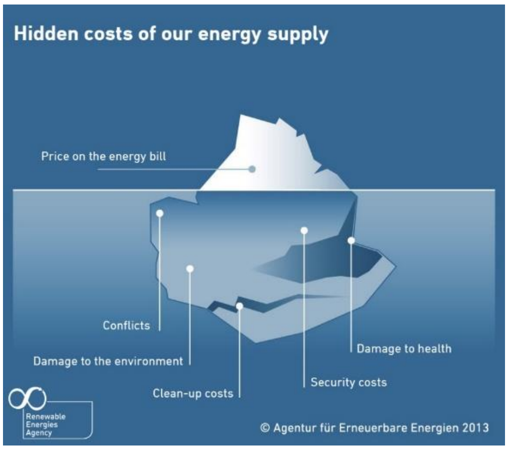
Summary of the exploitation of non-renewable energy resources (https://www.slideshare.net/fishugah/fossil-fuel-resources-for-sustainable-development).

- ***Discuss the sustainability of reserves of fossil fuels, and metallic and non-metallic resources.***

Fossil fuels



2014 commercial energy use by source for the world and the United States (https://www.slideshare.net/fishugah/fossil-fuel-resources-for-sustainable-development).



Graphical representation of the hidden costs of the world energy supply (https://www.unendlich-viel-energie.de/press/press-releases/renewables-and-sustainable-development-are-inseparable)

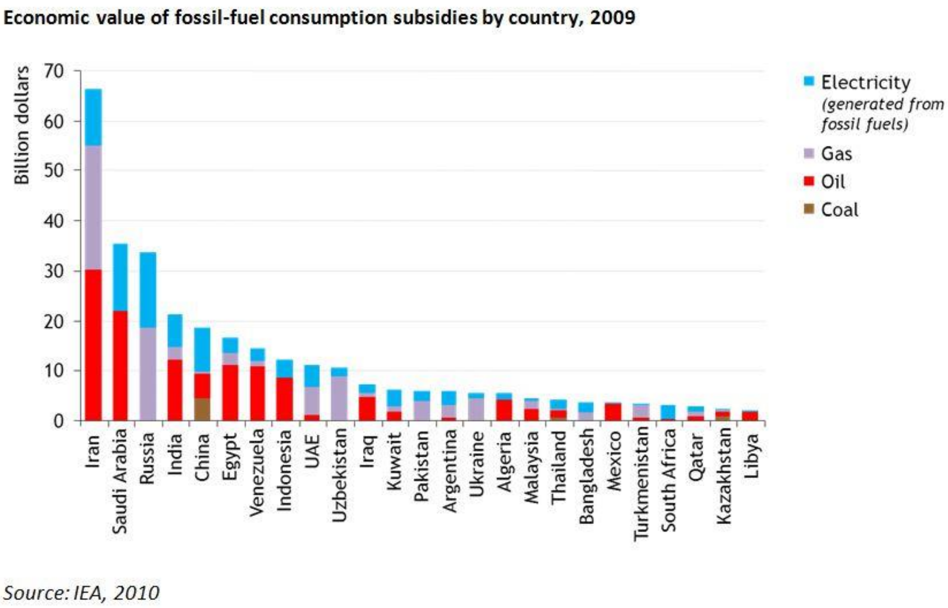
The world's changing GDP (Gross Domestic Product)

Please study the World GDP rankings since 1980 by country: https://knoema.com/nwnfkne/world-gdp-ranking-2017-gdp-by-country-data-and-charts

Construct a table to display non-renewable fuel resources, including uranium and unconventional petroleum, and the approximate known global reserves of each resource, and critically evaluate this information in terms of sustainability

Fossil fuel consumption subsidies

What is meant by the term "fossil fuel consumption subsidy"?



Economic value of fossil-fuel consumption subsidies by country in 2009 (https://www.ictsd.org/sites/default/files/news/2011/07/ff-subsidies.jpg)

The figure above shows the economic value (in 2009 US$ billion) of fossil fuel subsidies for 25 nations.

Research the main fossil-fuel subsidising counties on the internet, noting in particular their GDP (gross domestic product) and the HDI (human development index).

What relationship (if any) can be established between, say, GDP and fossil-fuel consumption?

Of the 10 countries with the world's highest HDI, which are on the short list of highest fossil-fuel consumption subsidies in the above figure?

What are the <u>intentional</u> and <u>unintentional</u> consequences of governments subsidising fossil fuel consumption?

What might be the lessons learned from the findings of your research?

Research global fossil fuel (oil, gas, coal, lignite) reserves by country and compare a shortlist of well-endowed fossil fuel countries with the 25 high subsidy countries.

What are your observations regarding fossil fuel reserves of these countries? In particular, which of the world's largest economies will have depleted their reserves of coal and petroleum the soonest? What strategies, both scientific and economic are these countries undertaking to address the impending shortfall of fossil fuels.

The formation of non-renewable energy resources, including fossil fuels and unconventional gas, is related to their geological setting

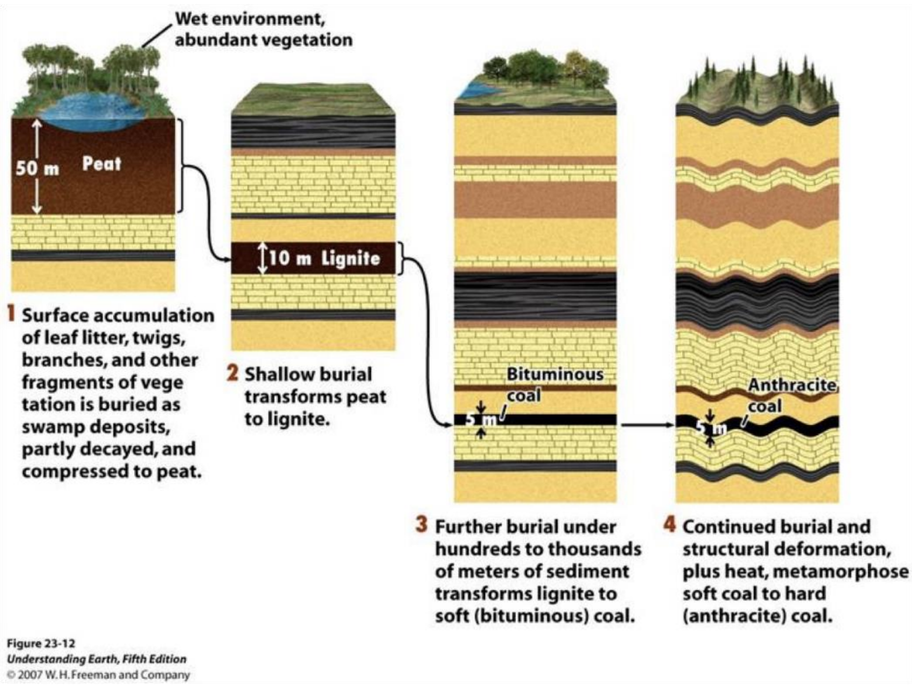
- ***Explain the processes by which coal is formed***

Formation of coal video

Watch the video on the formation of coal by the Open University in the UK: (http://www.wou.edu/las/physci/GS361/Fossil%20fuels/Coal.htm)

Artist's impression what a coal-forming environment may have looked like during the Permian (http://www.wou.edu/las/physci/GS361/Fossil%20fuels/Coal.htm)

- Coal is originally laid down as a sedimentary layer of **peat** (plant matter).
- Coal-forming plants thrived in flat, coastal, swampy areas.
- Coal formed with **soils** at or below the **water-table**.
- Gradual **subsidence** allows plant material to accumulate in **anaerobic** waters to form peat.
- During regional subsidence the sedimentary sequence containing peat and other **clastic sediments** (e.g. **clay**, **silt**, **sand**) becomes buried, compacted and subjected to **heat** (**geothermal gradient**) and **pressure**.
- With sufficient temperature and pressure, complex physical and chemical changes take place and peat is converted to lignite (**brown coal**).

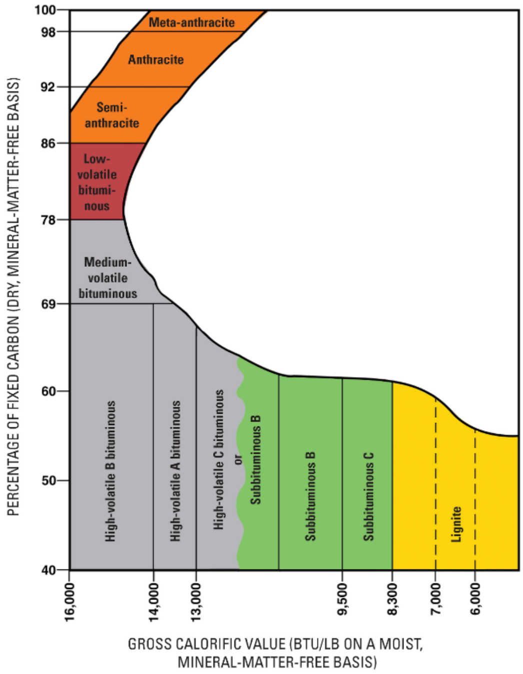


Diagrammatical representation of the formation of coals of different rank from the surface accumulation of peat in a sedimentary environment with high water-table and subsidence.

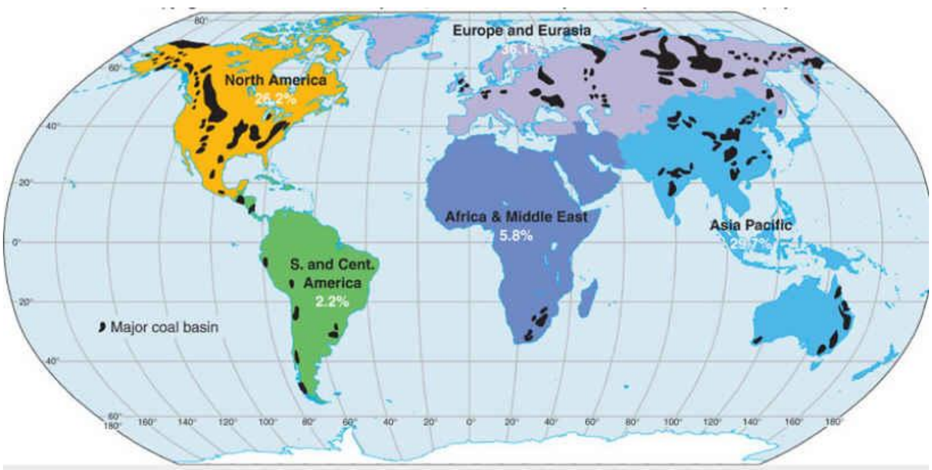
Some coal terminology

- Coal is a non-renewable **fossil fuel**.

- The terms **lignite**, **sub-bituminous coal**, **bituminous coal**, **semi-anthracite**, **anthracite** and **meta-anthracite** are terms that refer to different **coal ranks**, and the rank is determined by the amount of temperature and pressure the coal is subjected to.
- "Brown coal" refers to lignite (low rank coal) only. "Black coal" refers to sub-bituminous coal, bituminous coal and anthracite (high rank coal).
- In general terms, as coal rank increases the proportion of C also increases, but H, O and S content decrease, i.e. lower rank coals are dirty and produce more pollutants upon combustion than anthracite.
- The **calorific value** (contained energy) of coal also increases with increased rank.



Coal rank classification system used in the United States (United States Geological Survey: USGS) and used more-or-less throughout the English-speaking world (https://en.wikipedia.org/wiki/Coal)

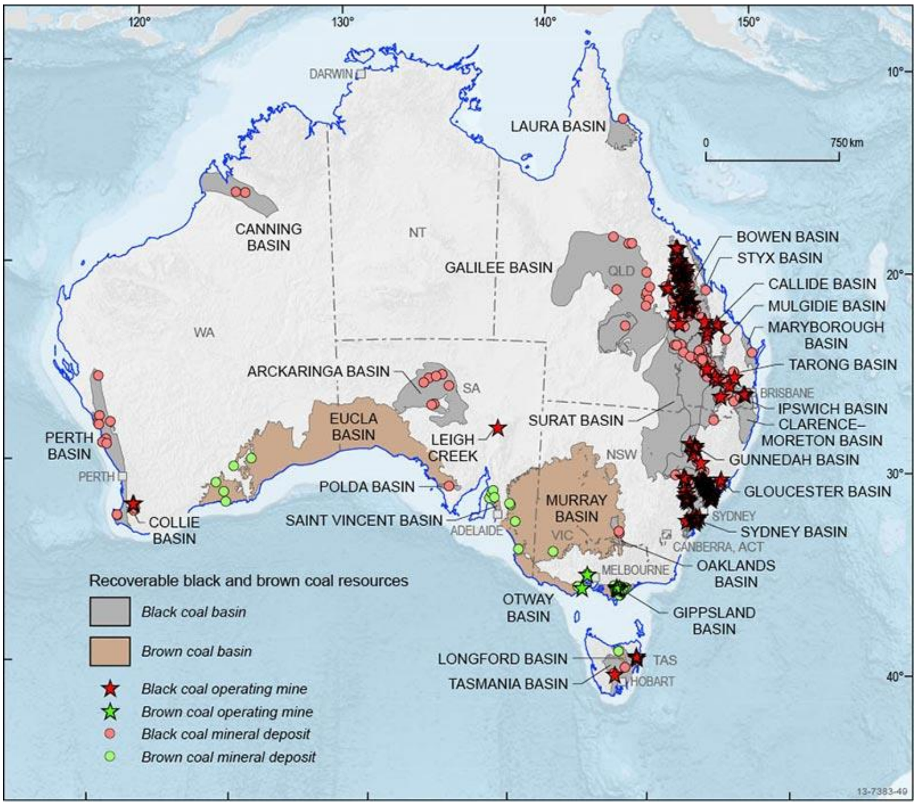


Major coal basins of the world. Note the skewed distribution of coal basins, whereby a higher proportion of coal basins are located in the northern hemisphere. Note also how little coal there is in Africa and the Middle East (http://www.geo.hunter.cuny.edu/tbw/ncc/Notes/chapter5.nat.res/regional.shares.proved.coal.reserves.2003.jpg)

As a starting point, consider the above figure – What country(s) in southern Africa is endowed with major coal-bearing basins? What type of coal is mined in those *countries? And what proportion of generated electricity in those countries comes from coal?*

What about the rest of Africa? What "coal-like" substitutes are used for cooking and heating elsewhere in Africa? (be careful not to over-generalise your answer to this question). What are the environmental consequences of using "coal-like" substitutes throughout Africa?

China has the world's largest population and is the world's largest miner of coal – its resources are expected to be depleted within a few decades. At the current rate of consumption, and assuming resources estimates remain materially unchanged, exactly when will China's coal resources be depleted? What are the Chinese planning to use to replace coal in their electricity market?



Australia's economic coal basins, and locations of operating mines, December 2012 (http://www.ga.gov.au/data-pubs/data-and-publications-search/publications/australian-minerals-resource-assessment/coal)

- ***Describe the processes by which petroleum and coal-seam gas are formed and trapped***

Petroleum formation and occurrence

Definition of petroleum

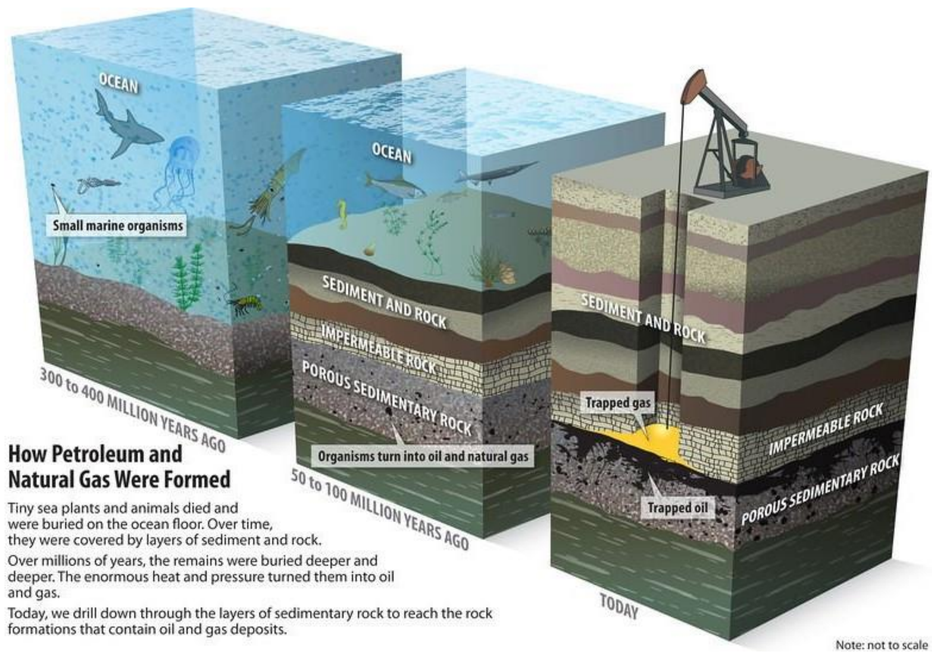
One definition is that **petroleum** is *"A liquid mixture of hydrocarbons which is present in suitable rock strata and can be extracted and refined to produce fuels including petrol, paraffin and diesel oil"*. However, this definition is too narrow, as petroleum contains significant quantities of non-hydrocarbons, and natural gas is a type of petroleum that may not be covered if we accept that description.

A better definition is that petroleum is *"A naturally occurring liquid or gas found in geological formations beneath Earth's surface. It comprises mostly **hydrocarbons** of differing molecular mass but also **non-hydrocarbon** species".*

- Petroleum is a fossil fuel.
- In addition to **liquid** hydrocarbons, petroleum also includes **gaseous** hydrocarbons (**methane**, **ethane**, **propane**, **butane** etc.) and S, O and N-bearing compounds, organometallic compounds (e.g. petro-porphyrins containing V and Ni), and many other chemical species including, H_2S and S.
- "Natural gas" produced from oil and gas fields is typically 70–90% methane, 0–20% ethane + propane + butane, 0–8% CO_2, 0–0.2% O_2, 0–5% N_2, 0–5% H_2S, and trace amounts of noble element gas (He, Ne etc.). See also https://www.ems.psu.edu/~pisupati/ACSOutreach/Petroleum_1.html

Theory of petroleum formation

The modern and scientifically substantiated theory for the formation of petroleum is that it formed from the thermal breakdown of organic matter buried within sedimentary basins, but originally preserved as part of sediments – phytoplankton and other organisms that live in the water column eventually die and settle to the sediment-water interface, and reworked by bacteria (both aerobic and anaerobic) and are eventually buried as more sediment is deposited.



Cartoon illustration the formation and occurrence of petroleum in a marine sedimentary basin (https://www.pmfias.com/formation-petroleum-mineral-oil-distribution-india-on-shore-off-shore-oil-production-india/)

Note: There are some important exceptions to the origin of petroleum from marine organic matter. For example, oil and gas in Bass Strait (offshore Gippsland Basin) is derived from coal seams buried beneath Bass Strait. Similarly, most of the oil and gas from the Cooper Basin in NE South Australia and SE Queensland is also derived from coal buried 2 to 4 km beneath ground surface.

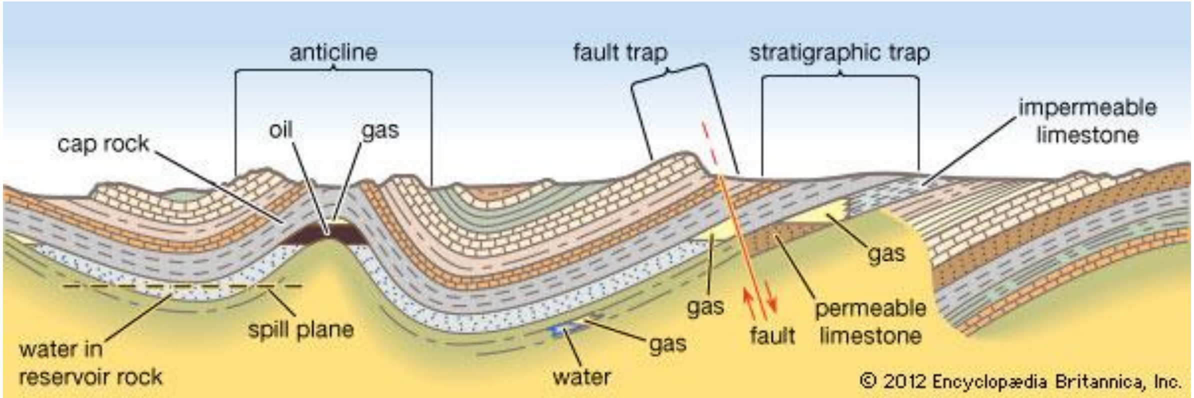
Abiogenic petroleum theory

Despite overwhelming evidence to the contrary, there is an alternative, somewhat pseudo-scientific theory for the origin of petroleum that claims it formed (and continues to form) very deep, even 100s of km inside Earth. One version of this theory is that short-chained hydrocarbons (methane and ethane) form within the mantle and migrate to Earth's surface via buoyancy, where they polymerise to form longer-chained hydrocarbons that are trapped within geological structures close to the surface. See also http://oilprice.com/Energy/Energy-General/Can-Hydrocarbons-Survive-In-The-Hot-Pressured-Mantle.html.

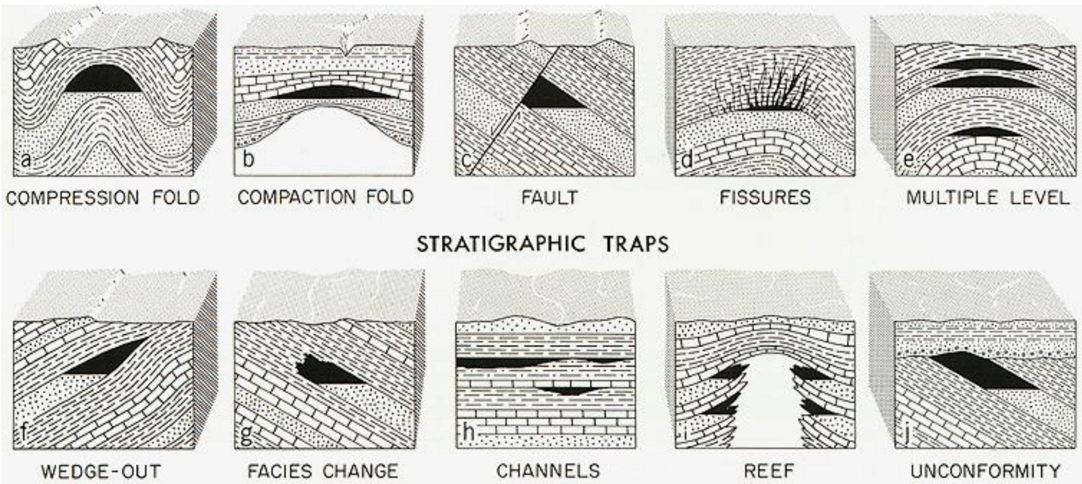
- ***Describe structures within which petroleum may be trapped***

Traps for conventional oil and gas

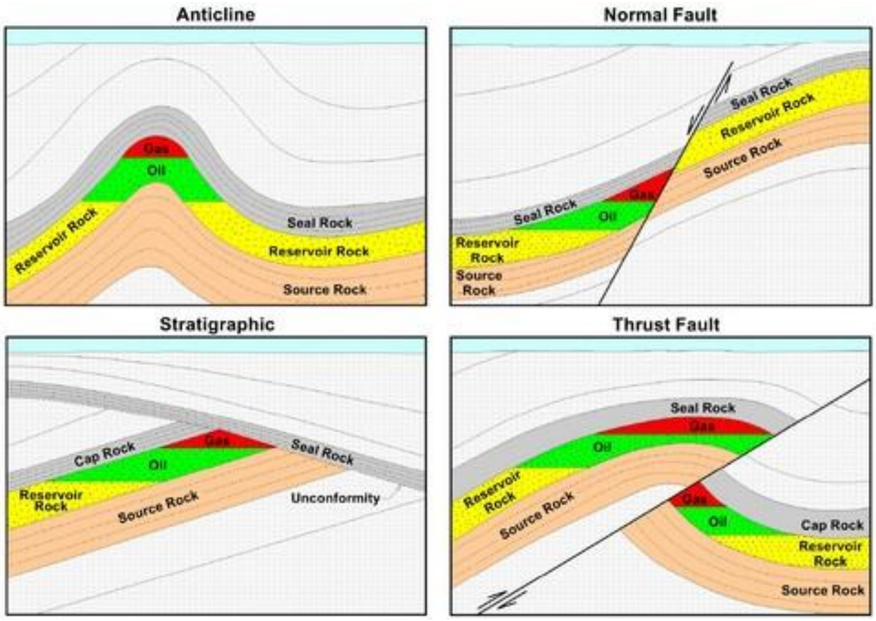
Once oil and gas (petroleum) is formed in **shale** or **claystone** or from **coal measures**, it can migrate through porous and permeable **lithologies** (rock types) to sites of entrapment.



*Geological trapping mechanisms for conventional oil and gas. Note the **gas "cap"** above the **oil "leg"**.*



"Black & White" drafted representations of geological trapping mechanisms for conventional oil and gas (http://geo.msu.edu/extra/geogmich/oil&gas.html). Note the deliberate use of sympols to represent limestone (bricks), sandstone (dots) shale and mudstone (dashed lines) and oil (black).



Colour drafted representations of geological trapping mechanisms for conventional oil and gas (http://energy-alaska.wikidot.com/natural-gas-as-a-resource). Note the deliberate use of colours, in particular green (oil) and red (gas).

<u>Unconventional gas</u>

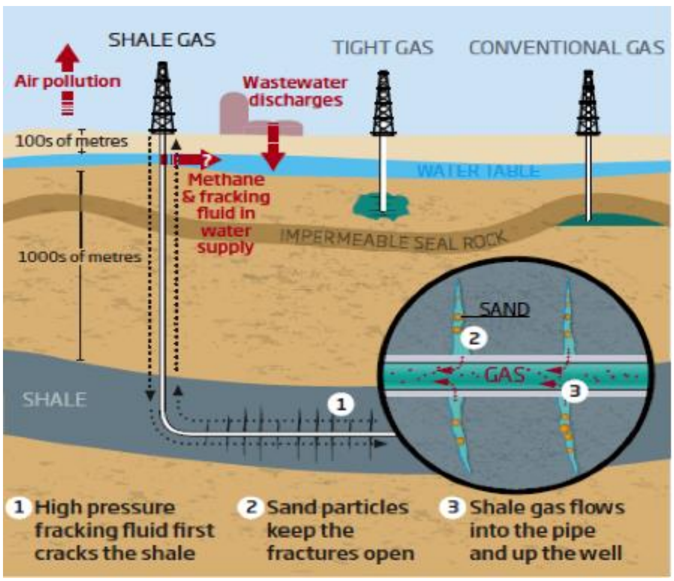
(https://www.csiro.au/en/Research/Energy/Hydraulic-fracturing/What-is-unconventional-gas)

Coal-seam gas also called **coal-bed methane** and coalbed gas is natural gas that derives from coal seams. Coal bed gas is methane that is adsorbed onto the structure of coal.

Shale gas is gas (mainly methane) trapped within shale, typically at depths greater than ~1500 metres. CSIRO reports that Australia has large reserves of shale gas; however, there is little or no development of this resource.

In the figure below, "tight gas" is indicated – but what exactly is that?

What is fracking and why is it a controversial practice? (the Victorian Government have banned it!)



Geological habitat of conventional gas versus shale gas and tight gas (Conventional gas Still to come (http://revolution-green.com/wp-content/uploads/backup/2016/09/)

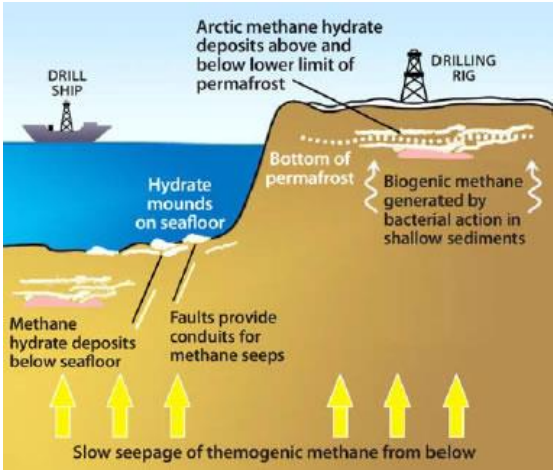
Clathrates

(http://geology.com/articles/methane-hydrates/)

Clathrates are known also as **methane hydrates**, or **methane ice**, are natural gas (~100% methane) trapped within permafrost (frozen water-saturated soil), or on the seabed in cold favourable conditions.

The origin of the methane bound within the clathrates may be **biogenic** (i.e. formed by bacteria as they decompose organic matter within arctic soil or marine sediments), or **thermogenic** (i.e. deep within geological structures from methane that has escaped from convention gas reservoirs and migrated upwards towards the cold surface environments.

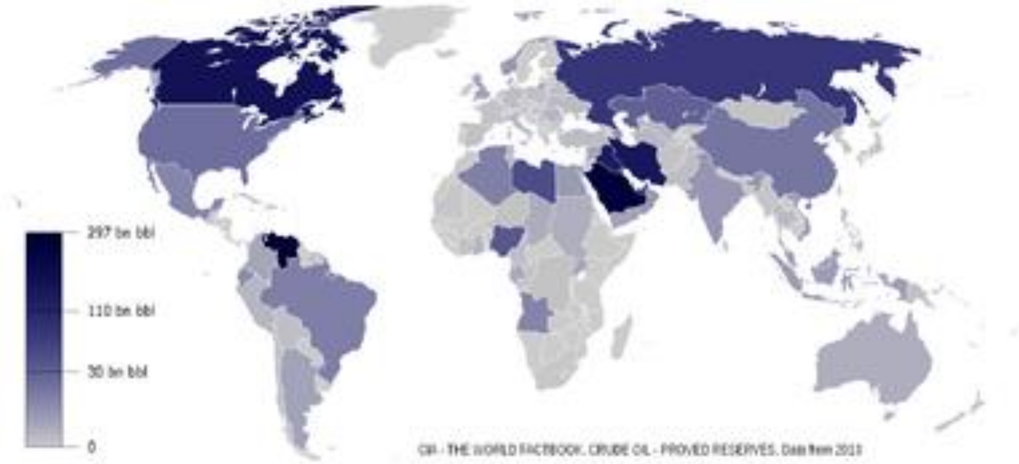
Worldwide, methane clathrates may possibly be a larger source of natural gas than all conventional gas reserves combined. However, to date they have never been exploited as a source of natural gas, and there is no efficient (economically feasible) way of extracting methane from **permafrost** or the seabed.



Schematic showing the location of methane clathrates in permafrost and the seafloor (http://geology.com/articles/methane-hydrates/)

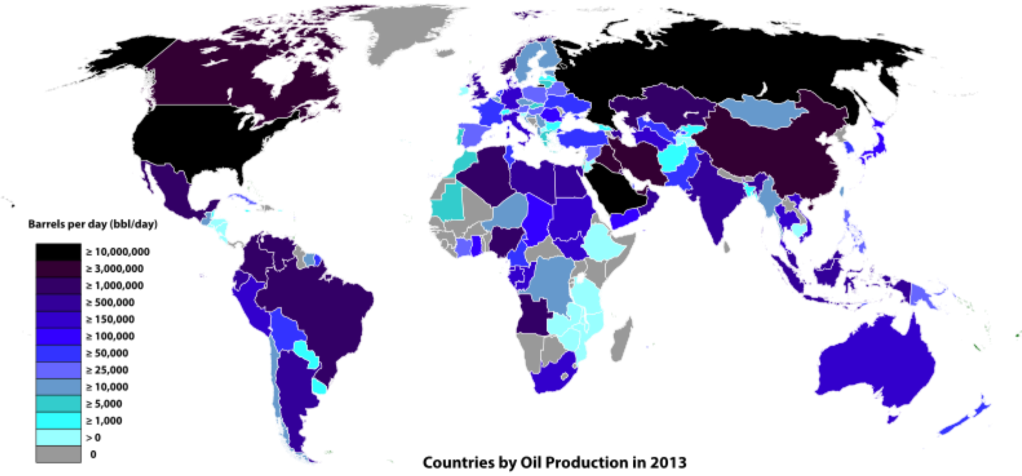
In Topic 3 (Climate Change) of *Earth & Environmental Science*, we shall revisit methane clathrates and see how the melting of permafrost, especially in the northern hemisphere, and liberation of methane clathrate pose a perilous danger to Earth's climate stability.

Oil reserves



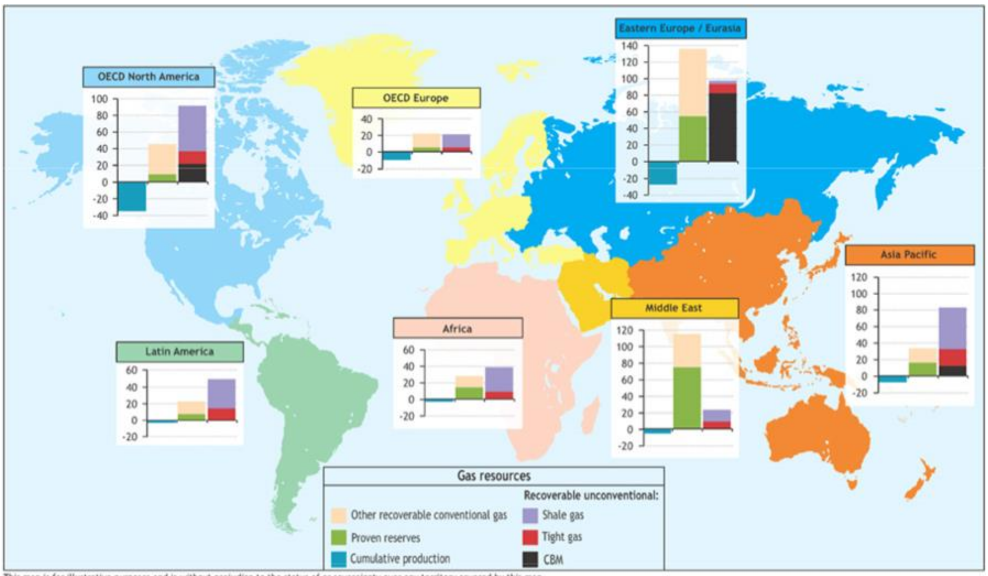
Proven world oil reserves in 2013. These figures include unconventional oil reserves such as natural heavy oil and oil sands (https://en.wikipedia.org/wiki/Petroleum)

Oil production



Oil producing counties of the world in 2013 (https://en.wikipedia.org/wiki/Peak_oil)

Gas resources



This map is for illustrative purposes and is without prejudice to the status of or sovereignty over any territory covered by this map.

Sources: Cedigaz (2010); USGS (2000 and 2008); BGR (2009); US DOE/EIA (2011); Kuuskraa and Stevens (2009); Gazprom (2010); IEA estimates and analysis.

World natural gas resources by major region, January 2010 (https://www.businessinsider.com.au/map-worlds-natural-gas-2012-5?r=US&IR=T)

Peak oil

What does the term "Peak oil" refer to in the context of world energy resources?

Collect data on global consumption and the rate of new discoveries of conventional petroleum during the 20th and early 21st centuries (e.g. 'peak oil'). Construct graphs to illustrate the findings.

In your own time, please watch the film "Oil Apocalypse: what if the oil runs out?" at https://www.youtube.com/watch?v=BYb73iiTBEA.

Based on present consumption rates and the world's known reserves of conventional petroleum, when will reserves be depleted?

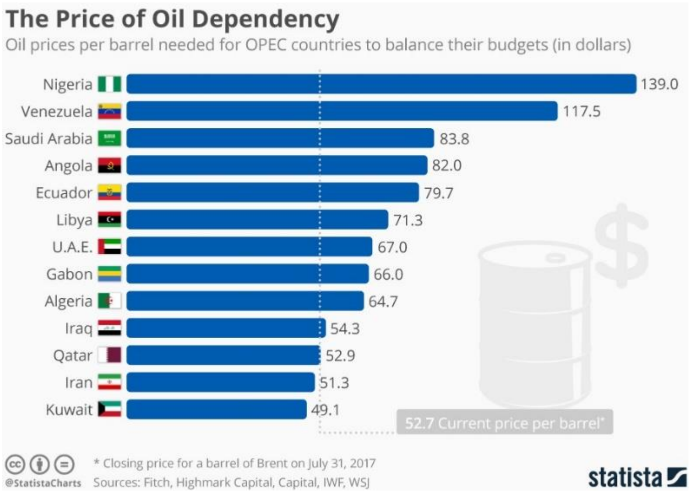
Having answered the above question, do you believe in "Peak oil"?

Put another way: Will the "Age of Oil" end because we run out of oil?

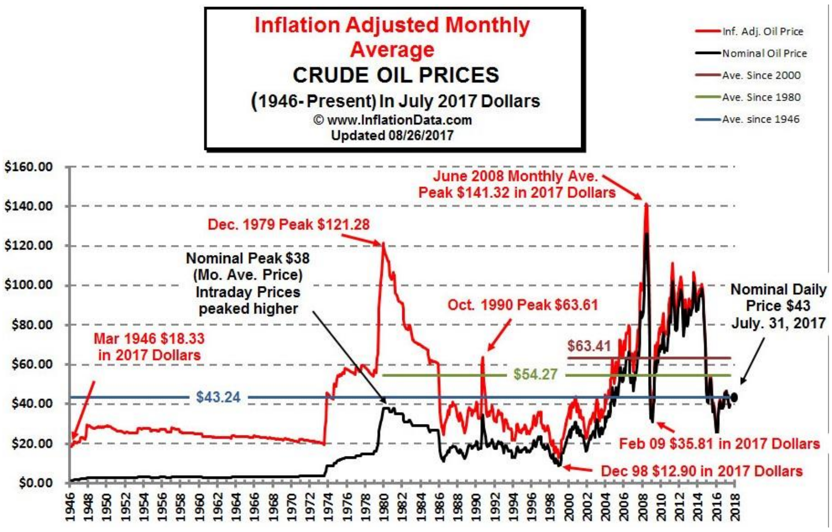
International Energy Agency

An excellent resource is the (IEA) International Energy Agency (http://www.iea.org/countries/membercountries/). The IEA website has links to other topics important to *Earth & Environmental Science* including **carbon capture**, **climate change**, **energy security**, **nuclear energy** and many others.

<u>Economic risk of producing oil and gas</u>



Oil prices per barrel needed for OPEC countries to balance their national budgets in US dollars (https://www.statista.com/chart/10498/oil-prices-per-barrel-needed-for-opec-countries-to-balance-their-budgets/)



Inflation adjusted oil price chart (https://inflationdata.com/Inflation/Inflation_Rate/Historical_Oil_Prices_Chart.asp)

Using the graph (above) of inflation adjusted oil prices between 1946 and 2017, can you identify any war(s) in the Middle East or world recessions?

Environmental risk of commercial petroleum extraction

Emissions of CO_2, CH_4 and other gases

Methane (CH_4) and other light hydrocarbon gases are a by-product of oil generation. Unless there is an immediate market are for natural gas, it must either be stored or burned off. Storage is very expensive and ultimately only of very short-term value (unless the gas were pumped back underground – maybe).

Burning methane produces **carbon dioxide** and **water** according to the following stoichiometry: $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$ and of course this an **exothermic** reaction that by definition produces **heat**.

But which is worse in term of greenhouse gas emissions – releasing CH_4 directly into the atmosphere or burning it at the well-head?

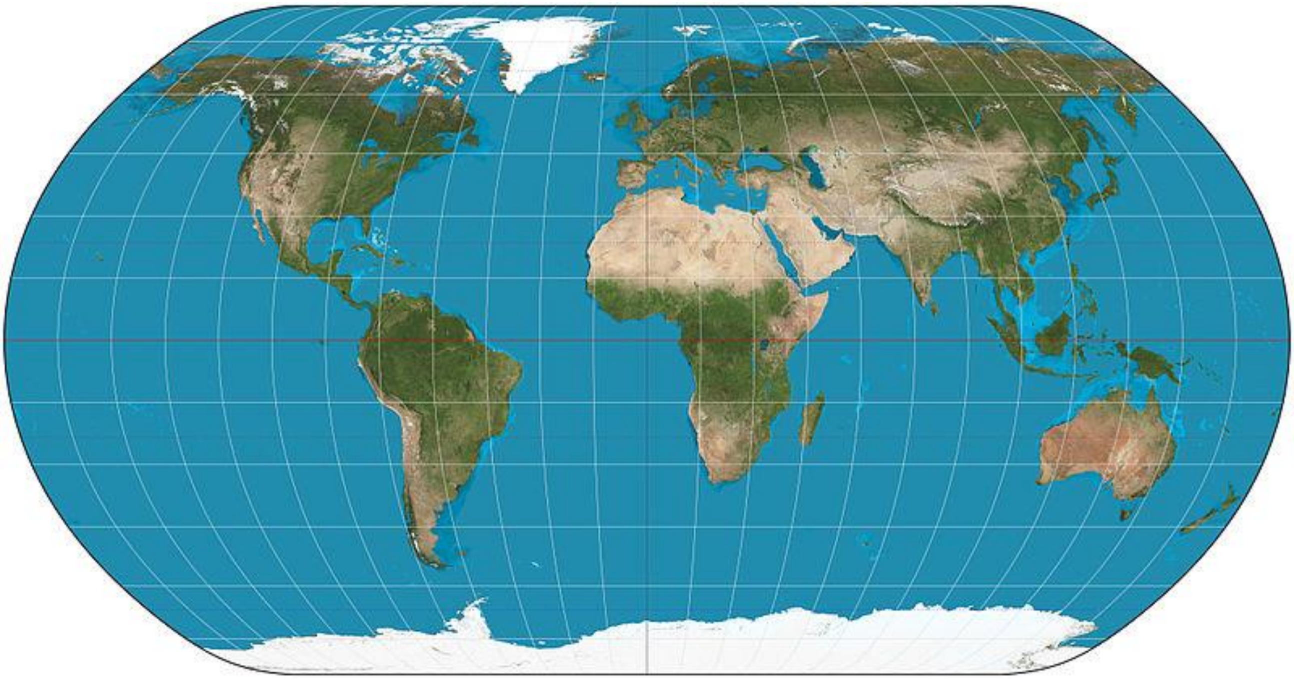
Burning-off excess gas at the Rumaila oil field, south of Basra in Iraq (https://www.theguardian.com/world/2016/feb/19/post-war-iraq-corruption-oil-prices-revenues).

In the Middle East and elsewhere, excess gas (as a by-product of oil generation) is burned-off in the wellfields. Why is the gas burned-off?

Oil spillage

Oil spillage is perhaps the greatest potential hazard of petroleum exploration and production.

In this regard, two environmental disasters stand-out – the 1989 *Exxon Valdez* oil spill and the 2010 Gulf of Mexico oil spill.



Natural Earth projection map (https://en.wikipedia.org/wiki/File:Natural_Earth_projection_SW.JPG)

Where on the natural Earth projection map are the locations of both the Exxon Valdez and Gulf of Mexico oil spills?

Case study 1: The *Exxon Valdez* oil spill occurred in Prince William Sound, when an oil tanker struck a reef in the very early hours of 24 March 1989. Approximately 260,000 bbl (41,000 m^3) barrels of oil were spilled into the marine environment.

The Exxon Valdez stuck on Bligh Reef, Prince William Sound. Photograph by Natalie Fobes/NG/Getty Images (https://www.theguardian.com/environment/blog/2014/mar/24/exxon-valdez-oil-spill-disaster-arctic)

Clean-up efforts after the Exxon Valdez oil spill (http://edition.cnn.com/2014/03/23/opinion/holleman-exxon-valdez-anniversary/index.html)

What systems failed to produce the Exxon Valdez catastrophe? And what were the environmental consequences of the incident? What effects of this incident still impact on the environment and economy of the region?

Case study 2: The *Deepwater Horizon* (BP) oil spill, perhaps more commonly known as the Gulf of Mexico Oil Spill was an environmental catastrophe that commenced on 20 April 2010 after an initial explosion. Some 4,900,000 bbl (780,000 m^3) making it the largest oil spill in history and by volume ~19 times that of the *Exxon Valdez* spill.

Gulf of Mexico, 2010: Fire boat response crews battling the fire that engulfed the offshore oil rig Deepwater Horizon (http://www.greenpeace.org/international/en/multimedia/photos/Deepwater-Horizon-Oil-Rig-Disaster/)

Oil slick post the Deepwater Horizon fire-fighting efforts (http://www.nytimes.com/2010/06/06/magazine/06fob-wwln-t.html)

In 2014, Anadarko, a large Texan oil exploration and production company was planning to undertake seismic (exploration) surveys in New Zealand's Pegasus Basin.

What systems failed that lead to the Gulf of Mexico catastrophe? And what were the environmental consequences of the incident?

Carefully compare and contrast the environmental consequences of the 1989 Exxon Valdez oil spill with those of the Gulf of Mexico oil spill?

Use the internet to carefully research both the 1989 and 2010 oil spillages. When doing so, be mindful of when the articles were posted on the internet, and the social/political context of the articles.

The volume of oil spilled in the Gulf of Mexico incident was ~19 times the volume spilled in Prince William Sound; however, which of these events caused the greatest environmental disaster and why?

Human development index (HDI)

Human Development Reports are published annually by the United Nations Development Programme. The **human development index** (HDI) is a summary measure of average achievement in key dimensions of human development: a long and healthy life, being knowledgeable and having a decent standard of living (http://hdr.undp.org/en/content/human-development-index-hdi)

Put another way, the HDI is a means of summarising a country's per capita wealth, and wealth-generative capacity, and its access to and utilisation of resources, including intellectual resources. The annual publication of HDI data is therefore an important aid in understanding the use of Earth's (limited) **renewable** and **non-renewable** resources.

Wikipedia is an excellent resource for learning more on the HDI (https://en.wikipedia.org/wiki/Human_Development_Index).

There has been a steady increase in HDI since 1980s (https://www.theguardian.com/global-development/datablog/2013/mar/14/un-human-development-index-2013-data), which is likely to reflect a dramatic increase in consumption of resources.

Non-renewable versus renewable

Use the IEA website to research how IEA member countries generate electricity. Compare and contrast the generation of electricity in Norway (#1 HDI), with Australia and Switzerland (equal #2 HDI), Germany (#4 HDI), Denmark (#5 HDI) the United States and Canada (equal #10 HDI), Japan (#17 HDI), China (#90 HDI), India (#131) and two countries of your choice.

How, since 1990, have these countries "changed their energy mix"?

How have the proportions of non-renewable versus renewable electricity generation changed in these 12 countries changed since 1990?

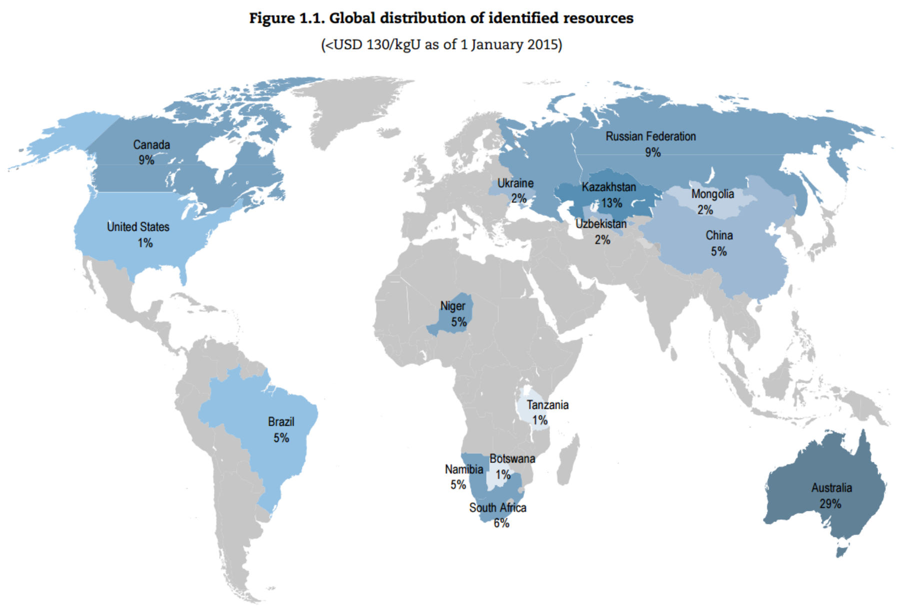
How reliable are the IEA data? Are there data on the internet that contradict or support the IEA data and/or your conclusions based on IEA data?

We shall revisit these countries' sustainable futures in Topic 4 of *Earth & Environmental Science*.

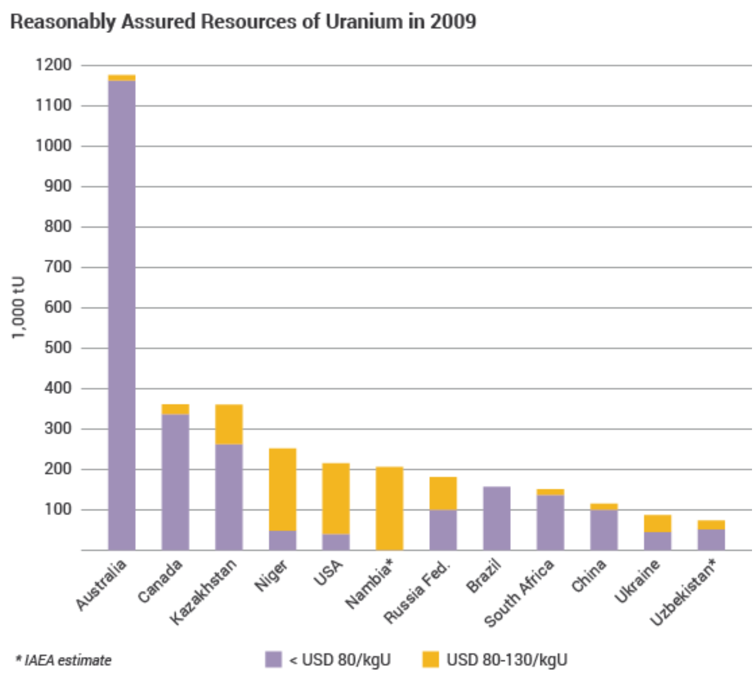
Nuclear energy

Other than fossil fuels, nuclear energy that uses uranium as a "fuel" is the other non-renewable energy source. Like other mineral commodities, the measured reserves are dependent on what the consumer market is willing to pay. Australia has ~ 34% of the world's "economically recoverable" uranium; however, Canada is the largest uranium miner with 15%, followed closely by Australia.

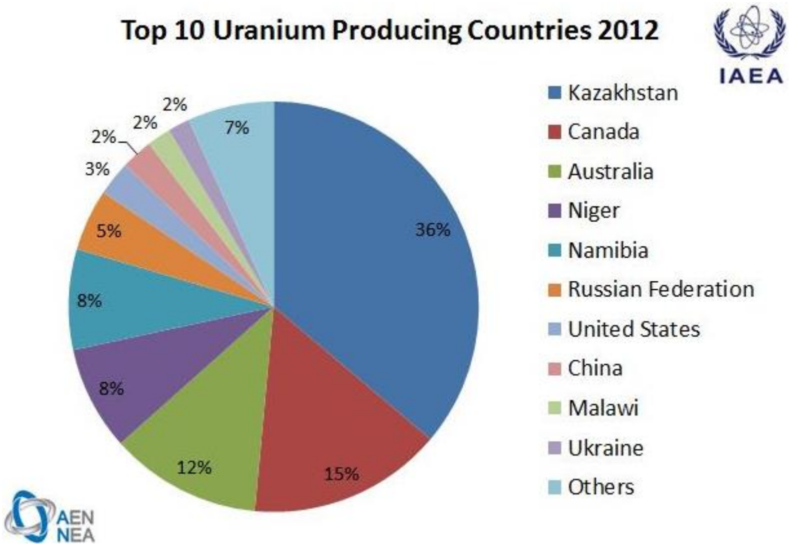
Despite such large reserves, other than for research purposes (Lucas Heights reactor, NSW) Australia has never had a domestic nuclear industry.



Global distribution of identified resources of uranium (http://uclnuclear.blogspot.com.au/2016/12/uranium-reserves-how-much-is-there.html)

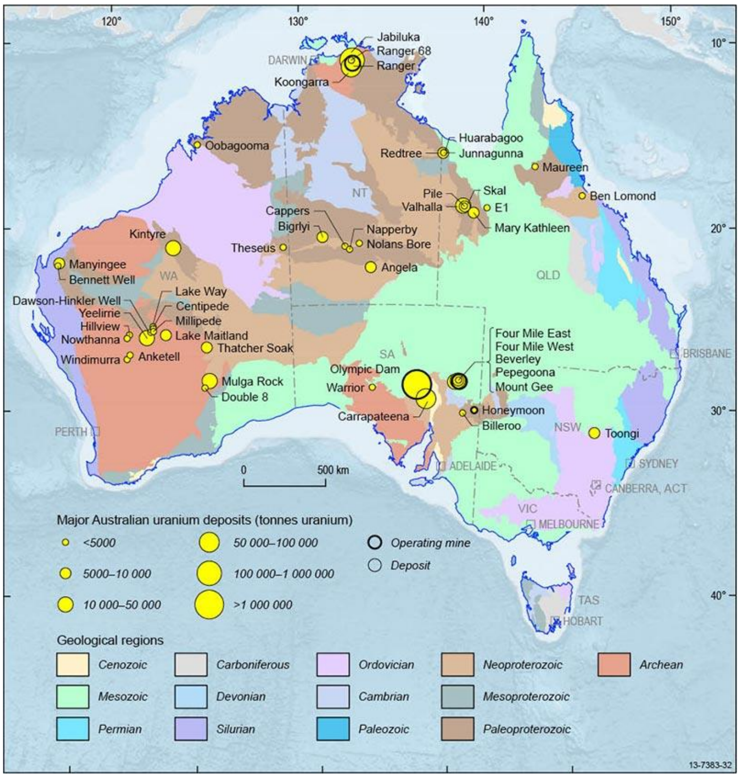


Reasonably assured resources of uranium in 2009 (http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/uranium-resources/supply-of-uranium.aspx)

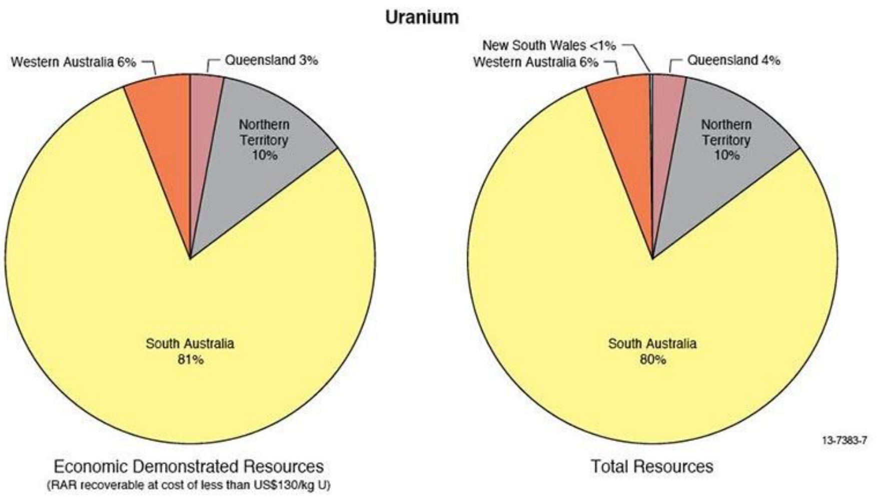


Top 10 uranium producing countries in 2012 (https://www.iaea.org/OurWork/ST/NE/NEFW/Technical-Areas/NFC/uranium-production-cycle-redbook.html)

In 2017, all of Australia's uranium production came from two mines in South Australia – Olympic Dam and Four Mile-Beverley.



Australia's major uranium deposits based on total "Identifiable Resources" by Geoscience Australia (http://www.ga.gov.au/data-pubs/data-and-publications-search/publications/australian-minerals-resource-assessment/uranium)



Percentages of Economic Demonstrated Resources (RAR: Reasonably Assured Recoverable) by Geoscience Australia (http://www.ga.gov.au/data-pubs/data-and-publications-search/publications/australian-minerals-resource-assessment/uranium)

The formation of non-renewable metallic mineral resources is related to their geological setting

Tectonic setting (see Topic 1: Earth Systems) is the first-order control on the localization of mineral deposits; e.g. if we wish to explore for mineralisation associated with volcanic rocks, it makes sense to explore in a volcanic arc setting such as Indonesia or the Andes Mountains in South America.

Some definitions:

A **mineral deposit/ore body** is defined as a volume of rock that contains one or more elements or minerals sufficiently above the average crustal abundance to be economically mined.

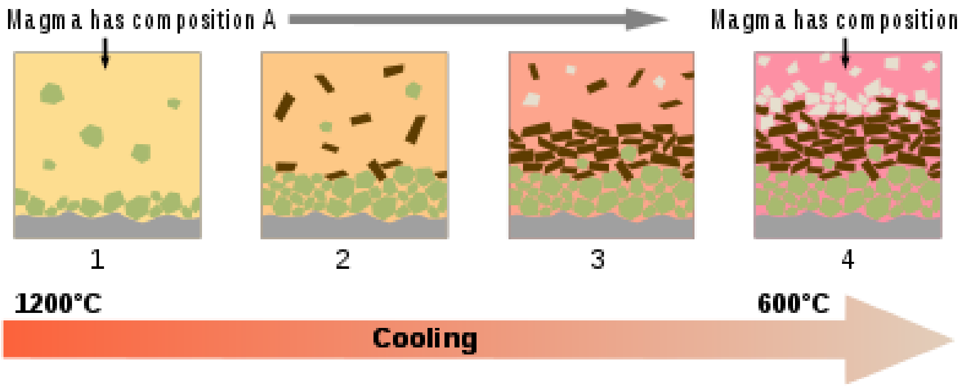
Within an ore body, minerals of economic interest are **ore minerals**, and the waste rock is called **gangue**.

Ore reserves depend on the degree of certainty of existence. The terms **measured** (most certain), **indicated**, or **inferred** (least certain) are typically used to describe ore reserves. The degree of certainty depends on many factors, particularly on the detail of the 3-dimensional model which is determined by the amount of drilling and assay work that has been undertaken. Drilling and assays are very expensive, so unless economics are favorable, many ore deposits are never "drilled-out" and have an "inferred" status for many decades.

- **Explain how metallic ores may be concentrated by gravity-settling and hydrothermal processes**

Gravity settling

Some ore bodies form within magma chambers from the crystallisation of mineral phases – these are called **orthomagmatic**. Chromite **seams** within large igneous bodies form in this way. Heavy minerals that form at higher temperature crystallise and sink to the base of the magma chamber, thereby altering the chemistry of the remaining magma.



Schematic representation showing crystallisation of different mineral phases from a magma chamber originally at ~1200 °C(https://sl.wikipedia.org/wiki/Frakcionirana_kristalizacija_(geologija))

In the above figure, it is useful to think of the dark-brown rectangles as representing **chromite** crystals (the phase of "economic" interest), the pale-green 5- and 6-sided as **olivine** crystals, and the white trapezoids are **feldspar**.

In South Africa and elsewhere, chromite seams within the Bushveld Complex are a major source of chromium and also Ni, Au, Ag, Pt, Pd and Rh.

*This outcrop of Bushveld Complex at Dwars River Gorge is heritage listed. The dark layers are chromite, and the pale layers contains **feldspar**, **pyroxene** and **olivine**. Photograph from a 2008 paper by James Mungall and Anthony Naldrett (http://elements.geoscienceworld.org/content/4/4/253/F5)*

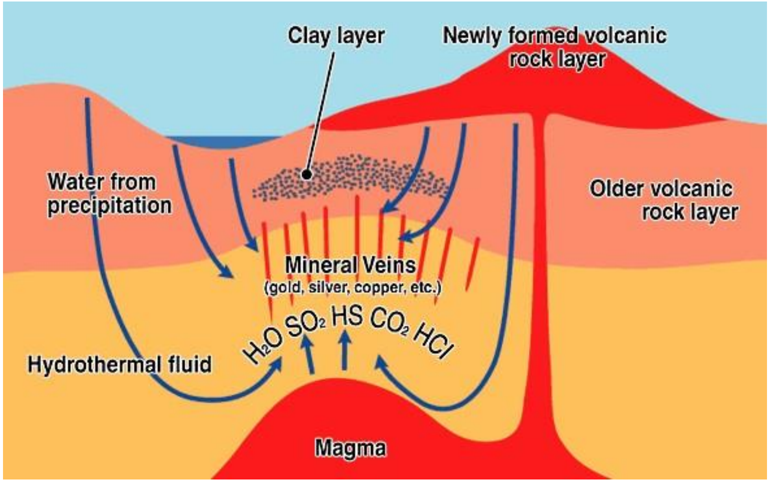
Google "historical price of rhodium" and compare your findings with the historic price of Au and Pt. What is Rh used for? Why did the price of Rh peak in 2008? [Hint: what other mined commodity(s) peaked in price around this time?]

Hydrothermal processes

Hydrothermal (hydro = water, thermal = hot) processes are geological processes that involve hot fluids (with quantities of dissolved NaCl, SO_2, HS, CO_2 and/or HCl) that carry metallic ions in hot (50–300 °C) solution and deposit them in sites that are cooler and chemically favourable for the precipitation of ore minerals.

The source of the metal ions can be either fluids associated with a magma intrusions or the **country rock** into which the magma has intruded.

Common hydrothermal minerals include **sulphide** minerals galena (PbS), chalcopyrite ($CuFeS_2$), bornite (Cu_5FeS_4), chalcocite (Cu_2S) and sphalerite (ZnS).

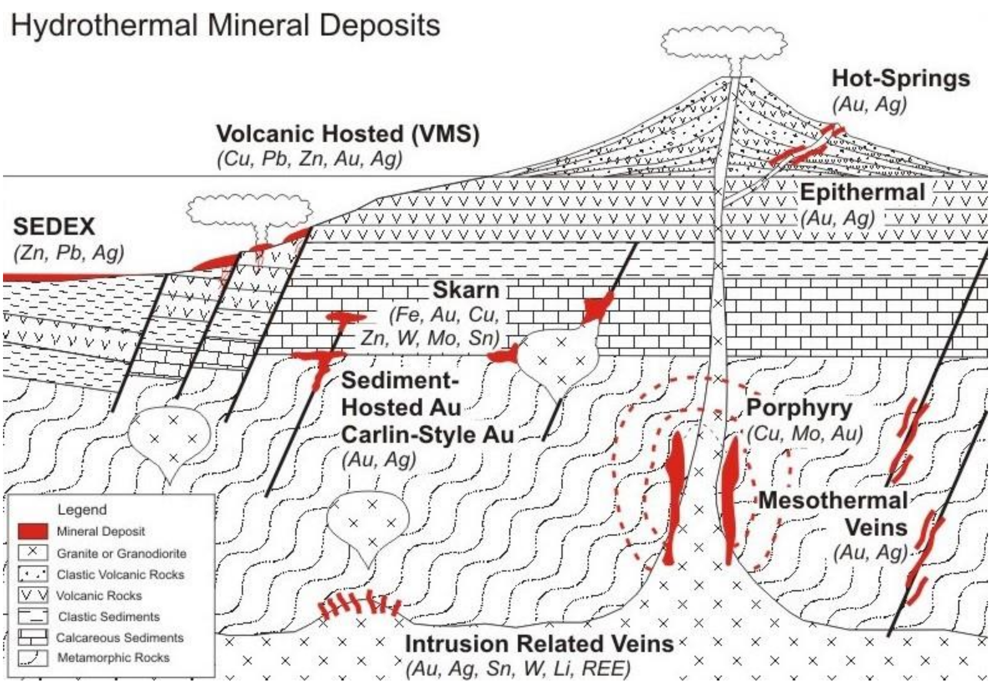


Generalised model for the formation of some types of hydrothermal ore: Schematic cross-section illustrating the concept of hydrothermal precipitation of ore minerals from hydrothermal fluid. "Country rock", much of which might be non-volcanic is shown in orange (https://www.geologyin.com/2014/12/magmatic-processes.html)

Unsurprisingly, areas with abundant hydrothermal deposits are located in (tectonically active) volcanic provinces like the Andes of South America.

The term "hydrothermal" is very broad in its meaning and includes mineralisation associated with black-smokers.

What is a black-smoker? Try to locate a black smoker on the figure below.



Types of hydrothermal mineral deposits.(http://solidusgeo.com/wordpress/home-3/deposits/). In this figure, the following rock types are indicated: igneous intrusions (crosses), metamorphic rocks (wavy lines) limestone (bricks), fine-grained sediments (dashes), volcanic lavas and sediments (v-symbols). The vertical scale in this figure is highly variable – intrusion related veins are likely to form at depths of 15–20 km.

*With respect to the igneous intrusion, volcanic rock and mineralisation, can you identify the so-called **country rock** on the figure?*

- **Explain how the processes of weathering, erosion, and deposition may concentrate metallic ores**

Placer deposits

Placer deposits form from the concentration of certain minerals that originally formed in igneous or metamorphic source rocks, but have since weathered out of the source rock, been transported as **sand-sized** grains and concentrated in a sedimentary **depositional environment**.

Weathering granite: Remarkable Rocks, Kangaroo Island (https://www.geocaching.com/geocache/GC23VG3_remarkable-rocks?guid=73a506e0-1467-4438-8a34-79bec5d030bf)

Weathering of granitic intrusions and metamorphic rocks of similar composition releases a variety of minerals. The essential minerals of **granite** are **quartz** and **feldspar** and usually a small percentage of dark minerals, chiefly the dark mica **biotite**. Of these, only quartz is physically and chemically resistive – eventually the feldspars and micas breakdown – both chemically and physically, undergo hydrolysis and are converted to clay minerals. Quartz crystals become quartz sand grains that are dispersed by streams, rivers and near-shore ocean currents.

See also geologycafe.com (http://geologycafe.com/erosion/weathering.html)

Apart from quartz there are **accessory minerals** present in small quantities within granitic rock. Typical accessory minerals that survive reasonably well in the sedimentary environment include **zircon** ($ZrSiO_4$), **cassiterite** (SnO_2), **ilmenite** ($FeTiO_3$), **apatite** ($Ca_5(PO_4)_3(F,Cl,OH)$), **rutile** (TiO_2), **leucoxene** (Ti-bearing but strictly not a mineral) and sphene (**titanite**: $CaTiSiO_5$).

When these, largely Ti-rich minerals accumulate in beaches or along **strandlines**, they can be referred to as **heavy mineral sands** because they are particularly dense and can be separated from quartz grains on the basis of their contrasting density with the later.

Which of the heavy mineral sands can be separated by their magnetic susceptibility?

Heavy mineral sands are a type of placer deposit preserved in ancient beach dunes. Visit Wikipedia to find out more on Australia's heavy mineral sand production (mostly ilmenite). Also use Google to research where Australia's heavy mineral sands deposits are located.

Gold, diamonds, cassiterite and garnet can also be preserved in placer deposits.

In which locality (country/basin) is the world's largest gold placer deposit? [we have already mentioned this previously]

What special properties does Ti have and what is it used for in the modern economy?

Laterite deposits

Laterite deposits also form by the weathering of rock – but the process is fundamentally different to the formation of placer deposits where mineral grains are transported. In the case of laterites, ore minerals are concentrated *in situ*. By the intensive weathering (notably under hot and wet tropical conditions) of fresh rock that breaks-down and dissolves silicate minerals, thereby concentrating metal ions. Essentially lateritic deposits form as a very deep soil profile.

Important laterite deposits exist for nickel, cobalt, aluminium and iron. In the case of nickel ore, the **fresh** (unaltered) rock type would have been e.g peridotite (a mafic rock formed in the mantle).

Perhaps the best-known lateritic ore is **bauxite**, the reddish-brown weathering product of basalt and the main ore of Al. The principal minerals of bauxite are **goethite** ($FeO(OH)$), **haematite** (Fe_2O_3) and **limonite** ($FeO(OH).nH_2O$). The **habit** of bauxite is typically **pisolitic**, as seen in the image below.

***Natural scale** (8 cm width) photo of a typical specimen of bauxite, comprising the reddish-brown iron oxides and the whitish clay **kaolinite**.*

Visit Sandatlas (http://www.sandatlas.org/laterite/) to learn more about laterites.

Which country has the largest reserves and largest output of bauxite?

- **Explain how the formation of iron ore (banded iron formations) occurred in an anaerobic environment**

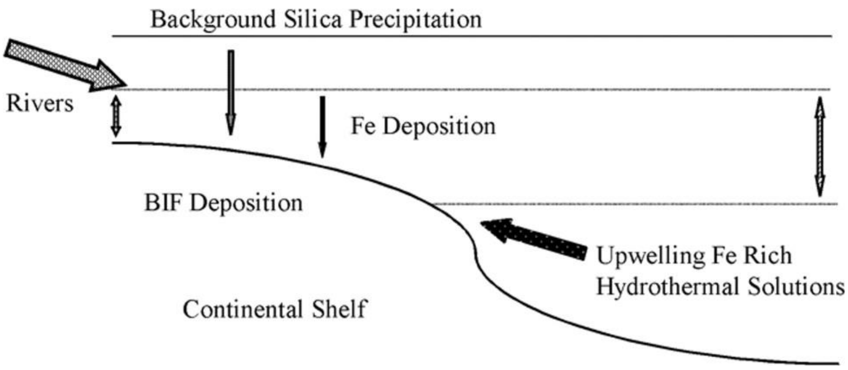
Banded iron formations (BIF) are reddish banded rock strata comprising alternating bands of iron-rich dark-greyish/black and iron-poor bands (reddish-orange). Bands are typically a few millimetres to a few centimetres in thickness.

- Iron-rich bands are rich in either magnetite (less oxidised: Fe_3O_4) or haematite (more oxidised: Fe_2O_3).
- Iron-poor bands are chert (jasper) or shale, comprising mostly silicates.

There are several theories concerning the formation of BIF. The most accepted idea is that BIF formed as the level of atmospheric oxygen (O_2) dramatically increased at around 2.5 Ga ("Great Oxygenation Event"). At this time atmospheric oxygen increased due to **photosynthesis** [$6CO_2 + 6H_2O +$ sunlight $\rightarrow C_6H_{12}O_6+6O_2$] by **cyanobacteria** in the saline ocean.

- When **dissolved** O_2 combines with dissolved Fe, **insoluble** iron oxides form and **precipitate** to form the iron-rich bands.

- Iron-poor bands form when there is a shortage of available O_2, due possibly to seasonal fluctuations or changes in water depth whereby in deeper water, especially below the **photic zone** (which can vary from a few cm to maybe 200 m) there is likely to be less oxygen available.
- BIF was deposited on continental shelves.
- Iron probably was derived from reduced hydrothermal fluids.
- Silica was probably derived from continental weathering.



Cartoon model to describe the formation of BIF upon continental shelves during the Proterozoic, from a paper by Hamade et al. (2002) in the journal Geology (http://geology.geoscienceworld.org/content/31/1/35)

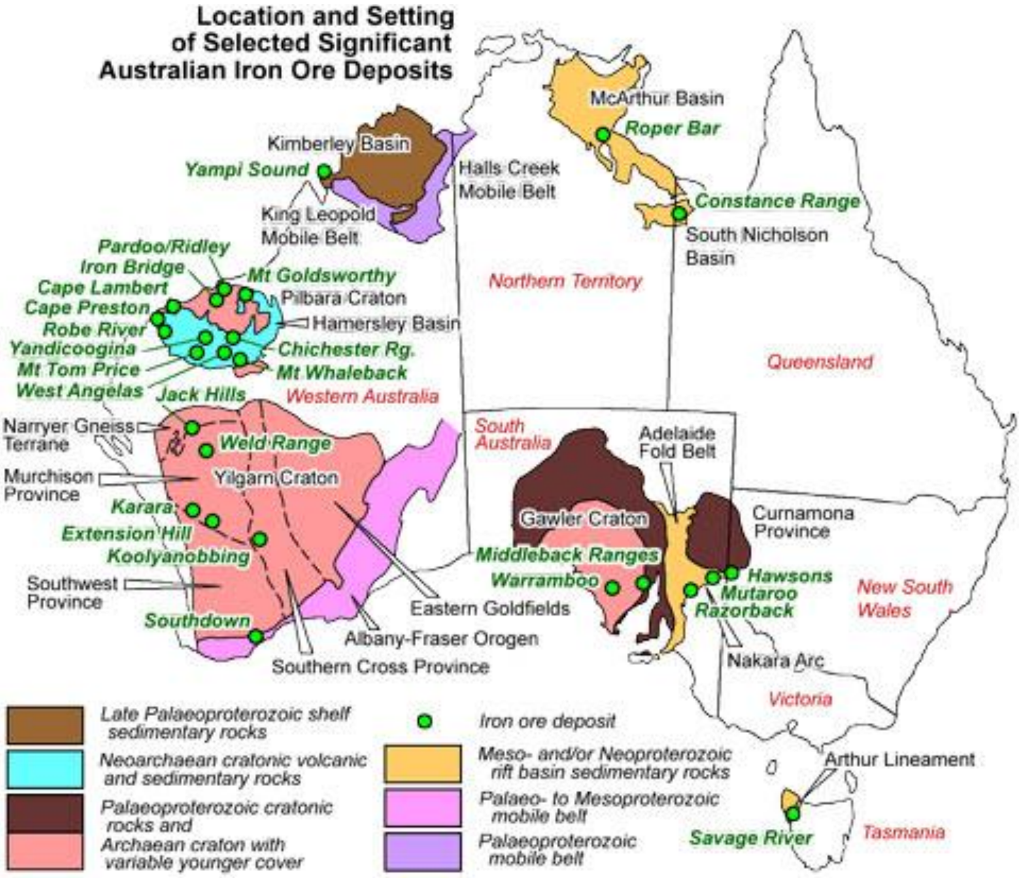
Most Precambrian BIF has an age of between 2.4 and 1.9 Ga, suggesting that, for whatever reason, from about 1.8 Ga iron oxides became more soluble (and/or less plentiful) in the oceans.

Banded iron formation (http://cdn0.cosmosmagazine.com/wp-content/uploads/20090309_banded_iron_format.jpg)

BIF formation became once again, more widespread later in Earth's history at 750 Ma during the time of "Snowball Earth". We shall briefly revisit the formation of BIF in Topic 3 (Climate Change).

Most of the world's large iron ore deposits are associated with BIF terranes. Indeed, the giant deposits of iron ore found in Western Australia and in South

Australia were originally BIF deposits; however, subsequent to their deposition in marginal marine environments, fluids have passed through the rock, thereby removing the non-Fe rich layers and upgrading the formations to iron ore.



Location of iron ore deposits with respect to Precambrian geological provinces by Porter Geoscience (http://www.portergeo.com.au/tours/iron2013/iron2013deposits.asp)

- **Identify metallic ores, using their physical and chemical properties.**

Minerals, can be identified using their physical properties. You have been supplied with a separate sheet of instructions on how to use properties such as **hardness**, mineral **cleavage**, **habit**, **density**, **magnetic susceptibility** and **streak** to identify some important ore minerals.

You have been supplied with hand specimens of various types of ore minerals, including magnetite, haematite, galena, sphalerite, chalcopyrite and others. Where might some of these ore minerals have originated?

A variety of techniques can be used to discover deposits of mineral and energy resources and identify the extent and quality of these resources

- **Discuss techniques for finding mineral resources, using magnetic and electromagnetic surveys, geochemical sampling, and drilling**

Magnetic surveys

Magnetic geophysical surveys measure very small variations in Earth's magnetic field. Rock strata have different magnetic properties, and local variations in the magnetic field reflect different **lithologies** (rock types) and their structure. Magnetic surveys are carried out using a **magnetometer** – either hand-held or mounted within an aircraft.

Magnetic surveys are particularly useful for mapping:

- mafic (Mg and Fe-rich) igneous intrusions
- faults
- the size and shape of ore bodies
- archaeological sites and in particular buried iron and steel objects.

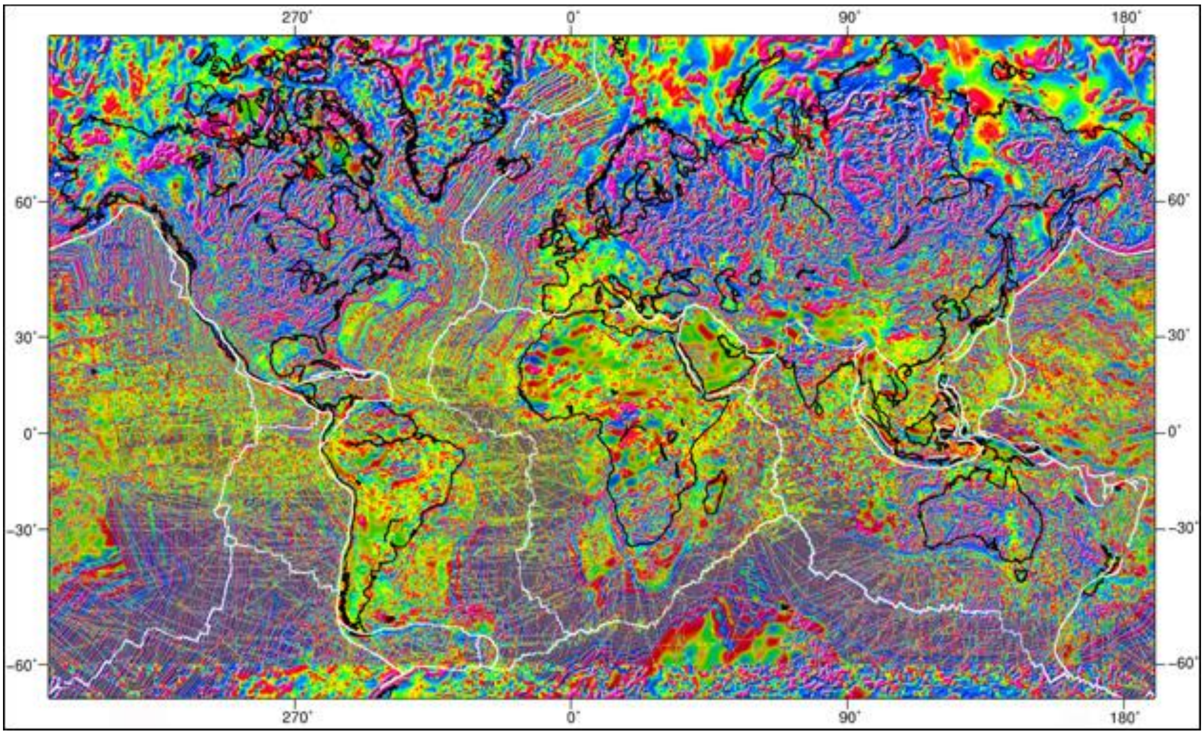
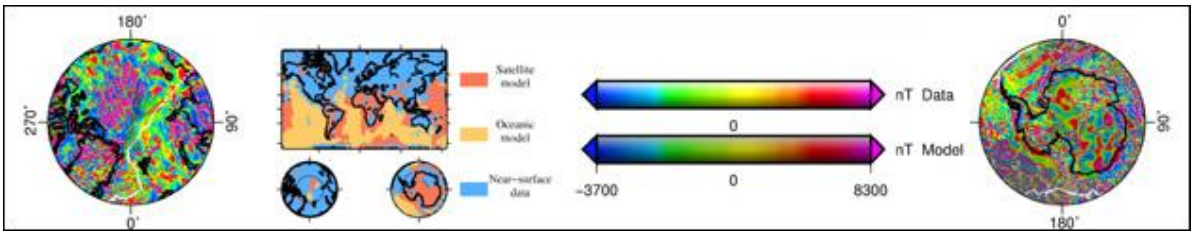
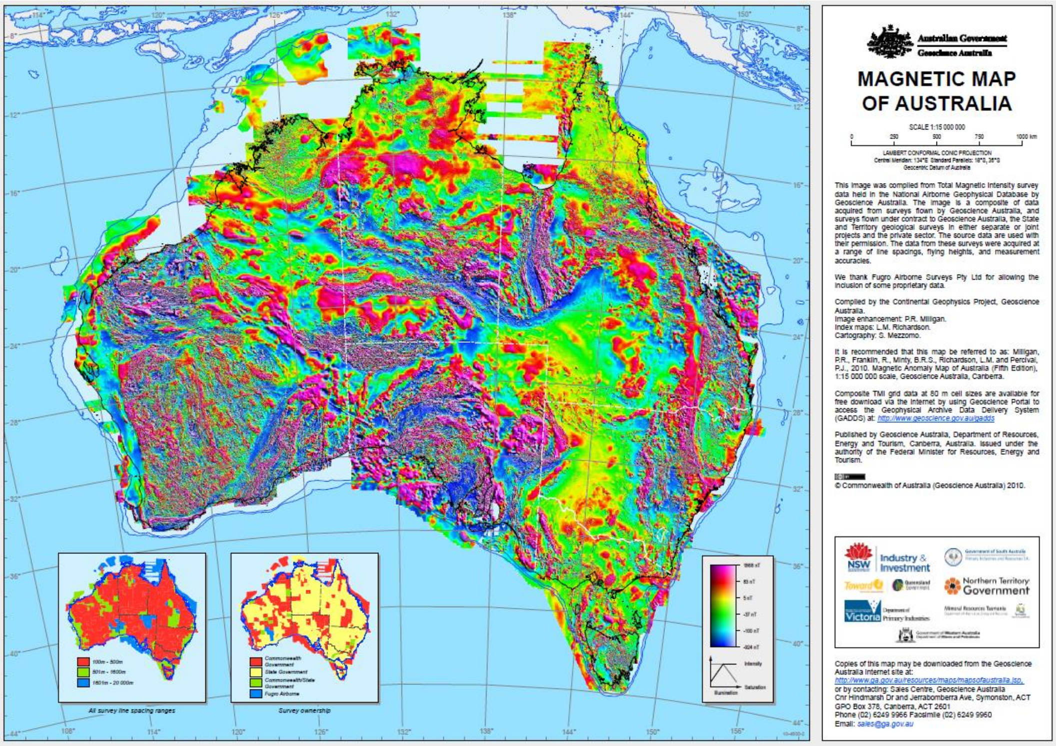


Image: Korhonen JV, Fairhead JD, Hamoudi M, Hemant K, Lesur V, Mandea M, Maus S, Purucker M, Ravat D, Sazonova T,and Thebault E, 2007, Magnetic Anomaly Map of the World (and associated DVD), Scale: 1:50,000,000, 1st edition, Commission for the Geological Map of the World, Paris, France.

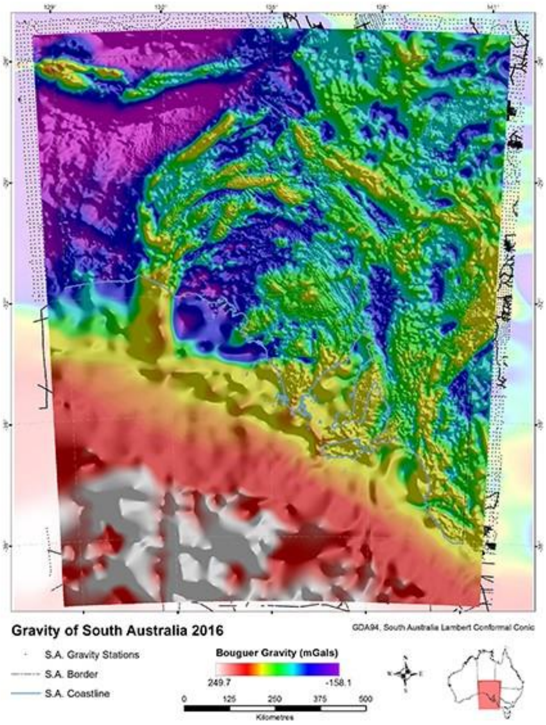


World Digital Magnetic Anomaly Map (WDMAM). This is a map of Earth's magnetic field the dipole field (magnetism from electrical current in Earth's mantle) have been removed (http://news.bbc.co.uk/2/hi/in_depth/629/629/7072715.stm).

The figure below (*Magnetic Map of Australia* by Geoscience Australia) shows the variation of measured magnetic intensity (nT) across the continental crust of onshore Australia. Compare the large-scale Geoscience Australia image with the part of the WDMAM corresponding to Australia. It is fundamentally the same because the Geoscience Australia data was used in constructing the smaller-scale Earth model.



Magnetic map of Australia by Geoscience Australia (https://d28rz98at9flks.cloudfront.net/70282/70282_A3.pdf



Bouguer ground-station gravity grid of South Australia. The onshore cell sizes used to construct this image range from ~ 50 m to ~11 km, and hence the level of detail varies (http://minerals.statedevelopment.sa.gov.au/knowledge_centre/mesa_journal/news/south_australia_gravity_gets_better).

For a geological (province-scale) interpretation of the 2016 Bouguer gravity map visit https://sarigbasis.pir.sa.gov.au/WebtopEw/ws/plans/sarig1/image/DDD/204782-001.

Electromagnetic surveys

Electromagnetic geophysical surveys (EM surveys) measure the conductivity at the surface using the principal of electromagnetic induction.

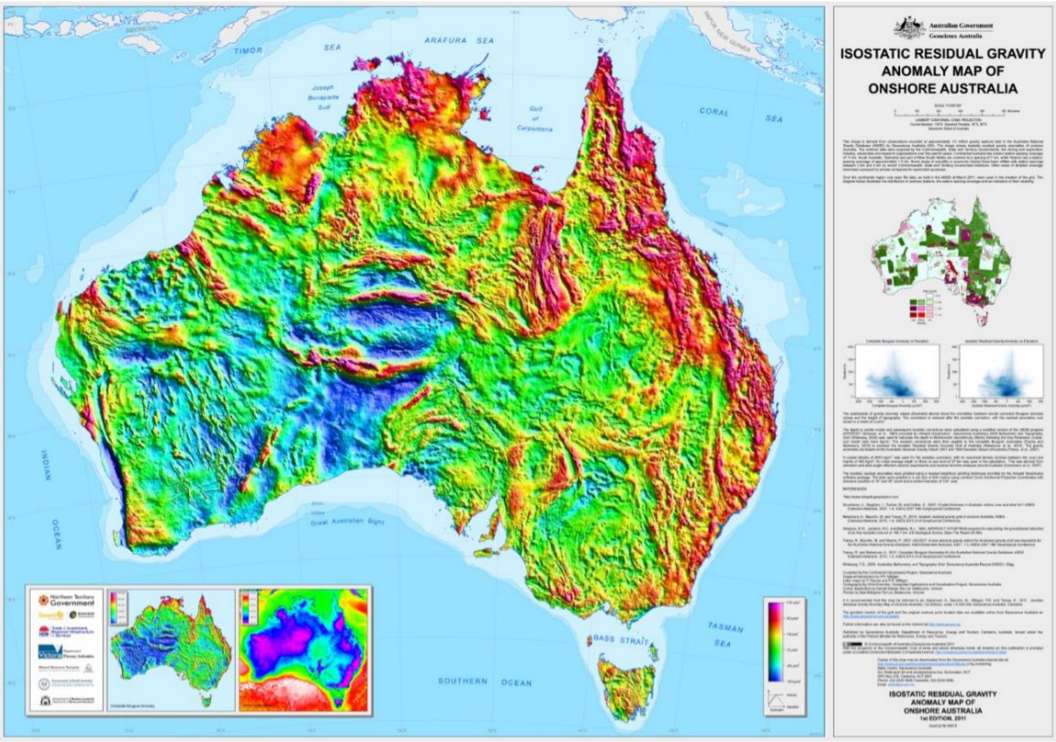
Ore minerals are typically more conductive that the surrounding **gangue** mineralisation and the host **country rock** (barren and unaltered rock) that surrounds the gangue.

EM surveys are useful for mapping:

- conductive (clay) and non-conductive (sand) lithologies
- saline groundwater *versus* fresh groundwater
- bedrock discontinuities and mineralised veining

Gravity surveys

Modern geological mapping includes gravity surveys and the production of gravity anomaly maps that have been assembled using sophisticated computer enhancement techniques. These kinds of images are used in conjunction with conventional geological maps by mineral exploration companies. Significantly, the position of the giant Olympic Dam Cu-Au-U mine in central South Australia is highlighted by both a positive magnetic and gravity anomaly.



Isostatic residual gravity anomaly map of onshore Australia
(*https://d28rz98at9flks.cloudfront.net/69878/69878.jpg*)

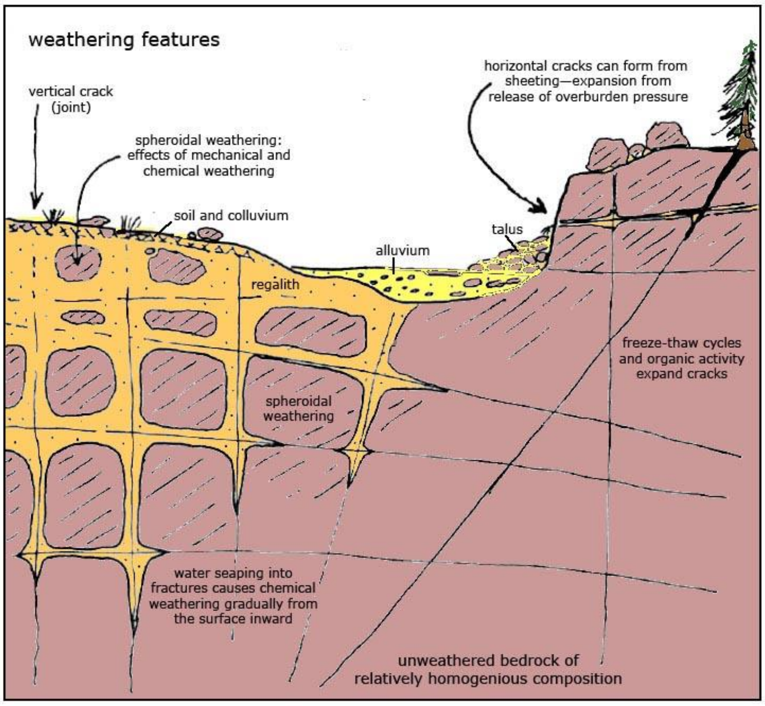
Geochemical sampling

Geochemical sampling is much cheaper than drilling, and is often undertaken after geophysical data have been acquired, processed and interpreted. All samples of soil and rock are recorded with a unique number that is referenced to **GPS** (global positioning system) coordinates, to allow the position of the sample to be located with respect to other **GIS** (geographic information system) data.

<u>Soil sampling</u>

Soil and other **regolith** (all loose and altered superficial material covering unweathered rock) are developed upon fresh bedrock by the process of weathering and transportation. If, prior to weathering, the fresh bedrock contained say anomalously high Au, it is logical that soil developed above the bedrock will be rich in Au. Thus it is possible to sample and geochemically analyse soil and other regolith samples as a vector towards mineralisation. Soil sampling is usually undertaken in the field by geological field assistants, or junior geologists.

Before despatch to a laboratory, soil samples are sieved to remove organic material and larger granule and sand-sized particles are also removed. Typically, the highest concentration of indicator elements, e.g. Cu, Pb, Zn and As (As is an **pathfinder** for Au), are present in the clay and silt-sized fractions.



Weathering features developed upon a granitic terrane, including soil, colluvium, talus and alluvium (http://geologycafe.com/erosion/weathering.html).

Biogeochemical sampling

Biogeochemical surveys involve the sampling of vegetation, animal faeces and termite mounds to as a proxy to sampling and assaying soil or rock. Vegetation takes in water through a root system and elements such Au, Ag, Pb and Zn can become concentrated in the plant.

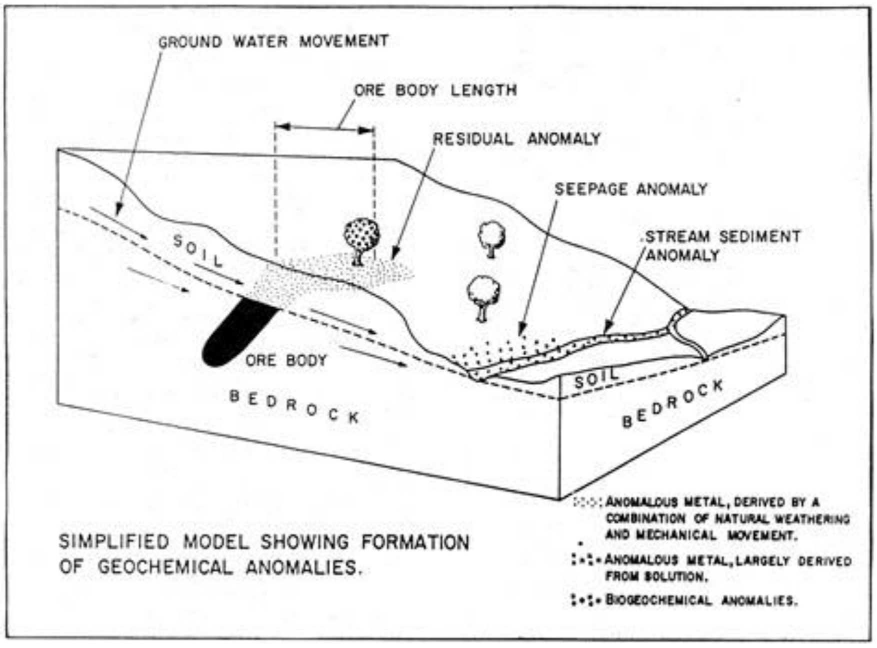
Herbivores such as kangaroos eat vegetation that can be enriched in elements of interest to explorers. Similarly, termite mounds can be enriched in metals that have been transported from deeper within the regolith.

Rock-chip sampling

With rock-chip rock sampling samples of fresh rock are collected for laboratory analysis, and this is done whilst geologist undertake field mapping, to provide context for the rock samples. The logic of rock sampling is similar to soil sampling – i.e. rock that is close to e.g. a gold ore body will have anomalously high Au content.

For additional details regarding soil and rock sampling in mineral exploration visit https://www.geologyforinvestors.com/rock-and-soil-sampling-the-key-to-most-exploration-projects/

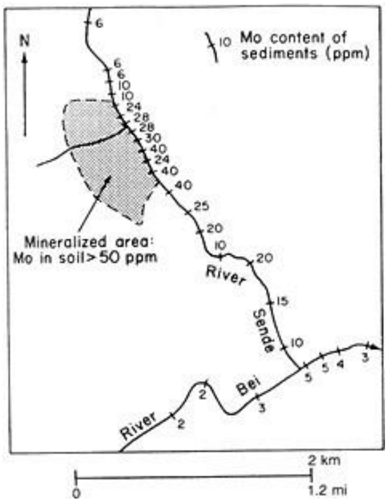
Recommended procedures for geochemical sampling and analysis: http://crcleme.org.au/Pubs/guides/curnamona/geochem_sampling_proc.pdf



Dispersion of metallic ions in soils and stream sediments near an ore body. Figure taken from the SME Mining & Engineering Handbook (http://www.unalmed.edu.co/~rrodriguez/geologia/mex/mex12.htm)

Stream sampling

Stream sediment sampling is a very effective way to test for mineralisation within a stream or river catchment. Silt-sized sediment has been shown to be that which is most likely to have metallic anomalies. As small streams merge to form large rivers it is likely that the concentrations of metallic ions will decrease resulting from dilution. It is therefore logical to follow the geochemical anomaly upstream to its source ore body.

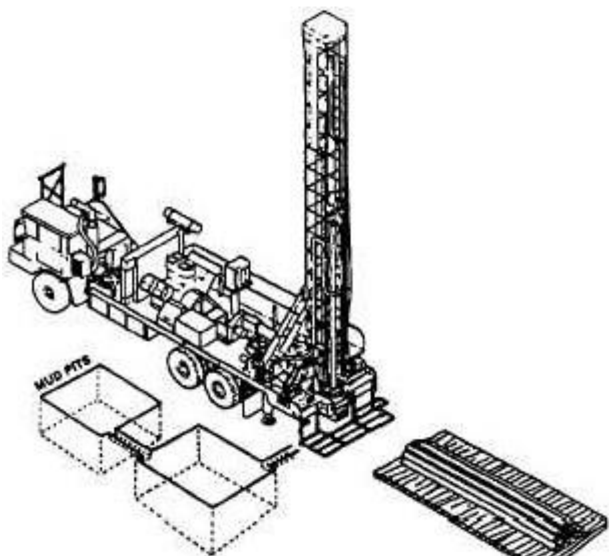


Stream sediment Mo anomaly in the vicinity of Mo mineralisation. Figure taken from the SME Mining & Engineering Handbook (http://www.unalmed.edu.co/~rrodriguez/geologia/mex/mex12.htm)

Drilling

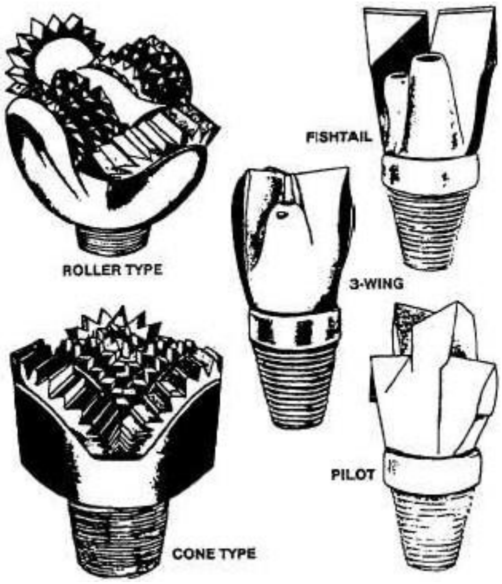
Rotary mud drilling

Rotary-mud drilling is a relatively cheap drilling technique, common for drilling through unlithified sediments or relatively soft rock. The technique is commonly used to drill water-wells and shallow (≤ 250 m) uranium exploration holes.



Types rotary-mud drilling set-up with two mud pits, and a stack of drilling rods (http://enginemechanics.tpub.com/14080/css/Kelly-Drive-Rotary-Drilling-Operations-207.htm)

As the name suggests, the **drilling-fluid** is mud (**bentonite** clay), and rotary-mud drilling involves a rotation of drill rods with various drill bits attached to the end of the deepest rod. The dense mud helps to hold the hole open during drilling. As the mud circulates, it also brings rock or sediment particles to the surface that can be washed clean and dried for study and chemical assay.



Types of drill-bits used in rotary-mud drilling. (http://enginemechanics.tpub.com/14080/css/Kelly-Drive-Rotary-Drilling-Operations-207.htm)

In the figure above, the three blade drill-bits on the right are the types used when the strata are comprised of clay and unlithified sand. The two rock-roller type drill-bits on the left are used for hard and lithified sedimentary rock. Rotary-mud drilling requires a water supply to make and maintain drilling fluid – typically 1000 to 4000 litres of water are required in one 8-hour shift.

Rotary-mud drilling is the form of drilling used for petroleum exploration and production holes.

Diamond core-drilling

The term "diamond drilling" is jargon for **diamond core-drilling**, where coherent rock or sediment core is recovered to the surface. The core is cut from the stratum by a cylindrical drill-bit, where the cutting edge is impregnated with **diamonds** set in **tungsten carbide**. Otherwise the drilling-rig set-up for diamond drilling is similar to that of rotary-mud drilling. Diamond core drilling is time-consuming, more technically demanding than rotary-mud drilling, and considerably more expensive.

What is tungsten carbide? And what are its uses?

RAB (rotary air blast) drilling

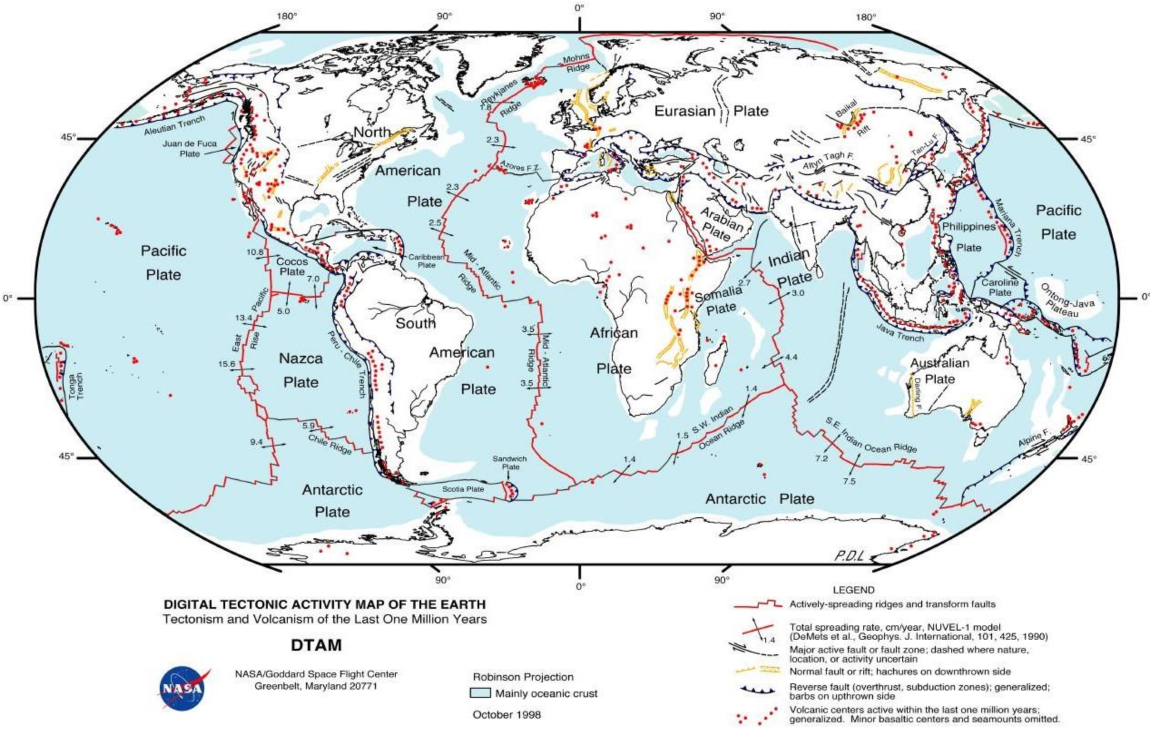
RAB drilling is one of the main (cheap and quick) drilling methods used in the "minerals industry" where drilling through hard crystalline rock is needed. RAB drilling utilises a pneumatic piston-driven hammer to drive a drill-bit into rock. Rock chips and dust (collectively called drill **cuttings**) are collected at the surface after being blown up the outside of the drill-rods. The RAB drilling technique is typically used to depths of only ~25 metres.

There are other types of drilling, descriptions of which can be found at https://en.wikipedia.org/wiki/Drilling_rig.

Tough question: Suggest why it is almost pointless drilling for mineral deposits below ~ 2 km in Australia? (This requires quite a bit of lateral thinking, but it is answerable)

Cryptic clue 1: there are operating mines in South Africa that are much deeper – the deepest mine in the world is AngloGold Ashanti's Mponeng gold mine in the Witwatersrand Basin near Johannesburg (South Africa), where the present operating depths are between 2.4 and 4.0 km.

Cryptic clue 2: Identify the location of Johannesburg and Australia on the tectonic activity map of Earth.



Tectonic activity map of Earth (https://globalchange.umich.edu/globalchange1/current/lectures/evolving_earth/tectonic_map.jpg)

Cryptic clue 3: How deep and where is the deepest underground mine in Australia?

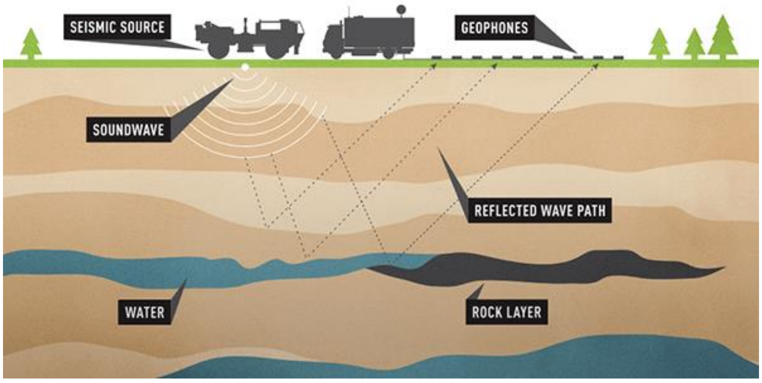
- **Explain how seismic and gravity surveys are used in petroleum exploration**

Seismic surveys in petroleum exploration

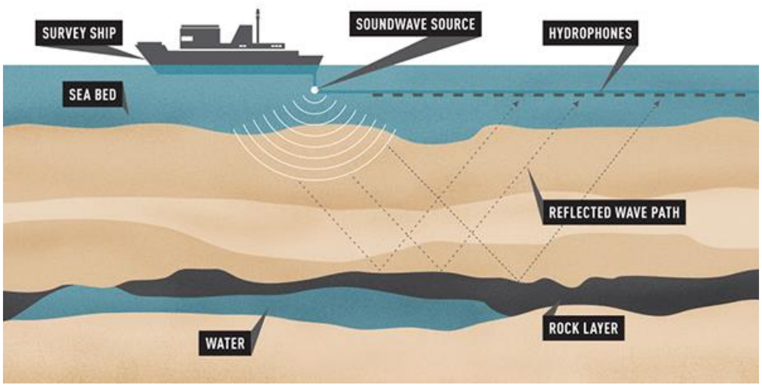
Seismic surveys are the most widely used geophysics technique in petroleum exploration – the principal underlying the technique is much like monitoring naturally occurring earthquakes – except in that in a seismic survey, the sound or shock wave is artificially induced.

Sound waves travel through media, i.e. rock, water saturated rock and oil-bearing rock, at different velocities. And sound waves reflect and refract at geological boundaries (i.e. where two rock types make contact).

The principals are similar between onshore and offshore seismic surveys, except that in the case of offshore surveys, a ship tows a soundwave source (sound-generating device) and hydrophones, that like the geophones on land, capture the soundwave after it has travelled through the rock layers.



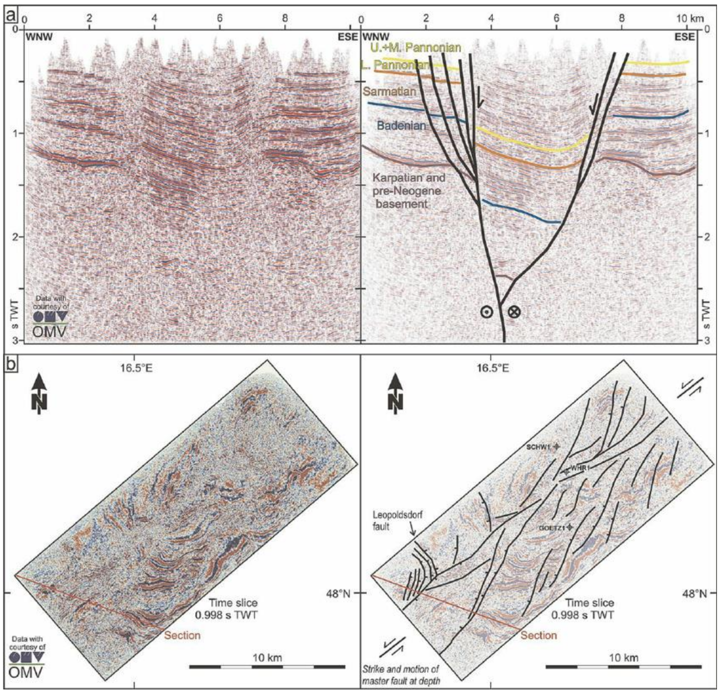
Cartoon of onshore seismic survey (https://www.appea.com.au/oil-gas-explained/operation/seismic-surveys/)



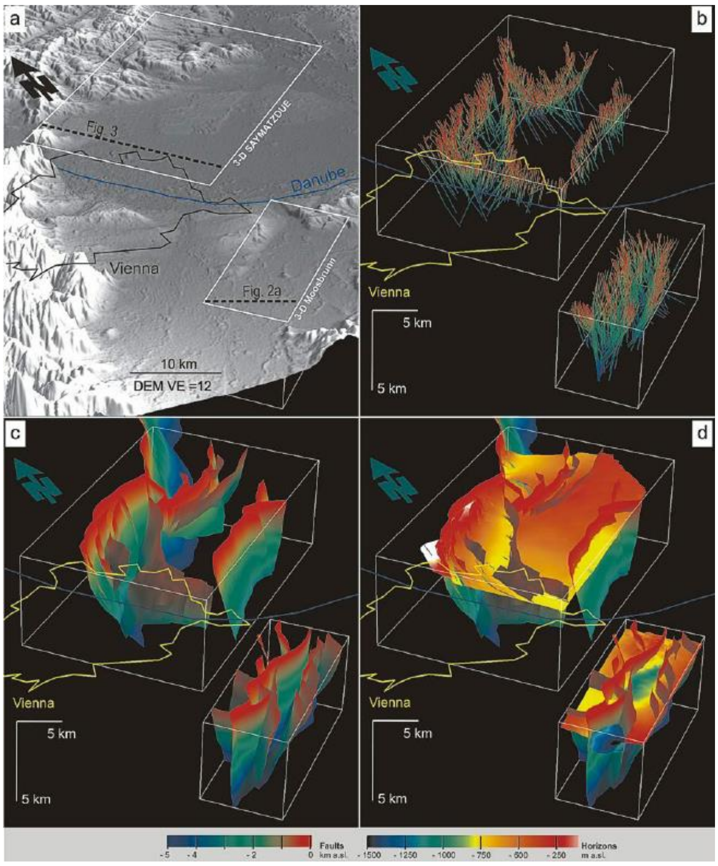
Cartoon of onshore seismic survey (https://www.appea.com.au/oil-gas-explained/operation/seismic-surveys/)

When compared to drilling expensive drillholes through, say 1500 – 4000 metres of sedimentary rock, seismic surveys are a very cheap and therefore necessary way to explore large areas. When conducted properly, seismic surveys will not impact on man-made structures, and arguably have little if any lasting impact on marine ecosystems. In the past, for seismic surveys to be conducted on land, tracks need to be established and there is significant local disturbance to vegetation. However, the current practice is for vegetation to be rolled-over with no disturbance to the roots of plants therefore allowing for rapid recovery of the vegetation.

<u>2-dimensional seismic data and interpretation</u>



Vienna Basin: 2D seismic data and interpretation published by Hinsch et al. (2005) in the Austrian Journal of Earth Sciences (https://www.researchgate.net/figure/279790241_fig1_Figure-2-3-D-seismic-interpretation-in-the-southern-Vienna-Basin-3D-Moosbrunn-of-OMV



Vienna Basin: More sophisticated and expensive 3D seismic data and interpretation published by Hinsch et al. (2005) in the Austrian Journal of Earth Sciences (https://www.researchgate.net/figure/279790241_fig2_Figure-4-Modeling-of-faults-and-horizons-from-3-D-seismic-interpretation-data)

Based on the seismic data and interpretations (above), if you had funding to drill one well to explore for oil, where would you place it?

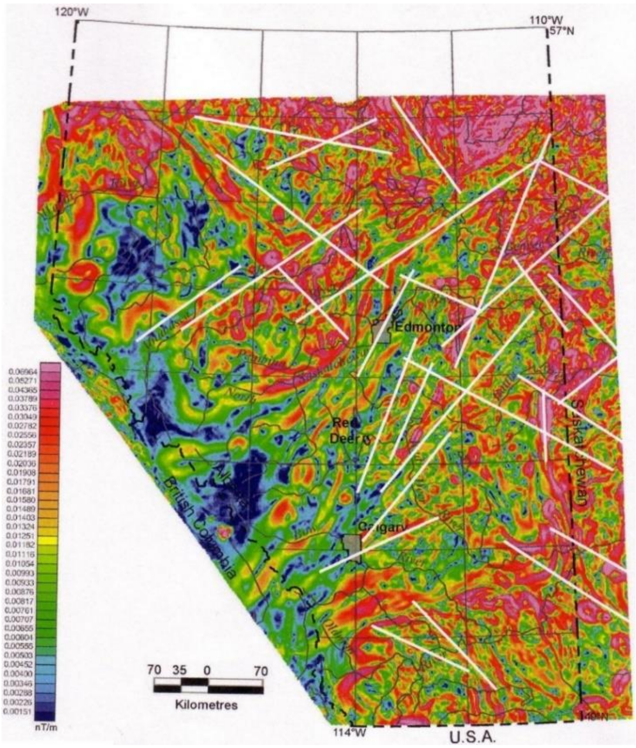
Gravity surveys in petroleum exploration

Variations in gravity across an area can be caused by variations in topographic relief as well as changes in rock density of rock units beneath the ground surface.

A **gravity low (negative anomaly)** occurs where the subsurface has a lower density than its immediately surrounding or **background** gravity. All things being equal, a gravity high is present where rock density is relatively high causing a **gravity high (positive anomaly)**.

To conduct an **airborne gravity survey** over, for example the Himalayas in search of a mineral or petroleum field would be pointless because variations in gravity will result from the extreme variations in topography. However, an airborne gravity survey over most of relatively flatAustralia is a very sensible enterprise, because variations in gravity result in changes in rock density. Thus geophysical surveys (e.g. gravity) result in useful maps that provide explorers with important information about what is buried beneath the surface.

Gravity (and magnetic) surveys help to delineate hidden faults and fault networks, that may or may not be favourable for the petroleum entrapment.



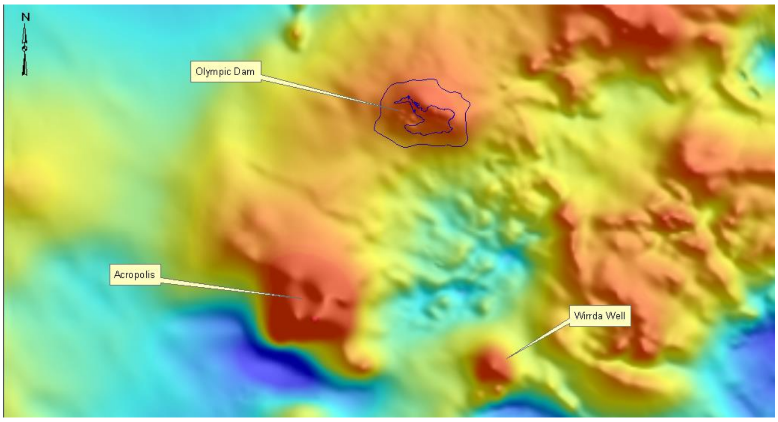
Regional magnetic map of central and southern Alberta (Canada) indicating lineaments as white lines, after Lyatsky et al. (2005) and Lyatsky Geoscience Reseach and Consulting Ltd (https://www.epmag.com/gravity-and-magnetic-geophysical-methods-oil-exploration-1364421#p=5)

Olympic Dam (Cu-Au-U-Ag) deposit

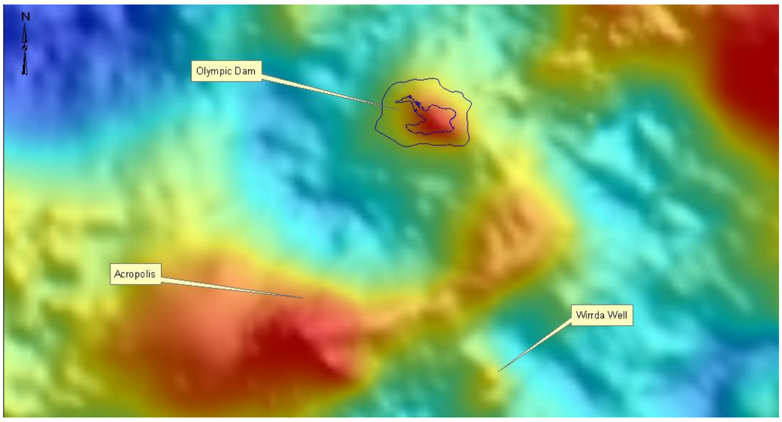
The **polymetallic** Olympic Dam deposit in central South Australia is the world's fourth largest copper deposit and largest uranium deposit. Most of the mine's revenue is derived from copper with lesser income streams from uranium, gold and silver. The large iron in the deposit is not recovered nor are the **platinum group elements** that occur in sub-economic quantities.

Magnetic & gravity signature of Olympic Dam

Olympic Dam, like many ore bodies has a magnetic signature; however, this may have little or nothing to do with the ore minerals themselves. For example, magnetic anomalies associated with gold mineralisation are invariably due to either **magnetite** or **pyrrhotite** (FeS) which are **gangue** minerals.



Olympic Dam geophysics – Total Magnetic Intensity (East-West dimension of Olympic Dam is ~ 6 km)



Olympic Dam geophysics – Bouger Gravity (East-West dimension of Olympic Dam is ~ 6 km)

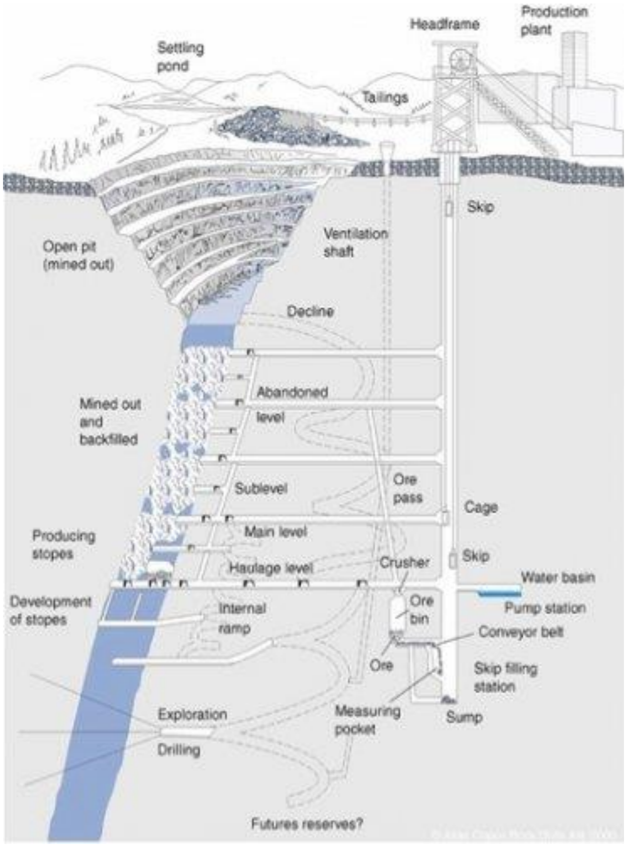
Buried beneath ~350 metres of barren regolith, Olympic Dam deposit, has both a positive magnetic and positive gravity response. The magnetic response is derived from huge quantities of magnetite that host the ore minerals, and the gravity response is due to the fact that the ore body is considerably denser than the surrounding **country rock**, comprising Proterozoic Hiltaba Granite.

The depth, extent, and location of mineral and energy resources determine the method of extraction

- Describe the essential features of underground, open-cut, and *in situ* leaching methods of extraction of mineral resources

Underground mineral extraction

As the name suggest, underground mining operations occur in the subsurface, especially if the shape of the ore body is complex and of sufficiently high grade to be economic. To warrant going deep underground, the ore body must be of very high grade. In China and other counties where the workforce costs are relatively cheap, and safety concerns are not as stringent as in western countries, black coal is still mined underground.



Generalised design of an underground mine (http://www.allaboutmining.org/page/offerings/field-trip-component)

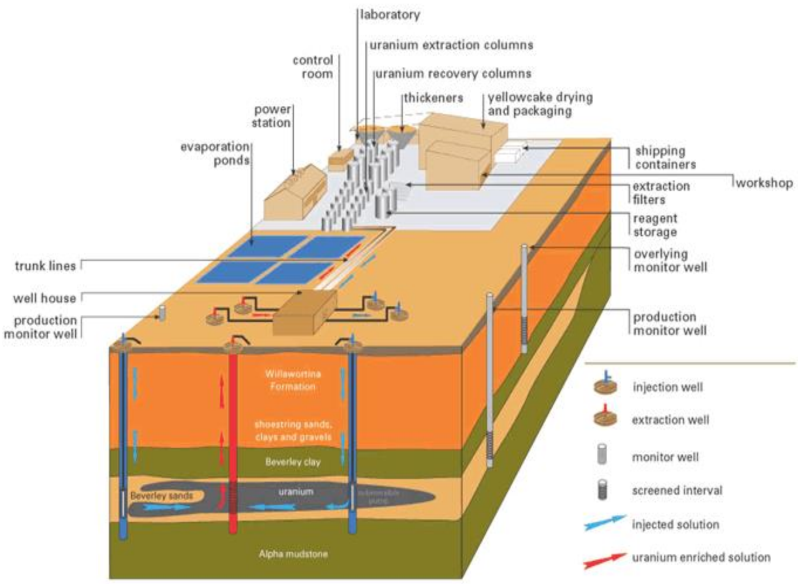
Open-cut mining

Open-cut mining is particularly suitable where the ore body is near the surface and is a common way of mining what is more-or-less considered a "bulk commodity" like iron ore or coal (see below).

In situ leach (ISL) mining

Whereas conventional mining involves physically breaking-up rock and removing the ore from the ground, ***in situ* leaching** (ISL), also known as ***in situ* recovery** (ISR) or **solution mining**, involved leaching the ore beneath the subsurface within an aquifer. This mining method is particularly applicable to **sandstone-hosted** uranium ore if it is located within a **permeable aquifer**. ISL mining is used in the USA, Australia, Kazakhstan and Uzbekistan, and when compared to open-cut or underground mining is very cost effective. In 2015, ISL operations accounted for approximately half of all world-wide uranium production.

ISL mining involves very little disturbance of the surface environment. In South Australia the ISL is used by Heathgate Resources Pty Ltd to mine the Beverley and Four Mile East deposits.



Schematic representation of ISL operations at Beverley Uranium mine, South Australia (http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/mining-of-uranium/in-situ-leach-mining-of-uranium.aspx)

At Beverley uranium mine, a mixture of **sulphuric acid** (H_2SO_4) and **hydrogen peroxide** (H_2O_2) is injected into the uranium bearing aquifer. The hydrogen peroxide oxidises (breaks-down) the uranium ore or what consists of **coffinite** and **uraninite**, and uranium forms a complex with sulphuric acid that keeps uranium in solution to be pumped to the surface and processed to produce **yellow cake** (U_3O_8).

- **Explain how the size, shape, and depth of a mineral deposit influence the choice of extraction method**

If deposits are close to or at the surface, it is cheaper to undertake **open-pit mining**. In this form of ore extraction, a large hole is excavated; however even with relatively shallow mine excavations, there is a large quality of overburden that needs removal and storage (either permanent or temporary).

On the other hand, underground mining is more expensive, but typically has less impact on the environment. Underground mining is

Examples of open-pit mining in SA and elsewhere in Australia:

- Sub-bituminous coal, Leigh Creek, SA (now closed but previously the largest open pit operation in Australia)
- Iron ore, Middleback Ranges, SA (e.g. Iron Chieftain, Iron Duke etc)
- Gold, Portia, SA
- Cu-Au-Ag Prominent Hill, SA (U is a dilute contaminant)
- Cu-Au-Ag, Kanmantoo, SA
- Iron Ore, Pilbara region, WA
- Golden Mile, Kalgoorlie, WA
- Lignite, Latrobe Valley, Victoria
- Bituminous coal, Hunter Valley, NSW
- Bituminous coal, Queensland
- Au, Challenger, central SA – now being developed as an underground operation.

What other major open-pit mining ventures are presently operation?

Examples of underground mining in SA and elsewhere in Australia:

- Cu-Au-U-Ag, Olympic Dam, central SA – potentially the world's largest open-cut operation in the future
- Cu-Au, Carrapateena, central SA – being developed with production expected in late 2019
- Au, Challenger, central SA – previously open-pit.

Examples of ISL mining in SA:

- Four Mile East-Beverley, Frome Embayment, SA

What other major underground mining ventures are presently operational?

Open-pit mining

Advantages of open-pit mining:

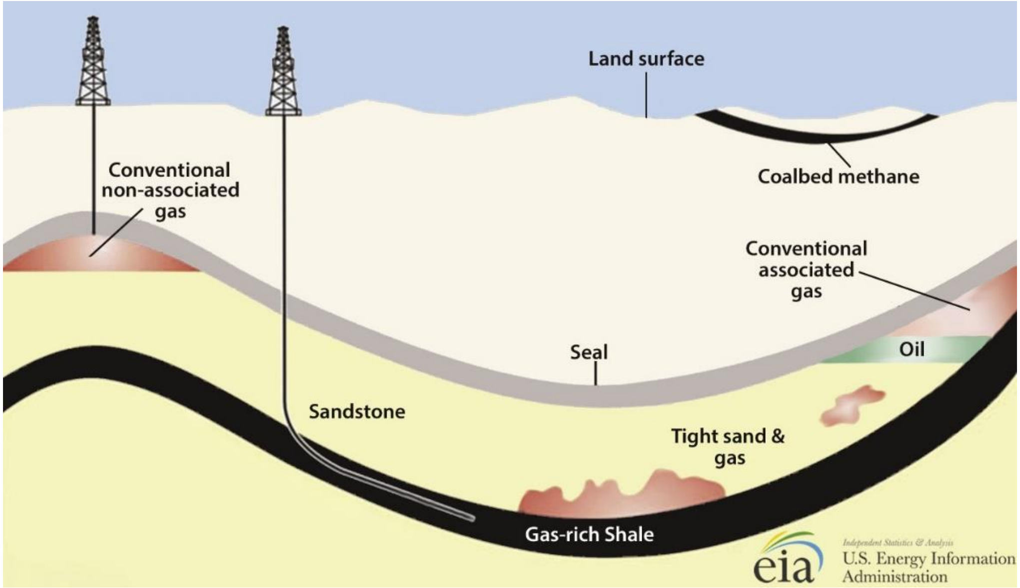
- Less expensive than underground mining
- Better ventilation - this is important in U mining where (radioactive) Ra gas will be encountered, or coal mining where (combustible/explosive) coal-seam gas will be encountered

Disadvantages of open-pit mining:

- Very large "footprint" scar left after mining operations are complete.

- Rock waste piles enormous and are typically even larger than the open-pit.
- Once exposed to the atmosphere, waste rock piles can produce hazards, e.g. acid mine leakage, or dust.
- Waste rock management can become very expensive – both returning waste to the open-pit is expensive, as is landscaping and revegetating the site (especially in arid or semiarid environments).
- Groundwater restoration can be very expensive and often the groundwater table becomes permanently impacted.

• Explain how petroleum, shale oil, coal, and coal-seam gas are extracted from the Earth in different locations



Schematic showing geology of natural gas resources (https://www.eia.gov/oil_gas/natural_gas/special/ngresources/ngresources.html)

Petroleum

Conventional oil and gas is extracted from reservoirs in both onshore and offshore environments. Onshore exploration and production is relatively cheap compared to offshore.

Onshore

Onshore oil production: Snatch-9 oil well (Senex Energy Ltd), Cooper Basin, NE South Australia (http://www.adelaidenow.com.au/business/new-economic-reserves-and-technology-to-improve-output-imperative-to-future-of-south-australias-cooper-basin/news-story/ee6e087efe1dc034a548d9afd79ddb02)

Offshore

Offshore oil production: Production rigs in Kingfisher oil field, Bass Strait, Victoria (http://www.theaustralian.com.au/business/mining-energy/exxon-bhp-bass-strait-oilfields-sale-may-lead-to-closure-costs-headache/news-story/f0437416d934b7f575292f69d686ba00)

Irrespective of whether production is offshore or onshore, during **primary recovery** the energy required to bring the oil and gas to the surface comes from within the reservoir. Gas pressure within the reservoir can force oil to the surface – much of the energy required for this comes from the gas dissolved within oil. As oil and gas comes to the surface, it is displaced in the reservoir by water.

Once a well has been drilled into the reservoir, there is connectivity between the reservoir and the atmosphere and oil flows to the surface; however, primary recovery only accounts for up to 15% of the oil in the reservoir because once pressure between the reservoir and the atmosphere equalizes, flow will stop.

Secondary recovery methods are used once oil recovery drops below an economically critical rate. Secondary recovery uses external energy to pump fluid (e.g. water, air, CO_2, or natural gas) into the reservoir, thereby increasing its fluid pressure and resulting in continued flow of oil to the surface. As the amount of oil in the reservoir is depleted during secondary recovery, once again, eventually oil recovery drops below an economically critical rate and this is usually when 35 – 45% of the oil has been recovered.

If the price of oil is sufficiently high, **enhanced recovery**, also known as **tertiary recovery** becomes justifiable and can recover an additional 5 – 15% oil. Enhanced recovery involves steam injection (often a byproduct of generating electricity in a gas turbine), CO_2 flooding (to reduce the viscosity of the remaining reservoir oil) or the injection of water/polymer (surfactant) mixture to reduce the surface tension between the *in situ* water and oil. All three methods might be used depending on the reservoir properties. Understanding and optimizing oil (and gas recovery is a highly specialized are of knowledge, the domain of **petroleum reservoir engineers**.

Thus at best, production of conventional oil will only recover, at best, 65% of the total oil in the reservoir. Even this figure is very much influenced by the world's energy economics during the life of the petroleum field.

Coal

Most coal mining operations in western countries are open-cut mines. Underground coal mines are expensive to engineer safely and therefore only suitable for high rank coal, i.e. low-volatile bituminous coal and anthracite which has the highest calorific value.

However, the economic considerations of whether to extract coal from a surface pit or underground also depend on the depth of the coal seam, the strength of the rock above and below the seam, seam continuity, groundwater conditions etc. Often it will be technically impractical to mine coal; coal in the Cooper Basin of South Australia, although of high rank (semi anthracite – anthracite) will never be mined because it occurs at depth below 3 km and at temperatures exceeding 100 °C.

Worldwide, ~60% of coal production is from underground mines, mainly in countries where labour costs are low and safety standards are not as stringent as in western countries.

In Australia 80% of coal mined is from open-cut operations; all underground mining is restricted to bituminous coal and anthracite. In Australia, brown coal (e.g. Latrobe Valley lignite) is exclusively mined from open-cuts.

Coal dredger operating in Loy Yang brown coal mine, Latrobe Valley, Victoria. Photo by Getty (http://www.gq.com.au/success/opinions/why+australia+is+headed+for+an+avoidable+climate+calamity,38385)

Brown coal mine in the Latrobe Valley, Victoria (http://www.abc.net.au/radionational/programs/scienceshow/coal-mine.jpg/5769782)

Visit the Latrobe Valley on Google Earth. How many open-pit coal mines are there and what is the order of magnitude of the land taken-up by coal mining? When calculating this, be sure to take into account the area required for all mine operations, not just the open pit themselves.

Underground mining of coal is arguably the most hazardous mining. In 2010, 29 miners were killed in the Pike River underground coal mine in New Zealand.

What caused the Pike River mine disaster?

Shale oil

Shale oil is **unconventional oil** produced from **oil shale**, a dark fine-grained sedimentary rock with a high content of **organic matter**.

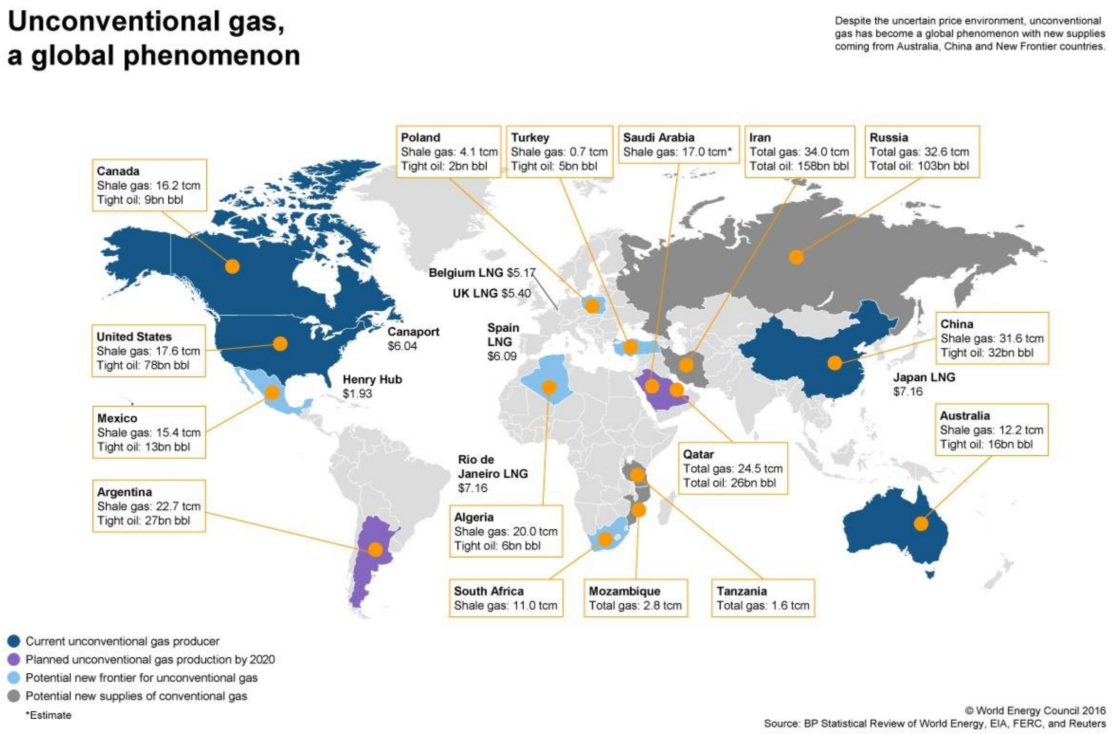
It is very expensive to produce shale oil because the shale requires considerable treatment to form oil from the organic matter. Treatments include **pyrolysis** (heating in an inert atmosphere) and **hydrogenation** (adding hydrogen to organic matter using H_2). However, the processes required to generate oil from oil shale are in themselves very energy intensive.

Due to its high cost, oil production from oil shale is presently only undertaken commercially in Estonia (from a special type of oil shale called **kukersite**), and in China. Estonia presently mines about 70% of mined oil shale. In Estonia, the mining of oil shale is a major industry – about 70% of the oil shale is used for electricity generation, which account for ~85% of Estonia's electricity generation.

Open-pit mining: Selective mining of oil shale within limestone beds, Estonia (http://mining-estonia.blogspot.com.au/)

Underground mining: Room-and-pillar mining of oil shale, Estonia (http://archives.aapg.org/explorer/divisions/2006/05emd.cfm)

For the production of shale oil to be economically viable, the price of conventional oil would need to be in the range of US$90–120 per bbl.



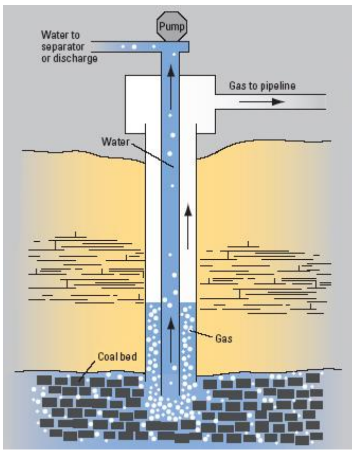
World unconventional gas resources (https://www.worldenergy.org/wp-content/uploads/2016/02/World-map-Unconventional-gas-a-global-phenomenon-World-Energy-Resources.jpg)

The above figure refers to is made to "tight oil" – but what is "tight oil"?

What's wrong about the information in this graphical representation? (Hint: there are multiple problems with this graphic that in totality make it very misleading)

Coal-seam gas

Water pressure can be lowered within a coal seam – either by pumping water to the surface, or letting it flow naturally to the surface if the aquifer is artesian. This also causes methane to move out of the coal seam and flow to the surface with the water. Coal-bed gas is commercially produced in Australia, China, the USA, Canada and elsewhere.



Recovery of coal-seam gas (https://serc.carleton.edu/research_education/cretaceous/coalbed.html)

The extraction and use of mineral and energy resources influences interactions between the abiotic and biotic components of ecosystems, including hydrologic systems

- **Describe potential environmental impacts that can be associated with the extraction, use, and processing of mineral and energy resources**

According to the Australian Bureau of Statistics, potential environmental impacts of mining include (but is not restricted to):

- Acid mine drainage
- Heavy metal contamination and leaching
- Processing chemical pollution
- Erosion and sedimentation

The above list is incomplete – can you suggest other environmental impacts that are especially pertinent to South Australia?

Compare and contrast how biotic components of an ecosystem be affected between open-cut mining, underground mining and in situ leach mining. Which of these extraction methods impacts least on the environment? Can this question really be objectively answered?

Processing of mineral resources can require very large quantities of energy. In Australia this energy needs to be sourced from coal-fired power stations, gas-fired power stations or from renewable sources of energy such as wind turbines, hydro-electric facilities and solar energy.

In 2016, South Australia decommissioned the Port Augusta power station that used coal from Leigh Creek. Consequently, the Leigh Creek open-cut needs to be decommissioned and the site rehabilitated.

Using Google Earth visit the Leigh Creek open-cut and, using the measuring tool, measure the scale of the open cut and other mine-related features.

Use the internet to research how the Government of South Australia intends to remediate toe Leigh Creek open-cut. What is planned?

Another mine in South Australia was decommissioned decades ago – the Brukunga mine in the Adelaide Hills near Adelaide.

Use the internet to research the Brukunga mine noting in particular the problem(s) that has arising since the mine closed. How have these problems been addressed by the relevant Government authorities?

Construct a table to display non-renewable fuel resources, including uranium and unconventional petroleum, and the approximate known global reserves of each resource, and critically evaluate this information in terms of sustainability

Collect and graph data on global reserves and current rate of use of a range of metallic resources, and critically evaluate this information in terms of sustainability

Use data from the Geoscience Australia website and elsewhere to calculate:

1. *When will the world's uranium resources be depleted (assuming a present-day rate of consumption)?*
2. *When will the world's supply of uranium be depleted assuming that China, India and other nations have many nuclear reactors planned for the near future?*

When researching these questions, bear in mind that in the aftermath of the 2011 Fukushima disaster in Japan, many countries have begun, or planning to phase out nuclear energy. What countries are these and how are they addressing the eminent shortfall of energy to in their economy? Are the energy policies of these countries realistic? Or are they leaving the problem of energy shortfall to future generations of politicians?

Your first set of calculations should assume that no uranium from nuclear weapons is "recycled" as uranium fuel. However, if you are able to obtain what you consider reliable figures, you should also determine what peaceful energy might be "won" by abolishing all nuclear weapons and using the uranium in those weapons for civilian electricity generation.

You should present your answer to these questions as a brief report of no more than 5 pages total (excluding a front cover), including tables of data, and a reference list of the sources of your data. You may use figures borrowed from the internet, but are advised to do so with great discretion, and will be marked-down for unnecessary/irrelevant material.

What economic subsidies (e.g. tax relief and/or incentives) does the "nuclear industry" receive in Australia or elsewhere?