U3A Geology Group

Summary – The Rock Cycle

The materials of the Earth's crust are continually being recycled (and so are materials in the mantle). The sum of all the processes involved in this is called the ROCK CYCLE.

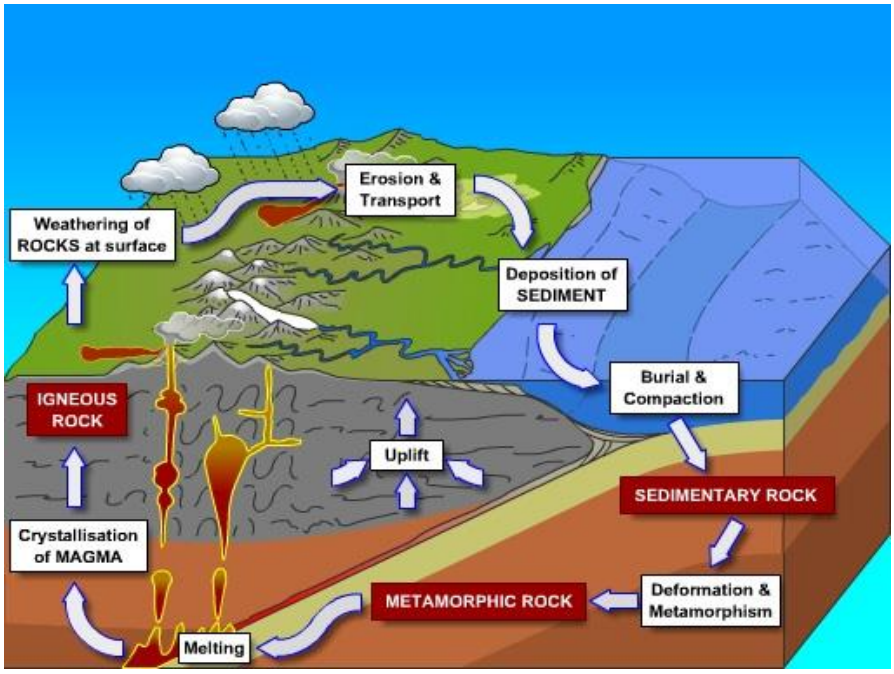
The Rock Cycle: a simple view of the processes:

1. Existing rocks are subject to processes of weathering and erosion, producing sediment.
2. Transport processes sort and carry sediments to low points on the Earth's surface, especially the seas and oceans, and deposit them there.
3. Burial under more sediments eventually turns loose sediment into sedimentary rock.
4. Sedimentary rocks subject to extremes of pressure and/or temperature may be changed into new types of rock – metamorphic rocks.
5. Heating at depth may cause rocks to melt, forming magma ('molten rock') which can work its way upwards, being less dense than solid rock around it. Magma may cool slowly and solidify below the surface to form an igneous intrusion (e.g. granite) with large crystals. Or it may reach the surface and flow across the surface, cool fast and solidify to form an igneous extrusion (e.g. a basalt lava flow) with tiny crystals.
6. Igneous rocks can also be altered by heat and pressure to form metamorphic rocks.
7. Weathering and erosion eventually bring all these buried rocks back to the surface, and round we go again!

And we assume that the same processes which we still see today have been going on throughout the lifespan of the Earth, cycle upon cycle. This is the **Principle of Uniformitarianism** – *the present is the key to the past!*

Even for one cycle, all this takes a very long time! Geological timescales are immense, and geological events are the result mainly of tiny stepwise processes, day after day, year after year, century after century, millennium after millennium … until added up, the sum is visible for us to observe.

Within this, the visible product of sedimentary processes is the formation of strata, one upon another, layer upon layer, older buried by younger … the **Principle of Superposition**.



Nevertheless, some events are faster, more dramatic, often catastrophic – volcanoes, earthquakes, melting of icecaps, storms and floods, all with geological consequences. But in the end it is the slow grind of the rock cycle that shapes most of the Earth's surface.

Simple Rock Cycle

Timescales and the Age of the Earth – Deep Time!

The slow processes of the rock cycle require millions of years for a grain of material to go round just once – even if an individual particle survives to tell its tale! The total thickness of sedimentary strata is so great that a timescale of at least hundreds of millions of years is needed.

Darwin's detailed study of fossils on his voyage in the *Beagle* led him to conclude in 1859 that at least 500 million years was needed for the evolution of life as he observed it through the fossil record.

The physicist William Thomson (later Lord Kelvin) in 1862 calculated an age for the Earth of around 100 million years, based on:

- the measured rate of heat transfer from inside the earth to the surface,
- the assumptions that it had cooled from a ball of molten material, and that no other source of heat was involved.

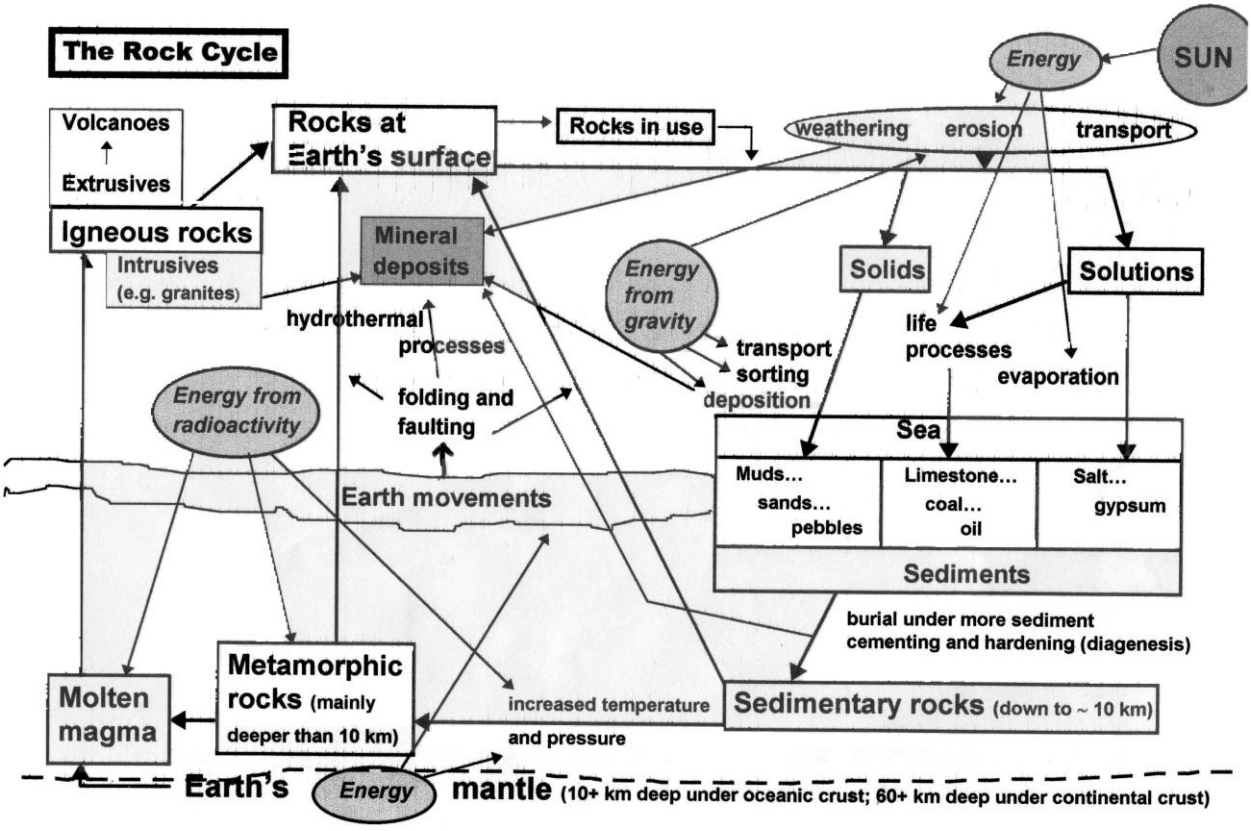
His mathematics was impeccably correct, but not his assumptions!

The debate raged for the rest of the 19th century, until the discovery of radioactivity (Becquerel, 1896). Radioactive processes give out heat – plenty of it! So Kelvin's assumptions were wrong.

Furthermore, the rate of radioactive decay was found to be a very predictable, leading to the possibility of calculating the age of Earth materials. Eventually Arthur Holmes established in 1921 a reliable method of radiometric dating, and in 1956 C. Patterson used radiometric dating of a number of meteorites to establish the accepted figure of 4.54 billion years.

All these timescales are so far beyond normal human experience that we have difficulty understanding them. In recent years the term 'Deep Time' has come into use to signal this issue. Not that any of us find a time period of 1 million years easy to grasp!

Full Rock Cycle



The Rock Cycle: a more detailed view

So the simple view of the rock cycle needs to be elaborated. We need to consider what drives the processes of the rock cycle. The main missing aspect is **ENERGY.**

Energy sources available:

- Sun – radiant energy reaching the Earth, and transformed into a variety of energy sources on Earth, providing life processes with geological roles!
- Radioactivity inside the Earth
- Residual heat inside the Earth
- Gravity – a one-way trip, downwards!

Weathering and Erosion

Weathering is the breakdown of rocks at the Earth's surface, by extremes of temperature (physical), the action of rainwater (chemical), and biological activity. It does not involve the removal of rock material - no moving agent of transport.

Erosion is the process by which soil and rock particles are worn away (eroded) and moved (transported) elsewhere by wind, water or ice.

Note the roles of energy from Sun and gravity in these processes.

Simple Geological Column

<table>
<tr><th>Start: Ma</th><th>Eon</th><th>Data</th><th>Era</th><th></th></tr>
<tr><td>0</td><td></td><td></td><td></td><td></td></tr>
<tr><td>545</td><td>Phanerozoic</td><td>lots!</td><td colspan="2">three, recognised by fossils found in UK history</td></tr>
<tr><td>1,000</td><td rowspan="7">Precambrian
(fossils found in mid C20, before that not known)</td><td rowspan="7">very little, then less & less to almost none!</td><td rowspan="3">Proterozoic</td><td rowspan="3">Ediacaran fauna 635-590
(discovered ~1980)</td></tr>
<tr><td>1,500</td></tr>
<tr><td>2,000</td></tr>
<tr><td>2,500</td><td rowspan="3">Archean</td><td rowspan="3">2,900 oldest UK rocks dated
single-cell structures found</td></tr>
<tr><td>3,000</td></tr>
<tr><td>3,500</td></tr>
<tr><td>4,000</td><td rowspan="2">Hadean</td><td rowspan="2">?4,100 start(s) of life
4,2080 oldest dated rock</td></tr>
<tr><td>4,500</td></tr>
<tr><td>13,700</td><td>“BIG BANG”</td><td></td><td></td><td>Start of the Universe</td></tr>
</table>

Detailed Geological Column

Eon:	Era:	Period:	Derivation of Period	Start: Ma BP
Phanerozoic (=visible life)	Cenozoic (=recent life)	Quaternary	(fourth age)	~1.64
		Neogene	Tertiary (old name for third age)	23.5
		Paleogene		65
	Mesozoic (=middle life) (second age)	Cretaceous	"creta" Latin for chalk	142
		Jurassic	Jura Mts	206
		Triassic	3-fold division Germany	248
	Palaeozoic (=ancient life) (first age)	Permian	Perm, province in Russia	290
		Carboniferous	Element carbon (coal)	354
		Devonian	Devon, England	417
		Silurian	Silures, tribe in Wales	443
		Ordovician	Ordovices, tribe in Wales	495
		Cambrian	Cambrian Mts, Wales	545
Precambrian (originally believed to be all before life)	Proterozoic (=early life)		*by end*: cratons *at start*: strips of crust	2,500
	Archean		*at start*: no air, sea or land	4,000
	Hadean		Crust forms and melts …….	4,560

Website

Animated rock cycle! http://www.geolsoc.org.uk/page3892.html

Books

Earth's Restless Surface: Deirdre Janson-Smith with Gordon Cressey and Andrew Fleet; Natural History Museum; publ. Natural History Museum, £9.99

James Hutton, The Founder of Modern Geology: Donald McIntyre & Alan McKirdy; publ Stationery Office,(second edn, 2012), £9.99

Appendix 7B *The divisions of geological time and major events since the formation of the Earth*

Eon *Duration Ma* Start, Ma	Key stages in the evolution of life	Key events	Oxygen content of the atmosphere	Global temperture change
Phanerozoic *545*	See Phanerozoic geological column	See Phanerozoic geological column (Appendix 7A) for more details • Frequency of fires in Carb. coal forests indicates oxygen levels similar to or even higher than today • Land animals appear – need oxygen levels about present values		Ice Ice Ice
545				
Proterozoic *1930*	• Ediacaran faunas in Aust., Russia, China. Soft bodied animals • Silica skeletons in single celled algae • Stromatolites decline (grazers) • Stromatolites at their maximum; eukaryote diversification • Multicellular marine organisms evolve – Eukaryotes with nucleus and cytoplasm – needing oxygen above 0.1% • Size of cell doubles • Gunflint Chert (Canada/US) stromatolite • Single celled eukaryotes	• Break-up of early supercontinent • Orogeny in Scottish rocks • Soft bodied metazoan fossils first appear – need oxygen levels above 2% • Glaciation – Scotland, Greenland, Africa, China • Glaciation – Australia, China, S Africa • Glaciation – Greenland, Scandinavia • Formation of early supercontinent • Orogeny in Scottish rocks • End of major banded ironstone deposition (iron deposited in Fe^{2+} state, indicating low oxygen levels) • First red beds deposited, iron in Fe^{3+} state – must have been significant amount of oxygen in atmosphere	Present day	Major ice age Present day Ice age
2500			30% 20% 10%	Cold Warm
Archean *1300*	• Stromatolites • Prokaryotes – bacteria and photosynthesising blue green bacteria (algae)	• Continental cores of most major continents formed by this time • Orogeny in Scottish rocks • Oxygen produced by early life forms • Earliest banded ironstones deposited (iron deposited in Fe^{2+} state, indicating little or no oxygen present) • First sedimentary rocks formed (Greenland) • Greenstone belts in India, Australia, S Africa, Canada	None	
3800	None	• First oceans probably formed • Volcanic outgassing and contributions from asteroids, etc. produced secondary atmosphere • Volcanic activity widespread on cooling Earth. Radioactive decay at higher rate than now • Zircon dates from igneous source rocks in NW Australia • Continued bombardment by asteroid-like bodies caused Earth to become very hot – probably a few thousand degrees • Formation of Earth and growth through collision of many asteroid-like bodies	None	
Hadean *800*				
4600				

Precambrian

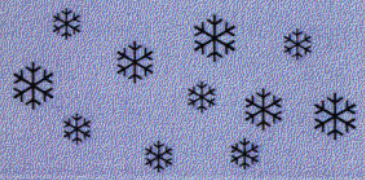
APPENDIX 7 Geological Time

Appendix 7A *The divisions of geological time and major events since 570 million years ago (Phanerozoic time*

Eon	Era	Period *Duration Ma* Start Ma	Key stages in the evolution of life and common life forms	The diversity of life (variation in number of families)	Key events	Global sea level change	UK latitude (approx.)
Phanerozoic	Cenozoic	**Quaternary** *1.64* **Tertiary** *63*	Early humans Increase in mammals Horses, cows, elephants, pigs, apes, dogs, bears, etc. appear and increase Flowering plants in full development	⇐ Inc. Dec. ⇒	• Major glaciation ICE • Linking of N & S America • Alpine Orogeny in UK; Alps formed as Tethys closed • Widespread igneous activity in northern UK • Collision of India with Asia • Separation of Australia & Antarc.	High Low	55°N N 40°N
		65					
	Mesozoic	**Cretaceous** *77*	Extinction of dinosaurs and ammonites Primates evolve Mammals and flowering plants (angiosperms) appear DEEP SEA	N.B. FOSSIL RECORD	• Opening of North Atlantic began	Present day	35°N
		142					
		Jurassic *64*	SHALLOW SEA Dinosaurs and ammonites abundant Birds and mammals appear				30°N
		206					
		Triassic *42*	Mammals evolve Flying dinosaurs and reptiles appear First modern corals Ammonites evolve	CHANGES USED FOR BOUNDARIES	• Opening of S Atlantic Ocean began		
		248	DESERT				
	Upper Palaeozoic	**Permian** *42*	Mass extinction Rise of reptiles and amphibians Conifers and beetles appear		• Formation of Pangea supercontinent • Major glaciation ICE • Hercynian/Variscan Orogeny in Europe – closing of the Rheic Ocean		10°N
		290					
		Carboniferous *64*	Coal forest plants JUNGLE First reptiles and winged insects Seed-bearing plants (gymnosperms)				0° EQU.
		354					
		Devonian *63*	First amphibians and ammonoids Earliest trees and spiders Rise of fishes Graptolites become extinct DESERT				20°S
		417					
	Lower Palaeozoic	**Silurian** *26*	↑ SHALLOW SEAS First spore-bearing land plants; first soils Earliest known coral reefs		• Climax of Caledonian Orogeny – closing of Iapetus. Laurentian plate joined to European plate		
		443					
		Ordovician *52*	First fish-like vertebrates Trilobites and graptolites abundant Corals appear	⇐ increasing	• Major glaciation ICE	Present day	30°S S
		495					
		Cambrian *50*	↓ Trilobites, graptolites, brachiopods, molluscs, crinoids, radiolaria and foraminifera The 'Cambrian explosion' – complex marine organisms evolve with $CaCO_3$ shells – abundant fossils first appear				
		545					

Scotland Through Time

QUATERNARY
2.4 million years ago to present day

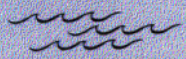


Present day material still moving down slopes and into river systems and some of it out to sea; new river terraces being formed at lower levels; sandy coasts in some places eroding and in other places accumulating; freezing and thawing of the ground continues with further development of periglacial landforms on the mountains.
5,000 years ago, sea levels rose up to 10m higher than the present, forming beaches around the sheltered parts of the coast.
10,000 years ago, final disappearance of mountain glaciers leaving re-shaped corries, new moraines and other debris; widespread occurrence of freezing and thawing leaving extensive areas of periglacial landforms.
15,000 years ago, the last Ice Age sheet began to thaw, meltwater cut new valleys and gorges, many quickly abandoned; valleys filled with sand and gravel, and estuaries with silt and clay. Many glacial deposits, especially eskers, kame terraces and kettleholes formed.
2.4 million years to 15,000 years ago, repeated growth and decay of ice sheets and glaciers with little evidence preserved from earlier glacial periods. Formation of major features of glacial erosion, such as troughs, corries, straightening of valleys, removal of weathered bedrock and uncovering of tors.
2.4 million years ago, major cooling of the climate with onset of Ice Age.

TERTIARY
65 to 2..4 million years ago

Development of a chain of volcanoes from Skye to Ailsa Craig, as the North Atlantic formed and Scotland drifted away from Laurentia. North Sea filled as sediments were carried eastwards by rivers draining the Scottish Highlands. The climate was sub-tropical for much of the time.

CRETACEOUS
65 to 135 million years ago



For much of this period, Scotland, with the exception of the highest ground, lay under a tropical sea. Thick layers of chalk were laid down on the sea floor, but were later removed by erosion.

JURASSIC
135 to 205 million years ago

Rapid sea-level rise marked the beginning of the Jurassic period, flooding much of Scotland. Meat and plant-eating dinosaurs roamed the coastal fringes and an abundance of sea-life existed including ammonites, sea lilies (crinoids) and corals.

TRIASSIC
205 to 250 million years ago

Scotland was located in near-equatorial latitudes, in a similar position to sub-Saharan Africa today, and desert conditions largely prevailed. Red sandstones of the Elgin area, formed under these conditions preserving the footprints of long-extinct reptiles.

PERMIAN
250 to 290 million years ago

Desert conditions. Violent earthquakes rocked Scotland causing widespread folding and faulting.

CARBONIFEROUS
290 to 360 million years ago

Scotland sat astride the equator. Rainforest covered much of the Midland Valley and coral reefs flourished in the adjacent tropical seas. Numerous volcanoes erupted lava flows and ash to form the Campsie Fells, with the Arthur's Seat, North Berwick Law and Garlton Hills volcanoes also active.

DEVONIAN
360 to 410 million years ago

The high mountains created by colliding continents were rapidly eroded and the debris carried to lower ground by streams and rivers. Layer upon layer of red sandstone was deposited in freshwater lakes, some containing the remains of primitive fish and early plants.

SILURIAN
410 to 440 million years ago

The Laurentian continent collided with Avalonia as the Iapetus Ocean closed, so uniting Scotland with England and Wales. The movement took place along the major faults to assemble Scotland from four previously separate continental fragments. Many granites and related igneous rocks date back to this period.

ORDOVICIAN
440 to 510 million years ago

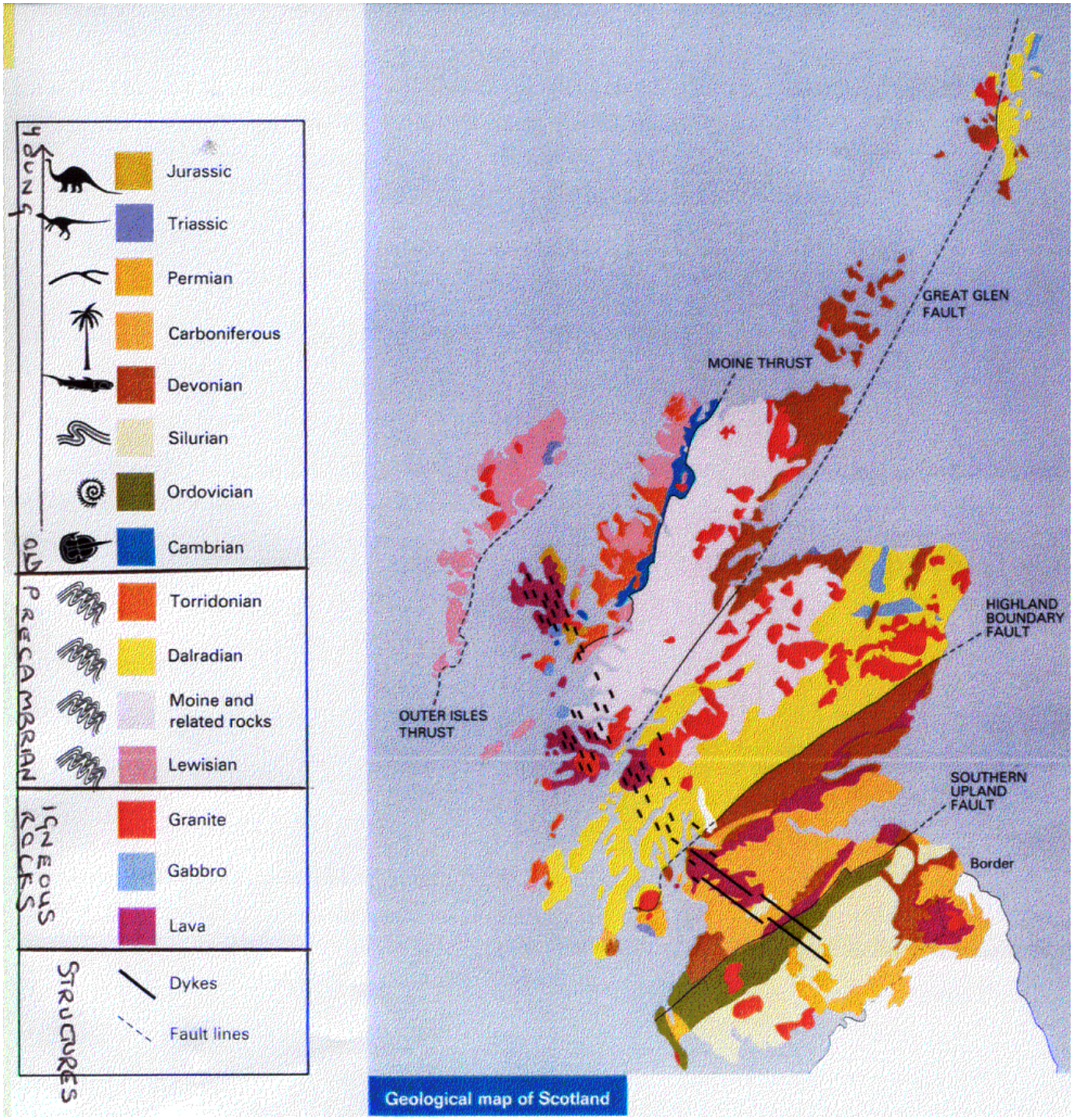
The Iapetus Ocean was at its widest as thick layers of sands and muds were laid down on the ocean floor. The remains of primitive life forms, such as graptolites and early corals, are preserved in these rocks. Towards the end of the Ordovician, the Iapetus Ocean narrowed considerably.

CAMBRIAN
510 to 550 million years ago

The Durness Limestones and quartzites were laid down as beach and near-shore sediments; the Pipe Rock preserves evidence of early life in the form of trumpet-shaped worm burrows.

PRECAMBRIAN
550 to 3 billion years ago

Great thicknesses of sandstone, limestone, muds and lava accumulated during later Precambrian times, which were later altered to form the rocks of the Dalradian. The earliest traces of life to be found anywhere in Scotland have been described from rocks of this age on Islay. Similarly, Moine rocks started life as layer upon layer of sandstone, only to be altered by deep burial in the Earth's crust. Torridonian sandstones accumulated at much the same time and have remained largely unaltered. However, the oldest rocks in Scotland, by far, are the Lewisian gneisses, which are interpreted as part of the Earth's crust, as it existed up to 3 billion years ago.



Geological map of Scotland

U3A Geology: Booklist and Websites

- Earth Story, by Simon Lamb and David Sington, publ. BBC books (secondhand from Amazon Marketplace)
- Journeys from the Centre of the Earth, by Iain Stewart, publ. Century, (secondhand from Amazon Marketplace)
- Land of Mountain and Flood: The Geology and Landforms of Scotland, by McKirdy, Gordon & Crofts, publ. Birlinn, (may be out of print)
- Origins: The Evolution of Continents, Oceans and Life, by Ron Redfern, publ. Cassell, £35 (secondhand from £3.56)
- Earth: The Definitive Visual Guide, ed. James Luhr, publ. Dorling Kindersley, £32.20 (new edition, May 2024)
- The Encyclopedia of Earth: A Complete Visual Guide, var. authors, publ. Weldon Owen, £25.00
- The Geology of Britain: An Introduction, by Peter Toghill, publ. Airlife, £12.99 (but probably o/p)
- Geological History of the British Isles, Hunter & Easterbrook, publ. Open University, (secondhand from Amazon Marketplace)
- Set in Stone: the Geology and Landscapes of Scotland by McKirdy, publ. Birlinn, £6.99 (introductory booklet to a series of booklets on each region of Scotland, including Argyll)
- Scotland's Beginnings, by Taylor and Kitchener, publ. National Museums of Scotland, £4.99

Website

Animated rock cycle! https://www.youtube.com/watch?v=U7YQ5vwaL98 – other youtube cartoons also available