AGSO

Geoscience Education

Time & Life

Geological Time and Palaeontology

Teacher Notes and Student Activities

by Gary B. Lewis

Record No. 1995/14

AGSO
AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

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Time & Life

1. How Old is the Earth?

The age of the Earth, like many scientific questions, has developed over time with the development of science itself. The one overwhelming feature of the development of the theories of the age of the Earth is that over the last few hundred years, the Earth's age has been increasing.

1.1 Estimates of Geological Time

Biblical Calculations

An early calculation of the Age of the Earth was undertaken by Archbishop Ussher in the 1600's. He calculated, using Hebrew chronology, that the Earth was created in 4004 BC. While his final age for the Earth may now be seen by scientists to be orders of magnitude too small, his method of obtaining the Earth's age by extrapolation of recorded dates was quite scientific.

Later theologians were not satisfied with Ussher's accuracy and did further calculations to get the date of 23 October, 9.00am 4004 BC.

Other religions have had similar calculations, however Christian estimates tend to be the smallest mainly because it equates the age of the earth to the beginning of human kind. Other religions have a cyclic belief about age, with the Earth having no beginning and no end.

Salinity

In 1715 English astronomer Edmund Halley (of Comet Halley fame) suggested that the age of the earth could be calculated using the change in the Earth's ocean salt content. He assumed that the Earth's oceans were originally fresh water and that salt was added to the oceans by rivers carrying salt from the land. Halley suggested that the age of the Earth could be calculated once the rate of salt increase was known. His method was to measure accurately the salt content at a given time then again exactly ten years later. If Halley ever carried out his experiment is not known.

In the late 1800's, the notion of using the oceans' salt content to measure the age of the Earth was again on the scientific agenda. After making corrections for wind blown salt and recycled salt from rocks which were once formed in oceans, John Jolly in 1899 calculated that the age of the Earth's oceans was about 90 million years.

Modern calculation have shown that the salt content of the Earth's oceans is not increasing as it is in equilibrium with the salt contained in the crustal rocks.

Deposition of sedimentary rocks

Geologists working at the end of the 1800's postulated that the age of the Earth could be calculated if the total thickness of sediments deposited over time was known. It was assumed that an average rate of sedimentation could be calculated for each sediment type.

As each location had different sequences of sedimentary layers, the calculations become very complex and the estimates varied greatly from scientist to scientist. Also, different scientist made calculations based on different thickness and different rates of deposition.

Date	Scientist	Age (millions of years)
1860	Phillips	96
1869	Huxley	100
1871	Haughton	1,526
1878	Haughton	200
1883	Winchell	3
1892	Wallace	28
1893	McGee	1,584
1908	Jolly	80

Lord Kelvin

At the time that Charles Darwin released his "Origin of the Species" book on evolution (1859), Lord Kelvin had made some estimates on the age of the earth which were widely regarded and were highly influential. Kelvin's estimates using heat loss and the Sun's release of heat, were also some of the lowest estimates. Darwin, and his followers, had difficulty in believing Kelvin's estimates and anti-evolutionists used Kelvin's estimates as arguments against natural selection.

Heat Loss

It was known that the temperature in deep mines increased uniformly with depth below the surface. Kelvin reasoned that this was because the Earth was losing heat from the surface, and that originally the Earth was molten. He estimated the loss of heat, based on the temperature increase in mines, and then the age of the Earth. While he never gave an exact age , he believed it to be less than 100 million years and possibly as little is 20 million years.

Sun's Heat

Prior to the discovery of radioactivity, scientists had trouble with the concept of the Sun's continual release of enormous amounts of energy. Kelvin suggested that the Sun could not have been active for very long and he suggested that the Sun had only been shining for 10 million years.

Kelvin also suggested that the Sun's heat was very much greater in the past and that as little as 1 million years ago it would have been so hot that life on Earth would have not been able to exist. This again gave fuel to the anti-evolutionists.

Radiometric Dating

In 1896 , Henri Becquerel, a French physicist, discovered that uranium emitted "mysterious rays" which could mark photographic plates in total darkness. Becquerel called this phenomenon "radioactivity". Within a short time, many scientists, such as the Curies, were to make more discoveries about radioactivity and these eventually led to new thoughts about ways to measure the age of the Earth.

In 1906 an English physicist R. Strutt estimated that the heat flow from the Earth's surface described by Kelvin could, in part, be explained by heat generated by the Earth's radioactive minerals. Likewise, physicists started to believe that the Sun's heat was being generated in a similar way on a much larger scale.

In 1902 Ernest Rutherford and Frederick Soddy postulated that radioactive elements changed into other elements releasing radioactive energy. In 1906 Rutherford attempted to measure the ages of minerals by using the ratio of a radioactive element to its elemental by-product. Unfortunately, the first elements used were uranium and helium, with errors in calculation occurring because of the escape of helium as a gas. However, many experiments were beginning to indicate the age of the Earth to be in the order of hundreds if not thousands of millions of years.

In 1905 B. Boltwood, an American chemist, recognised that uranium-lead was a better system and that found unaltered minerals of the same age had identical uranium-lead ratios. While the knowledge of decay rates was poor and the techniques were primitive, Boltwood obtained ages which had only small experimental errors.

In 1911 Arthur Holmes wrote the first paper on radioactive dating which outlined the methods and potential errors in the radiometric method.

1.2 Current Estimates

The current age of the Earth, based on the radiometric dating of terrestrial rocks, moon rocks and meteorites, mainly using U-Pb methods. The oldest known crustal rocks are 4,000 million years old (Acasta Gneiss, Alaska). Some mineral grains found in rocks in WA are even older! The dates from meteorites suggest older dates (up to 4,600 million years) for the formation of the planets.

2. Geological Time

Geoscientists use two methods for geological time - relative and absolute time. Relative Time refers to the system where one layer of rock is given an age as being younger or older than another layer. Absolute time refers to the system where a rock layer is given an age in years, or more commonly millions of years, before present.

2.1 Relative Time

The first realisation that rocks of similar ages contain fossils of similar type was made by William Smith in 1813. This allowed geoscientists to link different rock types containing the same fossils to one geological period. It was also recognised by Cuvier that the fossils changed over time so that one layer could be recognised as being younger or older than another.

Following their work geoscientsist started to group rock layers into time groups, each group being given a name, and so a relative geological time scale was developed. The names for this time scale either reflect the places where rocks of this age where recognised or some distinctive feature of rocks of that period.

Some names in the Geological Time Scale and their origins

Name	Reason
Cambrian, Silurian, Ordovician	Ancient Welsh Tribes - age first named in Wales
Devonian	Age first named in the Devonshire in southern England
Carboniferous	"Coal-bearing" rocks in central England
Permian	Age first named in the Perm province of Russia
Triassic	Name refers to the original three-fold sequence of rocks of this age
Jurassic	Age first named in the Jura Mountains in Switzerland
Cretaceous	"creta" - Latin word for chalk

Over the last hundred years, the time scale has evolved with time units becoming better defined. This has been a result of greater understanding of fossil groups particularly microfossils.

The Relative Time Scale is now broken down into the following age categories :

		Example
Largest time unit	**Eon**	*Phanerozoic*
	Era	*Paleozoic*
↓	Period	*Silurian*
	Epoch	*Ludlow*
Smallest time unit	Age	*Gorstian*

Geological Time Scale

Eon	*Era*	*Period*	*Epoch*	*Basal Age (millions of years)*	*Age*
PHANEROZOIC	CAINOZOIC	QUATERNARY	Holocene (recent)	0.015	
			Pleistocene	1.8	Calabrian
		TERTIARY	Pliocene	5.3	Piacenzian Zanclean
			Miocene	23.8.0	Messinian Tortonian Serravallian Langhian Burdigalian Aquitanian
			Oligocene	37.0	Chattian Repelian
			Eocene	54.5	Priabonian Bartonian Lutetian Ypresian
			Paleocene	65.0	Thanetian Danian
	MESOZOIC	CRETACEOUS	Late		Maastrichtian Campanian Santonian Coniacian Turonian Cenomanian
			Early	141	Albian Aptian Barremian Hauterivian Valanginian Berriasian
		JURASSIC	Late		Tithonian Kimmeridgian Oxfordian
			Middle		Callovian Bathonian Bajocian Aalenian
			Early	205	Toarcian Pliensbachian Sinemurian Hettangian
		TRIASSIC	Late		Rhaetian Norian Carnian
			Middle		Ladinian Anisian
			Early	251	Spathian Nammalian Griesbachian

PALAEOZOIC	**PERMIAN**	Late		Changxingian Dzulfian Midian Kazanain Ufimian
		Early	298	Kungurian Artinskian Sakmarian Asselian
	CARBONIFEROUS	Stephanian		Gzhelian Kasimovian
		Westphalian		Moscovian
		Namurian		Bashkirian Serpukhovian
		Visean		Brigantian Asbian Holkerian Arundian Chadian
		Tournaisian	354	Ivorian Hastarian
	DEVONIAN	Late		Famennian Frasnian
		Middle		Givetian Eifelian
		Early	410	Emsian Pragian Lochkovian
	SILURIAN	Pridoli		
		Ludlow		Ludfordian Gorstian
		Wenlock		Homerian Sheinwoodian
		Llandovery	434	Telychian Aeronian Rhuddnian
	ORDOVICIAN	Ashgill		Bolindian
		Caradoc		Eastonian Gisbornian
		Llandeilo		Darriwilian
		Llanvirn		
		Arenig		Yapeenian Castlemainian Chewtonian Bendigonian
		Tremadoc	490	Lancefieldian Warendian
	CAMBRIAN	Late		Datsonian Payntonian Idamean Mindyallan
		Middle		Boomerangian Undillan Floran Ordian
		Early	545	Botoman Atdabanian Tommotian
PRECAMBRIAN	**PROTEROZOIC**	Late	1000	
		Middle	1600	
		Early	2500	
	ARCHAEAN		>3800	

2.2 Absolute Time

Giving an age of a rock formation, mineral or fossil in years before present is referred to absolute dating. Absolute Time is therefore a numerical ageing of materials using a process which can mathematically define an age.

The mathematical method used is radiometric dating.

Radioactive decay

A number of elements, or isotopes of elements, occur as unstable atoms in nature and they change spontaneously to more stable atoms releasing energy. This process is known as radioactive decay. The original radioactive atom is referred to as the parent atom and the subsequent changed atom is referred to as the daughter atom.

> The process of decay is complex. Refer to chemistry and/or physics texts for more detailed information of the processes.

Each radioactive atom has a particular rate of decay. The decay rate can be calculated over time and is unaltered by chemical changes such as oxidation, heat or pressure Therefore, when radioactive atoms are incorporated into a mineral when it crystallises, the amount of those radioactive atoms which decay to their daughter atoms is controlled by the amount of elapsed time.

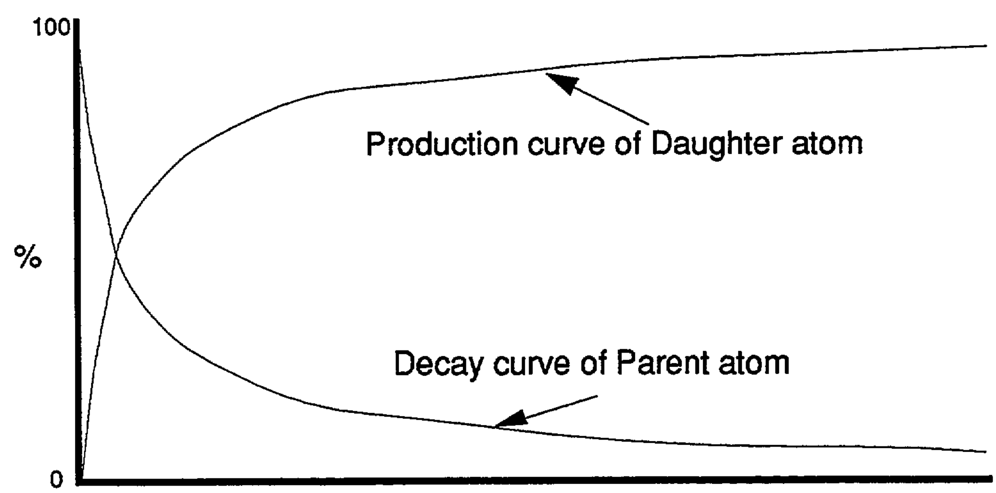
In 1902 Rutherford and Soddy discovered the very simple law for the decay of all radioactive atoms. The number of atoms (n) which decay during a set period of time is directly proportional to the number of radioactive atoms in the sample (N). For example, out of ten million atoms (N=10,000,000) of the radioactive element radium, 4,273 will decay each year (n=4,273). The fraction n/N is known as the decay constant (λ), and in the case of radium $\lambda = 4{,}273 \div 10{,}000{,}000$ or 0.0004273 per year.

It is easier to think in terms of the half-life (T) of the radioactive atom, which is the period of time it takes for half of the original atoms to decay to the daughter atoms. T is always equal to $0.693 \div \lambda$. Therefore in the case of radium, $T = 0.693 \div 0.0004273$ or $T = 1{,}622$ years.

The rate of production of the decay products is not unlike the increase in rabbits - the rate depends on the number of radioactive atoms before decay. i.e. the rate of increase in a rabbit population that starts with two rabbits will be different from the population that has 100 rabbits.

Therefore the rate of radiometric decay is not linear, but exponential. The amount of parent atoms that decay in one year is proportional to the total amount of parent atoms at the start of the year.

Likewise, the production of the decay products - the daughter atoms - is also exponential as one radioactive parent atom decays to one daughter atom.



The Jumping Cane Toad
A cane toad wants to cross a busy road that is 10m wide. The distance it can cover in a jump is exactly half the distance of the previous jump. How many jumps does it need to clear the road?

Like the cane toad example, radioactive decays will reduce the amount of parent atoms but there will always be some atoms remaining. However, with the radioactive atoms used for radiometric dating, because their half-lives are very long (hundred or thousands of millions of years) even the oldest sample of Earth rock will contain a large proportions of the original radioactive atoms.

Radiometric Dating

Knowing the half-life of radioactive atoms which are found in some rock forming minerals enables geoscientists to find the age of the mineral. The geoscientists needs to work out the percentage of parent atoms to daughter atoms and work backwards to calculate an age.

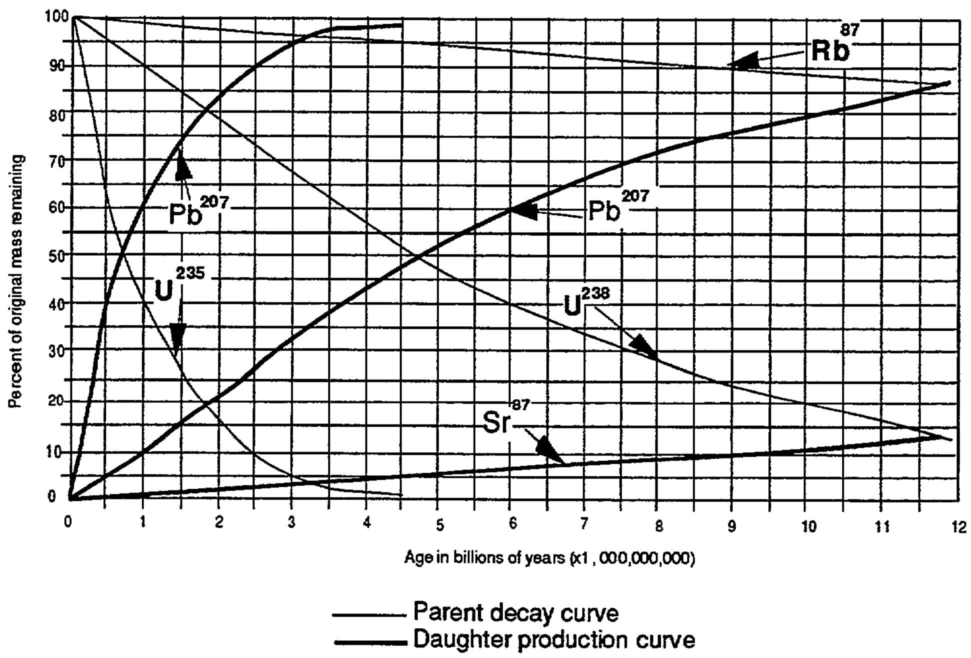
The most common radioactive atoms used are :

Parent	Daughter	Half-life (years)	Minerals commonly used.
Uranium-238	Lead-206	4,510 million	Zircon, Uranite, Pitchblende
Uranium - 235	Lead-207	713 million	Zircon, Uranite, Pitchblende
Potassium-40	Argon-40	1,300 million	Muscovite, Biotite, Hornblende, Glauconite, Sanidine
Rubidium-87	Strontium-87	47,000 million	Muscovite, Biotite, Lepidolite, Microcline, Glauconite

As it is easier to measure the daughter atoms, especially in Uranium-lead dating, geoscientists use decay product curves to calculate ages.

The radioactive decay and product curves for some of these radioactive atoms and their daughter atoms are shown below.

Radioactive decay curves



When using this radiometric dating methods, geoscientists make three assumptions.

1. When a mineral forms it has only parent atoms and no daughter atoms.

2. No daughter atoms "escape" the mineral crystal or no parent atoms are added. This is an especially important factor in using K-Ar dating. Argon, being a gas, is more easily removed from a crystal.

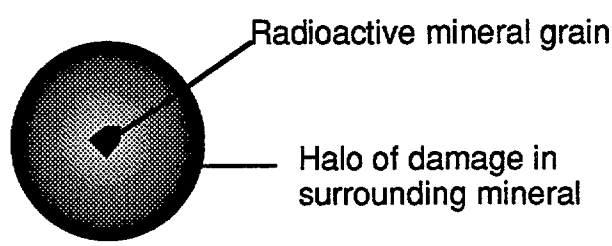
3. No geological process has restarted the "clock" - by removing the daughter atoms.

Has the rate of decay changed over time?

How do we know that the rate of decay of radioactive atoms has not slowed down overtime giving ages much older than those calculated by geoscientists?

As a radioactive atom decays it releases sub-atomic particles which move rapidly away from the atom. The energy for their movement is directly proportional to the rate of decay.

These rapidly moving sub-atomic particles damage the mineral material through which they pass. As a result they cause a ring or halo to occur around the radioactive elements in a mineral lattice. These halos can be seen under a microscope and their size can be measured.



All of these halos, no matter the age of the mineral, occur for exactly the same distance from the radioactive element. This shows that the energy of the particles, and therefore the rate of decay has been constant

If the rate of decay had decrease over time, then the distance these particles would have travelled in very old rocks would have been greater than in young rocks. This has never been found to be the case.

How do we know when the clock started?
Uranium is incorporated into the crystal lattice of minerals as part of normal mineral forming processes. Because of the size of the atoms, some crystal structures, such as that of the mineral zircon, will readily incorporate uranium atoms but never lead. Because of this, any lead found in the crystal structure where only uranium atoms would fit must be the products of the decay of uranium.

Also, the element lead has a number of isotopes - ^{207}Pb, ^{206}Pb and ^{208}Pb, which are the products of decay- and ^{204}Pb is not. Therefore the amount of ^{204}Pb in a mineral is constant over time. By using this "constant", geoscientists can calculate accurately the amount of lead originally incorporated in the crystal lattice and the amount of lead formed as decay products. Once these proportions are known, an accurate date can be found using the decay product curves.

2.3 SHRIMP Zircon Dating

SHRIMP, the Sensitive High Resolution Ion Microprobe, is an instrument developed at the Research School of Earth Sciences, Australian National University, in association with AGSO. It uses an ion microbeam to drill tiny craters 1/100th of a millimetre across, and 1/1000th of a millimetre deep, in rock forming crystals. The excavated material (about 1/10,000th of a gram) is split into its constituent elements, the elements are split into their constituent isotopes of different masses, and a sensitive analyser measures the amounts of each of these.

SHRIMP has revolutionised isotopic dating of rocks with its ability to probe, and date, the individual growth zones within crystals such as zircon. Zircon is a Uranium-bearing mineral found in rocks. By this method, AGSO is dating terrains across Australia to measure the timing, and rates, of processes that drive mineralisation and petroleum generation. Contributing to the program of SHRIMP age control are palaeontologists, stratigraphers, fossil fuel specialists, and minerals experts from AGSO, geological surveys, universities, and exploration companies. By using SHRIMP, geoscientists correlate petroleum and mineral forming events across basins, and internationally. The greater understanding of how, and when, petroleum and mineral terrains form can lead directly to exploration activity.

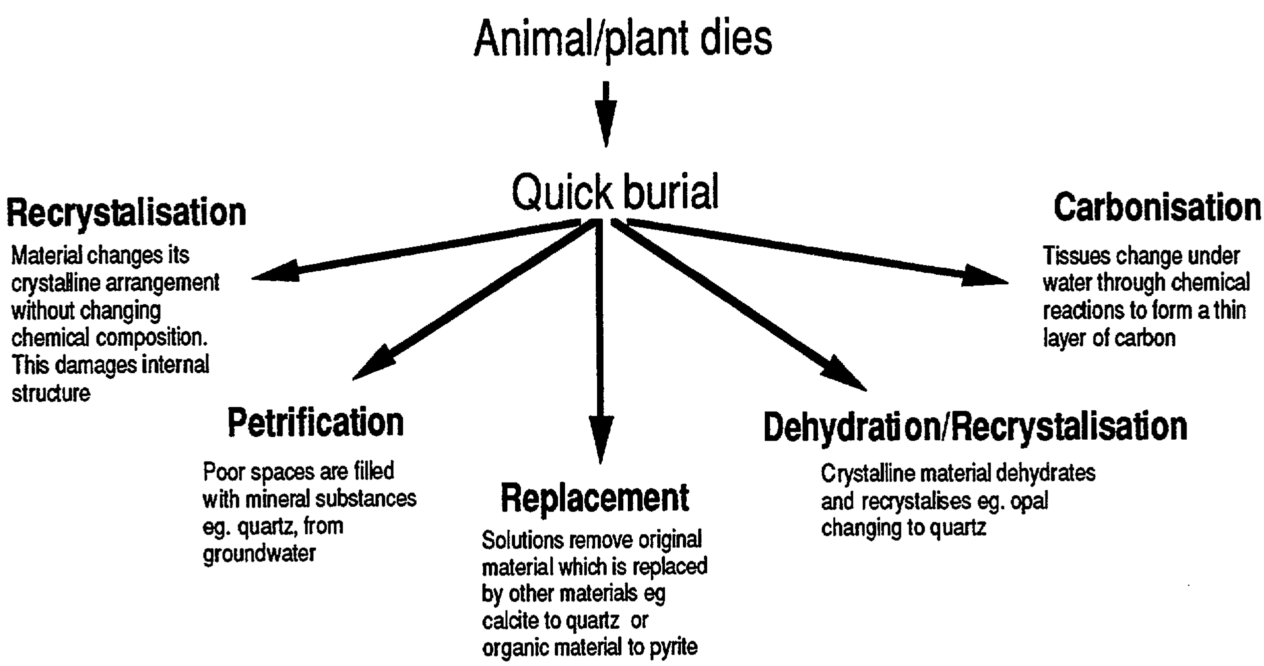
3. Palaeontology

Palaeontology is the study of fossil remains, both animal and plant, and their study to provide information on the geological history of Earth..

3.1 Fossilisation

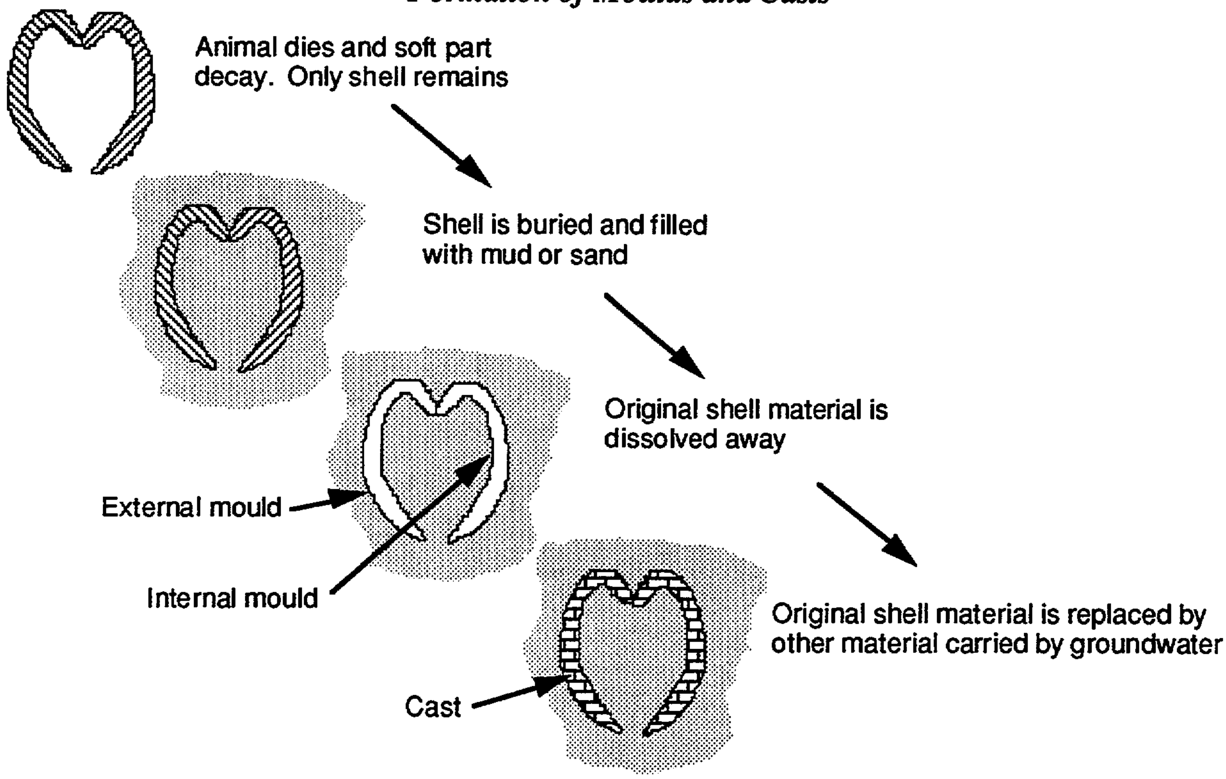
Fossils are the remains or traces of animals and plants which have been preserved in sedimentary rocks. For a fossil to form two conditions need to be met. The first is quick burial to prevent scavenging and to slow decay. The second condition is that animal needs to have hard parts, either shell or bone, to be preserved. There is occasionally special preservation conditions were soft animal tissue is preserved, such as insects encased in tree sap.

The process of preservation is summarised in the following diagram :



In many cases, the original material dissolves away leaving a cavity in the rock. These cavities represent moulds of the fossil. If the mould is later filled in by other material (replacement preservation) a cast is formed.

Formation of Moulds and Casts



Fossils can be divided into two groups based on size. The groups are :

Macrofossils - visible to the naked eye
Microfossils - visible only under a microscope

The Macrofossils can be further divided into three groups - invertebrates, vertebrates and plants. Of these groups the invertebrates are the most important for dating rocks.

> While vertebrates, particularly dinosaurs, are interesting for evolutionary studies their abundance in the fossil record is very small compared to the invertebrates and they will not be dealt with here.

3.2 Invertebrate Fossils

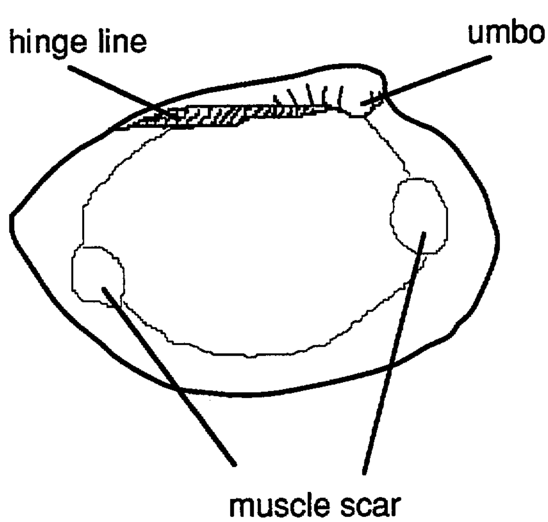
Molluscs

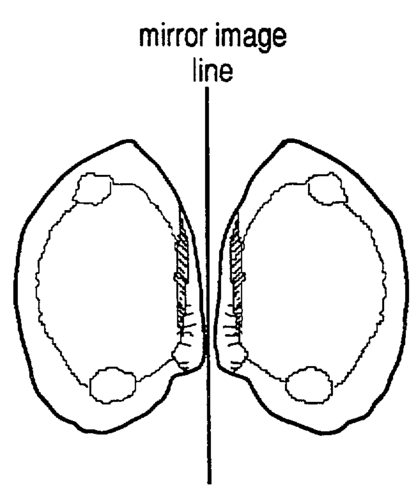
The mollusc family of animals can be divided into three major groups :

bivalves
gastropods
cephalopods

Bivalves

The bivalves are a shellfish (e.g. pippies, scallops, clams) whose shells, or valves, are virtually mirror images of each other. The two valves are joined together by a hinge and each valve has a hinge line. This hinge line is a surface on which small bumps or teeth and corresponding sockets occur so when the valves and placed together they lock into each other. The shell material above the outside of the hinge line forms a small hook, known as the umbo. The animal holds its shells together using strong muscles. These muscles attach to the valves in two places, leaving a "scar" on the shell.
The size and position of the muscle scars, hinge line and umbo is important for bivalve classification.



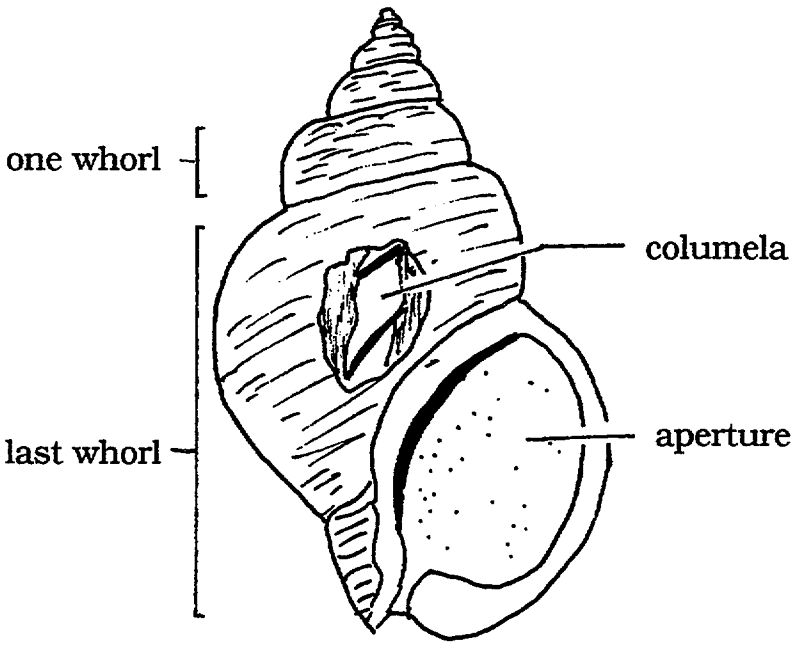


A pippi is a modern example of a bivalve.

Gastropods

Gastropods are a group of animals characterised by a coiled shell. Common garden snails are examples of gastropods. They are found in marine and fresh water environments as well as on land. They first appeared in the early Cambrian.

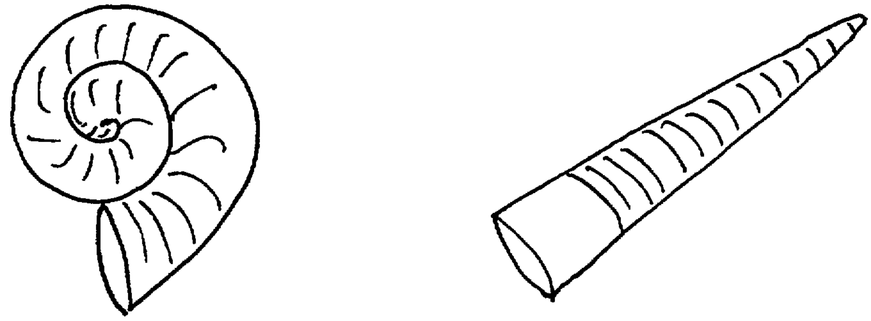
As many fossil gastropods are broken, they show the internal column, known as the columella. Each full turn of a gastropod is known as a whorl. Some gastropods have many whorls; others only a few.



Cephalopods

The cephalopods are entirely marine animals and the most highly evolved forms of molluscs. Within this group are the nautilus, squid and octopus and the extinct forms ammonoids and belemnites.

The shells of the ammonoids and belemnites are divided into gas-filled chambers which the animals could fill and empty to rise or fall in the water column. Ammonites usually have shells coiled in one plane while the belemnites have straight shells.

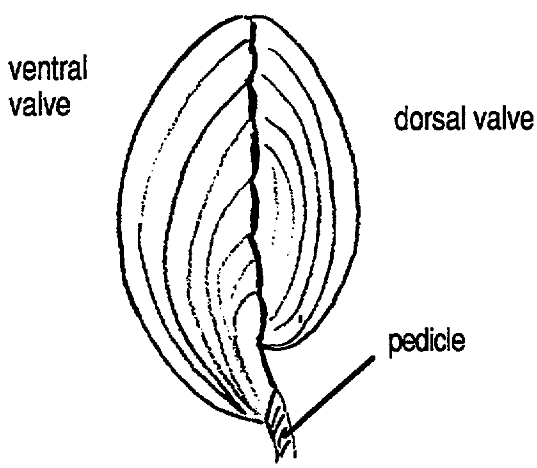


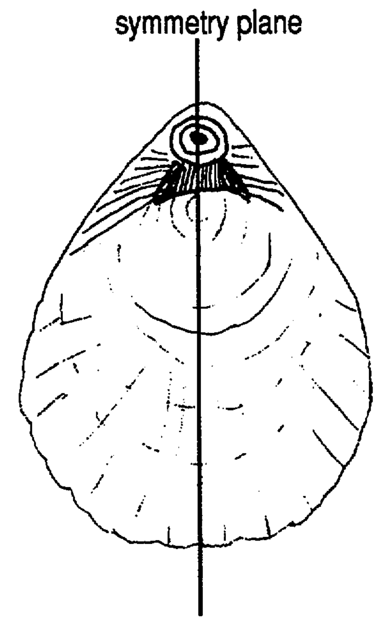
Ammonoid *Belemnite*

Belemnites are found only in rocks from the Jurassic to Cretaceous period, while ammonoids are found in rocks from the Devonian to the Cretaceous.

Brachiopods

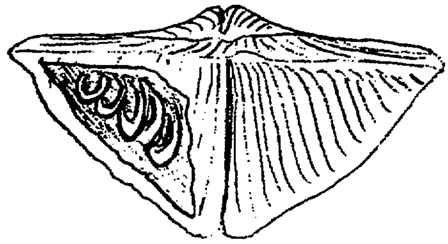
Brachiopods are shelled animals not unlike bivalves. In brachiopods the two valves are not the same size (i.e. not mirror images). The valves are however symmetrical along a central plane. The brachiopods first evolved in the Cambrian and some forms still exist today.





Some brachiopods were attached to the bottom of the ocean floor by a pedicle. Other forms developed spines to stabilise themselves in mud while rolling along the ocean floor and others were attached or cemented by their shell to rocks etc.

The spiriferid brachiopods are "bat" shaped, and have a spiral internal skeleton which supported the internal feeding organ, or lophophore.



Spiriferid brachiopod

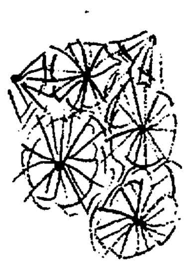
Corals

The corals belong to the Coelentrate group of animals. This family also includes jelly fish and sea anemones. They are almost entirely marine animals.

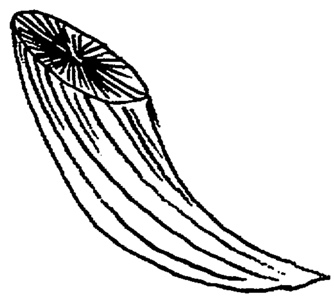
Two extinct coral forms are important in the fossil record, the rugose and the tabulate corals. Both forms were exclusively Palaeozoic.

Rugose Corals

The rugose corals occurred as either solitary or colonial forms. The solitary corals are usually horn shaped and lived in muddy sediment.



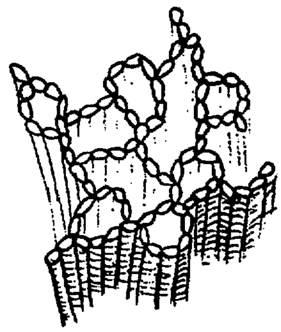
Colonial rugose



Solitary rugose

Tabulate corals

The tabulate corals were entirely colonial. The coralites were smaller than the rugose corals and each coralite was connected to other coralites via small pores.



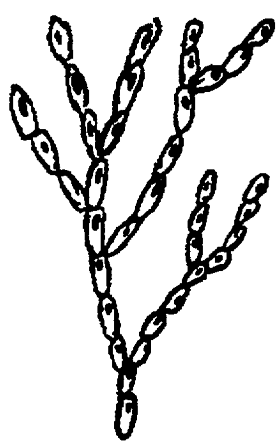
Halysites

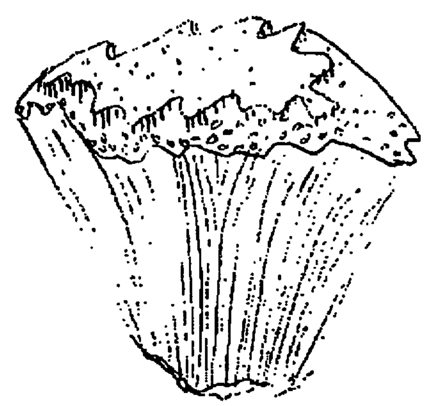
Heliolites

Bryozoans

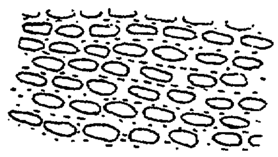
Bryozoans are not unlike corals except they have a more complex internal structure and have a full gut, mouth and anus (Corals feed and excrete through the same opening).

Each individual bryozoan builds a box-like living area which has two openings. One opening is for feeding while the other opening allows the animal to maintain a constant pressure inside its chamber which otherwise would change as it extended its body outside for feeding.





Bryozoans live in all waters, but are most common in colder areas of the oceans. They occur as fan-like, stick-like, or encrusting colonies usually attached to rocks or other materials..



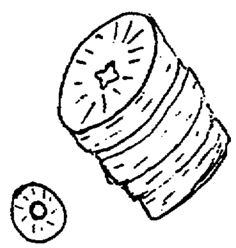
Fenestellid bryozoan

The bryozoans first evolved in the early Ordovician and still exist today.

Echinoderms

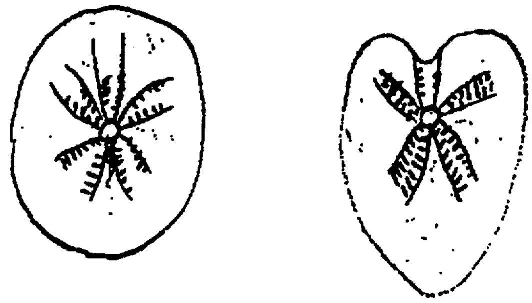
The echinoderm family includes animals such as the star fish, sea urchins and sea lilies. All echinoderms have an external skeleton.

Two types of echinoderms are important in the fossil record. The first are the crinoids (commonly called sealilies). These evolved in the Ordovician and while still in existence, were most prolific in the Palaeozoic era. Crinoids consisted of a stem consisting of many ring-like occicles of calcium carbonate at the top of which was a cup-shaped calyx made of calcium carbonate plates. At the margins of the cup were usually long feeding arms also with a calcium carbonate skeleton.



Crinoid ossicles

The second form of echinoderms are the echinoids. Echinoids are sea urchins and they first evolved in the Ordovician. Some echinoderms are regular i.e. almost circular in plan view, while others are irregular, some of which are called heart urchins because of their shape.

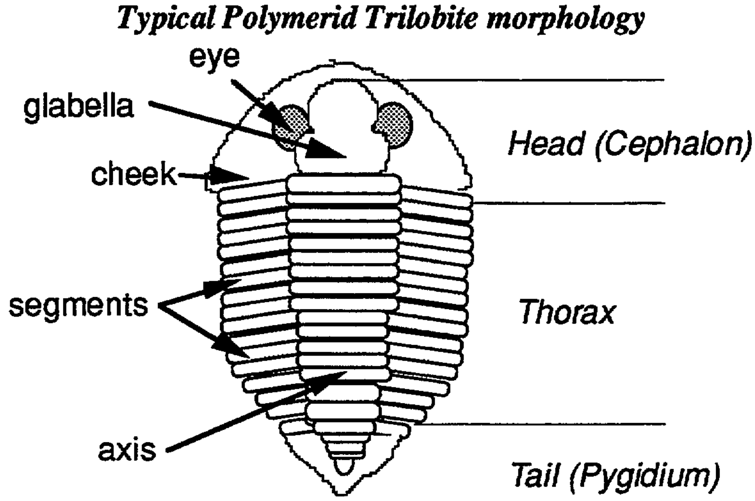


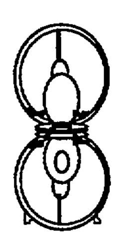
Trilobites

Trilobites belong to the group of animals which have segmented bodies and legs known as Arthropods. The trilobites are one of the earliest members of the arthropods with the first trilobites evolving in the early Cambrian. They became extinct in the late Permian some 300 million years later.

Trilobites were marine animals ranging in size from a few millimetres to up to 60cm long. There are two common types, polymerids and agnostids.

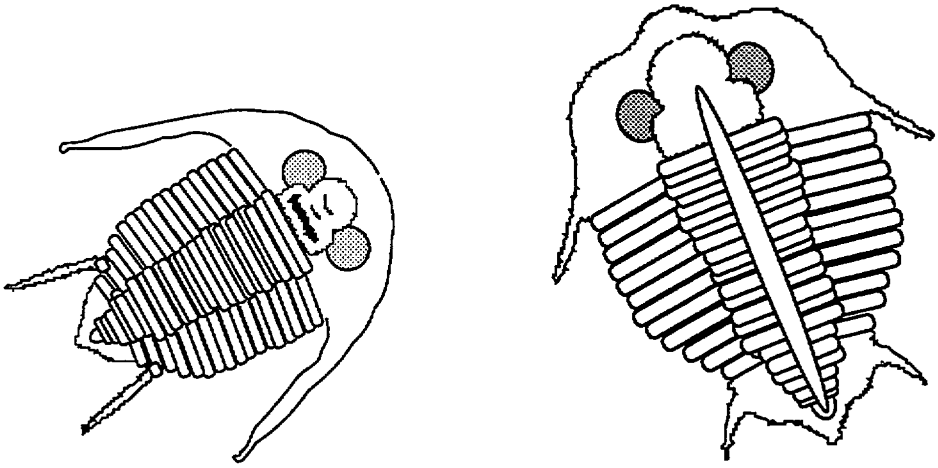
Typical Polymerid Trilobite morphology





Agnostid Trilobite

Trilobites can be found preserved as whole specimens or as parts of specimens, such as a tail or cheek. It is known that the trilobites shed their shells as they grew not unlike modern day crabs. Trilobites are classified usually by the structure of the glabella and other parts of the cephalon as well as by the structure of the pygidium.



Some other trilobite forms

Around 2000 different trilobite genera have been described by geologists. The changing form of the trilobites over their time on Earth allows geologists to use them as "index fossils" for specific periods in the Earth's history.

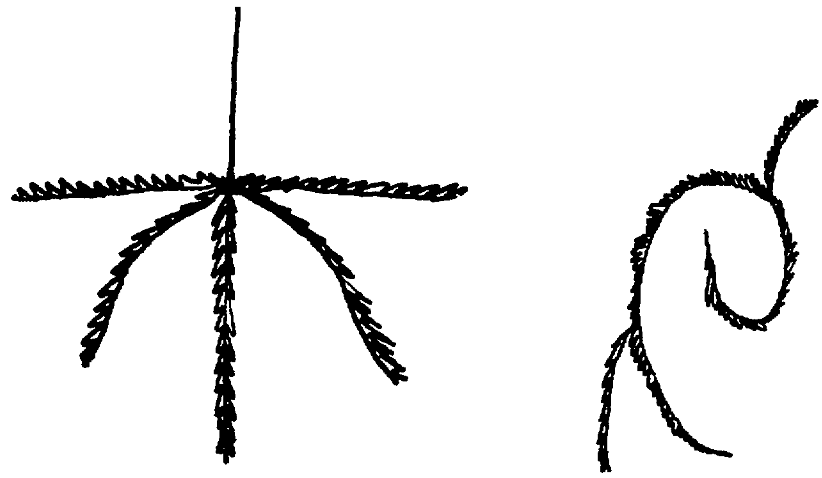
Graptolites

Graptolites are stick-like fossils that are found in the bedding planes of shales and slates. Graptolites floated in the ocean currents and probably fed on plankton.

They are found in rocks of the Palaeozoic era and evolved rapidly during this time, making them good index fossils.

The Graptolites can be subdivided into two main groups. The first group to evolve was the Dendroids. They existed from the Cambrian to the Carboniferous. They have networked branches and evolved slowly over time.
The second group is the Graptoloids. These evolved in the Ordovician and became extinct in the Devonian. The main evolutionary trend in the Graptoloids was a

reduction in the number of "branches" over time. Some of the later species had only one "branch" and belonged to the genus *Monograptus*.



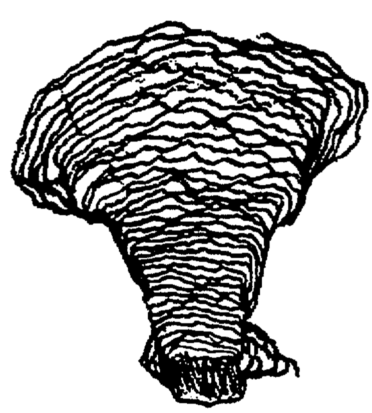
Some graptoloid forms

3.3 Plants

Land plants did not appear on Earth until the late Silurian. Prior to this, plant life on Earth was restricted to algae and bacteria. One of the most important groups of these early life forms were colonies known as stromatolites.

Stromatolites

Stromatolites structures which are built up from trapping of sediment by prokaryotic (cell with no nucleus) blue-green algae "mats". These algal mats were the first true reef-forming organisms on Earth, and still survive today in highly salty water lagoons, such as Hamelin Pool in Shark Bay, WA.

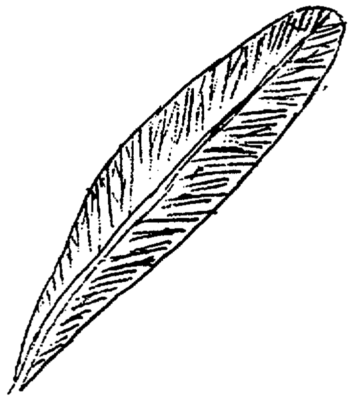


Cross section through a stromatolite

Land Plants

Fossils of land plants can be found in sedimentary rocks from the late Silurian to the Recent. Coal seams - coal being made up of massive accumulations of plant material - contain some distinctive fossils which are used to date the layers. Petrified wood is quite common, especially in the sediment layers between coal seams.

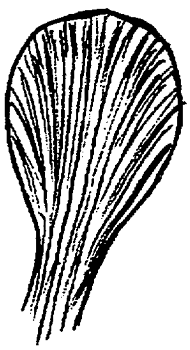
One interesting fossil plant is Glossopteris, which is only found in rocks of Permian age and is restricted to the southern continents. (India, South Africa, Australia)



Glossopteris leaf

Other common Australian plant fossils are shown below :

Stem fragment of Lepidodendron showing diamond shaped leaf bases (Carboniferous)



Gangamopteris leaf (Permian)

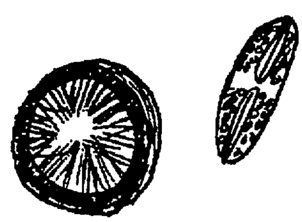
Rhacopteris frond (Jurassic)

3.4 Micropalaeontology

The study of microfossils has become important through the increased use of drill hole data, especially in the petroleum exploration industry. With drill holes producing small rock chips or cores around 50mm in diameter, the chance of a complete macrofossil being found and identified is very slim. However, the chance of finding fossils which are less than a few millimetre is much greater.

Diatoms

Diatoms are single celled plankton which precipitate silica from water to build up a shell known as a test. Diatoms occur both in fresh water and in the sea, living near the surface and being most abundant in colder waters. Deposits rich in diatoms are found in freshwater lakes and when turned to rock (lithofied) they are used in pool filters as diatomaceous earth.



Examples of Diatoms

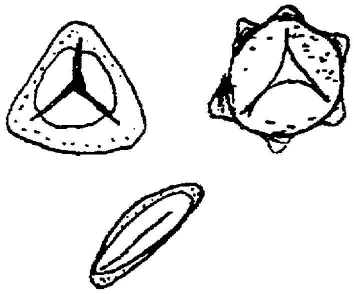
Coccoliths

Coocoliths are small circular plates of calcium carbonate which are embedded in the cell walls of the single celled marine algae known as cocolithophores.

Coccolithophore and Coccolith

Spores and Pollen

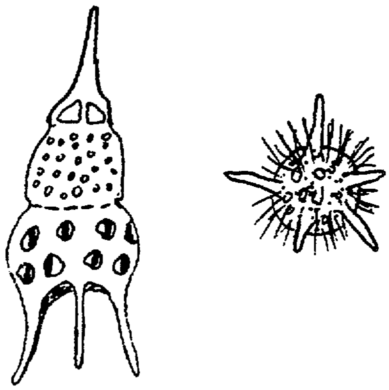
Plant spores and pollen are important microfossils because they are very resistant to decay due to their composition of complex organic substances. They are also very small and are carried vast distances by winds, making very good index fossils.



Spores and Pollen

Radiolarian

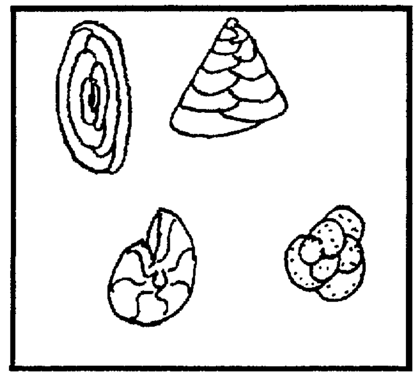
Radiolarians are single celled marine planktonic animals. They secrete symmetrical skeleton usually of silica, with an elaborate lattice structure. They have a wide distribution but their remains are most conspicuous in the deeper parts of the ocean where calcium carbonate is dissolved.



Radiolarian

Foraminifera

The forams are single celled animals that exist in both planktonic and benthonic (bottom dwelling) environments. They form calcium carbonate tests. They are very abundant in the ocean at all depths and in all latitudes. They are used extensively to date rocks laid down in the last 100 million years or so and some are excellent climatic indicators.



Forams

Ostracods

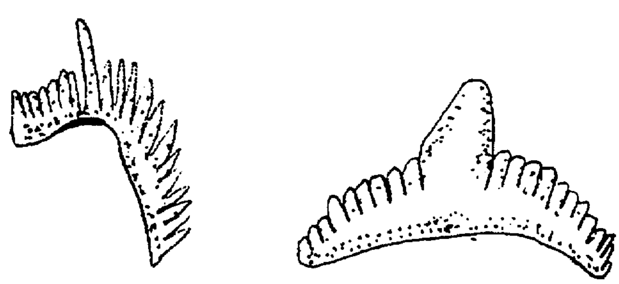
Ostracods are bivalved microcrustaceans which live in all types of aquatic habitats, and are common microfossils in marine, esturine and freshwater sediments. They range from the Cambrian to Recent, and are useful indicators of age and past environments.

Ostracods

Conodonts

Conodonts are small tooth-like structures composed of calcium phosphate. Recently, fossils of the entire animal have been found in Scotland. They indicate that the animal was a protochordate.

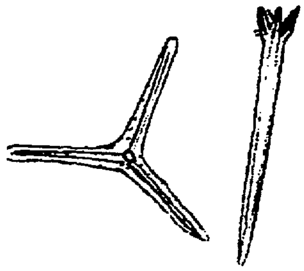
Conodonts are widely distributed and evolved rapidly. They used extensively to date rocks from the late Cambrian to the Triassic when they became extinct.



Conodonts

Sponge Spicules

Sponges build up their framework often from microscopic needles of silica called spicules. These needles are common in some ocean sediments.



Sponge Spicules

3.5 Trace Fossils

Trace fossils are fossilised animals tracks or burrows. Worm burrows are very common trace fossils. Others include such things as footprints of dinosaurs or walking tracks of trilobites.

4. Using Fossils

Geoscientists use fossils to work out a relative age of rocks and to establish the type of environment in which the rock was formed.

Dating rocks -using Index Fossils

Index fossils are fossils which clearly indicate a known period of geological time. Fort a fossil group to be useful as index fossils they must :

i. be found over a large geographical distribution
ii. have evolved fairly rapidly

When an index fossil is found, it can be used to establish the relative age of the rock layer.

Establishing Environment

Fossils are also good indicators of the type of environment in which the rock layers formed. Rocks found in cold climates containing fossils which lived in shallow warm ocean waters, such as many of the corals, indicate a change in environment. More importantly, fossils which live in distinctive areas of the ocean, such as forams, are important to work out the ancient depth of water of areas to establish if they are potential oil bearing areas.

In some cases, fossils are found preserved in their actual "living position". This gives palaeontologists much information about the animal's way of life and enables them to be compared to modern day equivalents. However, the majority of fossils have been reworked by ocean or river currents, because they are the remains of dead individuals.

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Australian Geological Survey Organisation (AGSO)

The Australian Geological Survey Organisation (AGSO) was established in 1946 as the Bureau of Mineral Resources, Geology and Geophysics, and is the Australian leader in geoscientific mapping and information services.

Currently AGSO is undertaking second-generation geological mapping, both on and off shore, to provide geoscientific information to all sectors of the Australian community.

To support this survey work, AGSO undertakes macro and micro palaeontological studies.

AGSO

AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

Geoscience Education

Activities

Gary Lewis
1994

Further Information : (06) 249 9570

Geological Time

Getting it to scale

Geological time is so immense (geoscientists believe that the earth is 3,800,000,000 years old) that it is often difficult for us to understand the vast amounts of time over which our Earth has developed.

One way of representing geological time is to make a time line, in which every millimetre equals a number of years.

Calculate how long a piece of paper you would need to use to draw a time line for the ages of the Earth, using the following scales.

Hint : there are 1 million millimetres in a kilometre

				Length of paper
1mm =	10 years	3,800,000,000 ÷ 10 =	380,000,000mm =	380 km
1mm =	100 years	3,800,000,000 ÷ =	mm =	km
1mm =	1,000 years	3,800,000,000 ÷ =	mm =	km
1mm =	10,000 years	3,800,000,000 ÷ =	mm =	m
1mm =	100,000 years	3,800,000,000 ÷ =	mm =	m
1mm =	1,000,000 years	3,800,000,000 ÷ =	mm =	m
1mm =	10,000,000 years	3,800,000,000 ÷ =	mm =	cm

Using the 1:10,000,000 scale and the 1:10,000 scale, calculate the distance from the present time to the various periods of geological time using the table below.

The Geological Time scale is used both as a relative time scale (comparing ages to each other) and an absolute time scale (giving an actual time in years before present). This activity is about absolute time.

Scale 1:10,000,000

(1mm=*10,000,000 years or 1 year=0.0000001mm)*

Era	Period	Start of period in years before present	Distance (mm)
CAINOZOIC	RECENT	15,000	
	QUATERNARY	1,800,000	
	TERTIARY	65 million	
MESOZOIC	CRETACEOUS	141 million	
	JURASSIC	205 million	
	TRIASSIC	251 million	
PALAEOZOIC	PERMIAN	298 million	
	CARBONIFEROUS	354 million	
	DEVONIAN	410 million	
	SILURIAN	434 million	
	ORDOVICIAN	490 million	
	CAMBRIAN	545 million	
PRECAMBRIAN	PROTEROZOIC	2500 million	
	ARCHAEAN	3800 million	

Scale 1:10,000

(1mm=*10,000 years or 1 year=0.0001)*

Era	Period	Start of period in years before present	Distance (mm)	Distance (m)
CAINOZOIC	RECENT	15,000		
	QUATERNARY	1,800,000		
	TERTIARY	65 million		
MESOZOIC	CRETACEOUS	141 million		
	JURASSIC	205 million		
	TRIASSIC	251 million		
PALAEOZOIC	PERMIAN	298 million		
	CARBONIFEROUS	354 million		
	DEVONIAN	410 million		
	SILURIAN	434 million		
	ORDOVICIAN	490 million		
	CAMBRIAN	545 million		
PRECAMBRIAN	PROTEROZOIC	2500 million		
	ARCHAEAN	3800 million		

Find out the year (known or estimated) for the following events and then calculate the distance from the present time using the 1:10,000,000 scale and the 1:10,000 scale.

Event	Year	1:10,000,000 (mm)	1:10,000 (mm)
Birthday			
First Moon landing			
First artificial satellite			
First powered aircraft flight			
Invention of the printing press			
First motor car			
Gold rushes			
Captain Cook discovers Eastern Australia			
Birth of the Prophet Mohammed			
Birth of Christ			
Birth of Buddha			
Birth of Confucius			
Start of Aboriginal occupation			
Last Ice age			
Oldest known Homo sapien fossil			
Extinction of Dinosaurs			
Oldest dinosaur fossil			
Oldest flowering plant fossil			
Oldest plant fossil			
Oldest fish fossil			

With your teacher, select one scale and draw out the time line for the geological history of the Earth.

Hints :

1:10,000,000 Scale

You will be able to draw your time line on a piece of paper around 40cm long. However, it will be very hard to separate some of the dates as they will be in fractions of millimetres.

1:10,000 Scale

You will need to do this on a footpath alongside a straight road. You can use chalk to make the marks on the foot path. It will need to be around 400m long. This will allow you to separate more, but not all, dates.

Another Scale

An alternative is to calculate a different scale so as to fit a time line along one wall of the classroom. To calculate this scale, use the following formula :

L= length of wall (m)

1mm = 3,800,000,000 (L x 1000) years

e.g. A classroom wall of 11m

L=11

1mm = 3,800,000,000 (11 x 1000) years

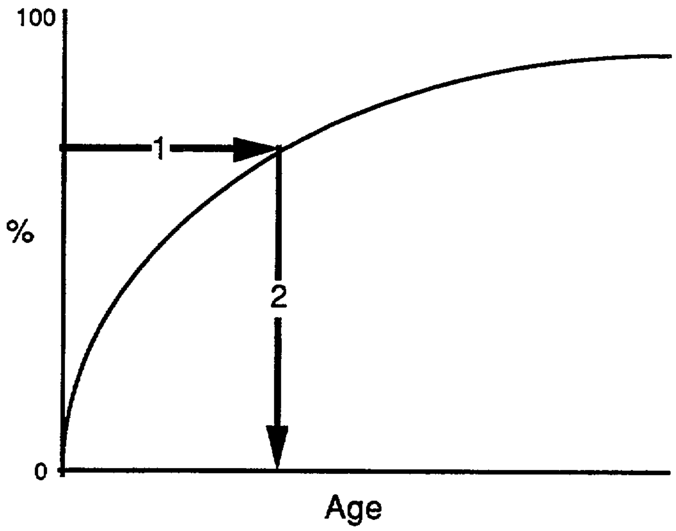
= 345,454 years

Reading Decay Product Curves

During the process of radioactive decay a "parent" radioactive atom decays to form a "daughter" atom over time. To calculate a radiometric age, geoscientists measure, using a mass spectrometer, the amount of daughter atoms that have accumulated in the sample through decay.

They then use known decay product curves to find the age of the sample.

To read the decay product curves, use the vertical (y-axis) to find the percent of decay product in the sample and read across (1) until you touch the curve representing that daughter atom. Then drop straight down (2) to find the age. Note that the scale on the decay curves is X 1,000,000,000 years.



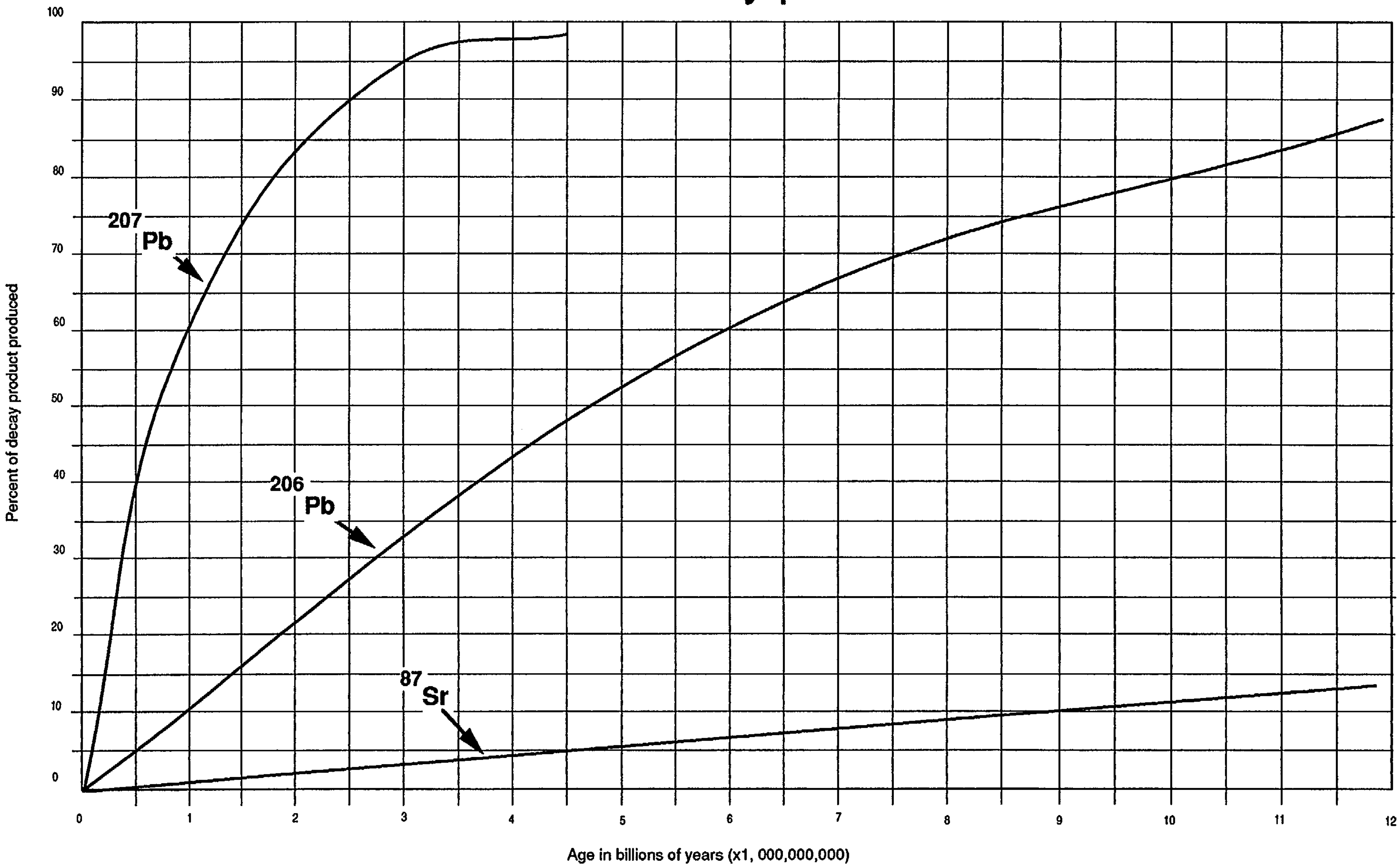
Find the ages of the following samples

Daughter Atom	% of daughter atom accumulated	Age (years)
^{207}Pb	60	
^{207}Pb	40	
^{207}Pb	50	
^{206}Pb	9	
^{206}Pb	50	
^{87}Sr	5	
^{87}Sr	4	

If the age of the Earth is 4 600 000 years, what percentage of the daughter atoms will have accumulated .

^{207}Pb __________ ^{206}Pb __________ ^{87}Sr __________

Radioactive decay product curves



Radioactive Ages

You have discovered a new radioactive element, which you have called Kryptonite (after Superman's home planet). You have given it the chemical symbol Kp.

You have found that Kryptonite decays to Xenon (a noble gas) after a period of time.

Kp	→	Xe
parent atom	**decays**	**daughter atom**

You want to use Kryptonite to date rocks found in Australia. Unfortunately, you do not know the half-life of Kryptonite — that is the period of time it takes for one half of Kp to decay to Xe. However, using other radiometric dating elements such as Uranium 235, you do know the ages of some rocks containing Kp. You have summarised these in the table below.

Rock no.	U^{235} age	% Kp	% Xe
1	5,000,000	23	77
2	500,000	75	25
3	2,350,000	40	60
4	4,475,000	25	75
5	7,200,000	14	86
6	300,000	82	18
7	1,250,000	56	44
8	3,150,000	33	67
9	9,900,000	9	91
10	11,400,000	7	93
11	1,800,000	47	53
12	5,750,000	18	82

On the blank graph, plot the twelve points then draw a curve of best fit.

?

What is the half-life of Kp (how long does it take for 50% to decay to Xe?)

______________________________ years

?

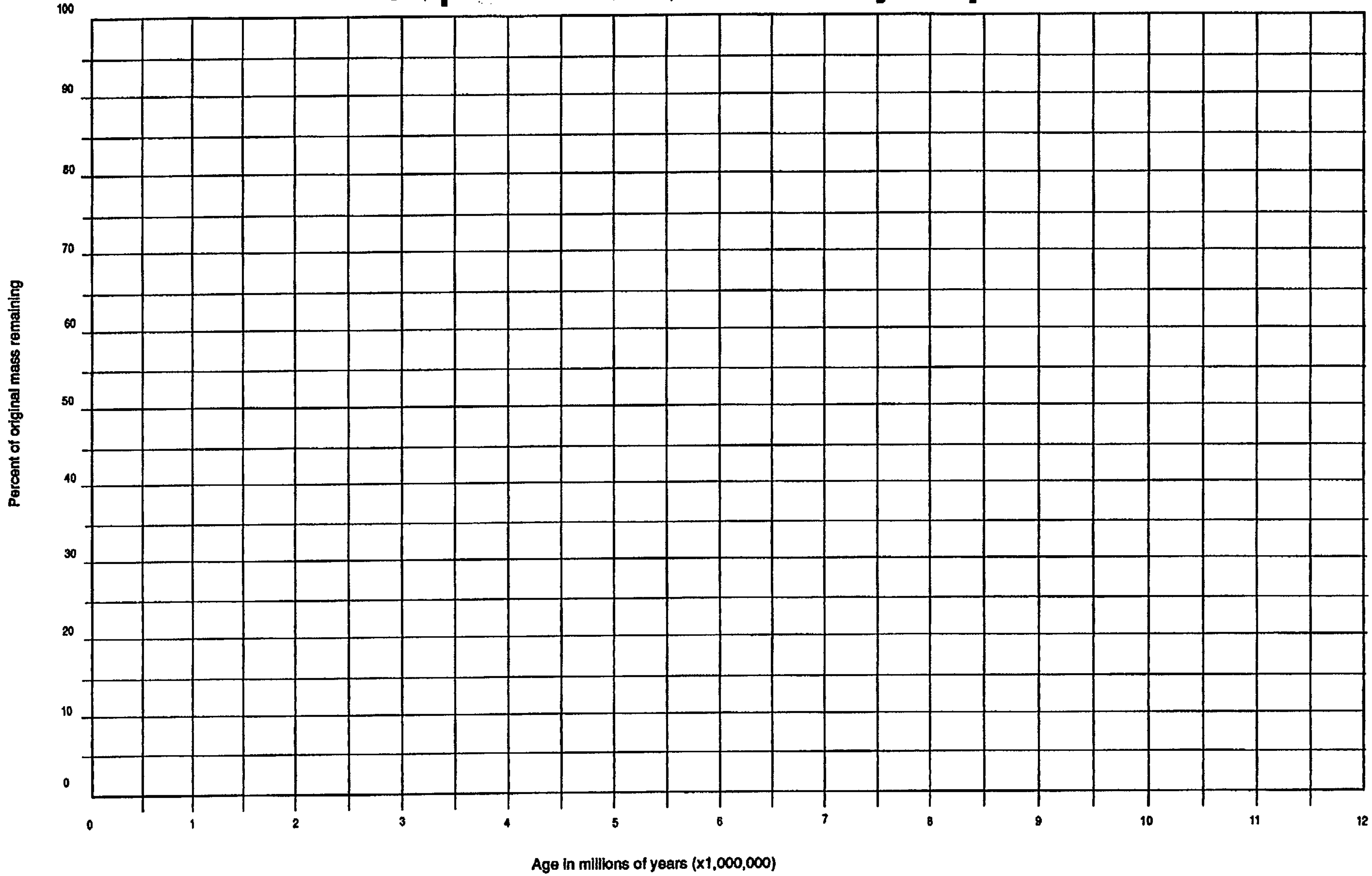
What are the ages of the rocks listed in the table below

Rock no.	% Kp	% Kp	AGE
13	30	70	
14	15	85	

?

Another geoscientist dated Rock 13 using U^{235} and found an age of 8,500,00 years. What may have happened to the rock to give you an incorrect answer?

Graph of the Radioactive Decay of Kp to Xe



Decay Machine

The Decay Machine simulates the radioactive decay of atoms over time. During each time period a number of "parent" atoms will decay to "daughter" atoms. The rate of decay is fixed.

What to do

1. Set the Decay Machine on a bench so that the Parent Input Tray end is slightly higher (about 2 cm) than the other end. Place a container under the Parent out tray and one under the Daughter out tray.

2. Place 100 marbles slowly into the Parent Input Tray end allowing them to run through the Machine. This is the first time period.

3. Count the marbles which have ended up in the Daughter Out Tray. These marbles represent the atoms which have decayed during the first time period. Write the number against Event 1 in the table below, then put these mables to one side.

4. Place the marbles from the Parent Out Tray in to the Parent Input Tray as in step 2. (Make sure that you have a container under the Parent Out Tray and the Daughter Out Tray!). Let the marbles flow through the machine. This is the second time period. Count the number of marbles in the Daughter Out Tray and write the number in the Table below. Also write the cummulative total of daughter marbles (Event 1 daughter marbles + Event 2 Daughter marbles) in the column provided.

5. Repeat step 4 until there are no marbles in the Parent Out Tray. Record every time period in the table below, even if no marbles end up in the Daughter Out Tray.

Event	Daughter Marbles	Total
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

Event	Daughter Marbles	Total
11		
12		
13		
14		
15		
16		
17		
18		
18		
20		

Event	Daughter Marbles	Total
21		
22		
23		
24		
25		
26		
27		
28		
29		
30		

6. Repeat the whole process three time so you have three sets of data. Write your other sets of data on another piece of paper.

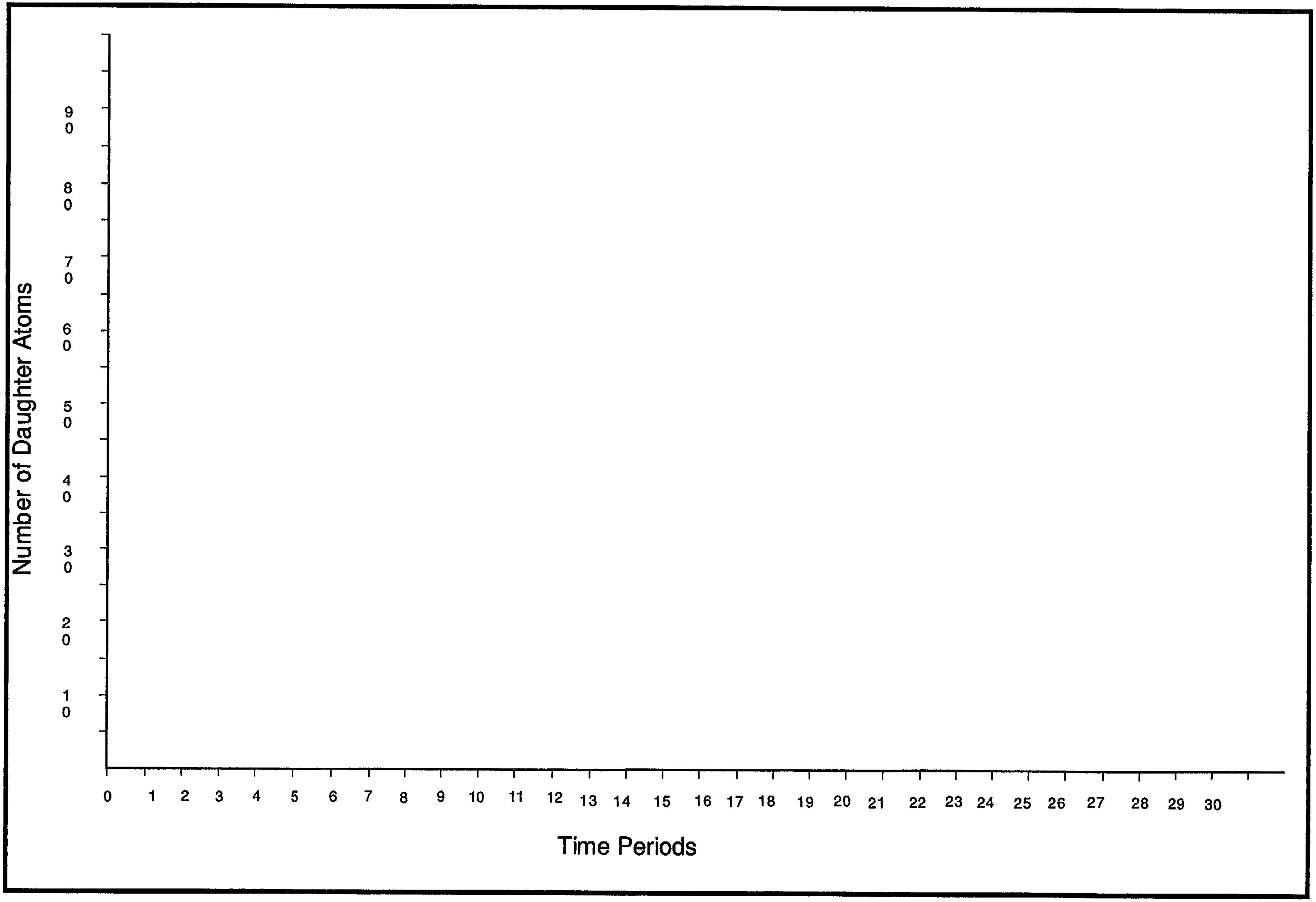
7. From your three data sets calculate an average cummulative total number of daughter atoms. Write these in the next table.

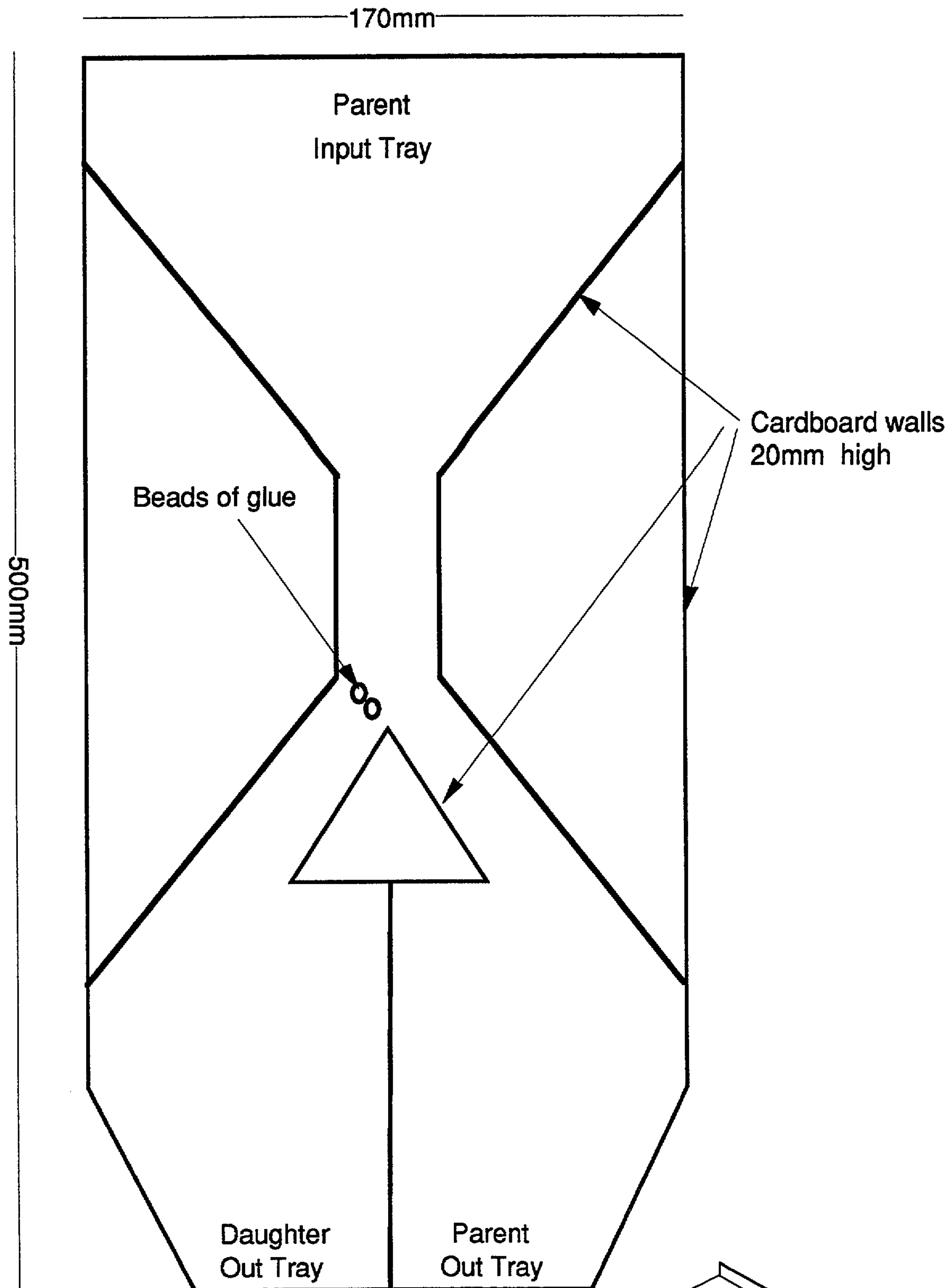
Event	Average Total	Event	Average Total	Event	Average Total
1		11		21	
2		12		22	
3		13		23	
4		14		24	
5		15		25	
6		16		26	
7		17		27	
8		18		28	
9		18		29	
10		20		30	

8. Plot these average values on the graph provided and draw a curve which best fits your plotted points.

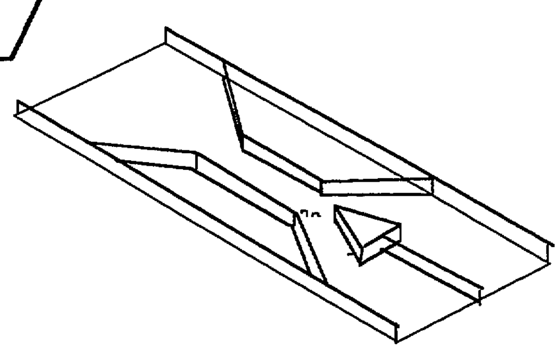
9. Use your graph to find the half life of the Decay Machine marbles. This is when exactly 50 Parent marbles have decayed to Daughter marbles.

Half Life :____________________Time periods


Number of Daughter Atoms
90
80
70
60
50
40
30
20
10
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Time Periods



Plan View



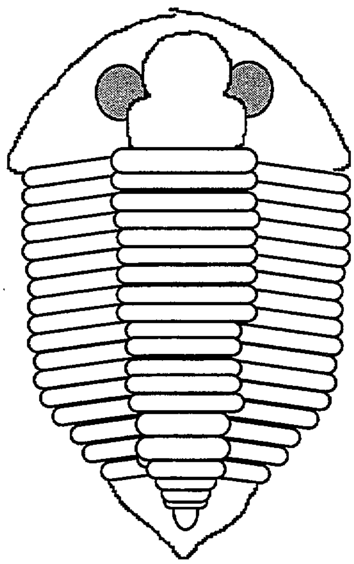
Decay Machine

Made from an old cardboard box

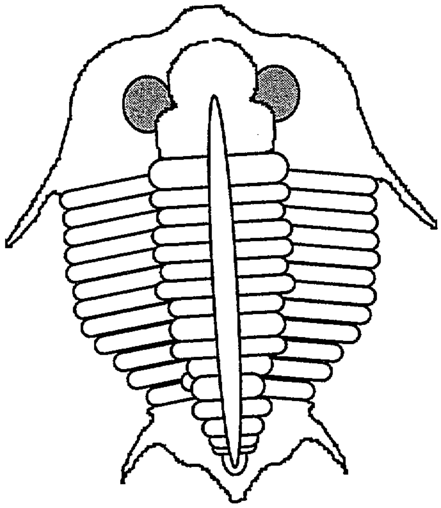
Critter Identification

A geologist, Sally Welsh, has returned from a field trip with rock samples containing two unknown trilobites. Your job, as a trilobite palaeontologist, is to describe the two trilobites so that other palaeontologists will be able to recognise them in the field.

Below are diagrams you have had drawn of the two trilobites. They are life-size in these drawings.

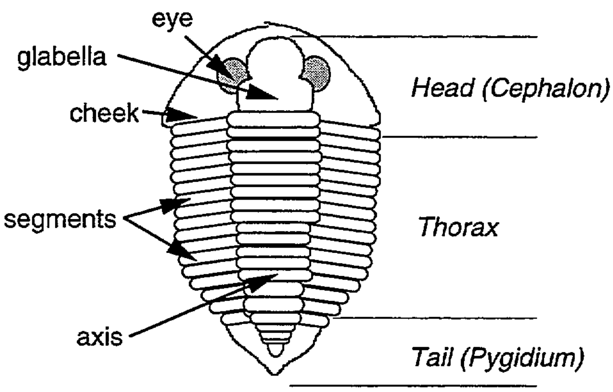


Trilobite A



Trilobite B

When you describe the trilobites, you should use the correct names for each of the trilobite parts. The correct parts

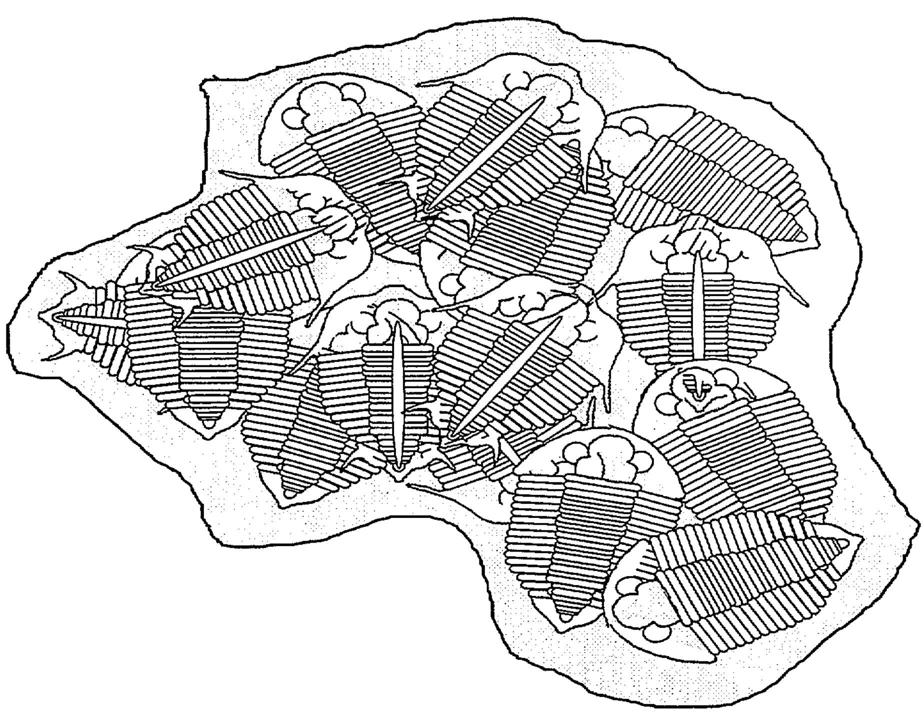


You have already completed the description of the Trilobite A and have named it after the geologist who found it. Your description reads :

Trilobitus welshi is 67mm long and up to 43mm wide. Its thorax and axis have 17 segments. It does not have a ridge running along its axis. It has smooth rounded cheeks with no cheek spines. Its glabella is smooth and it has two eyes each of 6mm diameter.

Write a description and name Trilobite B.

On the next field trip, Sally brought back a rock containing a number of trilobites which you have described. How many of each type are there?



While you are looking through the old papers of a long dead trilobite expert you come across a description of a trilobite he had described. From his description, can you sketch what the trilobite might have looked like?

"Trilobitus lewisi is 50mm long. Its widest part is at the boundary of the cephalon and thorax where it is 27mm. The cephalon is a perfect semi-circle with a perfect oval glabellar. It has small (2mm) eyes. The thorax has 12 segments. The four segment from the head has a spine which points towards the tail. The axis also has twelve segments. The pygidium is 20mm long."

Fossil Frazzle

On the way back from her last field camp, Caroline had to drive her four-wheel drive through a flooded creek. All her fossils samples became wet and the labels washed off. Caroline quickly put new labels on the samples (A,B,C,D). Can you help Caroline by identifying the fossils and working out the ages for her samples?

What to do.

1. Examine the pictures of the eight fossil types which Caroline had researched before going into the field. Examine each of Caroline's samples and identify the fossils they contain.
Note : Some fossils are incomplete! Write the name and number of the fossil in the space provided below :

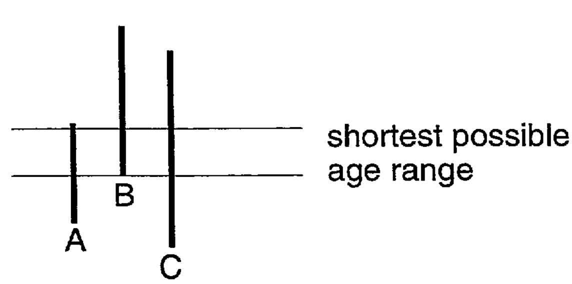
Sample A :

Sample B :

Sample C :

Sample D :

2. Using the Geological Time scale (with fossils groups), give a shortest relative age range for each of Caroline's samples using the Epoh/Period names. Each of the fossils is shown on the time scale with a line repesenting the period that they existed on Earth. This age range for the sample will correspond to the ages where all the fossils in the sample existed.



eg. Range from : Llandeilo Ordovician to Ashgill Ordovician

Sample A : Range From :	**to**

Sample B : Range From :	**to**

Sample C : Range From :	**to**

Sample D : Range From :	**to**

3. Place the samples in order, from oldest to youngest

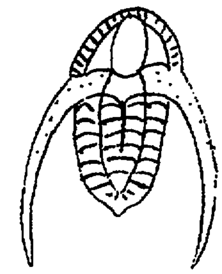
Oldest **Youngest**

Fossil Types

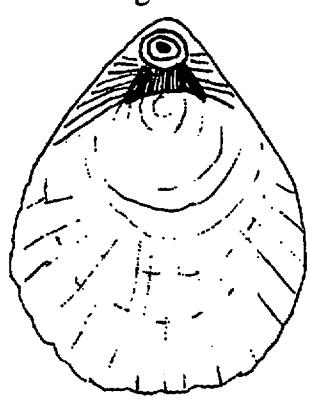
Researched by Caroline

1. Fossil group : Graptolite
"Sinograptidae"

2. Fossil group : Trilobite
"Trinucleina"

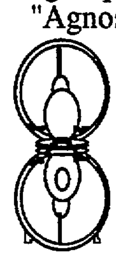


3. Fossil group : Brachiopod
"Magellania"

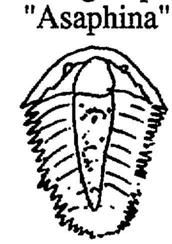


4. Fossil group : Tabulate Coral
"Heliolites"

5. Fossil group : Trilobite
"Agnostina"

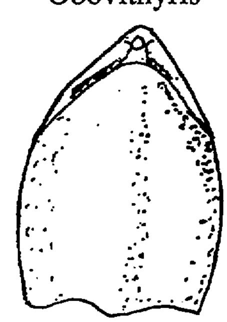


6. Fossil group : Trilobite
"Asaphina"



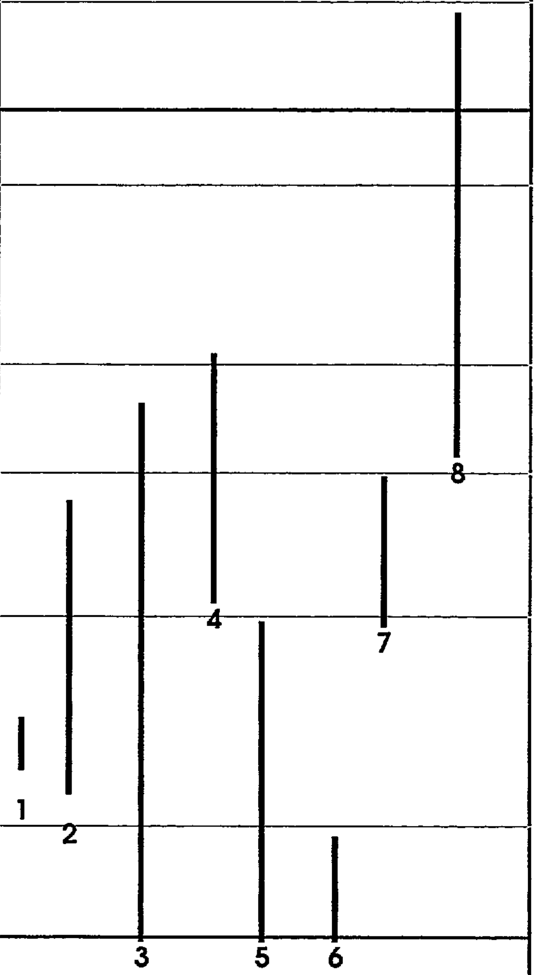
7. Fossil group : Graptolite
"Cyrtograptidae"

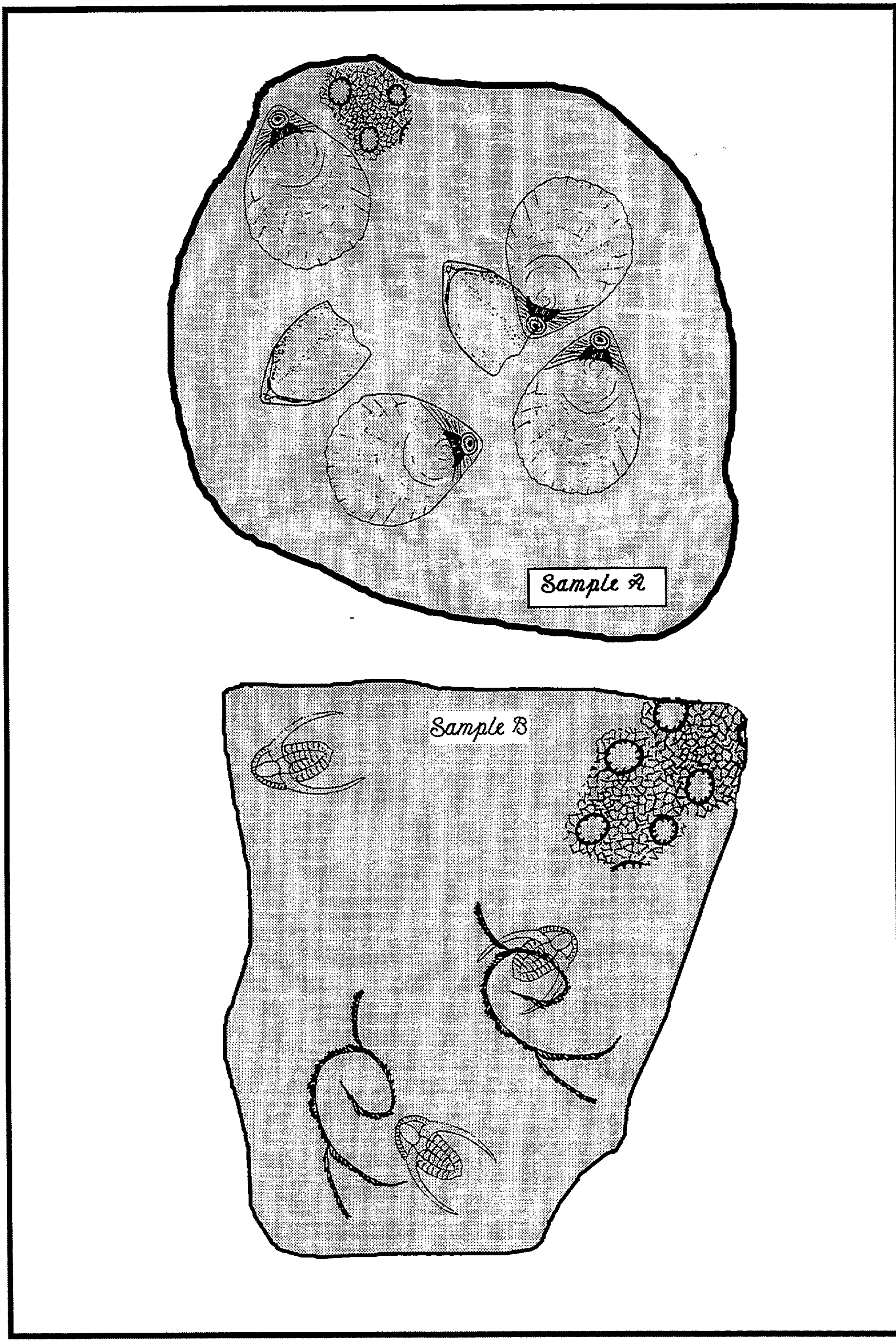
8. Fossil group : Brachiopod
"Obovithyris"

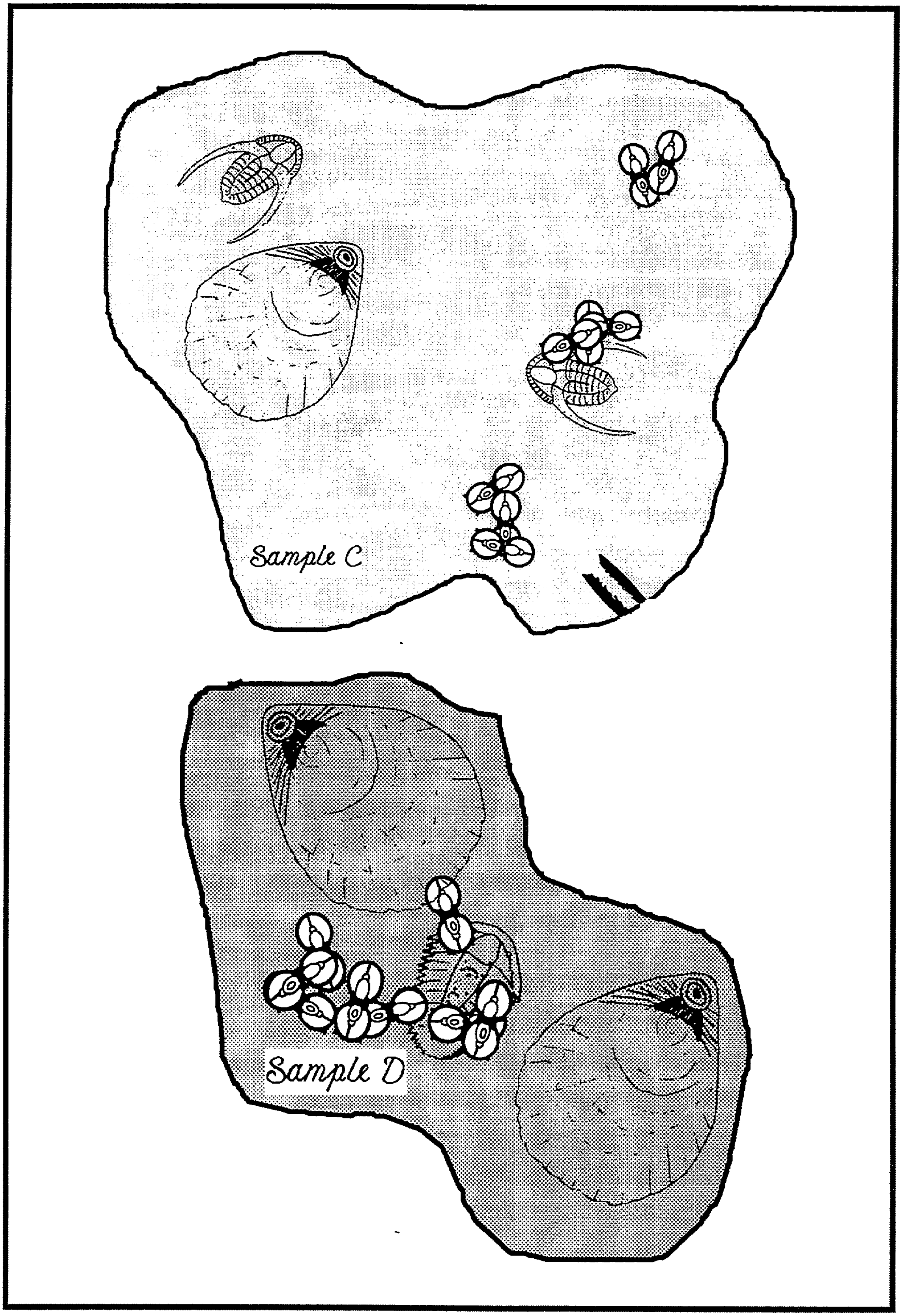


Geological Time Scale with Fossil Groups

Era	Period	Epoch	Fossil Types
CAINOZOIC	QUATERNARY	Holocene (recent) Pleistocene	
	TERTIARY	Pliocene Miocene Oligocene Eocene Paleocene	
MESOZOIC	CRETACEOUS	Late Early	
	JURASSIC	Late Middle Early	
	TRIASSIC	Late Middle Early	
PALAEOZOIC	PERMIAN	Late Early	
	CARBONIFEROUS	Stephanian Westphalian Namurian Visean Tournaisian	
	DEVONIAN	Late Middle Early	
	SILURIAN	Pridoli Ludlow Wenlock Llandovery	
	ORDOVICIAN	Ashgill Caradoc Llandeilo Llanvirn Arenig Tremadoc	
	CAMBRIAN	Late Middle Early	
PRECAMBRIAN	PROTEROZOIC	Late Middle Early	
	ARCHAEAN		



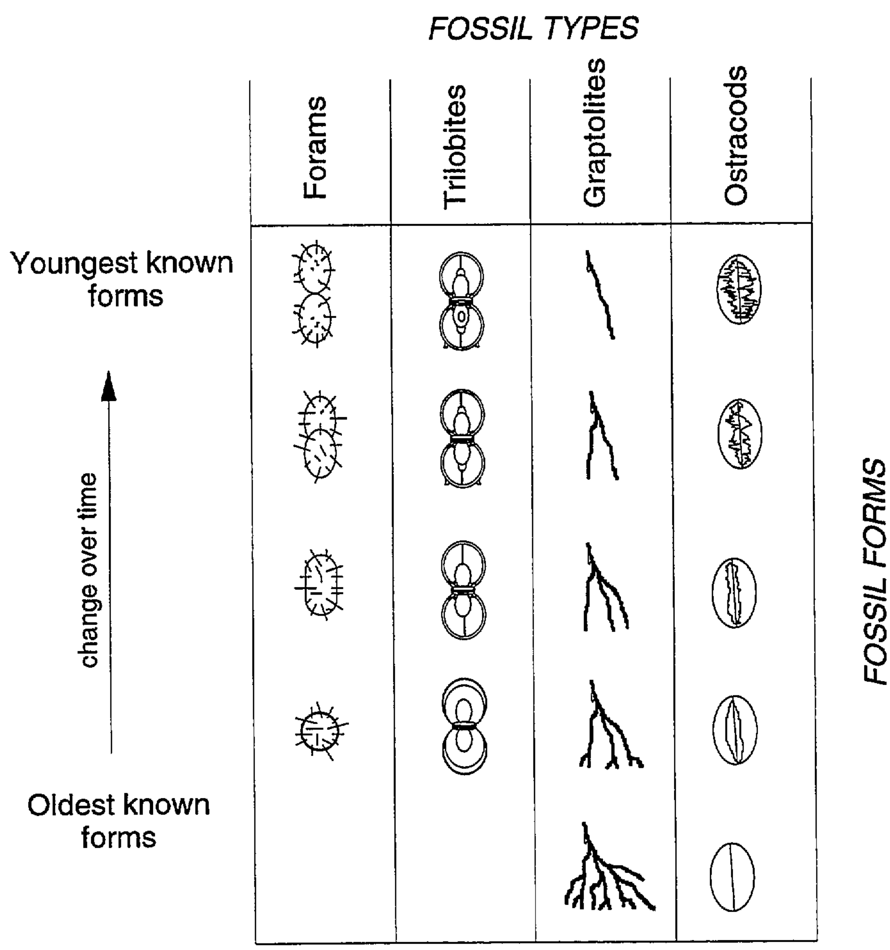

Sample A
Sample B


Sample C
Sample D

Drill Hole Stratigraphy

A petroleum exploration company has drilled a number of drill holes on the ocean floor to find out the relative ages of the rock layers in their hunt for oil. They have had a geologist identify the fossils, but they have not been able to work out the relative ages of all the rock layers. Can you do it?

The fossil types identified by the geologist are trilobites, graptolites, forams and ostrocods. Each of these types have a number of different forms, which have evolved over time. Research you have already undertaken gives the relative ages of each member of the fossils types. You have summarised these in a table :



Your table does not compare fossils types, only the known ages between different forms of the same fossil i.e.. the form of graptolite at the bottom is older than the form of graptolite above it, but it may be older or younger than the form of ostracod at the bottom.

What to do.

1. You have been given information about the fossils contained in four drill holes (A, B, C, D and E). Cut out each of the drill holes into strips (do not cut between the fossil layers). In each drill hole, the fossils at the bottom are older than the fossils at the top.

2. Line up like fossils. *Note* that in some cases fossils of different types will have the same age. You may have to swap the strips around so you get the best amount of information you can from each drill hole.

3. Give each layer of the same age a number, the youngest layer at the top being 1 with the layer below being 2 and so on until you find the layer containing the oldest fossil. These number represent relative ages for the layers

4. Use the layer numbers to give each fossil in the table above a relative age.

Describe the youngest fossils.

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How does this form differ from other forms of the same fossil type?

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Describe the oldest fossil form.

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How does this form differ from other forms of the same fossil type.

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OCEAN FLOOR DRILL HOLES