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Handout 9 of 14

(*Topic 3.3*)

The Geological Time-scale

The Grand Canyon, eroded by the Colorado River, viewed from the South Rim (http://en.wikipedia.org/wiki/Image:Grandcanyon_laban.jpg). The canyon is less than six million years old, but exposes Proterozoic, Palaeozoic and Mesozoic sedimentary strata.

The History of the Earth

The Geological Time-Scale

Key Ideas	Intended Student Learning
Fossil evidence was used to develop the geological time-scale.	Explain the relationship between the fossil record and the eras in the geological time-scale. Explain why the fossil record is inevitably incomplete, especially for organisms that lived more than 600 million years ago. Identify each of the following fossils and explain its significance within the geological time-scale: Ediacaran fauna, Archaeocyatha Trilobites, Graptolites Dinosaurs, Mammals. Ammonites
Isotopic dating is a means of assigning absolute ages to rocks.	Explain, in terms of parent/daughter elements and half-life, the concept of radioactive decay. Interpret decay curves.

The Geological Time-Scale

This is the revised Geological Time-Scale and will be provided to you in the 2006 examination.

Eon	Era	Period	Epoch	Date at Boundary (Ma = million years ago)
Phanerozoic	Cainozoic	Neogene (previously Quaternary) Old Tertiary-Quaternary boundary	Holocene	0.01
			Pleistocene	1.5
			Pliocene	5
			Miocene	24
		Palaeogene (previously Tertiary)	Oligocene	35
			Eocene	55
			Palaeocene	65
	Mesozoic	Cretaceous		145
		Jurassic		210
		Triassic		250
	Palaeozoic	Permian		300
		Carboniferous		350
		Devonian		400
		Silurian		440
		Ordovician		500
		Cambrian		540
Proterozoic		Ediacaran		600
				2500
Archaean				4500

3.3 – The Geological Time-Scale

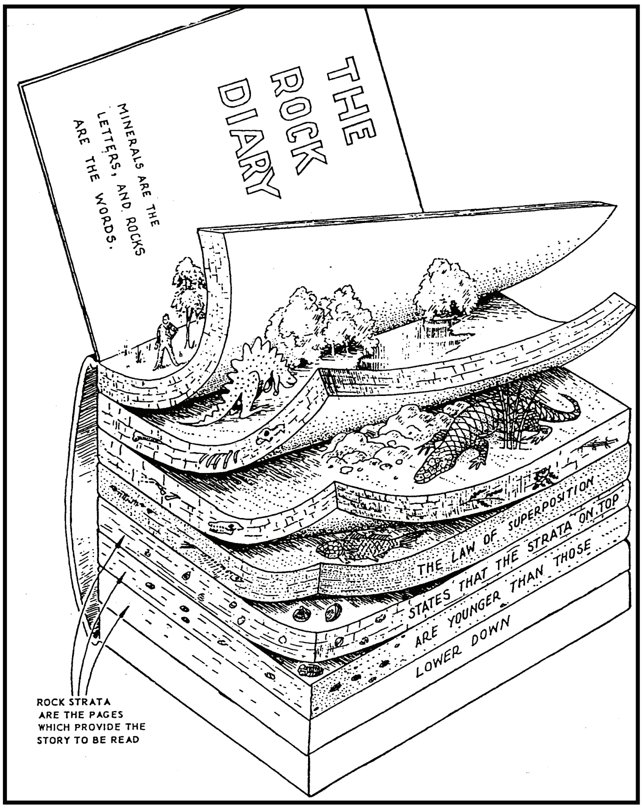
THE PALAEONTOLOGICAL RECORD

The history of life on Earth is recorded in rock strata which may be compared to the pages of a book. Unfortunately, the earliest pages of the book are illegible, and a number of other pages are missing…

Fossil Evidence

The study of fossils (palaeontology), together with other geological and biological evidence, provides information on the history of Earth and the evolution of life. Fossils provide evidence about the relative ages of rock strata, palaeo-environments and evolution of life. The fossil record has been used to develop the worldwide geological time-scale.

Organisms may leave traces of their existence in the sediments formed during, or shortly after their lifetimes.



FOSSILS are preserved remains of living organisms.
(Minerals have replaced the carbon-based structure within the mould, or the organism has left an impression in the rock.)

They may be preserved in rocks formed from sediments that were deposited in a wide variety of environments.

TRACE FOSSILS are disruptions of sediments caused by the normal activities of animals.

Examples are footprints, feeding traces, worm burrows or coprolites (fossilised faeces).

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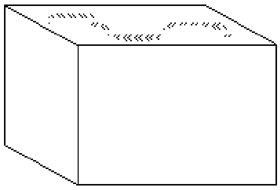
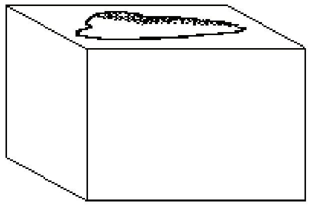
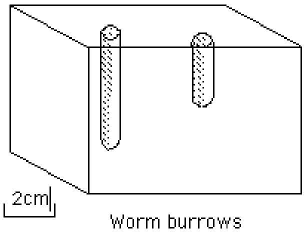






Features of the Fossil Record

Below is a list of some of the significant features of the fossil record as we know it today:

1. The oldest known fossils, of single-celled organisms, are from about 3800-3500 Ma.

2. Evolution proceeded very slowly at first. The oldest known fossils of multicellular organisms are the Ediacaran fauna (580 to 550 Ma) of the Flinders Ranges, South Australia.

   The first organisms with hard parts evolved during the Cambrian era, when there was a 'sudden' increase in the number and diversity of living organisms — the **Cambrian Explosion**

3. The rate of evolution has been ever-increasing. More organisms have evolved in the 60 million years of the Cainozoic era than in the whole of geological time before the beginning of the Cainozoic.

4. Evolution has not proceeded at a uniform rate. There have been intervals during which a large number of new life forms has evolved (*e.g.* the Cambrian Explosion), and periods of 'sudden' extinction of many life forms.

5. Life forms have evolved from the simple to more complex: from single-celled organisms to humans.

   Within a group of organisms, such as ammonites, the same tendency has been noted. The earliest members of the group to evolve were much simpler in form and structure than those that evolved later.

6. Increasing diversity — from a few species of single-celled organisms to the enormous variety of life on earth today.

7. Organisms have succeeded each other in a sequence that is the same in all parts of the world.

   e.g. Trilobite fossils are always older than ammonite fossils, no matter where these fossils are found.

Once an organism disappears from the fossil record, it never reappears in younger strata. It has gone forever!

A group became which extinct, may have been replaced by another, more 'modern' group of organisms.

The Geological Time-scale

The ideas of **superposition** and **evolution** provide the basis of the geological time-scale, which was developed in a somewhat random fashion (mostly in Europe) during the 19th century. It is a worldwide scale developed by correlation of fossils from all around the world. It is based on the features of the fossil record discussed above.

The geological time-scale divides the history of Earth is divided into **eons, eras**, **periods** and **epochs**.

Eons are the largest intervals of geologic time. A single eon covers a period of several hundred million years. The history of Earth has been divided into three eons: **Archaean, Proterozoic** and **Phanerozoic**. Life began to evolve during the Archaean (at least by 3700 Ma), but multicellular organisms did not appear until about 580 Ma (in the middle of the Ediacaran period), some 30 million years before the end of the Proterozoic. Nearly all the evolution of life has occurred during the Phanerozoic (in which we live).

NB: The time between Earth's formation and the beginning of the Palaeozoic era (*i.e.* the Proterozoic and Archaean eons together) are often collectively called the **Precambrian**.

The Phanerozoic eon has therefore been divided into three **eras** — the **Palaeozoic** (early life) , **Mesozoic** (middle life), and **Cainozoic** (recent life). A significant change in the dominant life forms marks the transition from one era to the next one. The changes that mark the transitions between eras are summarised in the table below.

Name of era	Transition events	Ma
Cainozoic (recent life)		
	Extinction of dinosaurs and many other organisms	65
Mesozoic (middle life)		
	Extinction of over 90% of living organisms, including trilobites	250
Palaeozoic (ancient life)		
	First appearance of organisms with hard parts *i.e.* the **Cambrian Explosion**	540

The Cambrian period — the first period of the Palaeozoic era — is of major significance in the history of evolution. The earliest organisms **with hard parts** evolved during this era. In addition, so many organisms first appeared in the fossil record during this period that it has been called the time of the **Cambrian Explosion**.

All the eras named in the above table are divided into **periods**, which are generally named after the places in Europe where the rocks of that period were first studied. For example, rocks of the Jurassic age were first studied in the Jura Mountains, in Switzerland and southern Germany, and the Cambrian is named after the Cambrian Mountains in Wales.

The periods of the Cainozoic era are further subdivided into **epochs**.

An Incomplete Record

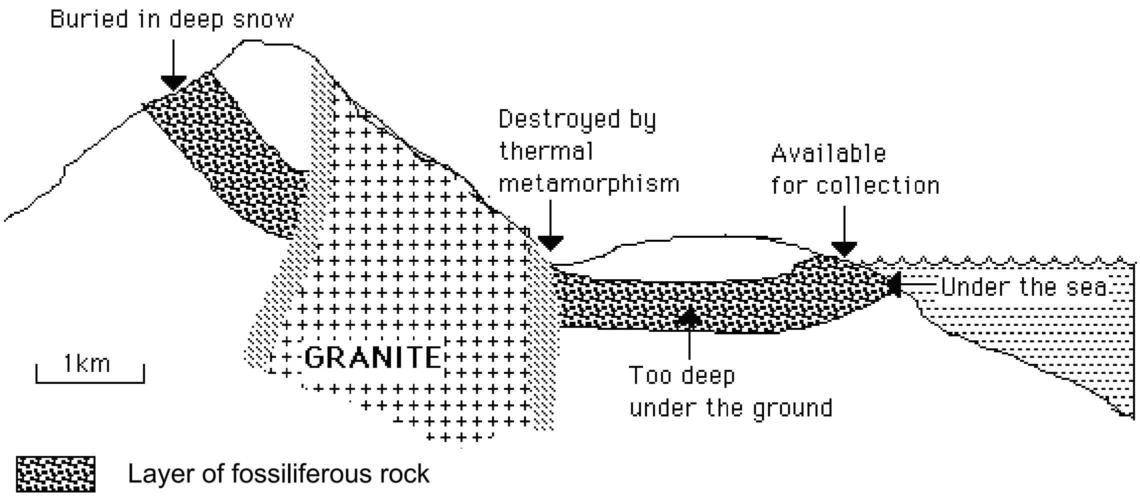
Fossils provide all the evidence we have about evolution of life on earth, but this record is far from complete. Special conditions are necessary if an organism is to be fossilised, rather than decay, after death. The ever-increasing rate at which palaeontologists are finding fossils, of hitherto unknown organisms, indicates that fossil evidence of many life-forms has not yet been found — and will never be found!

Some reasons why the fossil record is inevitably incomplete are:

1. Most organisms either decay or are eaten by predators soon after death. Special conditions must exist for a dead organism to be preserved and become a fossil. Some of these conditions include:
   - extreme cold — woolly mammoths in Siberia.
   - extreme dryness — mummification in desert sand.
   - anaerobic conditions (exclusion of oxygen).
   - rapid burial in sediment deposited in water (hence fossils of marine organisms are significantly more common than those of terrestrial organisms).
   - burial in volcanic ash (Pompeii), or tar (La Brea tar pits)
   - covering of amber (*i.e.* the film *Jurassic Park*).

2. Even if an organism does become fossilised, it is highly probable that no palaeontologist will ever study it. It may remain buried, or it may become exposed at the surface in a remote and unexplored area.

   The diagram below shows that only a very small proportion of the fossils present in an extensive layer of fossiliferous rock may be available for collection.



3. Organisms that lived more than 600 Ma (*i.e.* before the Cambrian Explosion) are even less likely to appear in the fossil record for the following reasons:

   i. There were very few organisms, compared with today's numbers.

   ii. During the Ediacaran period, organisms did not contain any hard parts, and it is usually hard parts — such as bones and teeth — which become fossilised.

   iii. Any rocks in which these very ancient fossils were formed may have been eroded or metamorphosed in the intervening 600 Ma.

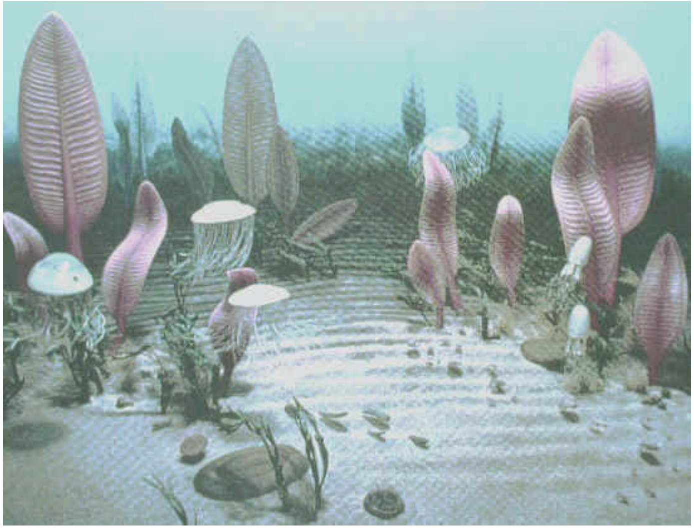
Significant Time-scale Fossils

1. Ediacaran Fauna

In 1947, Reg Sprigg discovered the Ediacaran fossil assemblage, in the Ediacara Hills, on the western edge of the Flinders Ranges. When he reported his find to the ANZAAS conference, fellow geologists scorned him, and his fossils were described as 'fortuitous markings on the rocks'.

However, the assemblage is now accepted as being international significance. These fossils represent some of the **earliest known multicellular organisms**, which lived from about 580 to 560 Ma (and a small number beyond). All the fossils are of soft-bodied animals, many of which cannot be matched with living species. However, some resemble modern annelid worms, jellyfish and other Coelenterates.

The reconstructed Ediacaran seafloor (below) shows some examples of the Ediacaran Fauna. The heights of the vertical leaf-like organisms are approximately 35 cm.



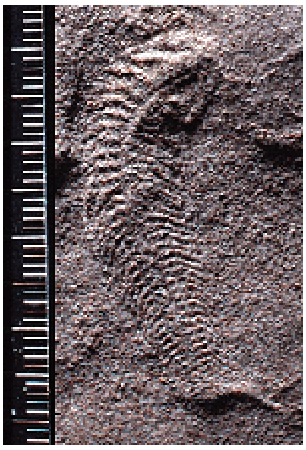
http://www-rohan.sdsu.edu/~rhmiller/fossilrecord/FossilRecord.htm (US Natural History Museum)

The Ediacaran assemblage is of worldwide significance because:

- These fossils filled a gap in our knowledge of evolution. Prior to their discovery there was no evidence of life between single celled organisms, and the complex, hard-bodied organisms of the early Cambrian. Probably **most of the Ediacaran fossils represent <u>animals</u>**.
- Since it is normally only the hard parts of organisms which are preserved as fossils, special conditions must be necessary to enable these soft-bodied organisms to be fossilised.

Some Ediacaran fossils are shown below:

Charniodiscus



Spriggina

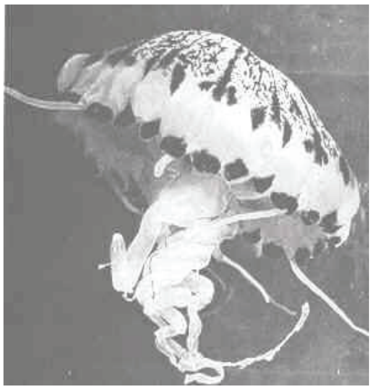
Dickinsonia

Parvacorina *Cyclomedusa* *Tribrachidium*

Palaeontologists believe that the organisms must have lived in a low energy tidal marine environment. As the tide went out, dead or dying organisms were stranded on the beach. When the tide returned, the organisms were covered with sediment (in this case sand). As the organisms decayed and the sediment hardened, their imprints were left in the newly formed sandstone.

Mawsonites (Ediacaran ? jellyfish)



Aurelia (modern-day jellyfish)

Similar fossils have since been found (in rare localities) on all continents except Antarctica, indicating that this was a significant period in the evolution of life. Since 2004, the official geological time-scale now includes the Ediacaran period, at the end of the Proterozoic era.

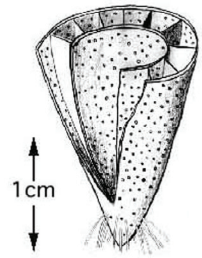
The base of the newest official geological period, the Ediacaran Period (*very* approximately 600 to 540 Ma), is defined as the boundary beneath the geologists right foot, *i.e.* the base of the "Nuccaleena Dolomite" in Enorama Creek, central Flinders Ranges). Source of photo: Knoll *et al.* 2004.

2. **Archaeocyatha** (= ancient cups)

Members of the now extinct phylum **Archaeocyatha** featured in the Cambrian Explosion, and were amongst the earliest organisms with hard parts. They were cup-shaped organisms which resembled both sponges and corals. They lived in shallow seas between 540 and 520 Ma (*i.e.* they became extinct well before the end of the Cambrian) and constructed huge reefs, similar to those built by modern corals.

Limestone-containing archaeocyatha fossils can be found in the Flinders Ranges, and in rocks of similar age on the Fleurieu Peninsula.

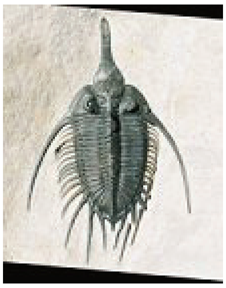
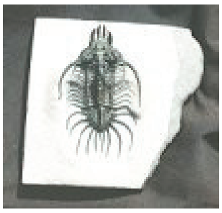
Archaeocyatha fossils frequently consist of the cross-section of the organism, appearing simply as a circle (or oval) within a larger one, the two being joined by spoke-like septa.



Probable appearance of organism

A cut and polished limestone containing abundant archaeocyatha at natural scale.

3. **Trilobites** (= three lobes/segments)


Trilobites assumed a variety of bizarre shapes, ranging in size from a few millimetres to 20 cm or more.

Trilobite fossils are easily recognised by their distinctive three-lobed, three-segmented form. Trilobites, exclusively marine animals, were amongst the earliest organisms to possess hard parts. They were primitive crustaceans (related to shrimps, crabs *etc*). Some must have swarmed on the sea floor, and others swam on the surface of the sea.

Trilobites first appeared at the beginning of the Cambrian Period, when they dominated the seas, flourishing in considerable numbers and changing variety. They became less abundant before becoming extinct, and relatively few forms persisted until the end of the Permian Period.

Like other arthropods, trilobites had an external skeleton, called an exoskeleton, composed of chitinous (fingernail-like) material. For the animal to grow, the exoskeleton was shed, and shed trilobite exoskeletons, or portions of them, are relatively common fossils.

Each trilobite body-segment bore a pair of jointed appendages. The front appendages were modified into sensory and feeding organs. Most trilobites had a pair of compound eyes, the earliest eyes to evolve. However, some trilobites were eyeless.

Some trilobites were active predators, whereas others were scavengers, and still others probably ate plankton. Some trilobites grew quite large, up to 45 cm in length and may have weighed as much as 4.5 kg. Others were as small as a few millimetres.

Trilobites meet all the requirements for index fossils, and are frequently used for stratigraphic correlation. The trilobites (along with about 90% of all living organisms) became extinct at the boundary of the Palaeozoic and Mesozoic eras (250 Ma), the biggest (known) extinction event in Earth's history.

Trilobite fossils may be found in several areas of South Australia, including the Flinders Ranges, Yorke Peninsula and the north coast of Kangaroo Island.

4. Graptolites

Graptolites were small, aquatic colonial animals that first appeared during the Cambrian Period and persisted into the Early Carboniferous Period. A graptolite colony consisted of branches lined by one or two rows of cups that contained the individual animals of the colony.

Tetragraptus *Isograptus* *Climacograptus*

Three examples of Ordovician graptolites (approximately natural scale) preserved in shale. *Tetragraptus* and *Isograptus* are from the Early Ordovician, whereas *Climacograptus* is from the Late Ordovician.

The animals were bilaterally symmetrical and tentacled. They possessed a chitinous outer covering and lacked mineralised hard-parts. It has been suggested that graptolites are related to the hemichordates, a primitive group of vertebrates.

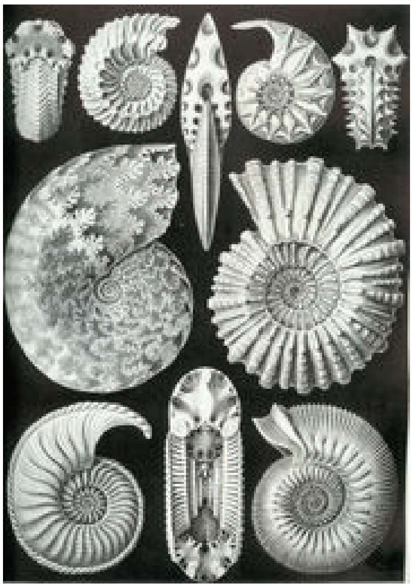
The colonies floated on the sea, and have been most frequently preserved as carbonaceous impressions on black shales, but their fossils have been found in a relatively uncompressed state in limestones. When found as impressions, the specimens are flattened, and much detail is lost.

Graptolites have proved to be very useful for the stratigraphic correlation of widely separated rock units. Because they show a gradual development through time, they are useful for dating the finer division of Early Palaeozoic rock units. They are the index fossils for the **Ordovician period**.

- Graptolites may have been the ancestors of primitive vertebrates.
- They were colonial organisms which floated in the sea. They had air sacks (almost never preserved) attached to their stipes.
- Graptolite fossils are commonly found in shales.

5. Ammonites

Ammonites lived in all the oceans (shallow seas) of the world from the Devonian period to the end of the Mesozoic era. They were free-swimming molluscs with flat, coiled shells that were separated by partitions into gas-filled chambers.



Many ammonites were elaborately ornamented

Environmental reconstruction of a Mesozoic ammonite

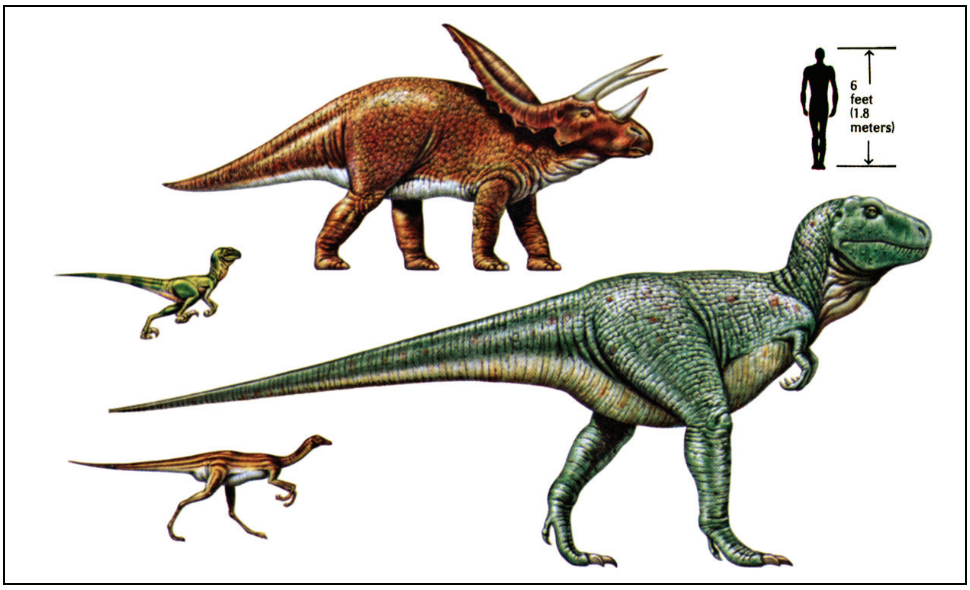
The outermost and largest chamber held the soft parts of the animal, which probably looked like a cuttlefish or a squid. Many ammonites were predators. Their shells protected and supported their soft bodies, as well as enabling the animal to swim at different water depths by filling individual chambers with air or water.

Ammonites are important index fossils because of their wide geographic distribution, rapid evolution, and easily recognizable features. **Three groups of ammonites succeeded one another through time, each group having a more complex shell pattern**.

Left: Many ammonites were giants: this specimen is more than 1 metre in diameter.

Right: The chambered, modern nautilus (above) is a living descendent of ammonites.

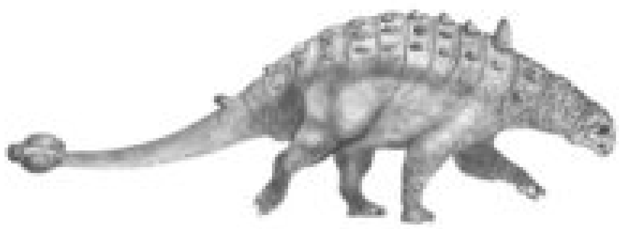
6. Dinosaurs



Dinosaurs came in many shapes and sizes.

Dinosaurs are classified as reptiles, although there is evidence that some types were warm-blooded. They dominated Earth's landscape for 140 million years in the Mesozoic era, which has been called the "Age of Dinosaurs". The earliest known dinosaur lived around 225 Ma in present-day South America. Dinosaurs were terrestrial animals that inhabited all parts of the globe. They adapted to a wide range of environments and climates. Their habitat covered a range of ecosystems, including tropical forests and drier desert regions. Dinosaur fossils have been found in all continents, including Antarctica.

Contrary to popular belief, not all dinosaurs were gigantic and ferocious. They were a diverse group of creatures that came in all sizes and shapes. They all had hairless bodies and scaly skins like the modern-day reptiles. Some dinosaurs walked upright and had long tails, whilst others walked on all fours. Some were carnivores, while others were herbivores. Dinosaurs varied greatly in size. One of the largest creatures was *Seismosaurus*, a plant-eating dinosaur that is believed to have been 43 m long. Amongst the smallest was *Compsognathus*, a bipedal predator about 0.9 m in length. Some unusual dinosaurs were armoured and horned.



Euoplocephalus was a dinosaur with a club at the end of its tail.

There are many theories for the 'sudden' disappearance of the dinosaurs and the extinction of many other organisms at the end of the Mesozoic era. However, the most plausible and commonly accepted theory is that this mass extinction was caused by a meteor colliding with Earth.

The mass extinction of the dinosaurs, ammonites and many other forms of life at 65 Ma defines the boundary between the Mesozoic and Cainozoic eras.

7. Mammals

The mammals are a group of vertebrates where the young are nourished with milk from special secreting glands (mammae) of the mother. In addition to these characteristic milk glands, several other unique features distinguish mammals:

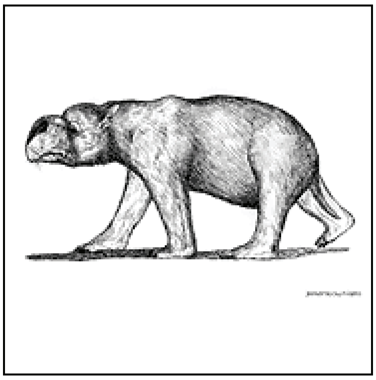
- Hair is a typical mammalian feature, although in many whales it has disappeared except in the foetal stage.
- The mammalian lower jaw is hinged directly to the skull, instead of through a separate bone (the quadrate) as in all other vertebrates.
- A chain of three tiny bones transmits sound waves across the middle ear. A muscular diaphragm separates the heart and the lungs from the abdominal cavity.
- Only the left aortic arch of the primitive fourth pair persists (in birds the right arch persists; in reptiles, amphibians, and fishes both arches are retained).
- Mature red blood cells in all mammals lack a nucleus; all other vertebrates have nucleated red blood cells.

Most mammals bear live young. In the placental mammals (including humans) the young are carried within the mother's womb, reaching a relatively advanced stage of development before being born. In the marsupials (*e.g.* kangaroos, koalas) the newborn, incompletely developed at birth, continue to develop outside the womb, attaching themselves to the female's body in the area of her mammary glands.

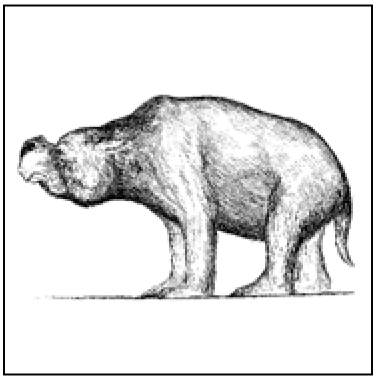
The class Mammalia is worldwide in distribution. It has been said that mammals have a wider distribution and are more adaptable than any other single class of animals, with the exception of certain less complex forms such as insects. Their ability to exploit Earth's diverse environments (excessive heat or cold) is attributed, in large part, to the ability of mammals to regulate their body temperatures and internal environment.

Mammals evolved at about the same time as the dinosaurs, and coexisted with them. However, all Mesozoic mammals were small and insignificant. After the extinction of the dinosaurs, mammals grew in size and diversified, to become the dominant forms of terrestrial life.

The Neogene fossil record contains examples of the **megafauna**, a diverse fauna of large animals.



Diprotodon



Zygomaturus

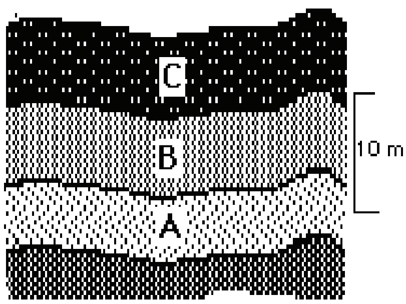
Two examples of giant marsupials (Australian megafauna) are illustrated above: both were diprotodontids (*i.e.* they had two very large teeth as incisors). *Diprotodon* (the largest known marsupial) was a grassland dweller, whereas *Zygomaturus* lived in forest.

The Victoria Fossil Cave at Naracoorte, discovered in 1969, contains the fossilised bones of a wide variety of giant marsupials, which lived about 40 000 years ago. In 1984, a large and diverse assemblage of vertebrate fossils was also discovered at Riversleigh, in northern Queensland. The descendants of the giant marsupials are the kangaroos and wombats we are familiar with today. The large size of the extinct animals provides evidence for a much wetter climate than exists today.

ISOTOPIC DATING

Absolute and Relative Ages

The adjacent diagram shows several rock layers that have not been overturned. We know the **relative** ages of these layers. We know that A is the oldest layer and C is the youngest layer.



However, if the rocks do not contain any fossils, we have no information about the actual or **absolute** ages of the rocks, in millions of years.

The Principles of Superposition and Cross-cutting Relationships tell us that one rock layer or igneous intrusion is older than another — *i.e.* they enable the **relative** ages of the rocks to be determined, **BUT** they do not tell us how old any of the rocks are. They do not provide any information about the **absolute** ages (Ma) of any of the rocks.

An entirely different process is needed to provide this information. This process is known as **isotopic dating**. It enables the **absolute** ages of igneous rocks, some metamorphic rocks and some organic remains to be determined.

Radioactive Decay

Some elements undergo a process called **radioactive decay**, by which particles are emitted from the nucleus of an atom, which then changes to an atom of another element.

e.g. a form of uranium changes (decays) to lead

The atom that undergoes radioactive decay is called the **parent**, and the atom that is formed is called the **daughter.**

In the above example, the parent element is uranium (U) and the daughter element is lead (Pb).

The process of radioactive decay can be used for dating rocks because:

Radioactive decay proceeds at a CONSTANT RATE, regardless of changes in conditions such as temperature, pressure or the chemical environment.

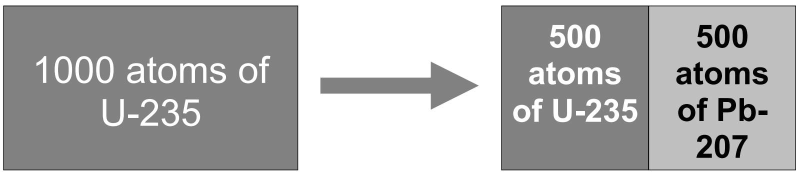
Half-Life

In radioactive decay, is almost impossible to say when the last of the parent atoms will decay, but the time taken for **half** the atoms to decay is comparatively easy to predict.

The half-life of a radioactive decay process is the time taken for HALF the original parent atoms to decay.

The length of half-life is a unique feature of each decay process. The half-life of the process given in the above example is 713 million years.

This means that if an igneous rock contained 1000 atoms of U-235 when it solidified:



After 713 million years it would contain 500 atoms of U-235 and 500 atoms of the daughter element for the decay process, Pb-207.

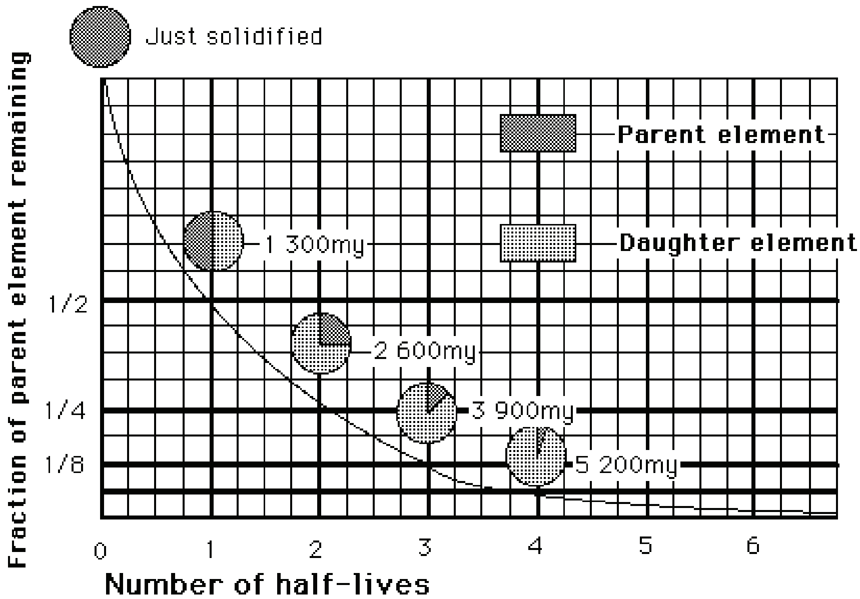
The proportion of parent atoms/daughter atoms present in an igneous rock gives the age of the rock — or the number of million years since the rock solidified.

Use of Half-Lives for Dating Rocks

In another example of a radioactive process, an isotope of potassium (K) decays to argon (Ar). The half-life of this process is 1300 million years.

The diagram below, a typical **radioactive decay** curve, and a series of pie charts, shows how the original potassium in the number of half-lives since the rock solidified.

The age of each of the rocks can be determined from the proportions of parent and daughter atoms: therefore, after 1300 million years (1 half-life) one half (50%) of the original potassium is present; after 2600 million years (2 half-lives) one quarter (25%) of the original potassium is present; after 3900 million years (3 half-lives), one-eight (12.5%) is left, and so on.



The actual procedure used involves collecting a sample of the rock and analysing one of the minerals present in the rock. The instrument used for this work is a **mass spectrometer**.

Another method of using radioactivity to determine the numerical age of a material is the carbon (C) dating method (based on the decay of C-14). This method is used extensively in archaeological studies. However, it is of limited use to geologists, because the half-life of the relevant decay process is only about 6000 years, and it can only be used to date materials which were derived from organisms. Consequently, carbon dating is a useful technique for dating organic remains up to about 35 000 years old — after about seven half-lives, the proportion of C-14 which remains in the sample is too small to be accurately measured.

EXERCISES

Fossil Evidence

1. Explain the difference between a **fossil** and a **trace fossil**.

   ____

   ____

   ____

2. Underline any of the words in the following list **that are** names of **trace fossils**.

Opalised shell	Leaf imprint in shale
Petrified dinosaur faeces	Petrified wood
Mould of a mollusc shell preserved in limestone	Aboriginal cutting tool

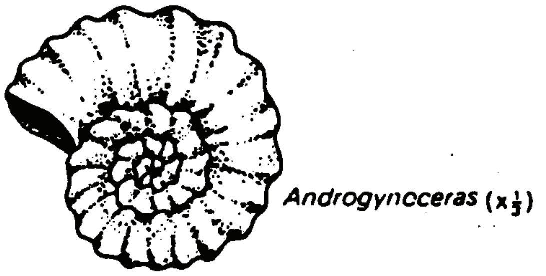
3. Give the **age** and one essential characteristic of the **oldest** known fossils.

   ____

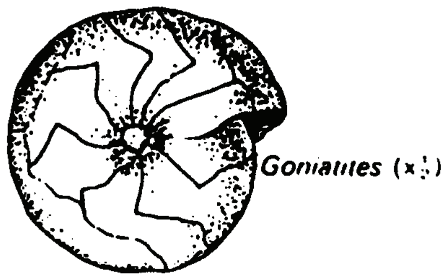
4. Cross out the **incorrect** words or phrases in the following statements, which concern the progress of evolution.

   a. In its early stages, evolution progressed **(rapidly / very slowly)**
   b. **(More / fewer)** organisms have evolved so far in the Cainozoic era compared to the Mesozoic era.
   c. Evolution **(has / has not)** proceeded at a uniform rate.
   d. One characteristic of the progress of evolution has been **(from simple to more complex organisms / towards increasing simplicity of organisms)**.
   e. A **(greater / smaller)** diversity of organisms exists today than at the beginning of the Palaeozoic era.
   f. We are **(likely / very unlikely)** to find an ammonite in strata which are very much younger than strata containing the ammonite fossils which have already been discovered.
   g. The age of dinosaurs **(may / definitely will never)** return.

5. The diagrams below show two types of ______________________ fossil.



A



B

Which of the two fossils is probably the older, and why?

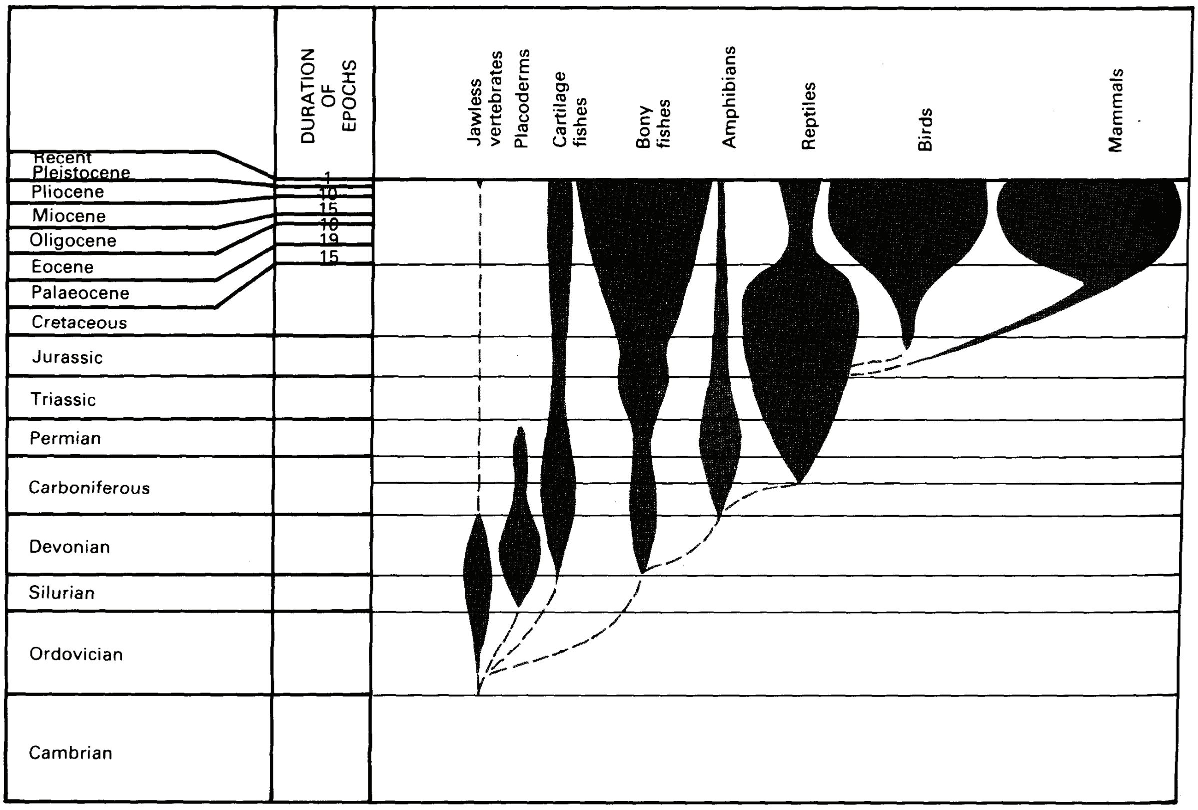
____

____

____

____

6. The diagram below shows the patterns of evolution and extinction of different classes of the vertebrates, from jawless fish to mammals.



a. Explain the significance of the sudden decrease in the number of reptile groups at the end of the Cretaceous period.

____

b. What might be the reason for the great increase in the number of mammal groups after the end of the Cretaceous period?

c. In which class of vertebrates is the number of groups increasing steadily today?

The Geological Time-Scale

1. a. What is the name given to the largest divisions of geological time?

   b. Approximately how long are these divisions? ____________________

   c. Name the three of these divisions which extend throughout Earth history.

   d. During which of these divisions has almost all the noticeable evolution of life occurred?

   e. Name the smaller divisions into which this eon has been divided.

2. What events mark the end of one era and the beginning of the next?

3. Describe two changes the make the **Cambrian** period especially significant in the evolution of life.

   1. ____________________

____

2. ____

____

4. In the table below, write the names of the eras of Earth history, the meanings of those names and describe the events that mark the divisions between the eras.

Name of era	Transition events	Ma
		65
		250
		540

5. Use your geological time-scale when answering the following questions:

   a. Name the longest eon in the history of Earth ____________________

   b. Which is the shortest eon? ______________________________________

   c. Why do you think the longest eon is the oldest, and the shortest eon is the most recent?

____

____

____

   d. An event which occurred at 250 Ma happened during the ________ period of the ____________________ era.

   e. The "Age of Dinosaurs" encompasses the _________________________ period of the ____________________ era.

   f. Why do you think that only the periods of the **Cainozoic** era have been divided into epochs?

____

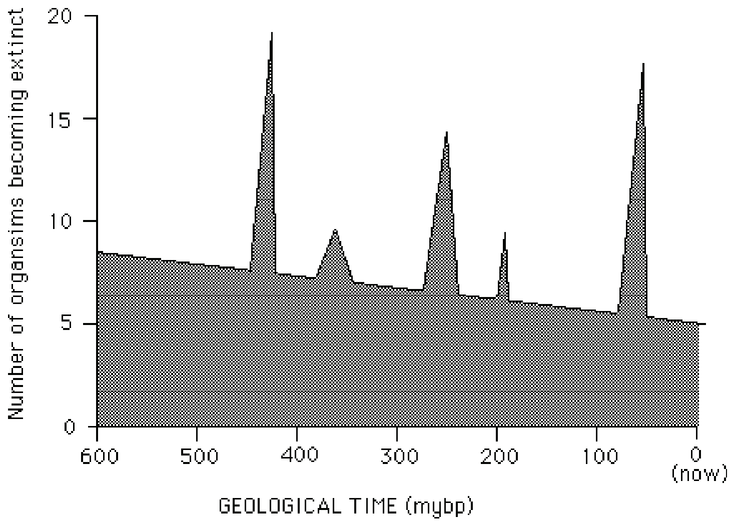
____

____

g. In which **eon**, **era**, **period** and **epoch** do we live?

___

6. The diagram below shows that, at several times during Earth's history, there were several major extinction events (of very large numbers of groups of organisms).



a. State the number of millions of years before present (Ma), when there were very high numbers of extinctions.

___

___

___

___

b. Using this information, mark on the graph the beginnings of the Mesozoic and Cainozoic eras.

An Incomplete Record

1. Give one piece of evidence to suggest that the fossil record is incomplete.

___

___

___

2. Describe three reasons why the fossil record is bound to be incomplete, especially for organisms that existed before 600 Ma.

1. ___

___

2. ____

____

3. ____

____

3. Describe 3 types of conditions that increase the likelihood of an organism being fossilised, rather than decaying after death? Give an example in each case.

1. ____

____

2. ____

____

3. ____

____

4. Suggest several reasons why the most abundant fossils are those of marine organisms.

____

____

____

____

____

Significant Time-Scale Fossils

1. Complete the table below for the organisms listed.

Name of organism	Time range	Appearance	Habitat *etc.*
Ediacaran fauna			
Archaeocyatha			
Trilobites			
Graptolites			
Ammonites			
Dinosaurs			
Mammals			

2. Give **two** reasons why Reg Sprigg's report of the discovery of fossils in the Ediacara Hills provoked so much scepticism in the scientific community in the late 1940s.

1. ____

____

2. ____

____

3. What special conditions would be necessary for a mould to be made of an organism without hard parts, such as a jellyfish?

____

____

____

Isotopic Dating

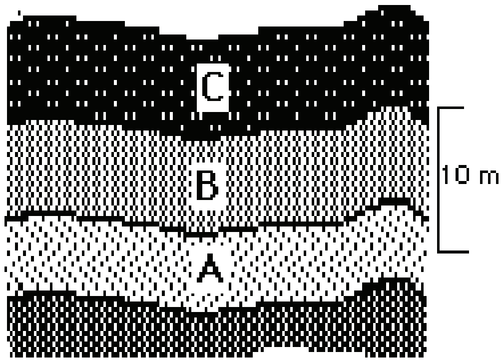
1. The adjacent diagram shows several rock layers which have not been overturned.

What do you know about the **relative** ages of these layers?

____

____

____



2. If the rocks do not contain any fossils, are you likely to have any information about the actual, or **absolute** ages of the rocks, in millions of years?

____

____

3. Explain the difference between **absolute** and **relative** dating of rocks.

____

____

____

4. Explain the meaning of the term **'radioactive decay'**.

____

____

____

____

5. In one example of radioactive decay, the element thorium (Th) decays to a form of lead (Pb).

   In this example, the parent element is ____________________

   and the daughter element is ______________________

6. Describe **one** other process of radioactive decay, naming the parent and daughter elements of this process.

____

____

____

7. For what groups of materials is isotopic dating a useful process?

____

____

8. What special property of radioactive decay processes makes isotopic dating a very useful technique for studying rocks?

____

9. Does isotopic dating give the **absolute** age, or the **relative** age of a rock?

____

10. Explain the meaning to the term **half-life** as applied to radioactive decay.

____

____

____

11. An experiment to simulate radioactive decay involves placing 100 coins, 'heads' side up, in a tray. After the tray has been shaken for a few minutes, all the coins that are 'tails' up are removed from the tray.

    Approximately how many coins would you expect to remove from the tray?

____

This process is repeated until the last coin is 'tails' up.
Although it is easy to predict when approximately 50% of the coins will turn over, can you predict how long it will take for the last coin to become 'tails' up.

____

____

12. Explain how the results of the experiment described in question 11 are similar to what happens in radioactive decay.

____

____

____

13. Use your answer to question 12 to explain why the times for radioactive decay processes to occur are described in terms of **half-lives** rather than the total time for **all** the atoms of the parent elements to decay.

____

____

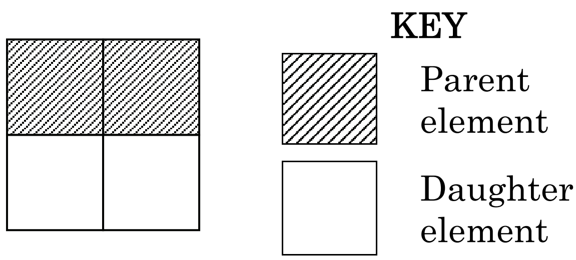
14. What feature of the radioactive elements present in igneous rocks is used to find the ages of these rocks?

____

____

____

15. If the half-life of a decay process is 1300 million years, and the ratio of parent atoms to daughter atoms is 1:1, as shown in the adjacent diagram.



a. How many half-lives have elapsed since the rock solidified?

____

b. How old is the rock?

____

16. Give **two** reasons why the technique of carbon dating is more useful to archaeologists than it is to geologists.

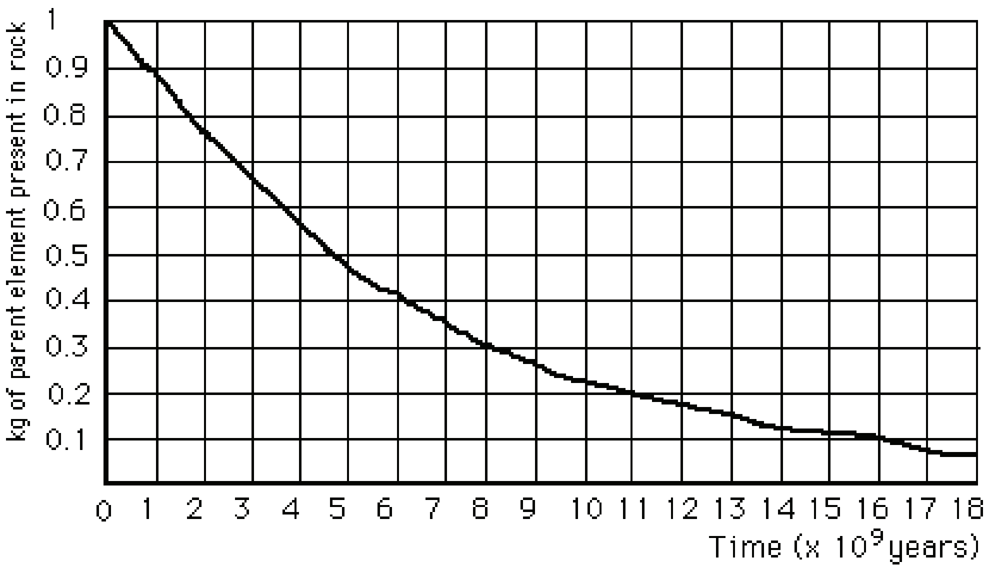
1. ____

____

2. ____

____

The graph below shows the radioactive decay of a 1 kg sample of one form of the element uranium. Use this graph to answer questions 18 to 22.



17. State the half-life of the uranium in years ____________________

18. Explain, in your own words, how the mass of uranium changes with time.

____

____

____

19. What mass of uranium would remain after 2×10^9 years? __________

20. What mass of uranium would remain after 8×10^9 years? __________

21. How long would it take until only 0.2 kg of the original sample was left?

____

22. An igneous rock contained 1000 atoms of U-235 when it solidified. If the half-life of the decay process is 713 million years, how many atoms of U-235 and how many atoms of the daughter element for the decay process (Pb-207) would it contain after 713 million years?

____