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# Preliminary Biology

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Life on Earth

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Week 2

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## WEEK 2 – THEORY

### THE FOSSIL RECORD PROVIDES INFORMATION ABOUT THE SUBSEQUENT EVOLUTION OF LIVING THINGS

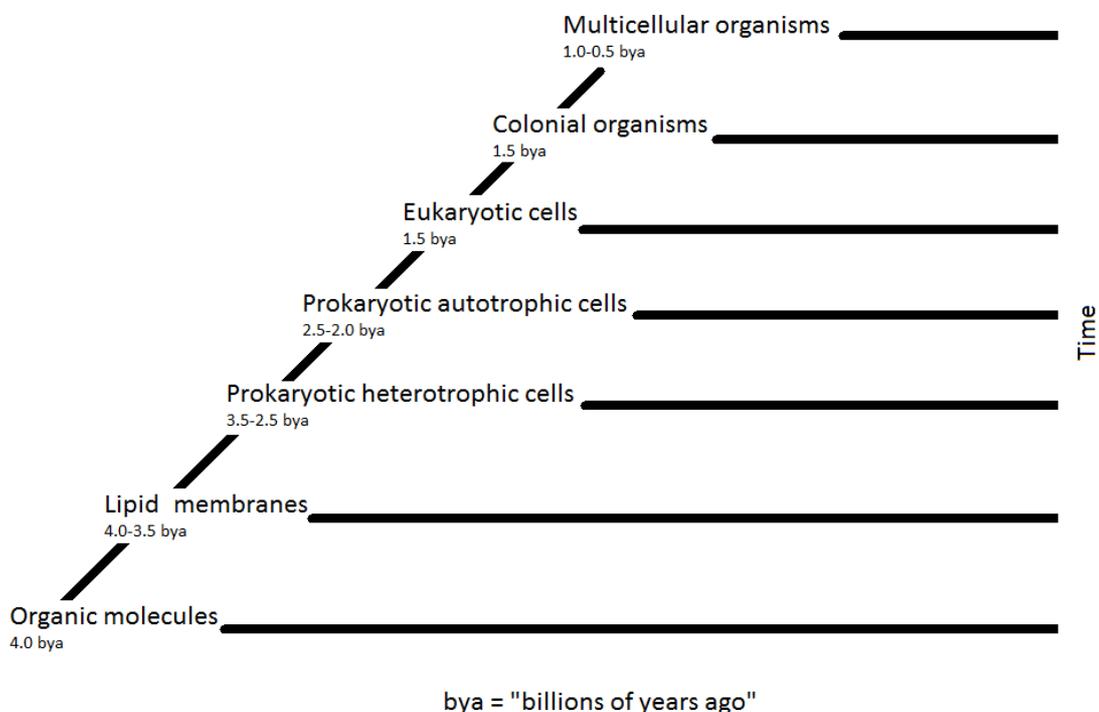
- **Identify the major stages of in the evolution of living things, including the formation of:**
  - **Organic molecules**
  - **Membranes**
  - **Prokaryotic heterotrophic cells**
  - **Prokaryotic autotrophic cells**
  - **Eukaryotic cells**
  - **Colonial organisms**
  - **Multicellular organisms**

### EVOLUTION OF LIVING THINGS

Recall that although the origin of living things is still a matter of debate, the idea that all living things existing on Earth today arose from a common ancestor is widely accepted in the scientific community.

No matter if the first living cell arose from chemosynthesis or arrived from space on a meteor, it would still have been able to reproduce and use the resources available on Earth.

We will now examine the major stages in what is believed to be the timeline of the evolution of living things.



Shown above is a simple tree timeline of the main stages of the evolution of living things. Note: members of each group are believed to evolve to the group that follows it. Some members of each group still exist in what is thought to be their original forms to this day.

## ORGANIC MOLECULES

Organic molecules were possibly formed by inorganic molecules that interact with each other over a long time.

Urey and Miller's experiments have showed that organic molecules can be formed by providing energy to inorganic molecules in the form of a spark.

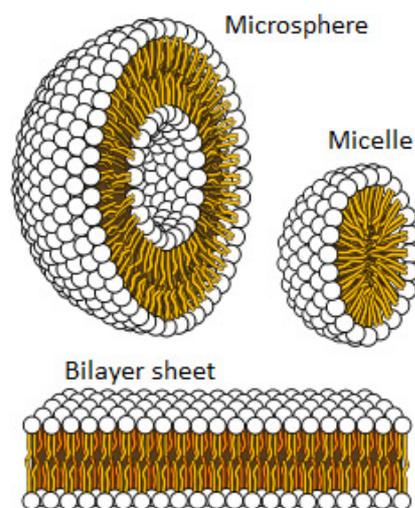
Supporters of the chemosynthetic believe that organic molecules could have been formed from the inorganic molecules which were abundant in the atmosphere on early Earth.

- The large amounts of energy required to break molecular bonds could have been provided for by electrical storms and cosmic radiation which were common in early Earth.
- The higher average temperature would have made molecules more active, which made the energy from the two sources above sufficient to drive chemosynthesis.
- Since molecules have more energy from the higher average temperature, the additional energy that is required for chemosynthesis to occur would be lowered.
- Imagine trying to dissolve sugar in water.
- At warm temperatures, sugar dissolves faster. This is due to the extra energy in water molecules that allow them to interact more efficiently with sugar molecules.

## MEMBRANES

As the concentration of organic molecules increased over millions of years, they are able to interact and react with each other more and more frequently, forming more complex molecules as well as more complex structures.

- To understand this point, imagine walking into an empty shopping centre. At first, you can easily walk from one side to the other of a shopping centre with no interaction with other people.
- As the day goes on, more people enter the shopping centre. This makes it more likely that you will interact with another person while within the shopping centre.
- As the number of people increase, you will soon be interacting with people at almost every step of the way from one side of the shopping centre to the other.



An example of the three forms that lipids take when in contact with water. Note how the hydrophobic regions (yellow) are 'protected' by the hydrophilic regions.

One of the many organic molecules formed are lipids.

- Lipids have a property of having both hydrophobic and hydrophilic ends.
- Hydrophobic molecules have a tendency to clump together, forming micelles, microspheres and bilayers.
- Micelles are small collections of lipid molecules, arranged so that the hydrophobic ends are 'protected' from the water by the hydrophilic ends.
- Bilayer sheets are formed by lipid molecules on the surface of water in order to keep the hydrophilic ends away from water.
- Microspheres are bilayers which form within water, keeping the hydrophobic regions away from water while allowing hydrophilic ends to come into contact with water.

Microspheres which are formed by the natural interactions between lipids and waters may have been the precursors of cells.

- The lipid microspheres provided protection from the environment outside of the bilayer, possibly allowing more complex and fragile reactions to occur within.
- It is possible that some molecules took on the role of catalysts that allow these complex reactions to occur.
- Eventually, fragile molecules such as RNA and DNA may have formed within these microspheres, eventually leading to the first prokaryotes.

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#### PROKARYOTIC HETEROTROPHIC CELLS

- Prokaryotic cells are cells which are living, but without distinct organelles found in eukaryotes.
- Heterotrophs are organisms that use up chemicals from outside sources to provide themselves with energy.
- The first living cells were most probably heterotrophic prokaryotes.
- The first cells would have free access to all of the resources on early Earth since there is no competition.
- It is possible that the first cells were only able to be formed due to organic molecules being taken up by microspheres, eventually leading to a heterotrophic ancestral cell.

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#### PROKARYOTIC AUTOTROPHIC CELLS

- Autotrophs are able to create their own food from inorganic molecules.
- As the numbers of heterotrophic cells began to rise, there were less and less nutrients available to provide for the needs of the cells.
  - Selective pressure for cells that were able to synthesise their own nutrients was created.
  - If a cell could make their own nutrients, even a minute amount, it increased their chances for survival.
  - Once the cell reproduces, its daughter cells would share the same genetic information as the parent cell.

- The daughter cells would then also have the ability to create small amounts of their own nutrients.
- Over time, selective pressure ensured that the cells with more and more effective methods for creating their own food survived to reproduce.
- If autotrophs did not have a chance to develop, scientists believe that life would have come to an end.
- Heterotrophic cells would have quickly used up all the nutrients in the environment.
- Autotrophic cells provided the ecosystem with nutrients that are created by them, allowing heterotrophs to continue to live.
- Cyanobacteria are believed to be the most effective autotrophs that were formed during this time.
  - Cyanobacteria are photosynthetic autotrophic prokaryotic cells, and are still found floating around in the ocean today – just like they did 3 billion years ago.

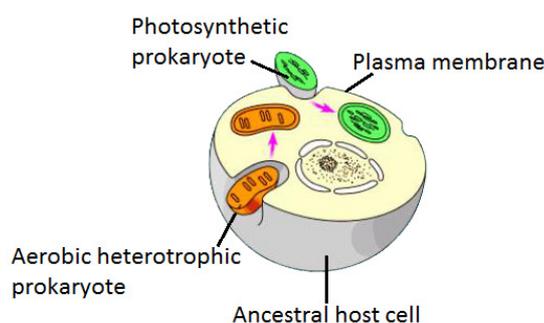
## EUKARYOTIC CELLS

Eukaryotic cells are thought to have developed from the interactions between prokaryotic cells.

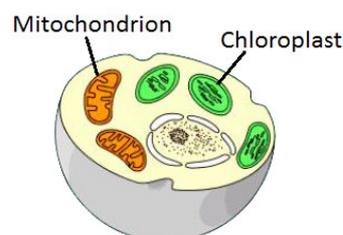
- Eukaryotes are characterised as having membrane bound organelles, and are much bigger than prokaryotes.

Hypothesis for the formation of eukaryotic cells is the **endosymbiotic hypothesis**.

- Having membrane bound organelles gave researchers the idea that eukaryotic cells were created after a prokaryotic cell took a smaller prokaryotic cell into its membrane.
- This effectively gives the cell two membranes – one outside the larger cell and one around the smaller cell.
- There could have been some benefit for the larger ‘host’ cell to keep the smaller ‘tenant’ cell alive.
  - The tenant cell may have been autotrophic, providing the host with energy.
  - Tenant cell may have been able to break down some molecules for energy that the host cell was unable to do.
- Thus, a symbiotic relationship was formed:
  - The host cell provided protection for the tenant cell.
  - The tenant cell provided services for the host cell.



The endosymbiotic hypothesis is that larger host cells may have taken in smaller ‘tenant’ cells. The tenant cells may have provided a service for the host that gave the host an incentive to keep them alive to profit off the services.



Over time, these cells may have become dependent on each other for survival, such that the cells only existed together.

- Over time, the tenant and host cells may have become so dependent on each other for survival that they only existed together.

After cyanobacteria started producing oxygen via photosynthesis, the atmosphere changed from an anaerobic environment to an aerobic environment.

- Prokaryotes which developed in an anaerobic environment would be negatively affected by the highly oxidising environment.
  - Oxidation, when in organic molecules, is an extremely damaging chemical reaction.
  - Larger cells which were less affected by the aerobic environment were a shelter for smaller anaerobic cells.

Mitochondria and chloroplasts in eukaryotic cells today show characteristics of once being an individual prokaryote.

- Both mitochondria and chloroplasts have circular DNA which is only found in prokaryotic cells.
- These two organelles show characteristics of the endosymbiosis theory:
  - Mitochondria provide the host cell with a way to create an energy rich molecule, ATP.
  - Chloroplast provide the host cell with the ability to catch sunlight for photosynthesis.

## COLONIAL ORGANISMS

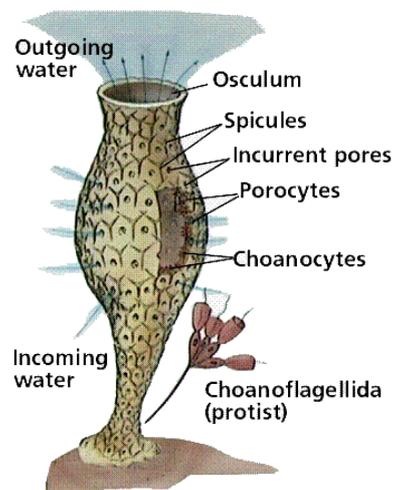
Daughter cells of a parent cell are identical to each other.

- They would share the same genetic material and signalling molecules, allowing them to communicate with each other and find each other.
- When subjected to environmental selective pressure, they will tend to group together to form colonies.

When a cell colony is formed, the individual cells are linked together by their proteins as well as sharing their cytoplasm (to a small degree).

- Cells are able to share nutrients and communicate with each other.

In cell colonies, individual cells have independence but would work together for the overall benefit of all the cells. For example, there are several types of cells that make up the sponge. Each cell has a different function, but together they work for the mutual benefit of all the cells.



The sponge (porifera) is a prime example of a colony of cells working together for the benefit of all the cells. If a sponge was disrupted, the individual cells are able to re-form the sponge.



Cell colonies are much more efficient for protection and obtaining nutrients from the environment than single cells alone.

- By grouping together, there is a much lower chance that a heterotrophs would be able to eat the individual cells.
- By working together as a group, resources can be obtained at greater speeds and wastes eliminated more efficiently.

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## MULTICELLULAR ORGANISMS

Multicellular organisms share several characteristics which are similar to colonial organisms.

- Cells in a multicellular organism are able to communicate with each other.
- Cells can identify each other.
- Cells share their cytoplasm (to some degree).

Cells that become more attached to and dependant on each other than in colonial organisms formed the bases for multicellular organisms.

- Instead of each cell being able to perform all the functions required by the colonial organism, cells in a multicellular organism have specialised functions.
- Unlike colonial organisms, multicellular organisms are made of cells which are genetically identical to each other.
- It is possible that over time, cells that make up colonial organisms shared their genetic information with each other, creating a final product that was a collection of all their genetic information.
- This became the DNA of the multicellular organism which is found in every cell that makes it up.

An alternate hypothesis for the formation of multicellular organisms is through repeated cell division of a single cell without complete cytokinesis.

- Recall that cytokinesis is the final step of cell division, occurring after mitosis.
- Cytokinesis allows the daughter cells to be two independent entities.
- If complete cytokinesis does not occur, the result would be a collection of cells which are partly attached to one another.
- Over time, each cell that makes up the collection of cells may have evolved a specific function that benefits the group of cells.



- **Describe some of the paleontological and geological evidence that suggests when life originated on Earth**

## THE FOSSIL RECORD

Fossils (from Latin, *fossus*: “having been dug up”) are the preserved remains or traces of living creatures from the past. The collection of all fossils discovered, as well as those yet to be discovered, is part of the **fossil record**.

**Fossils** may be found in different layers of rock:

- Their position within the rock is a crucial part of the fossil record that plays a role in identifying the time period in which these fossils were formed.
- Recall that radioisotope dating can be used to determine the age of an object.
  - By comparing the carbon-14, uranium-238 and lead concentrations, the age of an object can be estimated with about 95% accuracy.
- If two fossils were found in similar rocks, they would have existed in the same time frame
  - The time taken for fossilisation can be tens of years.
  - Organisms that are fossilised under the same conditions and at around the same time would appear in the same layer of rock.
- The layers of rock form as a result of changing conditions on Earth.
- For example, if there was an unusually high concentration of calcium carbonate at one point in time, the rocks formed during this time would show calcium carbonate and would look different to rocks formed by basalt.

Since they are either remains or traces of living creatures, fossils can vary from being microscopic in size to being many meters long.

- The smallest fossils may contain a single bacterial cell, being one micrometer in diameter.
- Fossils may contain dinosaur bones, which are many meters long and weigh up to several tons.

It is common for fossils to only preserve a part of an organism, as fossilisation requires a very stable and protected environment.

- In order for fossils to form, the dead organism first has to be kept in an area that is not exposed to damaging chemical processes such as oxidation or fermentation. Thus, fossils can only form in areas that are anaerobic, such as the bottom of lakes, mud or snow.
- After the dead organism floats to the bottom, it is covered by a layer of sediment. Sediment includes small dust or sand particles that form a thin layer above the organism. In time, layers of sediment build up and a fossil is formed.



There are three types of fossils: original, moulds and casts.

## ORIGINALS

**Originals** are fossils which are preserved in their original form.

- Originals found are usually the hard mineralised parts of organism such as bones, teeth and nails.
- The strength of these mineralised parts of an organism resist damage from compression or tectonic plate movement.

## MOULDS

**Moulds** are fossils that retain the shape of an organism.

- After fossilisation, parts of the fossilised organism may decompose, leaving behind a gap in the rock.
- Since the rock was formed around the organism, it would retain any external characteristics of that organism.
- Imagine the jelly moulds that have unique patterns on its surface. If the jelly was an organism and the mould was the rock that formed around the jelly, then when the jelly was removed (probably eaten by a greedy younger sibling), the mould will be left.

## CASTS

**Casts** are fossils which are made from different inorganic molecules entering moulds and hardening.

- A mould is an empty space within a rock, caused by the fossilised organism decaying away.
- If another compound finds its way into the mould, it can harden within and take on the shape of the original organism.
- Imagine filling the jelly mould with cement then allowing the cement to set. What happens is that the cement takes on the form of the jelly, using the mould as a template.

## PALEONTOLOGY AND GEOLOGY

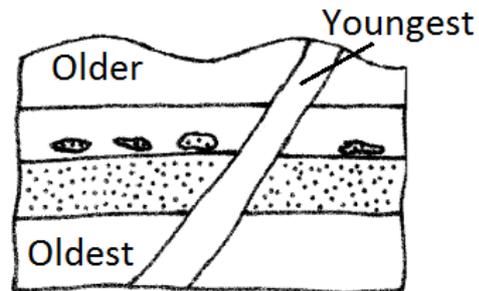
**Palaeontology** is the study of fossils across the world as they occurred in the rocks, the ways in which they are formed as well as the evolutionary relationship between fossilised organisms. **Geology** is the study of Earth and the processes that cause it to be shaped and changed.

The study of fossils has given us an idea of how primitive cells evolved into more complex ones. Furthermore, the development of colonial and multicellular organisms was estimated through the analysis of fossils.

Palaeontologists and geologists have worked together to try to create an idea of when certain fossils were formed. Palaeontologists focus on identifying the types of fossils and what characteristics were shared by these fossils; geologists focus on examining the rock structure and composition in which the fossils are found.

In general, the older rocks are found in the bottom most layers, while the youngest rocks are found on the top most layers of rock formations.

- This is called the **law of superposition**.
- This is understandable, as younger sediments are placed on top of older sediment, building up the rock formation.
- An exception to the rule is a rock type that is constant and transverse the horizontal layers.
  - This rock would be the youngest compared to the rocks which it covers.
  - If a rock layer is covered by another rock layer, the covered layer has to be older.



However, there are exceptions to the rule as geological movements can cause rock formations to be bent or inverted.

The law of superposition allows geologists to estimate the relative age of different layers of rocks

For example, an earthquake may bring much older rock from under the Earth and place it on top of younger soil. After the earthquake, sedimentation continues to occur and the layers of the Earth would no longer follow the 'oldest at bottom, youngest at top' rule. To prevent their measurements from being thrown off due to these natural movements of rock, geologists have to obtain data from many sites around the world.

- Since the atmosphere of the Earth is quite regular, there would be similar amounts of minerals and deposits found in rock layers that are from a similar era.
- By comparing the composition of the rock from one area with those from other areas, the problems faced when the layers of a rock is inverted can be solved.
  - If the composition in the 3<sup>rd</sup> layer of rock formation A matches those in the 7<sup>th</sup> layer in rock formation B, as well as the 7<sup>th</sup> layer in rock formation C, we can assume that there was natural movement in the ground in rock formation A which caused the layer to be moved around.
- The comparison of fossils found within rocks is also a good way of comparing the age of different rocks.
  - Not all rocks are created by the same type of sediments.
  - As a result, rocks which are of the same age can appear to be drastically different.
  - By enlisting the help of palaeontologists and comparing the appearance of fossils in the rocks, geologists are able to have a better understanding of a certain rock layer is the same age as another.

A comparison of fossils from around the world and the type of rock they were found in has allowed scientists to divide the past into distinct eons.

- Each eon is characterised by its age and the presence of fossils.
- The eons are: Hadean, Archean, Proterozoic and Phenarozoic.
- The **Hadean** eon is the oldest eon and believed to be the time where first signs of life were formed.

- The **Archean** eon is characterised by the appearance of the oldest prokaryotic fossils.
- The **Proterozoic** eon shows the development of the oldest eukaryotic fossils.
- The **Phenarozoic eon** is when fossils of multicellular organisms were believed to be formed.
  - Subdivided again into Paleozoic, Mesozoic and Cenozoic eras.
    - **Paleozoic** era saw the rise of aquatic life, the first land plants, the first vertebrates, the first land animals, the first amphibians and the first insects.
    - **Mesozoic** era saw the first mammals, reptiles dominated the Earth, dinosaurs appeared and the first birds and flowering plants appeared
    - The **Cenozoic** era was when mammals began to dominate Earth.
- Note that you do not need to remember the names of these eons and eras.

Using the fossil record as well as the age of each fossil, an evolutionary pathway of living things can be traced back into the past. By comparing similar fossils and their ancestral fossils, an understanding of how life originated and developed on Earth can be gained.

For example, the presence of the first prokaryotic cells in rocks which are estimated to be around 3.8 billion years ago gives researches the conclusion that life on Earth had to begin from simple prokaryotic cells. These cells then developed into more complex structures, which are reflected in the fossil record. As we uncover more and more fossils, we are able to put together more pieces of this precious clue that gives us a glimpse into the past.



## WEEK 2 – HOMEWORK

- **Identify the major stages of in the evolution of living things, including the formation of:**
  - **Organic molecules**
  - **Membranes**
  - **Prokaryotic heterotrophic cells**
  - **Prokaryotic autotrophic cells**
  - **Eukaryotic cells**
  - **Colonial organisms**
  - **Multicellular organisms**
- 1. Which of the following describes the correct sequence in the evolution of living things? **[1 mark]**
  - a. Membranes, Autotrophic cells, Heterotrophic cells, Eukaryotic cells
  - b. Heterotrophic cells, Autotrophic cells, Membranes, Eukaryotic cells
  - c. Membranes, Heterotrophic cells, Eukaryotic cells, Autotrophic cells
  - d. Membranes, Autotrophic cells, Heterotrophic cells, Eukaryotic cells
- 2. How long ago were eukaryotic cells estimated to have developed? **[1 mark]**
  - a. 15 million years ago
  - b. 150 million years ago
  - c. 1.5 billion years ago
  - d. 15 billion years ago
- 3. Identify the properties of organic molecules that make up membranes which allow membranes to be self-forming. **[2 marks]**

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4. Describe the importance of the evolution of cell membranes for the development of prokaryotes. **[3 marks]**

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5. Are prokaryotic autotrophs or heterotrophs believed to have formed earlier? Justify your answer. **[3 marks]**

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6. Identify ONE example of an autotrophic prokaryote that has had an impact on the evolution of living things. **[1 mark]**

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7. Compare the interactions of cells that make up a colonial organism and a multicellular organism. **[4 marks]**

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8.  
a. Identify what is meant by the 'endosymbiotic hypothesis'. **[1 mark]**

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- b. With the use of a diagram, explain the endosymbiotic hypothesis. [3 marks]

- **Describe some of the paleontological and geological evidence that suggests when life originated on Earth**

1. Identify the meaning of the term 'fossil record'. **[1 mark]**

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2. Most of the fossils found show only parts of animals or plants. Explain why fossils of entire organisms are very rare. **[3 marks]**

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3. Explain what is meant by the law of superposition. **[1 mark]**

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4. Describe how the relative age of fossils can be determined using the law of superposition. **[2 marks]**

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5. Identify factors that can affect the validity of rock ages based on the law of superposition. [2 marks]

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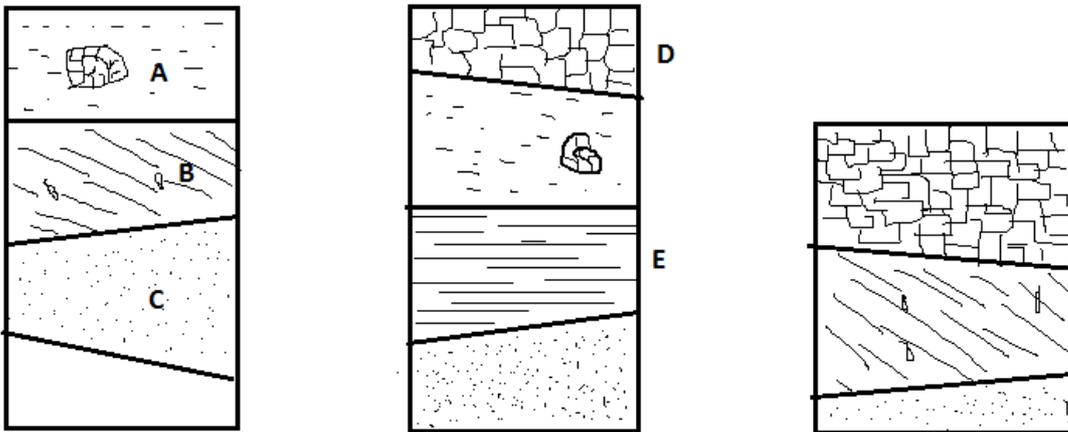
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6. Examine the above picture showing the layers of rocks found at three different sites.

Rank each rock type by age, youngest to oldest, assuming that there was no geological activity which caused the movement of rocks. [2 marks]

- A:  
B:  
C:  
D:  
E:

**End of homework**