EVIDENCE FOR EVOLUTION

1. INTRODUCTION

Attacks on evolution from often include the claim that there is no hard evidence for evolution ever actually occurring. Many people are swayed by such claims, in part because while the claim can be made dramatically and with ease, rebuttals are necessarily time consuming, academic, and far less dramatic. The truth, however, is that there exists abundant evidence for evolution. In this section we are going to look at different evidences for evolution.

2 PALEONTOLOGY

Modern paleontology sets ancient life in its contexts by studying how long-term physical changes of global geography paleogeography and climate paleoclimate have affected the evolution of organisms, how ecosystems have responded to these changes and have adapted the planetary environment in turn and how these mutual responses have affected today's patterns of biodiversity. Hence, paleontology overlaps with geology (the study of rocks and rock formations) as well as with botany, biology, zoology and ecology – fields concerned with life forms and how they interact.

The primary economic importance of paleontology lies in the use of fossils to determine the age and nature of the rocks that contain them or the layers above or below. This information is vital to the mining industry and especially the petroleum industry. Simply looking at the fossils contained in a rock remains one of the fastest and most accurate means of telling how old that rock is.

History includes a number of prominent paleontologists. Charles Darwin collected fossils of South American mammals during his trip on the Beagle and examined petrified forests in Patagonia. Big names in this field include Louis, Mary and Richard Leakey, Raymond Dart, Robert Broom, C.K. 'Bob' Brain, Kenneth Oakley, Robert Ardrey and Donald Johanson.

Fig 1: A paleontologist carefully chips rock from a column of dinosaur vertebrae.

3 FOSSILS AND FOSSILATION

Fossils are the remains, impressions or traces of ancient animals or plants, which have been preserved in the earth's crust for thousands of years. Fossils are thus, simply put, the remains or other evidence of ancient life forms. Many creatures found as fossils are extinct, while some may even be found today. Fossils as old as 550 million years have also been found. The study of fossils is called Paleontology.

The fossil record in general shows that the level of complexity of both plants and animals increases in subsequent strata in the fossil record. Despite the relative scarcity of suitably complete fossils and the current 'gaps' in the fossil record, the available evidence can be presented to make a compelling case for evolution. Remains found in sedimentary rock write a story of the history of the earth. Intermediate forms of animals have been discovered which illustrates the changing forms of animals and therefore common decent.

How are fossils made?

Only a few of ancient organisms are preserved as fossils. This is because usually only the organisms with **a solid and resistant skeleton** are easily **preserved**. Most fossils comprise the bones, teeth and shells of ancient animals and are found in **sedimentary rocks**. These rocks are formed when sand or other particles are carried to a place by water or wind and accumulated over time. After hundreds of years, these get hardened and form rocks. Shale, sandstone, and limestone are the most common types of sedimentary rocks. Besides sedimentary rocks, fossils may also be found in other materials, such as ancient tree resin (amber), tar pits, ice, volcanic lava, or even in a dried, mummified state in loose soil. After an animal or plant dies, its body is decomposed by bacteria or other organisms.

But if the creature is buried quickly after death, as in case of a flood, landslide, volcano, or snowstorm, or gets embedded in tar or tree resin, the body is not decayed. Hard parts of a body, such as teeth, bones and shells, are more likely to be preserved than soft parts. These are then subjected to various climatic changes. In the course of thousands of years, minerals may get deposited in the pores of the shell or bone. The remains may also be subjected to intense pressure and other factors, which may fossilise the remains.

In some cases, the original skeleton may be completely replaced by other mineral matter. The soft parts of animals or plants are very rarely preserved. However, there are some striking examples of soft tissues getting fossilised. The embedding of insects in amber and the preservation of Mammoths in ice are some of the examples. Majority of the fossils are preserved in a water environment, chiefly because those on land are more easily destroyed.

Anaerobic (oxygen-less) conditions at the bottom of the seas or other water bodies are especially favourable for preserving the forms, since very few microorganisms are present there to destroy the remains. In general, for an organism to be preserved two conditions must be met:

- rapid burial in order to slow decomposition and prevent the action of scavengers on the dead body
- possession of hard parts, which can be easily fossilised.

This **entire process** by which dead organisms or their parts are transformed into fossils is called **fossilisation**. The term fossilisation refers to the set of inorganic processes which enable the remains of a formerly living creature to be preserved after its death and subsequent burial under sediment.

Only a small number of dead organisms become fossilised, and it is estimated that just one species out of every 5,000 will have had a chance of surviving in fossil form until the present. Usually the hardest part of the organism (bone, husk, shell, etc) is fossilised, though these may be subject to physical alteration, impact fracture, disintegration or dispersal caused by atmospheric phemonena. The hard parts may survive even if subject to such traumas, but the softer parts of an organism rarely survive because they are vulnerable to predation and decomposition. The rapidity with which an organism becomes covered in sediment is important in fossilisation. In view of this consideration, it is easy to understand why most ancient organisms known to us are either marine or lacustrine; terrestrial organisms can only be preserved if they die in a marine or fluvial environment.

Some places, such as the Grand Canyon at northern Arizona in the USA, have interesting sights of fossils. One can observe thick and nearly horizontal layers of sediment on the seafloor, which have been deposited over millions of years. Each layer here contains fossils that are distinct from those of the layers above and below it. By comparing overlapping sequences, the scientists can build up a continuous record of animals and plants that existed during various time periods.

What are the uses of fossils?

Fossils provide information about the history of life on earth. By studying the fossil record, or the data recorded in fossils found over the world, scientists trace important information.
Some of the uses of fossils are:

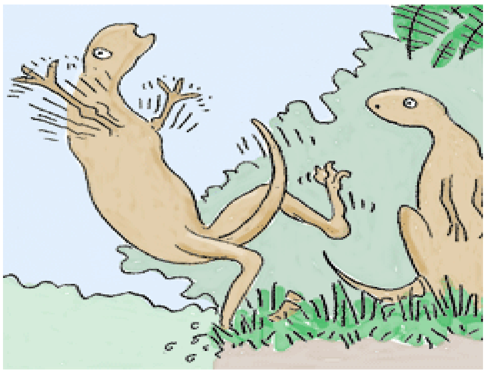
- They help us find out the progressive changes within an animal or plant group. Thus, the evolution of that group can be studied. For example, a fossil called Archaeopteryx, which showed certain characteristics of both reptiles and birds, was a transitional form between birds and reptiles. With the help of this fossil, scientists determined that birds evolved from reptiles.
- Through fossils, one can quickly and easily find out the age of the geological strata or the rock layers in which they occur. The accuracy with which this may be done depends on the nature and abundance of the fossils in that strata. Thus fossils can be used to identify geologic relationships.
- Fossils may provide information about the climate and environment of the site where they were deposited and at the time of their preservation.
- Fossils are useful in the exploration for minerals and mineral fuels. Geologists can find out the presence of oil and natural gas deposits at a place by analysing the microfossil samples obtained from these locations.

HOW DO FOSSILS FORM?

There are many ways that fossils can form.

1. Life

A small dinosaur loses its balance and falls off a cliff.



2. Death

It falls into a lake and drowns.

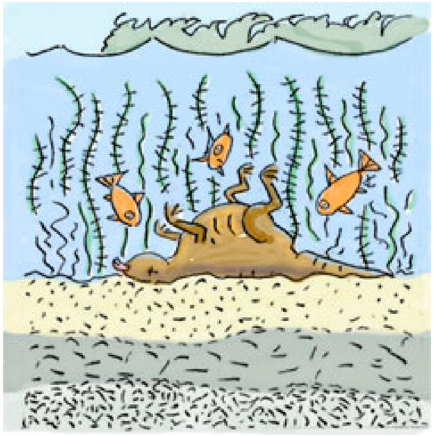
Bad news for the dinosaur but possibly good news for fossil hunters in a few million years' time.

3. Burial and preservation

The dinosaur can only become a fossil if it is covered over by sediments quickly.

The soft body parts decay and rot very soon after death. This is carried out by bacteria and scavengers.

The hard body parts such as bones are all that remains.

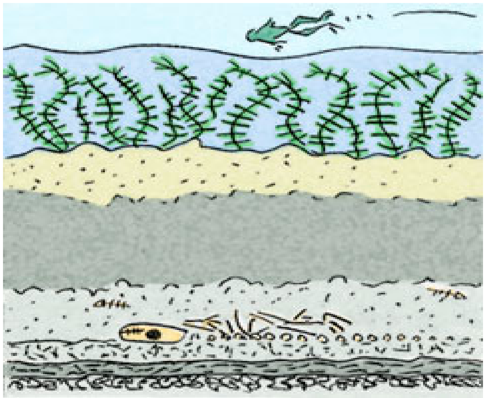


4. Compaction and Replacement

Over time, the body is buried under more and more layers of sediments.

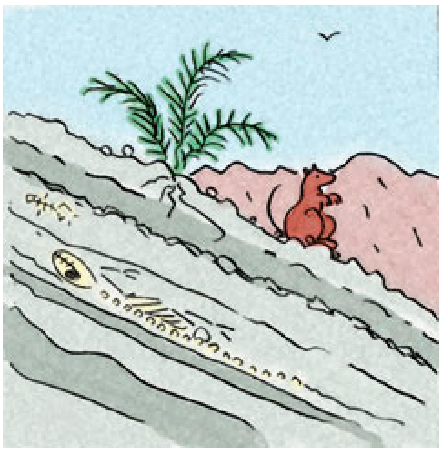
PETRIFICATION?

The weight of the rocks above will compact the sediments further.



5. Uplift

In time, the rocks might become pushed up to form a mountain chain such as the Alps or Himalayas.



6. Erosion and exposure
Finally after many millions of years, the rocks may become worn down enough to reveal the fossil at the surface.

The best places to find fossils is where the rocks have recently been lifted up or exposed. Cliffs, quarries or road cuttings are also good places to look.

Different methods of fossilisation:

Petrification –	the organic matter of the dead organism is replaced by mineral ions.
Mould –	the organic matter decays, but the vacated space becomes a mould, occupied by mineral matter.
Trace –	an impression of a form, for example, a leaf or a footprint is made in layers that then harden.
Preservation –	preservation of the intact whole organism, for example in amber, in tar, in ice or in anaerobic, acidic peat.

4. LIVING FOSSIL: COELACANTH

Coelacanth is the common name for an order of fish that includes the oldest living lineage of jawed fish known to date. The coelacanths, which are related to lungfishes and tetrapods, were believed to have been extinct since the end of the Cretaceous period, until the first *Latimeria* specimen was found off the east coast of South Africa, off the Chalumna River in 1938. Since 1938, *Latimeria chalumnae* have been found in the Comoros, Kenya, Tanzania, Mozambique, Madagascar, Greater St. Lucia Wetland Park in South Africa. The second species, *L. menadoensis*, was described from Sulawesi, Indonesia in 1999.

Biological characteristics

Coelacanths first appear in the fossil record in the Middle Devonian, about **410 million years ago**. Prehistoric species of coelacanth lived in many bodies of water in Late Paleozoic and Mesozoic times.Coelacanths are lobe-finned fish with the pectoral and anal fins on fleshy stalks supported by bones, and the tail or caudal fin divided into three lobes, the middle one of which also includes a continuation of the notochord. Coelacanths have modified cosmoid scales, which are thinner than true cosmoid scales, which can only be found on extinct fish. Coelacanths also have a special electro receptive device called a rostral organ in the front of the skull, which probably helps in prey detection.

Fossil record

Although now represented by only two known living species, as a group the coelacanths were once very successful with many genera and species that left an abundant fossil record from the Devonian to the end of the Cretaceous period, at which point they apparently suffered a nearly complete extinction. No fossils dated after this point is known to have been found. It is often claimed that the coelacanth has remained unchanged for millions of years but in fact the living species and even genus are unknown from the fossil record. However, some of the extinct species, particularly those of the last known fossil coelacanth, the Cretaceous genus *Macropoma*, closely resemble the living species. The most likely reason for the gap is the taxon having become extinct in shallow waters. Deep water fossils are only rarely lifted to levels where palaeontologists can recover them, making most deep water taxa disappear from the fossil record. This situation is still under investigation by scientists.

Timeline of discoveries

Date	Description
23 Dec 1938	Discovery of the first modern coelacanth 30 kilometres SW of East London, South Africa.
21 Dec 1952	Second specimen identified in the Comoros. Since then more than 200 have been caught around the islands.
1988	First photographs of coelacanths in their natural habitat, by Hans Fricke off Grand Comore.
1991	First coelacanth identified near Mozambique, 24 kilometres offshore NE of Quelimane.
1995	First recorded coelacanth on Madagascar, 30 kilometres S of Tuléar.
18 Sept 1997	New species of coelacanth found in Indonesia.
2000	A group found by divers off Sodwana Bay, South Africa.
2001	A group found off the coast of Kenya.
2003	First coelacanth caught by fisherman in Tanzania. Within the year, 22 were caught in total.
2004	Canadian researcher William Sommers captured the largest recorded specimen of coelacanth off the coast of Madagascar.
19 May 2007	Indonesian fisherman Justinus Lahama caught a 1.31 meter (4.30 ft) long, 51 kilogram (112 lb) coelacanth off Sulawesi Island, near Bunaken National Marine Park, that survived for 17 hours in a quarantined pool.
15 July 2007	Two fishermen from Zanzibar caught a coelacanth measuring 1.34 meters (4.40 ft), and weighing 27 kilograms (60 lb). The fish was caught off the north tip of the island, off the coast of Tanzania.

First find in South Africa

On December 23, 1938, Hendrik Goosen, the captain of the trawler *Nerine* returned to the harbour at East London after a trawl around the mouth of the Chalumna River. As he frequently did, he telephoned his friend, Marjorie Courtenay-Latimer, curator at East

London's small museum to see if she wanted to look over the contents of the catch for anything interesting. At the harbour Latimer noticed a blue fin and took a closer look. There she found what she later described as "the most beautiful fish I had ever seen, five feet long, and a pale mauve blue with iridescent silver markings."

Failing to find a description of the creature in any of her books, she attempted to contact her friend, Professor James Leonard Brierley Smith, but he was away for Christmas. Unable to preserve the fish, she reluctantly sent it to a taxidermist. When Smith returned, he immediately recognized it as a coelacanth, known only from fossils. Smith named the fish *Latimeria chalumnae* in honor of Marjorie Courtenay-Latimer and the waters in which it was found. The two discoverers received immediate recognition and the fish became known as a **"living fossil."** The 1938 coelacanth is still on display in the East London Museum.

5 COMPARATIVE ANATOMY

It was on the basis of structural and anatomical similarities that Carl Linnaeus (1707-1778) proposed his hierarchical system for the unambiguous naming of all plants and animals. The **anatomical** similarities between living, and later fossil, organisms, makes sense if they are related. Such an ordering of organisms is difficult to understand if each organism originated independently. In this scheme, each type of organism is given a unique **genus** and a **species** name, such as *Homo sapiens or Homo floresiensis* or *Escherichia coli* (both names are italicized and the species name is lower case).

The concept of **a species** is complex, in large part because populations vary and evolve. The biological species concept was defined by Mayr in 1942.

"Species are groups of actually (or potentially) interbreeding natural populations which are reproductively isolated from other such groups." – Ernst Mayr (1953)

This definition is not completely unambiguous, however. For example, when during the course of time does one species become distinct from its progenitor?

How do you define a species that does not interbreed?

When individuals do not interbreed. Reproduce only asexually.

Organisms are also placed within a classification hierarchy as indicated below:

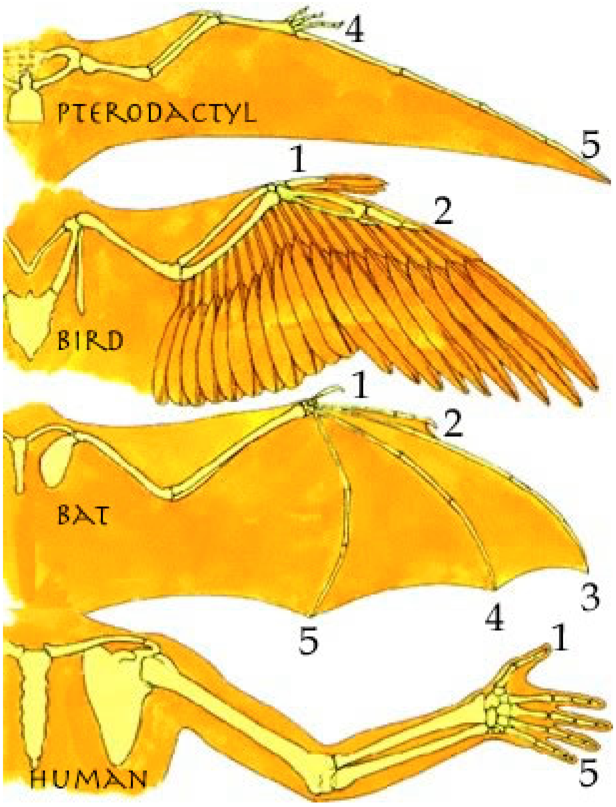
Kingdom
. . Phylum
. . . Class
. . . . Order
. . . . . Genus
. . . . . . Species
. . .. Variety

Analogous (Convergent) Structures

Some biological characteristics are analogous (also called "convergent"), which means that they serve **the same function** in **different species** but they **evolved independently** rather than from the **same embryological material** or from **the same structures in a common ancestor**. An example of an analogous structure would be the wings on butterflies, bats, and birds.

This type of reasoning leads to the prediction that fossil of the last common ancestor of the mammals will be found to have a forelimb with a structure similar to that of modern mammals.

When two structures are analogous, it means that they evolved independently, but perform the same functions.



Their form was determined by their function.

Consider the wing of a pterodactyl, a flying reptile, a bird, and a bat, a mammal.

Analysis of these structures indicates that they are distinct.

In the pterodactyl, the wing membrane is supported by the 5th finger of the forelimb, in the bird by the 2nd finger, and in the bat, by the 3rd, 4th and 5th fingers.

The last common ancestor of flying reptiles, birds and mammals did not have wings, although it certainly had forelimbs.

While wings of pterodactyls, birds, and bats are **analogous** structures, their forelimbs are **homologous**.

The physics of flight are constant. Organisms of similar size face the same aerodynamic and thermodynamic constraints. In general there are only a limited number of physically workable solutions to deal with these constraints.

Under these conditions different populations will, through the process of variation and selection, end up with structural similar solutions. This process is known as **convergent evolution**. **Convergent evolution** occurs when only certain solutions to a particular problem are possible.

Another important example would be the development of a camera-type eye in both mollusks and vertebrates. The fact that eyes in different species are analogous structures proves not only that the eye could evolve naturally, but that it in fact evolved several times, independently, and in slightly different ways. The same is true of other analogous structures as well, and this is because certain functions (like being able to see) are just so useful that it's inevitable they will evolve eventually.

- **Homologous Structures**

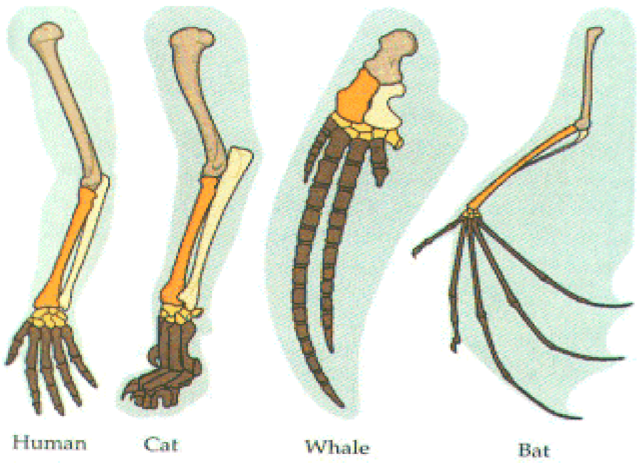
Homologous structures, on the other hand, are characteristics which **are shared by related species** because they have **been inherited in some way from a common ancestor**. For example, the bones on the front fins of a whale are homologous to the bones in a human arm and both are homologous to the bones in a chimpanzee arm. The bones in all of these different body parts on different animals are basically the same bones, but their sizes are different and they serve slightly different functions in the animals where they are found.

Homologous structures **provide evidence of evolution** because they allow biologists to **trace** the **evolutionary path** of different species, linking them up in the larger evolutionary tree that links all life back to **a common ancestor**.

The bones were adapted, over long stretches of time, for new purposes that they needed to just barely succeed at. Evolution only requires that one be better than competitors, not that one be the best that's theoretically possible. This is why imperfect features and structures are the norm in the natural world.

As a matter of fact, the entirely biological world can be said to be composed of homologous structures: all of life is based on the same types of nucleotides and the same amino acids. Why? The presence of the **same chemical structures** in all of life is evidence that all of life **is related** and developed from **a common ancestor**.

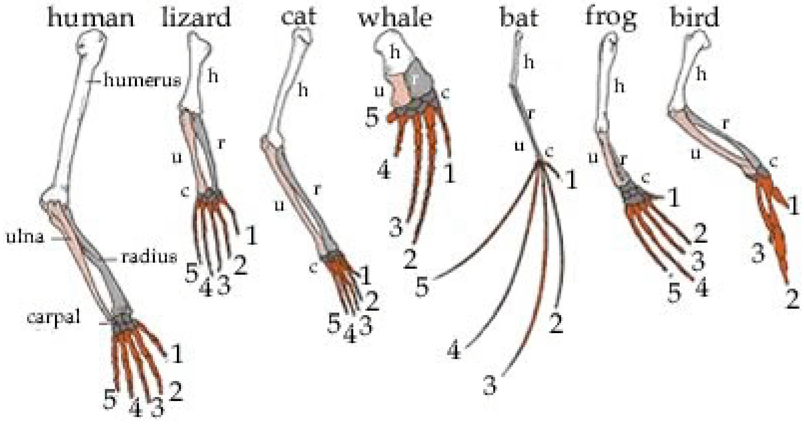
Similar structures due to a common ancestry. As seen below, the structures which are seen are utilized in different ways yet are all similar structurally. This is evidence for common ancestry because the best way to build a bat's wing is not also the best way to build a whale's flipper.



HOMOLOGOUS AND ANALOGOUS STRUCTURES

For example, an anatomical analysis of the forelimb of the **mammals** suggests that they are **homologous** structures.

To say that two structures are homologous means that they are derived from a common ancestor and that the feature was present in that common ancestor.



It is possible to see a progression in complexity over time throughout the animal kingdom in structures. In other words, despite the differences in a system such as the circulatory system in many animals, it is not difficult to reconcile these differences or to view a progression of how the system evolved.

Earlier organisms such as molluscs pump a blood-like fluid called hemocoel with a rudimentary heart. The inefficiency of this model due to the fact that the oxygenated and deoxygenated fluid can not be separated, favoured, an adaptation which would enclose the fluid into a vessel was selected for. The actual fluid evolved into blood by having first molecules which carried oxygen and then cells which specifically contained these molecules. Each of these steps increased efficiency and can be seen in different animals, for example arthropods still have an open circulatory system.

Another important piece of evidence in comparative anatomy is that of **vestigial structures**. These are structures found in animals that have **no functions** and are **merely remnants of evolution**. An example of this is that often times, whales are born with femurs (leg bones) despite the fact that they are marine, due**,** to their evolution from a land-living ancestor (probably bovine).

Another example would be the human appendix which is thought to be a vestigial caecum (an organ found in many herbivores which helps digest plant material).

6 COMPARATIVE EMBRYOLOGY

The idea that "ontogeny recapitulates phylogeny", suggested by Ernst Haeckel in 1866, refers to the idea that different stages in early development correlate with the adult form of the organism's ancestors. For example, in humans, gill slits (not functional) are visible in early development which indicates fish as an ancestor. Animals in early development look extremely similar, as development progresses, they begin to diverge in appearance. The thought is that the earlier that divergence occurs, the more distant the relation.

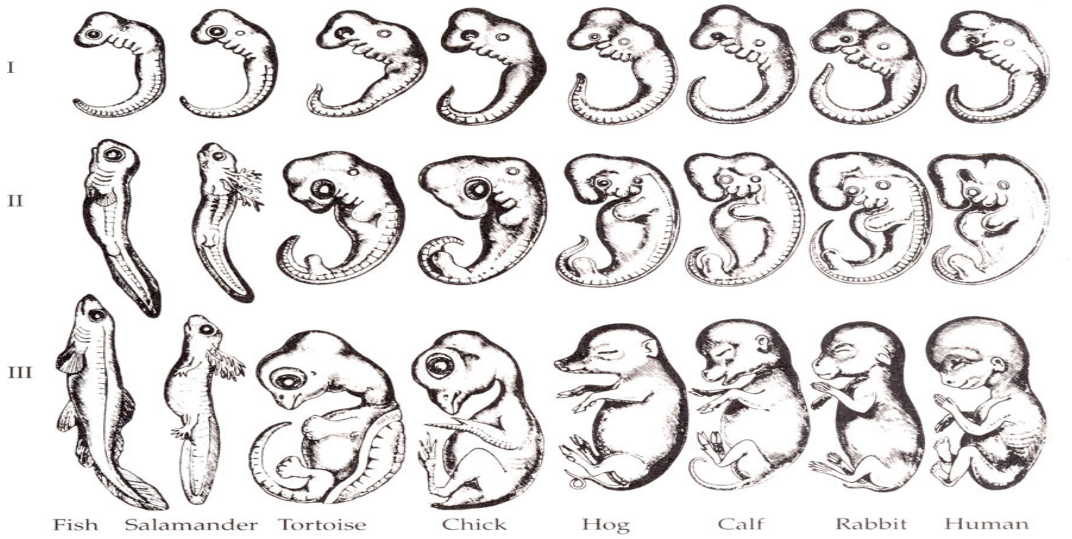


Fig A drawing by Haeckel which depicts development of several animals.

7 COMPARATIVE BIOCHEMISTRY

The biochemical make-up of most animals is remarkably similar. Certain molecules such as Cytochrome C which is used in cellular respiration is almost identical in vastly different animals.

Detailed analyses of many different types of organisms reveals the presence of a common "**molecular signature**" that strongly suggests that all living organisms are closely related; that is, that they that share a common ancestor.

What are these similarities? They range from the basic structure of cells to the molecular machinery involved in energy transduction, information storage and utilization.

For example, all organisms

- use the nucleic acid **DNA** as their genetic material
- use the same molecular system (**transcription** and **translation**) to access the information stored in DNA
- use a common **genetic code,** with few variations, to specify the sequence of polypeptides (proteins)
- use a common set of 20 **amino acids** to build polypeptides
- use a common set of 4 **ribonucleotides** and 4 **deoxyribonucleotide** to build **nucleic acids**
- use adenosine triphosphate (**ATP**) to store energy

As an example, all organisms use **ribosomes** to translate the information stored in **nucleic acids** into **proteins**. The ribosomes of bacteria, archea, and humans are quite similar in shape and molecular organization.

Evidence for a common ancestor:

Similar structures may arise independently, while apparently different structures, such as a human hand and a whale's flipper, are related.

How do we distinguish between these two possibilities? In general, we carry out a detailed comparative analysis of the development and final form of the structure. In the modern world of molecular biology, this involves the genes that are active as the structure forms. The more details two structures share, the more likely they are homologous.

8 BIOGEOGRAPHY:

Darwin, Wallace and the other 19th century naturalists who travelled widely were fascinated by the distribution of animals and plants in their habitats around the world. Why do the Galapagos Islands of South America and the Cape Verde Islands off Africa have strikingly different fauna and flora, despite having similar environments? Why does the Arctic have polar bears and Antarctica penguins?

These patterns impressed Darwin deeply. To him, they argued that species arose in single centers by descent with modification from existing species, and that their geographic range was limited by their ability to migrate to other suitable environments.

The distribution of flora and fauna of the oceanic islands provided Darwin with some of his strongest arguments. The islands contain a small number of species because immigration from the mainland was difficult, he said. Some categories of life are absent altogether, such as batrachians -- frogs, toads, and newts -- even though they would seem to be adapted for such habitats. The reason? They are killed by saltwater, so could not reach the islands by migration. Terrestrial mammals aren't found on oceanic islands more than 300 miles from the mainland. But bats, with their long-distance flying ability, are plentiful.

Another point: Most of the species on islands, while distinct from other species, are most closely related to species on the nearest mainland. Therefore, Darwin said, the island inhabitants must have migrated from the original, mainland area where the species originated. That explains why the species on the Galapagos Islands most closely resemble those on the nearby South American mainland, and those in the Cape Verdes resemble those of west Africa.

Aside from the islands, Darwin was intrigued by unusual distributions of animals and plants across the continents. He concluded that changes in locations of climatic zones over time -- the advance and retreat of glaciers, for example -- could explain some of the patterns in animals' habitats.

Just as intriguing to Darwin, and even more apparent now, is the fact that fossils of possible ancestors of living species are often found in the same parts of the globe where their descendants live today. Darwin observed this in the South American fossils he collected, relatives of today's capybaras and armadillos. Apes today live only in Africa and Asia, and that is where the fossils most resembling modern apes are also found. There are no apes, fossil, or living, known from anywhere in the Americas.

These same patterns are just as impressive today. And since Darwin's day, advances in scientific understanding have shown how accurate his conclusions were. For example, plate tectonics, undreamed of when Darwin was forming his ideas, fits elegantly into Darwin's theory as another major influence on dispersal, helping to produce the patterns in the distribution of both fossils and living organisms seen around the world in modern times.

9 PHYLOGENETIC TREES AND CLADOGRAMS TO INTERPRET EVOLUTIONARY TRENDS

A phylogenetic tree, also called an **evolutionary tree**, is a graphical representation of the evolutionary relationship between taxonomic groups. Taxonomy is the system of classifying plants and animals by grouping them into categories according to their similarities. The term phylogeny refers to the evolution or historical development of a plant or animal species, or even a human tribe or similar group. It is showing the evolutionary interrelationships among various species or other entities that are believed to have a common ancestor. In a phylogenetic tree, each node with descendants represents the most recent common ancestor of the descendants, and edge lengths correspond to time estimates. Each node in a phylogenetic tree is called a taxonomic unit. Internal nodes are generally referred to as Hypothetical Taxonomic Units (HTUs) as they cannot be directly observed.

A phylogenetic tree is a specific type of cladogram where the branch lengths are proportional to the predicted or hypothetical evolutionary time between organisms or sequences. Cladograms are branched diagrams, similar in appearance to family trees that illustrate patterns of relatedness where the branch lengths are not necessarily proportional to the evolutionary time between related organisms or sequences.

Limitations of phylogenetic trees

Although phylogenetic trees produced on the basis of sequenced genes or genomic data in different species can provide evolutionary insight, they do have important limitations. Phylogenetic trees do not necessarily (and likely do not) represent actual evolutionary history.

Furthermore, basing the analysis on a single type of character, such as a single gene or protein, or a morphological analysis only, can be problematic because such trees constructed from another unrelated data source often differ from the first, and therefore great care is needed in inferring phylogenetic relationships amongst species. This is most true of genetic material that is subject to lateral gene transfer and recombination, where different haplotype blocks can have different histories. In general, the output tree of a phylogenetic analysis is an estimate of the *character*'s phylogeny and not the phylogeny of the taxa from which these characters were sampled, though ideally, both should be very close.

When extinct species are included in a tree, they should always be terminal nodes, as it is unlikely that they are direct ancestors of any extant species. Scepticism must apply when extinct species are included in trees that are wholly or partly based on DNA sequence data, due to little useful "ancient DNA" is preserved for longer than 100,000 years, and except in the most unusual circumstances no DNA sequences long enough for use in phylogenetic analyses have yet been recovered from material over 1 million years old.

Types of phylogenetic trees

A **rooted** phylogenetic tree is a directed tree with a unique node corresponding to the (usually imputed) most recent common ancestor of all the entities at the leaves of the tree. The most common method for rooting trees is the use of an uncontroversial outgroup - close enough to allow inference from sequence or trait data, but far enough to be a clear outgroup.

Unrooted trees illustrate the relatedness of the leaf nodes without making assumptions about common ancestry. While unrooted trees can always be generated from rooted ones by simply omitting the root, a root cannot be inferred from an unrooted tree without some means of identifying ancestry; this is normally done by including an outgroup in the input data or introducing additional assumptions about the relative rates of evolution on each branch, such as an application of the molecular clock hypothesis. Figure 1 depicts an unrooted phylogenetic tree for myosin, a superfamily of proteins.

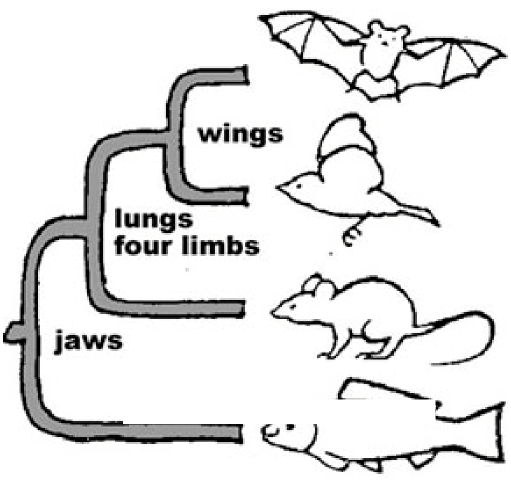
Both rooted and unrooted phylogenetic trees can be either **bifurcating** or **multifurcating**, and either *labeled* or *unlabeled*. A bifurcating tree has a maximum of two descendants arising from each interior node, while a multifurcating tree may have more than two. A labeled tree has specific values assigned to its leaves, while an unlabeled tree, sometimes called a **tree shape**, only defines a topology. The number of possible trees for a given number of leaf nodes depends on the specific type of tree, but there are always more multifurcating than bifurcating trees, more labeled than unlabeled trees, and more rooted than unrooted trees.

Defining relationships between species:

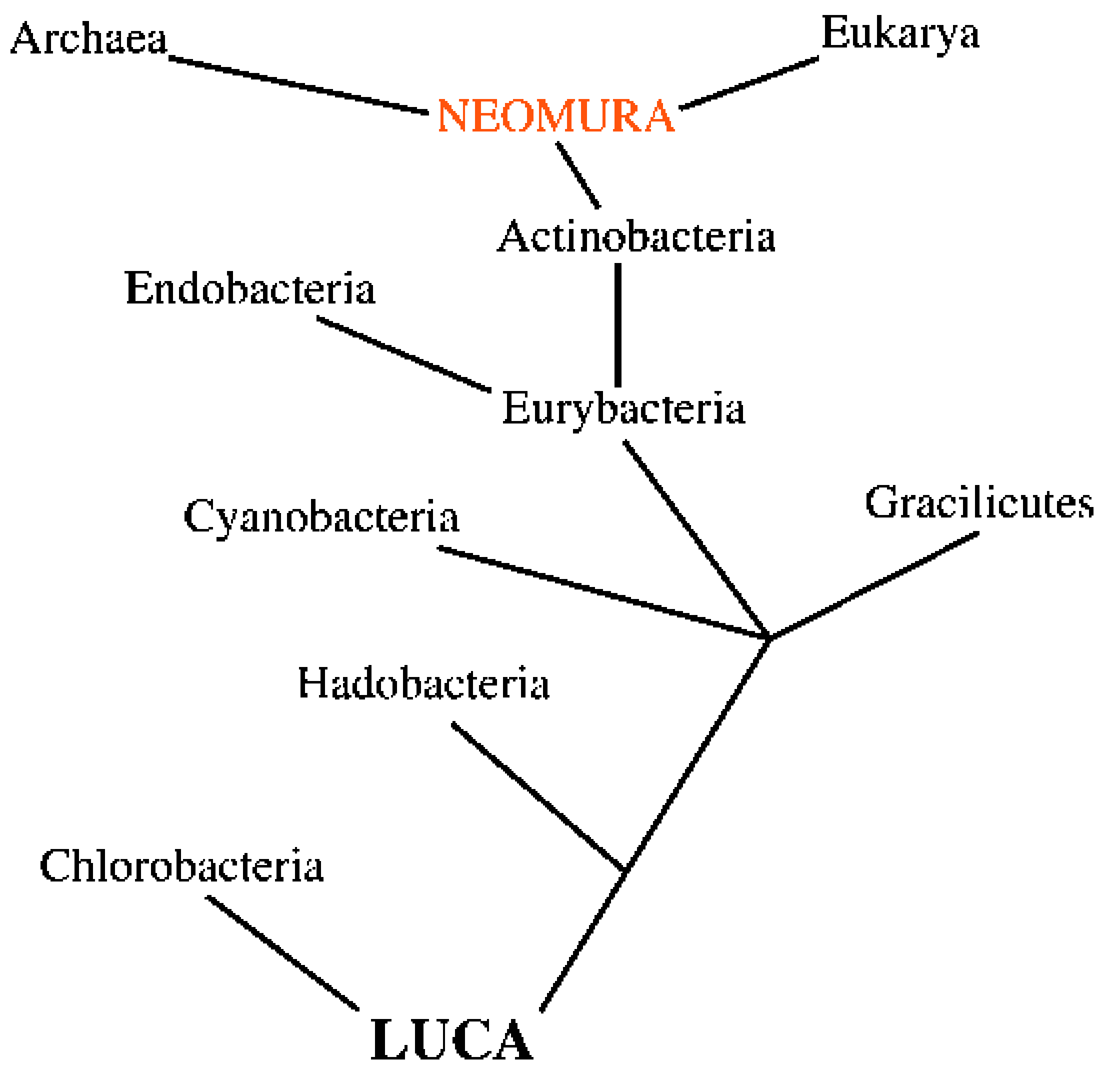
One approach is known as **cladistics**. In this approach, each type of organism is analyzed in terms of primitive and derived characteristics.

Based on these traits, organisms can be arranged into ancestral trees.

Of course, exactly how such a tree is structured depends upon which traits are considered to be primitive (and so present in ancestral forms) and which traits are considered to represent recent specializations.



roll over to see alternative tree



Phylogenetic tree, showing how Eukaryota and Archaea are more closely related to each other than to Bacteria, based on Cavalier-Smith's theory of bacterial evolution.

ADDENDUM A

ACTIVITIES

How to Make Your Own Fossils

You can make several kinds of fossils out of a leaf, bone, feather, shell, or other object.

1. **Mold Fossils**:

   Make the fossil mold in a soft material that will hold an imprint when you press a large, thick object such as a shell down into it. Place a layer of modeling clay (for a temporary fossil) or liquid plaster of paris (for a permanent fossil) into a greased shallow pan. Grease the surface of the clay or wet plaster to prevent your object from getting stuck. Press the object down onto the surface of the clay or plaster.

   These steps have given you the bottom half of your fossil, but remember that when fossils form underground, a layer of rock covers the object making the fossil. To make a complete fossil, you will need to add a top layer to sandwich your object, just like in nature. Lightly grease the surface of your object, and add another layer of clay or plaster to the top, completely covering your object. If you are using clay, gently press it down like the pressure of the rocks on the earth.

   You can now separate the layers of clay to see the fossil mold that has formed in between. If you used plaster, it must dry completely before being separated gently along the seam between the two layers. The space left in the plaster by the object is the mold fossil.

2. **Cast Fossil**:

   Next you can make a cast fossil by filling the hollow area in the plaster with liquid latex. After the latex dries, it will have the shape of the object that made the fossil.

3. **Trace Fossil**:

   Trace fossils are made the same way as mold fossils, but can be made with thinner, more fragile objects like leaves or feathers. Press the object into a layer of modeling clay or plaster of paris. After it has hardened ,remove the object, grease the surface and cover it with another layer of clay or plaster. After the top layer of plaster hardens, it can be removed. You have made an original print on one side and an upraised image on the other.

4. **Whole Animal Fossil**:

   Whole small animals can become trapped in ice and preserved frozen for thousands of years. Some animals been captured in tree sap which later solidified into amber. You can make a simulated amber fossil using a liquid resin hobby kit. Follow the directions for mixing the resin with hardener, following safety instructions very carefully. Pour some of the mixture into a small mold, and after it begins to harden, place a dead insect on the top. Add another layer of resin mix, and allow it to harden completely. When you remove your fossil from the mold, the insect will last a very long time.

ACTIVITY 2 (SLIDE SHOW)

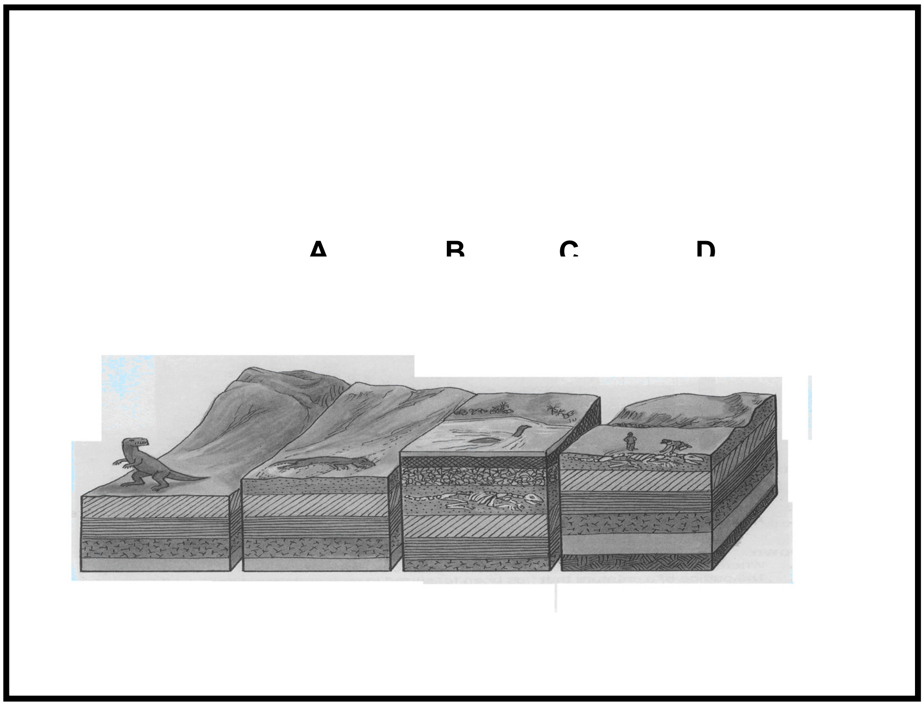
LO2 AS 1, 2, 3

Watch the slide show in class

Work in pairs to do the activity below

1. From the slide show suggest what you think a fossil is.
2. Explain how each fossil you have looked at was preserved?
3. Why is fossil study so important?
4. Under which conditions were the different fossils formed?
5. What is petrifaction?
6. What is the difference between:
   a paleontologist and
   an archeologist?

Study the diagrams below which are illustrating the different stages of fossil formation and answer the questions that follow:



1 Describe in your own words what do you observe in stages A to D.
2 What methods do scientists use to determine the age of a fossil?

ACTIVITY 3 (CASE STUDY)

LO2 AS 1, 2
LO3 AS 2

Coelacanth project takes off

12 April 2002 

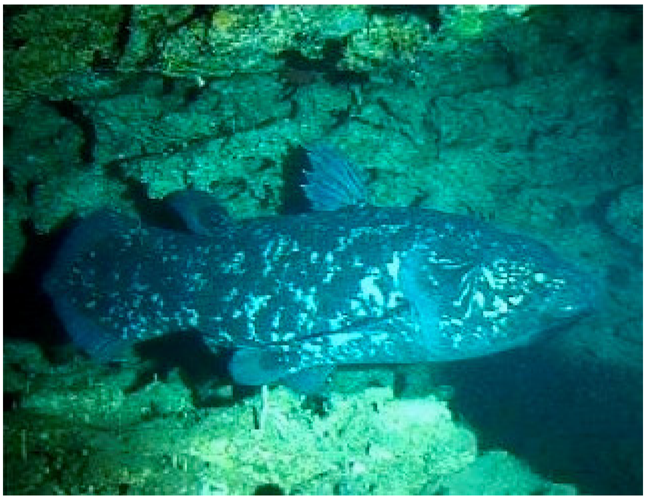
The coelacanth, a prehistoric fish that has lived in the Indian Ocean for 400 million years, and thought until 1938 to be extinct, is now the subject of a government-backed research project off the coast of Sodwana Bay, coupled with an educational programme in rural schools in KwaZulu-Natal.

The discovery of the world's most accessible population of coelacanths near Sodwana on the north-eastern coast of KwaZulu-Natal in November 2000 placed South Africa in a unique position to lead a national and international endeavour to understand this "living fossil".

The first discovery of a live coelacanth - in a trawl net in the East London harbour in 1938 - was hailed internationally as the most important zoological find of the century.

Until then the fish was known only from fossils dating back 400 million years, and was thought have become extinct around 70 million years ago. With its extraordinary leg-like fins, "Old Fourlegs" was thought to be the evolutionary great-grandfather of the reptiles, mammals - and humankind.

COELACANTH FOSSIL



The coelacanth first discovered in November 2000 and rediscovered on 31 March 2002. The divers who first found the fish named it 'Harding', after cameraman Dennis Harding, who died after a too rapid ascent from over 100 metres. *(Picture: SA Coelacanth Conservation and Genome Resource Programme)*

A team of experts, including world-famous Professor Hans Fricke of the German Max Planck Institute, will study the marine dinosaurs with the help of *Jago*, a submersible two-man craft custom-made for studying the coelacanth and supplied by Germany under a German/South African science, research and technology co-operation agreement.

SouthAfrica.info reporter

The coelacanth rediscovered

Jago has already shown its worth. Taking the craft for its first dive off Sodwana on March 31, Fricke and team member Jurgen Schauer took less than four hours to re-discover the coelacanth, sighting the same individual that Piet Venter and his team of divers discovered in November 2000. Coelacanths can be identified from the pattern of their spots, which like fingerprints in humans are unique.

Three days later, *Jago* spotted the same coelacanth along with six others in a cave at 113 metres. “These coelacanths appeared to be quite curious, several ... came out of the cave to inspect *Jago*”, the SA Coelacanth Conservation and Genome Research Programme says on its web site. “This is unusual because normally coelacanths remain passively within caves throughout the day. At night, coelacanths leave the caves to hunt for food.”

Jago being loaded onto the *Algoa* in Cape Town before setting off for Sodwana Bay *(Picture: SA Coelacanth Conservation and Genome Resource Programme)*

Altogether three of these coelacanths had been photographed in 2000, and one of the females appeared to be pregnant, suggesting that the South African population is larger than previously thought, and consists of resident breeding groups. Coelacanths are known to carry up to 26 pups, with a gestation period thought to be in the region of 13 months.

The coelacanth is thought to live mainly in the Indian Ocean, although specimens have recently been found off Indonesia. Since 1938, specimens have also been found off Mozambique, Madagascar, Comores and Kenya, with an unconfirmed catch off Tanzania.

The Sodwana population, however, is by far the most accessible found to date. The coelacanth is a large, mainly nocturnal, deep-water predatory fish.

Announcing plans for the research programme in February, Minister Ngubane said South Africa had much of the expertise and facilities required to conduct "a multi-disciplinary, well-rounded programme that could set a model for coelacanth studies internationally."

Adapted from Science and Technology 12 April 2002

www.southafrica.info

QUESTIONS:

1. Distinguish between
1.1 a fossil and (3)
1.2 a "living fossil" (3)

2. Coelacanths were thought to have gone extinct approximately at the same time (period) that dinosaurs disappeared.
What according to the geological time scale is this period called? (1)

3. Why do scientist have to use a submersible craft to study and observe living coelacanths? (1)

4. What do you think was the significance of the discovery of a living coelacanth in 1938? (3)

5. What made scientists believe that the coelacanth was the evolutionary ancestor of reptiles, mammals and humankind? (2)

6. Why did scientists think that the coelacanth was extinct? (2)

7. Explain why you think that scientists made a mistake in their earlier interpretations regarding the coelacanth. (2)

8. Explain how scientists can use a fossil record as evidence for evolution. (4)

9. Assume you want to be immortalised as a fossil. Explain how you should be buried to become a future fossil. (4)

10. Why are there so few fossils that represent organisms that lived on land? (2)

POSSIBLE MEMORANDUM

1.

1.1 Fossils are the remains of once living organisms, or traces of their activities, that has been preserved or fossilised within sedimentary rocks.

1.2 A prehistoric animal species, generally one that lived during the time of the dinosaurs, that continues to survive in its ancient form today.

2. Cretaceous period

3. Coelacanths live deep underwater.

4. The coelacanth was thought to be extinct, they have hardly changed in millions of years and morphologically they appear to be an evolutionary link between fish and reptiles.

5. The coelacanth has an arrangement of bones in its FOUR LEG – LIKE FINS similar to that in the limbs of modern land animals.

6. No fossils of the coelacanth younger than 70 million years old were known to exist.

7. Scientists believed that the coelacanth has become extinct about 70 million years ago but in 1938 a live specimen was caught.

8. Because fossils are the preserved remains of organisms that lived a long time ago they can show scientists the characteristics of those organisms. These can be compared to the characteristics of organisms that exist today. Fossils also show that living organisms have been gradually changing over millions of years. They also give information about the relationship between living and extinct life forms.

9. Rapid burial after death under a layer of fine sand, mud or clay, anaerobic conditions, no microbe activity and on a shallow sea floor.

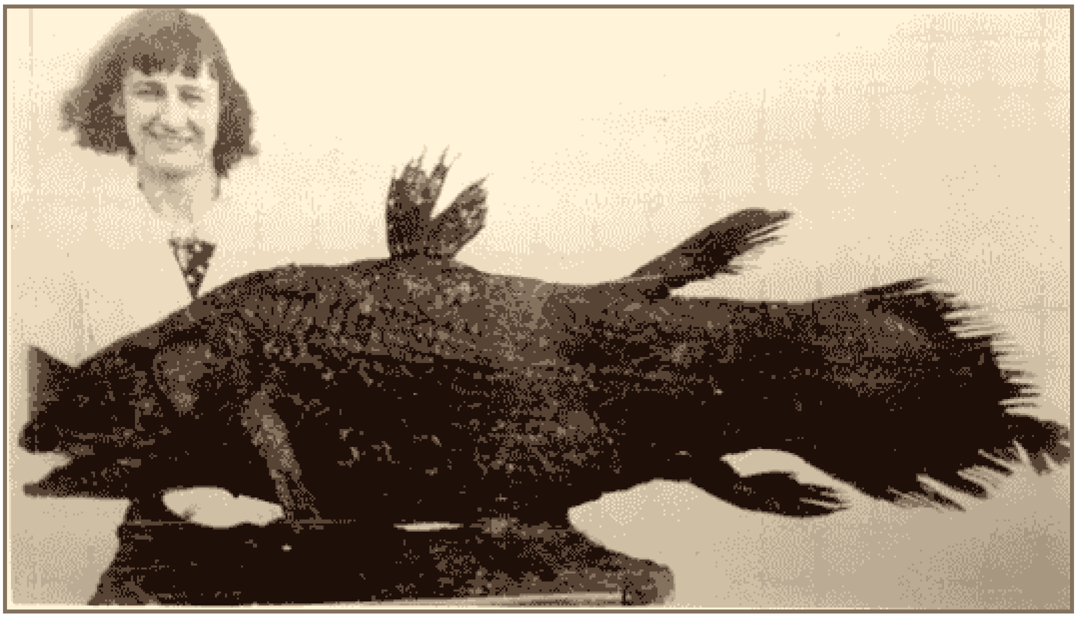
10. Sediments are normally associated with oceans and rivers, making rapid burial more certain for aquatic or marine animals.

ACTIVITY 4 (CASE STUDY)

LO2 AS 1, 2

A Strange Fish Indeed: The "Discovery" of a Living Fossil

By **Robert H. Grant,** School for Professional Studies, Saint Louis University



From the "diary" of Marjorie Courtenay-Latimer while serving as curator at the East London Museum, Cape Town, South Africa.

December 23, 1938.

This morning started out like so many others here in my isolated but peaceful corner of the world. The summer sun rose over the Indian Ocean and began its daily work of baking the ground outside and transforming the air inside our little museum into a palpable and oppressive stew of heat. A pile of recently unearthed reptile bones lay in a heap atop my desk, ready for reassembly and mounting. My day's work, and just the sort of puzzle that I love to solve.

Around lunchtime, Nigel rang to tell me that the *Nerine* had just pulled into port. My friend, Capt. Hendrick Goosen, had just returned from a trawling trip around the mouth of the nearby Chalumna River. Hendrick often calls on me when his catch is substantial so that I can look and see if there may be anything of scientific interest for the museum. More often than not, I find nothing but a pile of malodorous fish. For this reason, and because the proposition of venturing out into the midday heat and dust seemed torturous, I hesitated. Upon consideration, however, I figured that it might be the last opportunity I would have to visit with the Captain and to wish him and his crew a Merry Christmas before the 25^{th}.

I chatted idly with the amicable Captain while we circled the huge heap of fish lying on the deck of the trawler, scanning the pile for anything unusual. I was just about to leave when a strange bluish fin poking through the pile caught my eye. It was like no fish fin I had ever seen in all my years at the museum. The Captain and I shoved the other fish off the top of the pile to uncover the owner of the odd fin. There it lay before me, *the most beautiful fish I had ever seen, five feet long, and a pale mauve blue with iridescent silver markings*. I am no fish expert, but I had the strange feeling that somehow this fish was special. I decided to take the fish with me, and after a heated discussion with the taxi driver, we stuffed the huge fish into the backseat of the cab and headed off for the museum…

Questions

1. Look at the picture of a coelacanth. What do you see that might have led Ms. Courtenay-Latimer to believe that such a fish might be special?
2. What should Ms. Courtenay-Latimer do next? (Remember, she is *not* a fish expert.)

ACTIVITY 5 (CASE STUDY)

Fossilised fish 'ancestor' found in Cederberg

Scientists have found a 450-million-year-old fossil of a fish in the Cederberg - the oldest fish fossil yet found in Africa.

The fish lived at a time when there was life only in the oceans, not on land, and when Africa, India, South America and Antarctica were joined in the single land mass of Gondwanaland. The Cederberg area would have been under the sea.

One of the scientists who found the fish was Hannes Theron, a retired geologist and associate staff member of the University of Stellenbosch.

"These fish (were) the ancestors of modern fish, but had not yet developed backbones or teeth," Theron said on Monday.

"They looked more like earthworms than anything else.

"What makes these fossils unique is that the soft tissue has been fossilised.

"Normally, it is only the hard parts that are found fossilised - the bones and teeth and nails.
"There are only a few other places in the world where such fossils have been found."

Although the fish had no backbones or teeth, they did have scales and fins, Theron said. Nine specimens have been uncovered, with the largest about 15cm. The most recent find was made last month.

The fish lived during the late Ordovician period, during which the first vertebrates appeared. For their soft tissue to be preserved in the fossil record, specific conditions were needed.

"When these fish were alive, there was no life on land as conditions were unsuitable. They were alive just after an ice age and there would have been a lot of fine mud coming into the shallow ocean as the glaciers retreated. This covered the creatures very rapidly after they died.

"There are actual muscle fibres (that have been) preserved (and) which have become fossilised."
Theron has been collecting fossils near Algeria in the Cederberg for 15 years.

He sent some of them to the British Museum and to Cambridge University and in this way was put in touch with Professor Richard Aldrich of Leicester University in the United Kingdom.

Aldrich has been working on the fossils with Theron for several years and they have published several papers on them.

"Another thing that makes these fossils special is that those found in Canada and China are older than the Cederberg fossils, while those found in Europe are younger," Theron said.

Adapted from **Cape Times May 10, 2005**

ACTIVITY 6

LO2 AS 1, 2

BECOMING A FOSSIL

Background Essay /Video

The remains of the vast majority of organisms that die are eaten by scavengers or decompose beyond recognition before they can be preserved. The conditions under which fossils can successfully form are unusual, and the odds that a fossil will then be exposed at the surface again, and discovered, are smaller still.

The study of how life evolved would be impossible if not for the history that is told in the fossilized remains going back billions of years. Scientists have described about 250,000 different fossil species, yet that is a small fraction of those that lived in the past.

The oldest fossils are remains of marine organisms that populated the planet's oceans. When they died, the plants and animals were buried by mud, sand, or silt on the sea floor. Land animals and plants usually decomposed or were eaten, and mainly the hard parts -- teeth, bones, shells, or wood -- were preserved.

Fossils can be formed in several ways. Buried bone and shell contain tiny air spaces into which water can seep, depositing minerals. Reinforced by these mineral deposits, bone and shell can survive for millions of years. Even if the bone or shell dissolves, the mineral deposits in the shape of the body structure remain.

Besides rock, fossils may be found as the result of an organism being entombed in ice, tar (like the famous La Brea Tar Pits in Los Angeles), or amber, in which ancient insects have been found, wonderfully preserved. Rare but highly informative are fossils created by a sudden event, like a volcanic eruption, that traps living things or, in the famous case in Laetoli, Ethiopia, footprints of human ancestors millions of years old.

Fossil remains come to the attention of scientists when they are exposed at Earth's surface. Erosion, land movements, or excavations often have revealed important fossil finds.

Especially rich fossil troves are called Lagerstatten, a German word meaning storehouse. These are localities where conditions were right to preserve even soft-bodied animals, and they allow scientists to read a key portion of life's history. In the famous Burgess Shale in Canada, for example, scientists have found dozens of bizarre, previously unknown animals.

Interpretation of fossils poses another set of challenges, and their age can only be estimated by radiometric dating of rocks they were found near or within. Discovery of fossils is only the beginning of mining their secrets.

DISCUSSION QUESTIONS

1. Discuss the rather restricted set of circumstances under which a large mammal, such as an early hominid, could first become fossilized and then be discovered by researchers.
2. How might conditions for successful fossilization differ between mammals and plants? Why?
3. Discuss how different organisms living in different niches might have very different probabilities of being fossilized.
4. Why do most living things not leave fossils behind?
5. How are fossils formed?
6. How are fossils found?
7. How do scientists determine the age of fossils?
8. What are some key examples of fossil evidence that support the theory of evolution?
9. Why are fossils so rare and why is it difficult to find an evolutionary trail of fossil species leading from a common ancestor?
10. What questions remain unanswered by relying solely on the fossil record ?

ACTIVITY 7 (concepts of common ancestry, homology, analogy, adaptive radiation, and evolution)

LO1 AS 2, 3
LO2 AS 1, 2

The purpose of this hands on, inquiry activity is to introduce the students to concepts used in evolution by making observations and comparisons of organisms. Students observe collections of specimens and discuss answers to open-ended questions in a cooperative learning format. Students learn about the concepts of common ancestry, homology, analogy, adaptive radiation, and evolution, while formulating creative answers based on their observations. This activity can be adapted for whatever specimens are available to the class. It also gives you a way to use those specimens you inherited with your room and the "finds" the students drag in!

INFORMATION FOR THE TEACHER

MATERIALS

Each student group needs:

- Textbook (for checking definitions)
- Notebook paper
- Pen

The classroom is set up as 6 large tables (or push desks together), each containing a group of specimens and a list of questions for each table.
Table 1: Bat wing, bird wing, large moth, and dragon fly.
Table 2: Specimens of vertebrate hind feet, turtle, cat, human, frog, etc.
Table 3: Skulls with beaks and taxidermied birds, owl, chicken, duck, pigeon etc.
Table 4: Hands, forelimbs of cat, human, frog, bat.

Table 5: Skulls of human, dog, cat, sheep, rabbit.
Table 6: Branches of assorted conifers.
It is important to note here that the teacher should adapt the specimens to what is available. Some other specimens which could be used are exoskeletons, shells, leaves, fruits, insect or leaf collections.

TEACHING STRATEGY

1. Have the tables set up with specimens and questions when the students enter the room. It generates curiosity if they see the specimens when they enter.
2. Divide the class into groups of four or five. If the class is too small to have a group at each table, it is better to have empty tables than to have the groups too small to generate ideas.
3. Student groups can be seated at any table and can progress to any table in any order as space opens up. Each group will have a person who acts as recorder to write the group's answers. The recorder will write the names of the students in the group at the top of a sheet of notebook paper and label each set of answers with the appropriate table number. As the group finishes one table, they move on to another.
4. It is very important that the teacher allows the students to generate their own answers to the questions. A textbook is available to each group for checking definitions, but most of the answers rely on creative thinking and observations. If students are allowed to arrive at their own answers, they often think of things that the teacher might not anticipate.
5. Depending on the size of the class and their rate of activity, the teacher may wish to set a time limit at each table and have all tables switch at the same time.
6. When all groups have completed all tables (usually one and a half class periods) students give class reports. Each group chooses a member to act as a reporter and the group is assigned to a table. The reporter describes the group's answers for their assigned table to the rest of the class. The reporter then leads a class discussion and calls on other students to add ideas. When each group has reported about their table, the answer sheets are passed in to the teacher.

QUESTIONS FOR LEARNERS

TABLE 1: FLIGHT STRUCTURES

The structures on this table are all used for flight and are analogous.

1. Define the term analogous.
2. Which animals have an internal skeleton in their wings?
3. Which animals seem most closely related?
4. For each animal wing, list a feature which is characteristic of only that wing.
5. Choose a wing. Explain the advantages of that wing over the others.

TABLE 2: HIND FEET

The structures on this table are hind feet and they are homologous.

1. Define homologous .
2. For each animal, list the main function that the hind foot serves.
3. For each foot describe the special features that suit the form to its function.
4. List three similarities and three differences between the skeleton of the frog foot and the human foot.

TABLE 3: BEAKS

The structures here are all bird beaks and exhibit adaptive radiation.

1. Define adaptive radiation.
2. For each bird, describe the structure of its beak.
3. Relate the size and shape of each beak to the type of food each bird would eat.
4. How do differences in beak structure limit competition for food among these birds?

TABLE 4: FORELIMBS, HANDS

1. Are these structures analogous or homologous? Explain your answer.
2. Compare the skeletal structure of all four animals. List five similarities between the animals.
3. For each animal describe the main function of the hand.
4. For each hand, describe one feature that makes the hand well suited for its function.

TABLE 5: SKULLS

1. Are these structures analogous or homologous? Explain your answer.
2. List five functions of a skull.
3. List five ways these skulls differ.
4. For each skull, list a special feature of the skull and explain how it relates to one of the functions listed in question 2.
5. Identify the animals.

TABLE 6: CONIFERS

These plants belong to a group called conifers. They exhibit adaptive radiation.

1. Describe five differences you see among the needles.
2. How are these plants suited for low temperatures?
3. Which plant can best withstand harsh winds?
4. What is the advantage of long needles? Disadvantage?
5. How are needles advantageous to broad leaves?

ADDENDUM B

LESSON PLAN

EVOLUTION: BIOLOGICAL EVIDENCE FOR EVOLUTION

LESSON PLAN: EVOLUTION

<table>
<tr><td>Educators:</td><td colspan="3">Grade:12</td><td colspan="2">School:</td></tr>
<tr><td>Learning outcomes</td><td colspan="5">LO 1: Scientific inquiry and problem-solving skills
LO 2: Construction and application of Life Sciences Knowledge
LO 3: Life Sciences, Technology, Environment and Society (Influence of ethics and biases in Life Sciences)</td></tr>
<tr><td>Learning outcomes and assessment standards</td><td colspan="5">LO 1 | AS1 | AS2 | AS3
LO 2 | AS1 | AS2 | AS3
LO 3 | AS1 | AS2 | AS3</td></tr>
<tr><td>Integrated learning outcomes from other subjects</td><td colspan="5">Languages, Geography, History, Computer Applications Technology</td></tr>
<tr><td>Knowledge area</td><td colspan="5">Diversity and Change</td></tr>
<tr><td>Prior learning</td><td colspan="5">Grade 9:South Africa’s rich fossil record of plants and animals; similarities to fossils of ancient plants and animals</td></tr>
<tr><td>TEACHER ACTIVITIES</td><td>LEARNER ACTIVITIES</td><td colspan="2">RESOURCES</td><td>ASSESSMENT METHODS</td><td>TIME</td></tr>
<tr><td>The Educator shows a video or slide show on dinosaurs/fossils.

Educator provides the material and work sheet</td><td>▪ Learners watch the video or slide show.

• Learners complete a work sheet based on information from video/slide show (to unpack the concept: fossils.

• Learners plan and conduct a scientific investigation and complete a work sheet on the formation of sedimentary rocks to illustrate fossilisation.</td><td colspan="2">Video / Slide show / Images of fossils / examples of sedimentary rocks or fossils

Practical:
Samples of mud, sand, salt, plants, trays, ash, builder’s lime, flour, measuring containers, scale to measure mass, jars, water
The complete world of Human Evolution:Stringer&Andrews</td><td>Informal Assessment
❖ Work sheets

Informal Assessment
❖ Practical Investigation</td><td></td></tr>
</table>

Educators facilitates a class discussion on concepts	• Learners unpack their ideas to conceptualise and make meaning of information obtained from the previous two activities.(class discussion) ➢ Unpack other evidence of evolution, e.g. DNA and embryology.	Articles, textbooks, web-sites	**Informal Assessment** ➢ Group work ➢ Debate ➢ Presentation	**2 WEEKS**
Educators provide case studies	• Learners study the articles (case studies) on the coelacanth and complete the class work activity.	Web site: www.southafrica.info Type *coelacanth* in keyword search.	**Informal Assessment** ➢ Work sheets ➢ Discussion	
Educators provide information from resources	• Learners use information provided by educator to distinguish between Homologous (Divergent Evolution) and Analogous (Convergent Evolution)	Information from: articles; cooked chicken wings; human skeleton; various textbooks	**Informal Assessment** ➢ Practical work ➢ Work sheets	

Expanded opportunities / Special needs

- Learners should research information on the effects of ice age on fossil formation.
- Plan a tour to a local museum (Iziko in Cape Town) or an excursion to The West Coast Fossil Park.

TEACHERS` NOTES

Prior Learning:
Grade 9
Concepts: South Africa’s rich fossil record of plants and animals; similarities to fossils of ancient plants and animals

Lesson Sequence:

Fossilisation: The process of fossil formation by referring to sedimentation and the ideal conditions for fossil formation.

Fossil Records: Difference between homologous and Analogous structures by referring to examples.

Other Evidence of Evolution: Embryology and DNA

During the class discussions the teacher acts as a facilitator.

ENRICHMENT

Learners must prepare a questionnaire and conduct an interview with a Palaeontologist to find out about their job.

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