LIFE ON EARTH
UNIT ONE
SUMMARY

UNIT ONE MATERIAL

The videotapes to watch for this unit are:

Video Program 1 - THE INFINITE VARIETY
Video Program 2 - BUILDING BODIES

In the study guide:

Read the Introduction.
Read the CONCEPTS:
CONCEPTS FOR EPISODE 1
CONCEPTS FOR EPISODE 2

Answer the QUESTIONS in the study guide:

QUESTIONS FOR EPISODE 1
QUESTIONS FOR EPISODE 2

OVERVIEW OF LEARNING OBJECTIVES

Video Episode 1

To become acquainted with:

1. the theory of evolution
2. the theory of natural selection
3. adaptation
4. fossils as evidence of the development of life on earth
5. the formation of the early Earth
6. oxygen
7. DNA
8. bacteria and blue greens
9. single-celled organisms (Protozoa)
10. sponges
11. jellyfish and alternation of generations
12. corals

Video Episode 2

To become acquainted with:

1. the major forms of invertebrates and their characteristics (animals without backbone)
2. the changes that occurred in body structure and lifestyles as some of the invertebrates evolved into more complex forms
3. the importance of the shell
4. problems that had to be solved before animals could move from water to land
5. flatworms
6. brachiopods
7. mollusks
8. ammonites
9. crinoids
10. echinoderms
11. segmented worms
12. trilobites
13. crustaceans

CONCEPTS FOR EPISODE 1: THE INFINITE VARIETY

EVOLUTION

Simply put, **evolution** means **genetic change over time.** Evolution does not happen to an individual; evolution takes place within a ***group*** of individuals (a population).

DARWIN AND NATURAL SELECTION

The theory of **natural selection** was developed by Charles Darwin. He did NOT develop the idea of evolution; he did develop the first generally accepted mechanism to explain how evolution could take place.

Darwin suggested that organisms had many more offspring than actually survived to reproduce; therefore there was a "struggle for survival" among various individuals. He proposed that certain conditions existed in an environment that favored the survival of certain individuals more than others. In other words, some individuals have characteristics that are "better suited" for the environment than others. If these characteristics could be passed on to their offspring, then the offspring that received these "better" traits might also have a better chance to survive and reproduce. Over time, there are more and more members of the population with these "better" traits.

Let's look at a very simple example: mice who live in White Sands, New Mexico, a habitat with white sand dunes and little vegetation. Assume that these mice come in three colors: black, gray and white. As the mice go about their daily business, predators have a very easy time picking out the black mice on a white background. The gray mice are also relatively easy to spot. Predators have more difficulty in spotting the white mice on the white sands. Over time, the majority of the mice who **survive and live long enough to reproduce** are white -- so most of the offspring are white (who in turn must live long enough to reproduce and pass their white genes on to their offspring, and so on). Does that mean that "white coat color" is automatically a better color for a mouse? Not if the mouse lives in a prairie or a forest or on a lava bed. In those environments, a white mouse is a "fast food lunch" for a predator.

Here's a question. What's more important: survival or reproduction? Think about this for a moment and then read the parable below.

The Parable of the House Cat and the Alley Cat

Fluffy was a pampered Persian male "god" who lived in a glorious mansion, waited on hand-and-foot by his human pets. Fluffy never reproduced and died at the ripe old age of 20 from terminal Vender Vittles.

Scrappy was an ugly tomcat who lived in the alley behind the mansion, surviving off of scraps, mice and slow birds. He was quite a ladies man, fathering so many kittens he lost count. After four glorious years of Saturday night serenading, he met his end under the wheels of an SUV in a moment of distraction.

So, who won the evolutionary game? Fluffy or Scrappy? Fluffy is the pampered, well-fed sap since his genes died with him. Scrappy's genes live on in his innumerable great-great-great grandchildren.

(with apologies to Dr. Eric Pianka, an evolutionary ecologist at the University of Texas at Austin)

Additional Information:

1. Most people associate Darwin with the theory of natural selection. However, Alfred Wallace came up with a similar theory at the same time. So credit should be jointly shared between Darwin and Wallace for the theory of natural selection.
2. Darwin would have had a much easier time with his theory if he had known about genes and DNA. Even though Gregor Mendel was doing his pioneering genetic work with peas at about the same time, Darwin never learned about his work. So, Darwin didn't know **how** a trait could be passed from a parent to an offspring.
3. Natural selection is only one of many possible mechanisms of evolution but the only one that leads to adaptation. See below.
4. Recent work in the Galapagos Islands reveals that evolutionary changes in a population occur much faster than Darwin ever suspected. For a fascinating story, read *The Beak of the Finch* by Jonathan Weiner (Alfred Knopf, 1994).

ADAPTATION

Adaptation refers to the traits of an organism that allow it to be successful in a specific environment. These traits arise through selection. For example, certain plants live in salty conditions, such as at the beach. They have several adaptations to these conditions, including: (1) they have the ability to conserve water, (2) they either do not absorb salt through their roots or they excrete excess salt on their leaves, (3) they are able to survive when their roots are covered with water for a period of time, and (4) many send out long runners over the sand to anchor the plant firmly in shifting sand and to quickly produce new offshoots that might survive if the original plant becomes buried in sand.

Many people are confused about the concept of adaptation. A plant or animal does not **decide** to adapt to certain conditions. Adaptation is NOT a matter of choice. The organism either has the ability to survive under certain conditions or it does not. If it does not, the plant or animal either dies or leaves. For example, if the soil begins to accumulate lead, many plants cannot survive the new conditions. As they die out, other plants that can tolerate the lead find it easier to grow because they are not competing for space and light. As they thrive, these “lead-tolerant" traits are passed on to their offspring. The "lead-tolerant" plants now have adaptations to an environment where the soil contains a larger concentration of lead. This is a good example of natural selection in action.

ANTIBIOTICS AND ADAPTATION

The first antibiotic, penicillin, was discovered by Fleming in the 1930s and first mass produced in the 1940s during World War II. Within ten years after the end of the war, some bacteria were no longer affected by penicillin (antibiotic-resistant).

So, why did this occur? Think about natural selection and adaptation. Which bacteria survived an encounter with penicillin? The ones that had traits that made them resistant to penicillin. Which bacteria reproduced? Only the ones that survived. So, a new strain of penicillin-resistant bacteria evolved.

Now, for the really *scary* part of the story. Are you using anti-bacterial soap all the time? If so, you might consider the evolutionary consequences of a whole nation buying into the anti-bacterial craze. Do you ***really*** want all surviving strains of bacteria to be resistant to all known anti-bacterial products?

For more information, check out the website from the Alliance for the Prudent Use of Antibiotics at:

http://www.tufts.edu/med/apua/Q&A/Q&A_AR.html

FOSSILIZATION

Fossils are often used as evidence of evolution. A **fossil** is any evidence of past life, including chemical evidence, body parts, impressions, or traces of an animal or plant that has been preserved. Preservation can occur after burial in mud, quicksand, asphalt, volcanic ash, sandstorms or blizzards, lava flows, or water-borne sediments. Remains are also preserved in amber, permafrost, dry caverns, arid regions, and peat bogs. [A fascinating article on human remains in peat bogs can be found in *Discover* (August, 1997)]. Fossilization is a rare and chancy business. Very few of the organisms that ever lived became fossils. Those organisms that were fossilized do not necessarily represent all types of organisms that ever existed. Fewer still have been found by scientists who studied them. Because fossils are formed more often in water than on dry land, most fossils are of water-living species. Therefore, fossil evidence has a built-in bias.

Most land-dwelling organisms, after they die, are rapidly devoured and decomposed. But some plants and animals fall into or are washed into lakes, streams, or swamps. There, due to the conditions of the water or mud, decomposition is not rapid or maybe not possible at all. On the other hand, aquatic species can fall to the bottom and be buried before decomposing, which increases the chance of fossilization. Under weight (due to overlying water, layers of sediment or other material) and over long periods of time, the materials which made up the body of the plant or animal are leached out and replaced with minerals. This process is called **mineralization** and causes the formation of a replica of the organism in hard stone, including internal structures.

Sometimes instead of being mineralized, the tissues may dissolve and wash away, leaving a space with the form of the original organism that will be filled in by a harder material. This forms a **mold** (the cavity) or **cast** (filling of the cavity) of the animal or plant, but the internal structures are not preserved.

Trace fossils are formed by activities of an organism, for instance when animal footprints are left in mud which later hardens and preserves the shape of the footprint or worms burrowing through mud. We don't actually have any part of the organism as a fossil but we do have evidence of their activity. This is often the only evidence of an organism's behavior. (Of course, when we find dinosaur eggs within nests or *T. rex* teeth in the neck of an herbivorous dinosaur, we also get information about behavior.)

The age of fossils is determined by using two types of **dating,** relative and absolute:

1. **Relative dating** methods involve comparisons of the sequence of layers in which fossils are found. Those on the bottom are the oldest and those on top the youngest in undisturbed rock. Since this method is limited to regions where the rocks are all the same, another method called **faunal succession** was devised to compare the rock strata of one area of the world to other areas by using similar fossils. So, layers of rock in North America that contain a certain collection of fossil types are presumed to come from about the same time period as similar layers in Australia or Morocco. *(How is this faunal succession? Fauna are groups of organisms. Succession is change over time. The sequence of fossilized organisms through time is faunal succession.)*

For more information about fossilization and taphonomy (the study of what happens during fossilization), go to these websites:

http://www.tiac.net/~cri/1998/taphonomy.html
http://www.colostate.edu/Depts/Entomology/courses/en570/papers_1998/spriggs.htm

2. **Absolute dating** uses the radioactive isotopes found in all matter to estimate how long ago the object was formed. For example, all living material contains ^{14}C (carbon-14) an isotope of carbon that decays to ^{14}N (nitrogen-14) over a certain period of time. By measuring how much ^{14}C is left in a fossil, we can estimate how much of the original ^{14}C has decayed and about how long ago the organism was formed. This method assumes that the rate of assimilation of ^{14}C into living tissue and the rate of decay have been relatively constant over time. A drawback to ^{14}C dating is ^{14}C has a short half-life of 5730 years. So, it is only accurate for dating relatively recent fossils (less than 60,000 years old). Other radioactive elements are used to date other rocks. For example, ^{238}U (uranium-238) can be used to date old fossils because it has a half-life of 4.5 billion years as it changes to , ^{236}Pb (lead-206). These elements are used to date the rocks the fossils are in, not the actual fossils.

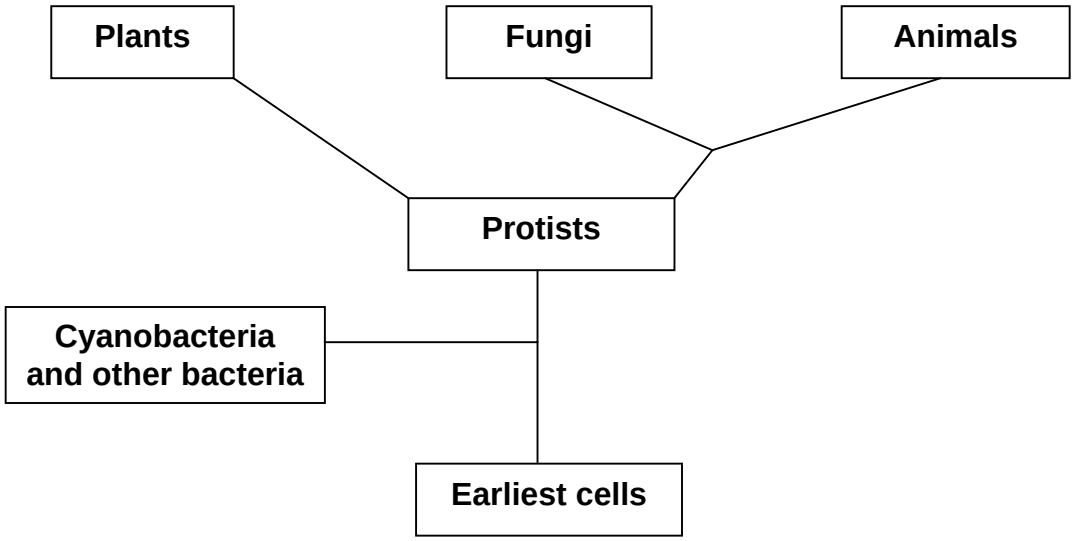
For more detailed information about dating, check out these websites:

http://www.talkorigins.org/faqs/dating.html
http://pubs.usgs.gov/gip/geotime/radiometric.html

(Many of these websites are related to the ongoing debate about creation/evolution. The websites listed above explicitly provide answers to perceived problems with geologic dating, but they give well balanced descriptions of the process.)

EVOLUTIONARY TREES

Evolutionary trees are often used to show the presumed relationships between an ancestor and its descendant forms. You can use it to determine how closely groups of organisms are related. Think of it as a tree, with the branches that are closer together on the main trunk **more closely related** to each other than to branches farther away. Start at the bottom and work towards the top of the tree. For example, cyanobacteria (formerly called blue greens) are closer on the tree to bacteria than they are to green algae, so they are more closely related to bacteria. Plants, fungi and animals evolved after bacteria, cyanobacteria and protists.



Notice that there is not a straight-line relationship between bacteria and protists. Today, the cyanobacteria (blue greens) are grouped with "true" bacteria. Protists did not directly evolve from any bacterial group living today. Instead, all bacteria and protists evolved separately from a common ancestral form. Animals and fungi evolved from a common protist ancestor. The plants evolved from a different protist ancestor.

Once you understand the principles behind evolutionary charts, you can use the charts to more easily determine relationships between different organisms. Keep in mind that there are many different versions of evolutionary charts. See page 152 for a different type of evolutionary tree that is commonly used. More information about evolutionary trees can be found at: **http://tolweb.org/tree.**

A BRIEF OVERVIEW OF THE 5 KINGDOM CLASSIFICATION SYSTEM

For many years, living organisms have been divided into 5 kingdoms. This somewhat arbitrary system of classification attempts to collect organisms that have similar characteristics into different categories. The five kingdoms are still discussed in many current biology texts. However, based on molecular and cellular data, biologists are discussing systems of classification that incorporate up to **14** different kingdoms. Since this is an area of continuing change, we are going to **briefly** outline the five kingdom system below.

KINGDOM MONERA
The members of this group have one common characteristic: a **prokaryotic** cell. A prokaryotic cell is typically small with no internal organelles in the cell. Even the DNA is not contained in a separate nucleus. The DNA is usually arranged in one circular ring. The organisms that are placed in this kingdom are bacteria and cyanobacteria (formerly called blue greens). Bacteria, as a general rule, are heterotrophs. Cyanobacteria are photosynthetic.

KINGDOM PROTISTA The members in this group share two characteristics: they are (1) **eukaryotic** and (2) unicellular, colonial or simple multicellular organisms. A eukaryotic cell contains internal organelles, each with its own function. The DNA is contained inside a nucleus. The DNA is typically arranged in strands that are called chromosomes. Members of this kingdom include algae (green algae, diatoms), protozoans (*Euglena*, *Amoeba*, *Paramecium*), slime molds and water molds.

Let's take pond scum as an example: a charming collection of numerous cyanobacteria, bacteria, algae and protozoans.

KINGDOM PLANTAE
The members of this group are multicellular, eukaryotic and make their own food by means of photosynthesis. Organisms include mosses, ferns, horsetails, conifers, flowering plants and other plants.

KINGDOM FUNGI
The organisms in this kingdom are multicellular, eukaryotic and heterotrophic. The major characteristic shared by the members of this group involves their method of digesting food: they secrete chemicals outside of their bodies onto food particles, digestion occurs outside the body, and then the fungus absorbs the digested particles. The organisms in this group include mushrooms, molds and yeasts.

KINGDOM ANIMALIA
The organisms in this kingdom are multicellular, eukaryotic and heterotrophic. The members of this group bring food into their bodies, internally secrete chemicals to break down the food substances and then absorb the particles. Organisms include invertebrates (sponges, worms, crustaceans, etc.) and vertebrates (fishes, reptiles, mammals, etc.).

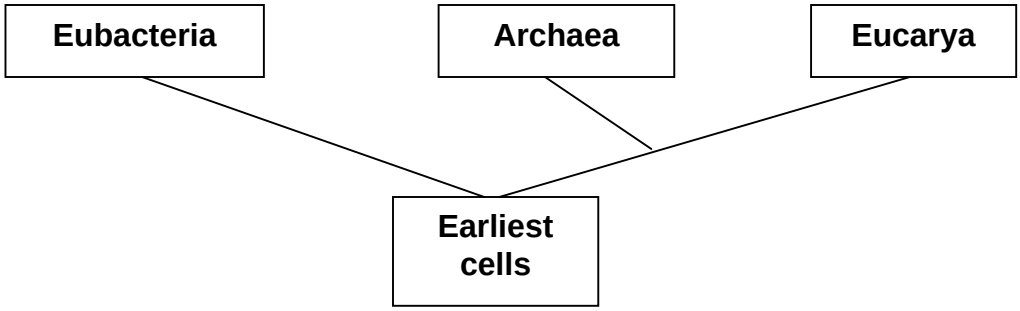
For more information, the five kingdom classification scheme is discussed at this website:

http://www.perspective.com/nature/index.html

A NEW CLASSIFICATION SCHEME - THREE DOMAINS

Carl Woese of the University of Illinois has proposed a different classification scheme based on molecular evidence (ribosomal RNA). In his scheme, organisms are divided into three **domains** (which is a level of classification **above** kingdom). Most biologists today use the three domain classification system.

Three Domain Classification Scheme



Domain Eubacteria ("true bacteria") contains the simple life forms described above in Kingdom Monera. These are unicellular organisms that usually lack a nucleus.

Domain Archaea *(Ar kee uh)* contains the simple life forms called **archaeans,** formerly part of Kingdom Monera**.** This group includes **thermoacidophiles** that live in very hot acidic environments, **methanogens** that produce methane gas, and **halophiles** that live in very salty environments. Recent analysis of the 1,738 genes of a species of this group showed that about half of its genes were totally unique. (In other words, these genes have not been found in any other plant, animal, bacterium, protist or fungus).

Domain Eucarya *(U care ee uh)* contains complex organisms (the eukaryotes) which have cells that contain a nucleus. These organisms include protists, plants, animals and fungi.

You can find additional information on the domain system in several places, including *Discover* (January 1997 or February 1995), *National Geographic* (March 1997, p 142), or *Science News* (03/22/97 or 09/14/96). You can also find more info at these web sites:

http://www.ucmp.berkeley.edu/alllife/threedomains.html

Now, let's look at how the domain classification scheme affects the five kingdom scheme. Domain Eubacteria and Domain Archaea replace the old kingdom Monera. The other four kingdoms (Protista, Plantae, Fungi and Animalia) fall under Domain Eucarya. However, molecular evidence now indicates that the protistans are not closely related to each other. This kingdom will probably be split into several separate kingdoms. While there will be some changes to the other three kingdoms (Plantae, Fungi and Animalia), the members of these kingdoms are closely related to each other and the kingdom names are still in use today.

QUESTIONS FOR EPISODE 1: THE INFINITE VARIETY

FOSSILS AND NATURAL SELECTION

1. What did Charles Darwin contribute to the study of life?

2. How did the Galapagos Islands influence Darwin's concept of change within species in order to suit their environment?

3. State the theory of natural selection.

4. a. How are fossils formed?

   b. Where are fossils most likely to be found?

   c. How are fossils dated? (2 ways)

   d. Why are fossils important to the study of evolution? (THINK)

5. What types of fossilized organisms can be associated with the following time periods?
   a. 200 million years

   b. 300 million years

   c. 400 million years

d. 500 million years

e. 2-3 billion years (2000 to 3000 million)

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CLARIFICATION: The age of the Earth is **now** estimated to be 4.5 to 4.6 billion years old. The oldest prokaryotic fossils are 3.5 billion years old, from rocks in Western Australia. See:
http://www.talkorigins.org/faqs/geohist.html.

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6. a. What is chert?

b. What fossilized organisms were found in gunflint chert?

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AUTHORS' NOTE: Even though Attenborough calls them "algae" or "blue greens" in the video, they are now called cyanobacteria. The term "algae" is also used for photosynthetic protists.

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c. Describe how these organisms were found.

7. Describe the early earth, with reference to the following conditions.
a. presence of volcanos?

b. types of gases present?

c. presence of oxygen?

d. presence of ultraviolet rays?

8. What impact did ultraviolet light, heat and other forms of radiation probably have during this early period of formation?

9. Attenborough discusses the development, aggregation and formation of molecules and early cells. Answer the following questions that are based on his discussion.

   a. Why are amino acids important?

   b. How did the early compounds increase in complexity?

   c. What are the two characteristics of DNA that are so important to life?

   d. What is a gene?

   e. When DNA duplicates, what is formed?

   f. What happens when mistakes (mutations) occur in DNA duplication?

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You can check out these websites for more information about abiogenesis (life from non-life):

http://www.americanscientist.org/template/AssetDetail/assetid/21438?fulltext=true

http://www.talkorigins.org/faqs/abioprob/

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Locator: Discussion of Yellowstone Park, Wyoming

BACTERIA AND BLUE GREENS (now called "cyanobacteria")

10. a. What was the first **organism** that probably developed?

    b. What did these forms use light energy from the sun and hydrogen to create?

    c. Where did the first organisms get hydrogen?

    d. New forms arose that used _____ as the source of hydrogens. These forms are called cyanobacteria (blue greens).

    e. Where does free oxygen come from?

11. What is the major contribution of blue greens to the development of life?

Locator: Bay, Western Australia

12. What is the relationship between blue greens and the rings in gunflint chert?

13. What is the significance of the ozone layer?

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ADDITIONAL INFORMATION: Bacteria and cyanobacteria (blue greens) are the simplest cellular forms of life. They are impossible to see individually without a microscope but may become visible when a great number accumulate in one area. Bacteria are helpful in decomposing body wastes and dead vegetation and animal matter into their smallest components. This releases nutrients (such as carbon, oxygen, iron, nitrogen, potassium, etc.) into the environment which other organisms can reuse. Bacteria are the original recyclers!

Cyanobacteria, algae and plants use water, carbon dioxide and the energy of sunlight to produce food (photosynthesis). As photosynthesis takes place, an important byproduct from water is released -- oxygen. In the earliest years of our planet's history, this step was crucial to life as we now know it. As atmospheric oxygen began to accumulate, other life forms that needed oxygen

to respire were able to develop.

Humans also study bacteria because bacteria cause many diseases (such as syphilis and cholera). Every November, we are warned about the dangers of *Salmonella* from undercooked turkeys. Hamburgers are served well-done due to risks of a particular strain of *Escherichia coli* (*E. coli*) infections.

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Locator: Local Pond

SINGLE-CELLED ORGANISMS (PROTISTS)

14. How old are the first fossilized single-celled organisms (Protists)?

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AUTHORS' NOTE: The earliest fossil protists are 2.1 billion years old.

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15. a. What are ciliates?

b. What are cilia?

c. What are cilia used for?

16. a. What is a colony?

b. What is unusual about *Volvox*?

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ADDITIONAL INFORMATION: **Protists** are unicellular organisms more complex than the bacteria and cyanobacteria. Their DNA is organized as chromosomes within a nucleus. During protist reproduction, genes may be recombined to produce unique individuals, producing genetic variation to drive natural selection. (Sex! As Cole Porter so eloquently sung – "the urge to merge".) Protists are a varied group, including flagellates, ciliates, diatoms, amoebas, etc. Sometimes, these unicellular creatures join together to form a colony, providing organization. Others are simple multicellular organisms (such as seaweeds).

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SPONGES

17. How many species of sponges currently exist?

18. a. How would you describe the bond between individual sponge cells?

    b. Do sponges have skeletons?

    c. Glass sponges have skeletons made of _____.

    d. Do sponges have any internal systems, such as a nervous system, digestive structures or muscles?

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ADDITIONAL INFORMATION: Sponges took their organization one step beyond the colony. They are simple aquatic animals that feed by filtering nutrients from the water. The cells are loosely coordinated and can reform the sponge if separated. You may have used the protein "skeleton" of a sponge to bathe with if you have used a natural sea sponge. Though some cells of a sponge are specialized for filter feeding, they have no backbone or internal systems (such as nervous or digestive systems). In some ways, they are less complex than some of the seaweeds which are protists.

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JELLYFISH

19. How are jellyfish different from sponges?

20. a. What is a medusa?

    b. What is the function of the tentacles with stinging cells?

    c. How do medusae feed?

21. a. Do jellyfish have muscle fibers?

    b. Do jellyfish have a nervous system?

    c. Do jellyfish cells work together as a coordinated group?

22. a. What is a polyp?

    b. How do polyps feed?

23. What is the relationship between a stationary polyp and a free-swimming medusa? (Two varieties)

24. a. What are the characteristics of true jellyfish?

    b. How far back in the fossil record can jellyfish be found?

25. a. Describe the Portuguese Man-of-War.

    b. How are these different from true jellyfish?

c. How far back in the fossil record can similar organisms be found?

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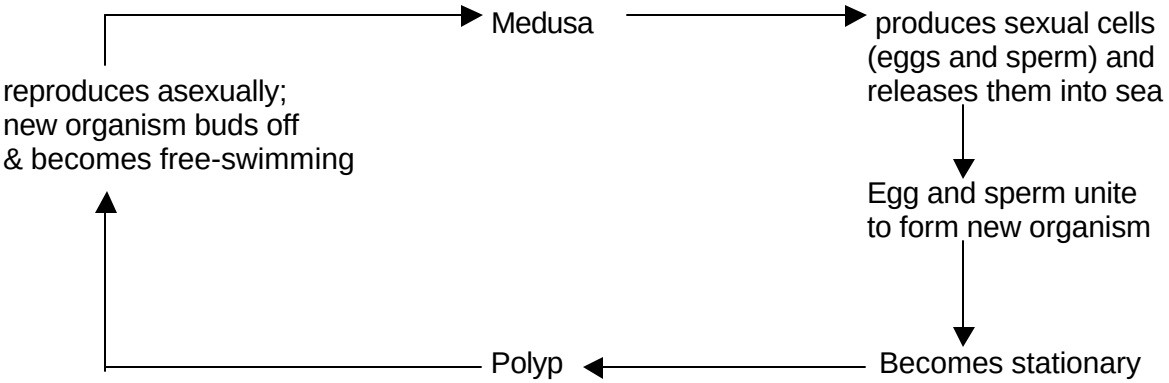
ADDITIONAL INFORMATION: Jellyfish are the first animals to have two cell layers organized with an interior cavity. Unlike the sponge, their cells cannot survive independently. Jellyfish have muscle tissues and a simple netlike arrangement of nervous tissue. Their method of reproduction is unusual because they alternate between sexual and asexual generations. You will see this "alternation of generation" concept again in the plants.

A Simple Line Drawing: Alternation of Generations in Jellyfish



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CORALS

26. a. Describe the soft corals. (Some are also called sea pens.)

b. To what depth can soft corals grow?

27. a. Describe the stony corals.

b. To what depth can stony corals grow?

c. How does stony coral grow? (This is how coral reefs are formed.)

28. What is the relationship between algae and stony corals? (How do the algae benefit? How does the coral benefit?)

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ADDITIONAL INFORMATION: Corals are another type of simple aquatic animal related to jellyfish and sea anemones. You can think of corals and sea anemones as skinny upside-down jellyfish living in a colony (corals) or alone (sea anemones). While you may be unfamiliar with soft corals, you are probably aware of stony corals and coral reefs. The stony corals have a symbiotic relationship with algae -- algae live inside a coral polyp and all benefit from the relationship. The algae photosynthesize during the daytime, providing food for themselves and the polyp. The coral polyp feeds at night with tentacles, providing food for itself and the algae.

With the aid of algae, colonies of coral polyps have built limestone reefs large enough to be seen from the moon.

A threat to corals are bleaching events where the algae are expelled, due to environmental stresses. You can read more about coral bleaching at:

http://www.marinebiology.org/coralbleaching.htm

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CONCEPTS FOR EPISODE 2: BUILDING BODIES

INVERTEBRATES

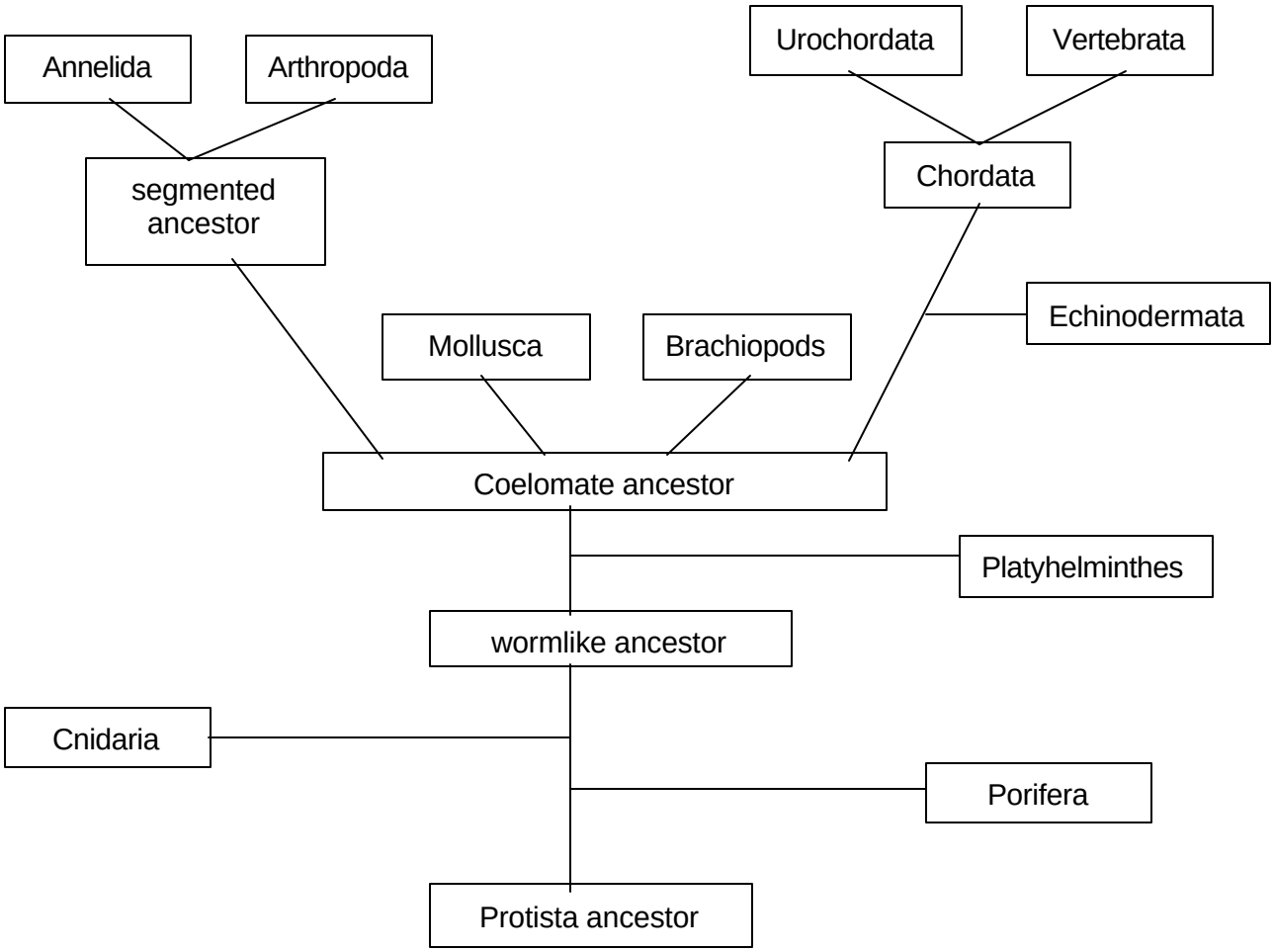
Animals without backbones are called **invertebrates**. There are many more invertebrate animals than vertebrates (animals with backbones). For instance, there are at least 1 million insects alone that have been identified.

Fossil evidence of soft-bodied animals such as jellyfish is difficult to find. Some of the earliest fossils of soft-bodied animals are worm traces -- fossilized traces that are left behind of the passage of long thin worm bodies through the mud. As animals became more complex with harder body parts, fossil evidence became more abundant. Shells, stalks and segments of hard-bodied animals are more easily preserved.

EVOLUTIONARY TREE

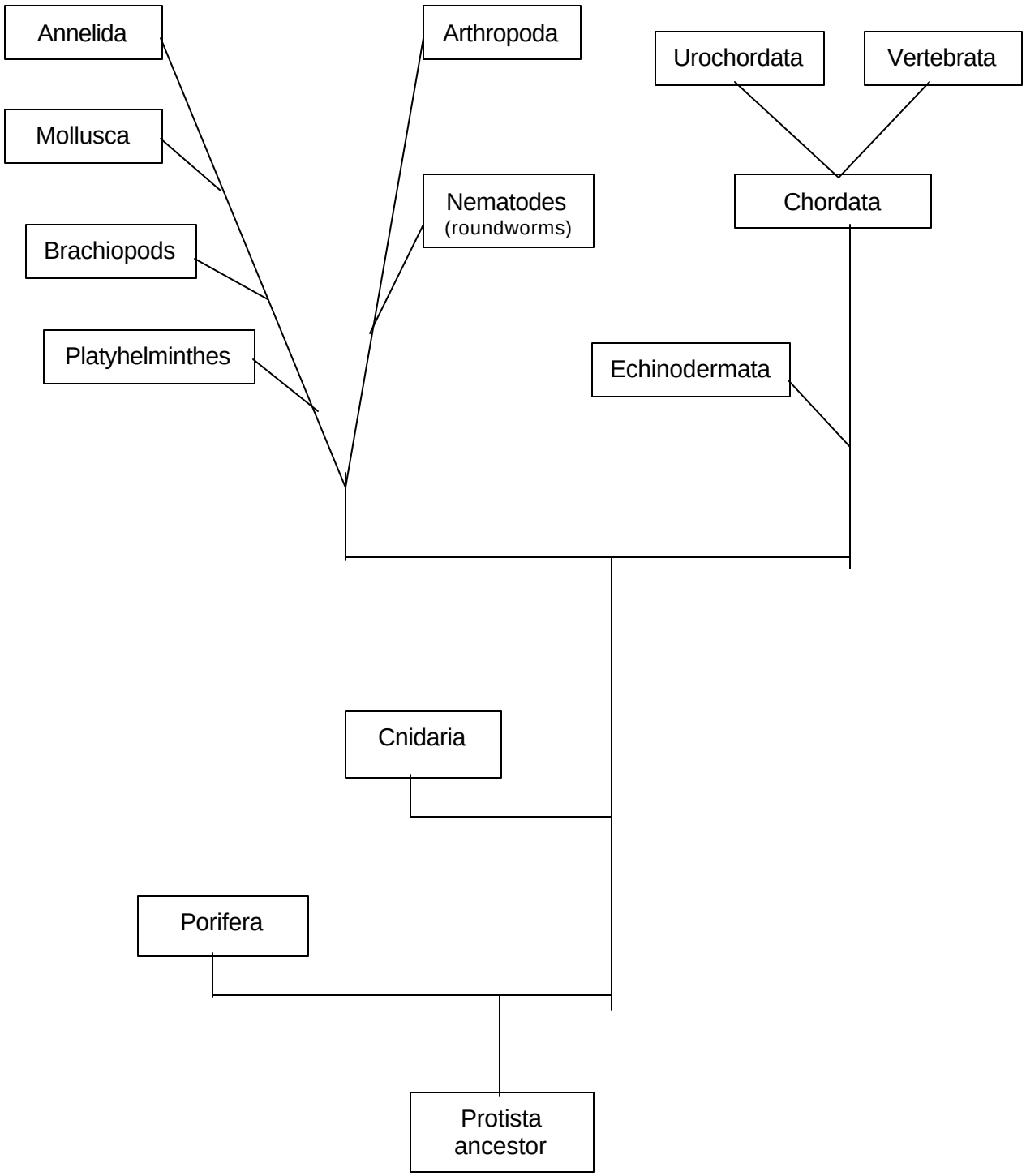
As mentioned before, there are a number of possible evolutionary pathways for animals. This chart below shows one possible tree.

Evolutionary Tree for Animals



Here's a second, more recent evolutionary tree based on molecular data.

A Different Evolutionary Tree for Animals



Additional information about evolutionary trees can be found at:

http://tolweb.org/tree

BODY PLANS

Before we go over the different animal groups, we need to discuss the basic "body plan" of animals.

One aspect of an animal's body plan is **symmetry**. Symmetry refers to how many ways you can divide an animal in half and get "mirror" images. Let's take people, for example. There's really only one way to do this – draw a line from the head down through the belly button and on, ending up with an equal right and left side. This is an example of **bilateral** symmetry (two-sided symmetry). Now, let's think about a pizza or doughnut. There are many ways to divide that pizza, each yielding two mirror images. That's an example of **radial** symmetry and it applies to animals such as jellyfish and corals.

There are other aspects of a body plan, such as segmentation and skeletons. **Segmentation** refers to repeating body parts, where the body is divided into multiple segments and the segments may become specialized. Think of an earthworm. Its body is made of multiple segments with little specialization beyond the head and some reproductive structure in the front of the body. On the other hand, look at an insect or crayfish. In crayfish, segments at the front have become specialized into a head with antennae and mouthparts. The segments in the middle have gills and big walking legs. The segments at the end have swimming legs.

How are skeletons related to body plan? Some animals have skeletons made of water (**hydrostatic skeletons**) and they can't support themselves very well outside of water. Think of a jellyfish. Take away the water and you have a "glob of glup". Some animals have **exoskeletons**, such as insects, crayfish, snails and clams. This type of skeleton is on the outside of the body. It gives good protection but has some limitations. Insects and crayfish have to shed their skeletons in order to grow – which makes them vulnerable until the new skeleton hardens. Another problem is weight – an external shell is heavy and inefficient to haul around in large organisms. While the image of enormous ants or spiders works for Hollywood, in reality, they can't get that big.

Other animals have **endoskeletons**, which are on the inside of the body. It is not quite as protective as an exoskeleton but can grow along with the body of the animal. Examples of animals with endoskeletons include humans, starfishes and snakes.

DIFFERENT ANIMAL GROUPS

PORIFERA: sponges; simple sessile (attached) animals; body made of cells; no tissues or organs present; radial or no symmetry; endoskeleton of silica, calcium carbonate and/or protein

CNIDARIA: jellyfish and corals; free-swimming medusa or sessile polyp; mouth surrounded by tentacles with stinging cells (nematocysts); radial symmetry; hydrostatic skeleton

PLATYHELMINTHES: free-living flatworms, flukes, tapeworms; flat body form with bilateral symmetry; gut with mouth but no anus; hydrostatic skeleton

COELOMATE ANCESTORS: ancestors of advanced invertebrates. The **coelom** is a major evolutionary advance for the animals. This is a fluid-filled body cavity that separates the muscles of the body wall from the muscles of the digestive tract. This has a number of advantages for the animal. First, it allows digestion to occur independent of body movement. Secondly, the fluid provides a primitive circulatory system of fluids throughout the internal body. Third, the cavity allows room for the development of a **true** circulatory system, with vessels and hearts, to develop inside the body. Animals with coeloms possess digestive systems with both mouth and anus. These advantages allow an animal to become more complex than the simple invertebrates.

BRACHIOPODS: mainly extinct; 300 living species; shells present; primarily marine; bilateral symmetry; exoskeleton

MOLLUSCA: snails, clams, scallops, nautilus, squid, octopi; no segmentation; body is covered by mantle; head and muscular foot present; shell usually present; shell is exoskeleton; bilateral symmetry

ANNELIDA: segmented worms; earthworms, polychaete worms, leeches; body arranged in repeating body segments; respiration across skin or gills; bilateral symmetry; hydrostatic skeleton

ARTHROPODA: Arthropods evolved from a segmented wormlike ancestor. Arthropod characteristics include bilateral symmetry; segmentation; jointed appendages; an exoskeleton made of chitin. Several arthropod groups are discussed in the videos:

Horseshoe crabs: 2 body parts with 5 pairs of walking legs

Millipedes: body with distinct head with antennae and chewing mouth parts; most segments grouped into pairs, each with 2 pairs of walking legs

Spiders and Scorpions (arachnids): 1 to 2 body parts with 4 pairs of walking legs

Crustaceans: shrimp, lobsters, crabs; most have two body parts (a cephalothorax and abdomen) with 2 pairs of antennae; chewing mouth parts; 4 or more pairs of walking legs

Insecta: insects such as dragonflies, butterflies; body divided into head, thorax and abdomen; antennae present; usually have 2 pairs of wings and 3 pairs of legs

ECHINODERMATA: crinoids (feather stars and sea lilies), sea stars, starfish, brittle stars, sea cucumbers; marine organisms; body divided into 5 parts around central disc with mouth in center; water vascular system present (hydraulic, fluid-filled tubes) with tube feet for movement; adults have pentaradial (5-fold) symmetry; endoskeleton

CHORDATA: We are a member of this group. Members of the chordates have four things in common, at some point in their lives:

1. stiff, rod-like notochord running down the back that serves as a skeleton
2. hollow dorsal nerve cord (dorsal = back region)
3. pharyngeal gill slits (in throat region)
4. muscular postanal tail

Chordates are segmented and have bilateral symmetry. Most develop an extensive endoskeleton made of cartilage or bone. For examples, sharks have endoskeletons of cartilage and frogs have endoskeletons of bone.

UROCHORDATA: sea squirts; tadpole-like larva with notochord and hollow dorsal nerve cord; bilateral symmetry; hydrostatic skeleton as adults.

VERTEBRATA: fishes, amphibians, reptiles, birds, mammals; these animals have the notochord replaced or surrounded by a vertebral column of bone or cartilage

QUESTIONS FOR EPISODE 2: BUILDING BODIES

Locator: Great Barrier Reef

1. a. What is an invertebrate?

   b. List several examples of invertebrates.

Locator: Limestone Cliffs, Morocco

2. How old are the first invertebrate fossils?

3. What are the three main kinds of body types that are found in the fossil record?

4. What explanations have been proposed to explain the absence of shelled organisms before 600 million years ago?

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AUTHORS' NOTE: To a casual observer, it might seem that "in a blink of an eye", life forms suddenly proliferated about 570 million years ago in an event often called the Cambrian explosion. The Cambrian "explosion" was not an instantaneous event. These organisms appear over a range of about 30 million years. Fossil evidence places their ancestors in older rocks. For more information, see:

http://www.ucmp.berkeley.edu/cambrian/camb.html
http://www.pbs.org/wgbh/evolution/library/03/4/l_034_02.html
http://www.accessexcellence.org/bioforum/bf02/lipps/index.html

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Flatworms

5. a. What structures can be seen in juvenile flatworms?

b. Describe the body of the flatworms.

c. How do flatworms absorb oxygen?

d. How do flatworms move?

e. Can flatworms burrow?

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A great website with marine flatworm pictures can be found at:
http://www.rzuser.uni-heidelberg.de/~bu6/

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6. What change in the oceanic environment probably lead to the development of tubular worms that could burrow? When did this change take place?

7. When burrowing worms evolved, what different types of body plans developed?

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ADDITIONAL INFORMATION: Flatworms were apparently the first worms to evolve. The free-living flatworms of today have a basic digestive system, a simple nervous system and other organs. As worms continued to evolve, certain changes occurred in the basic worm body. The flat body changed into a roundish fluid-filled body.

Eventually, worms burrowed into the ocean mud and developed protective shells of limestone. Some of these "shelled worms" became the brachiopods, which at one time had about 30,000 species. Today, there are about 300 species still living; the rest are extinct.

Other "shelled worms" became the mollusks, a diverse group which includes snails, bivalves (scallops, oysters, clams), nautilus, squid and octopi. The mollusks have a mantle covering their body, which has a head and a muscular foot. The mantle gives rise to the shell.

The nautilus, after millions of years, gave rise to the shelled ammonites which were very successful for about 200 million years but are now extinct. (See the video.)

The most intelligent mollusks include the nautilus, squids and octopi. The nautilus still has a shell, squids have a remnant of shell inside their bodies, and octopi have lost their shells entirely. While most people know about these animals squirting ink, many people are surprised to discover they have superb eyes (with a lens) and very large brains. Their behavior is quite complex and they have pigments in their skin that allow them to change color to match their backgrounds (camouflage). So when you are eating fried calamari, just remember --- squid are intelligent.

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BRACHIOPODS

8. What body structure is found in the brachiopods?

9. What were the functions of the pair of shields?

10. What types of adaptations (changes) occurred within the brachiopods?

11. When did the majority of the brachiopods die out?

Locator: Bay in Japan

12. What evolutionary concept is demonstrated by the samisan (a living brachiopod)?

MOLLUSKS

13. How many different species of mollusks exist?

14. What is the mantle? What is its function?

15. How are coiled shells formed?

16. List the characteristics found in the mollusks.

17. What does the electron microscope reveal about the tongue-like feeding organ of the mollusks?

18. What is the foot? What is its function?

19. What are the bivalves? Describe their body form and various life styles.

20. A few of the mollusks are free-swimming, without visible shells.
    a. What changes have occurred to their shells?

    b. What protection do these species have against predators?

    c. What is the function of their brilliant coloration?

21. What different type of gills have developed in the more complex and larger mollusks?

22. a. Briefly describe the *Glaucus*.

    b. What is its prey?

    c. How do they use the stinging cells of jellyfish?

23. The Portuguese Man-of-War has another molluscan predator, a snail. How does this snail construct a floating raft?

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There are lots of interesting snails. One of the prettiest groups of snails (coneshells) is also incredibly poisonous. See: http://grimwade.biochem.unimelb.edu.au/cone/

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24. a. When did fossils with flotation chambers appear in the fossil record?

b. What group developed the internal flotation chambers?

c. How are the flotation chambers useful?

25. a. Where does the nautilus live?

b. Describe the nautilus.

c. What does the nautilus eat?

Ammonites

26. a. Describe the ammonites.

b. The ammonites dominated the seas for _____ million years.

c. What changes occurred in the body pattern of the ammonites over time?

d. What is unusual about the junction between the flotation chambers in the fossilized ammonites?

e. Are there any living ammonites today?

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Website: http://www.humboldt.edu/~natmus/impFossilTypes/Ammonites/WhatAmm.html

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Locator: New Zealand

27. What characteristic of the Argonaut (a type of octopus) reveals the relationship between it and the ammonites?

28. a. Do octopuses have shells?

b. Describe the characteristics of octopuses.

c. What is the function of the siphon in the octopus?

29. a. How do squid differ from octopuses?

b. What is the function of the internal horny relict of the shell?

c. How do squid move?

d. What is the size of the largest squid?

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Websites: See information about cephalopods, including squid and octupus videos at:
http://www.cephbase.utmb.edu/viddb/viddb.cfm
http://www.thecephalopodpage.org/

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THE ECHINODERMS: CRINOIDS AND OTHERS

30. a. What was the ancestor of the sea lilies (crinoids)?

b. Why did they develop bony plates?

c. When do they appear in the fossil record?

Locator: Great Barrier Reef

31. Describe the feather stars.

32. The starfish demonstrates the unusual characteristics of this group of invertebrates (the echinoderms). List the major characteristics of this group.

33. What structure of the echinoderms uses hydraulic pressure?

34. Briefly describe the other members of the echinoderms that are listed below:
    a. brittle stars

    b. sea urchins

    c. sea cucumbers

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ADDITIONAL INFORMATION: Another group of worms eventually became the flowerlike crinoids, which gave rise to the other echinoderms. The crinoids include feather stars and sea lilies. The other echinoderms are more familiar. They include sea stars, starfish, brittle stars and sea cucumbers. All are marine organisms. Echinoderms have a body divided into 5 parts around a central disc containing a mouth. They move by a water vascular system (hydraulic, fluid-filled tubes) with tube feet.

National Geographic (December 1996) has an article on crinoids. You can also find more information about crinoids at:

http://easyweb.easynet.co.uk/~gcaselton/fossil/crinoid.html
http://tolweb.org/tree?group=crinoidea&contgroup=echinodermata
http://www.ucmp.berkeley.edu/echinodermata/crinoidea.html

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Larvae

35. Why are the larvae of marine invertebrates considered to be the reason for the success of the marine invertebrates and their presence throughout the ocean?

36. What is revealed about relationships between two different groups of organisms if their larval forms are similar?

INVERTEBRATES WITH SEGMENTED BODIES

37. a. What basic body plan is seen in the segmented worms?

b. What is the advantage of a segmented body?

Locator: Southern Australia

38. What are the earliest fossils of segmented invertebrates? How old are these fossils?

Locator: Rocky Mountains, British Columbia

39. What is unusual about the fossil record in this area? How did fossilization occur in this region?

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AUTHORS' NOTE: This area is called the Burgess shale. Fossils here are freaky and weird.

http://tabla.geo.ucalgary.ca/~macrae/Burgess_Shale/
http://www.trilobites.info/anohome.html

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40. Segmentation allows for greater evolutionary success. List some of the changes that occur to appendages in the segmented worms.

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ADDITIONAL INFORMATION: One group of worms developed segmented bodies with bristles. Most people are familiar with the earthworm. If you examine the anatomy of an earthworm, you will see that the segmentation is repeated internally as well as on the surface.

Websites: http://www.naturewatch.ca/english/wormwatch/about/anatomy.html
http://www.naturewatch.ca/english/wormwatch/resources/anatomy.html

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Trilobites

41. a. Describe the shell of the trilobites.

b. What is the age of the trilobites in the fossil record?

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AUTHORS' NOTE: The earliest trilobite fossil is now dated as 540 million years old. There are really good trilobite websites at:

http://www.trilobites.info/

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42. Describe the types of eyes that developed in the trilobites. What is significant about the lens in the more advanced trilobite eye?

43. a. What does the great variety of body sizes and body shapes in the trilobites reveal?

b. When did the trilobites die out?

44. What relative of the trilobites still exist today?

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ADDITIONAL INFORMATION: Segmentation led to specialization of body parts. The extinct trilobite is well represented in the fossil record, probably due to its segmented shell, aquatic lifestyle and large numbers. As animals developed, specialized organs became apparent. The mosaic eyes of the trilobite attest to their sophistication. Despite their vast numbers and sophisticated sensory organs, they became extinct. The arthropod alive today that is most closely related to the trilobites is the horseshoe crab.

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45. Describe the body structure of the horseshoe crab.

46. Describe the reproductive strategy of the horseshoe crab.

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THREATS TO DIVERSITY: Horseshoe crabs are seriously over-fished for bait for conch fishing in Florida and the eastern Atlantic. Governmental agencies are trying to develop catch limits. Websites about horseshoe crabs can be found at:

http://www.dnr.state.md.us/fisheries/general/hscindex.htm
http://www.audubon.org/campaign/horseshoe/

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Crustaceans

47. How many different species of crustaceans exist?

48. What is the major disadvantage of the external shell?

49. Describe the changes that occur when a crustacean molts.

Locator: Japan

50. Describe the jointed appendages (legs) of the crustaceans, as seen in the large crab.

51. What do crustaceans use pigments for?

52. List the different ways that appendages are modified in the crustaceans.

53. List several different types of crustaceans.

54. What is the major advantage of an external, jointed skeleton?

55. a. Which crustacean has made the move to land?

b. How does this organism absorb oxygen?

c. Why does this crustacean have to return to the sea?

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ADDITIONAL INFORMATION: Another group evolved about the same time as the trilobites: the crustaceans. Crustaceans have two pairs of antennae on their heads, two body parts (cephalothorax and abdomen) and at least 4 pairs of legs that may be specialized. Common examples are shrimp, crabs and lobsters. The exoskeleton of a crustacean must be shed (molted) as the animal grows; however, it provides protection in water or on land. Some crustaceans have made the move out of water onto the land.

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56. Which mollusk has also made the move to land?

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ADDITIONAL INFORMATION: Pulmonate snails were the last organism to leave the water and successfully move to land, about 100 million years ago. An interesting discussion about this topic can be found in the article "Why are there no lobsters on land or bats at sea?" in the February 2002 edition of *Natural History*.

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57. 400 million years ago, the segmented animals gave rise to the most advanced and successful group of the invertebrates, the _____.