Chapter 17: The History of Life on Earth

OVERVIEW

In this chapter, you will learn about the history of life on this planet. The authors trace the evolution of life from the beginning of the universe through prebiotic evolution, spontaneous generation of the first living prokaryotic cells, metabolic evolution, the rise of eukaryotes and multicellularity, the invasion of land, and finally human evolution. Europa, one of the 16 moons of Jupiter, is among the celestial objects deemed most likely to hold extraterrestrial life. Its surface is frozen ice littered with huge cracks, humps, and crevices, suggesting that the surface ice is floating on liquid water, warmed perhaps by heat from the moon's rocky core. Water is a key component of the conditions under which life can arise, as it did on Earth, and might have on Europa.

1) How Did Life Begin?

In the 1600s, biologists thought life arose through **spontaneous generation** from nonliving matter and unrelated life forms (like trees giving rise to fish and birds). This was not substantially refuted until the mid-1800s by Louis Pasteur. In the 1930s, Oparin and Haldane proposed **prebiotic** (or chemical) **evolution**: evolution before life began, when the atmosphere of the Earth contained hydrogen, methane, carbon dioxide, nitrogen, hydrogen sulfide, hydrochloric acid, water vapor, and ammonia gases but no free oxygen gas. In 1953, Miller and Urey did lab experiments to show that under prebiotic atmospheric conditions, organic molecules like amino acids, nucleotides, and ATP could be produced. Since no organisms or oxygen gas existed in prebiotic times, organic molecules could accumulate in shaded pools not subjected to ultraviolet solar radiation, forming a "primordial soup." So, organic molecules can be synthesized spontaneously under prebiotic conditions, and prebiotic conditions would allow organic molecules to accumulate.

RNA may have been the first self-reproducing molecule. In the 1980s, Cech and Altman discovered that certain small RNA molecules called **ribozymes** act as enzymes to make more RNA. Possibly, molecular evolution began in the primordial soup when ribozymes began to copy themselves and make other molecules. Cellular life requires self-replicating molecules enclosed within membranes. If water containing proteins and lipids is agitated, hollow membrane-like balls called **microspheres** form. If microspheres formed around ribozymes, nonliving **protocells** formed, possibly evolving into living cells.

None of this has been proven beyond doubt, but it is suggestive of what probably happened.

2) What Were the Earliest Organisms Like?

Life began about 3.5 billion years ago, according to fossils and chemical data. The first cells were prokaryotic and obtained nutrients and energy by absorbing organic molecules from the environment and breaking down these molecules anaerobically (no oxygen gas was present) and gaining a little energy. These cells were primitive anaerobic prokaryotes (bacteria). Eventually, some cells evolved photo-synthesis, the ability to use solar energy to make their own complex, energy-rich molecules from water and carbon dioxide. The cyanobacteria evolved, and through photosynthesis, released oxygen gas into the atmosphere. About 2.2 billion years ago, free oxygen gas began to accumulate, and atmospheric levels of oxygen gas increased steadily until reaching a stable level about 1.5 billion years ago. This, in turn, allowed the evolution of microbes capable of aerobic respiration, breaking down organic molecules completely using oxygen gas to release significant amounts of chemical energy.

of their mating behaviors towards each other, whether they can together produce normal, healthy, fertile offspring, and whether their chromosome numbers are identical or not, are valid ways to determine whether they represent one or two species.

43. According to P. Massicot of animalinfo.org, the saola is a forest-dwelling ox weighing about 100 kg (220 lb). All known locations for the species are mountainous with steep river valleys, covered by evergreen or semi-deciduous forests between 300–1800 meters (1000–6000 feet), with low human disturbance. Current knowledge indicates that the saola prefers the edge areas of wet lowland evergreen forest habitats and evergreen montane forests. Villagers say that the ox eats the leaves of fig trees and other bushes along riverbanks. The saola is said to travel in small groups of 2–3 animals, rarely up to 6–7 animals. The most serious threats to the saola are hunting and loss of forest habitat due to logging and conversion to farmland. In May 1992, the discovery of three pairs of horns in the only remaining area of pristine forest in northern Vietnam led to the first documentation by Western scientists of a new species of ox. Saola are shot for their meat. Because of their scarcity, local people place a higher value on saola than on more common species. Hunters were also aware of the intense interest from the world's scientific community, increasing their motivation to capture live specimens. Among local communities, there was some awareness that forest resources were declining, but the general perception was that resources were still plentiful. Moreover, the hunters showed little or no understanding of the principles of resource management of the species that they hunted. Everything that was encountered during hunting trips was shot or captured, if possible. Although the saola was valued by hunters, there seemed to be little concern about its decline or local extinction. There are an estimated several hundred saola left.

44. According to an Agence France-Presse article reprinted by forests.org, this mammal is a small stag belonging to the muntjac (or barking deer) family. It has black fur and weighs about 15 kilos (33 pounds), only half the weight of the other muntjac species in Vietnam. The scientists were not able to observe the animal directly and made the discovery from skulls found in villages in the area. They established it was a new species after analyzing the animal's tissue while further information was provided by Vietnamese hunters. This muntjac species lives in forests between 400 and 1,000 meters (1320 and 3,300 feet) in altitude. Its small size allows the animal to move easily through the dense vegetation.

45. Researchers at the University of East Anglia have identified a new and highly distinctive species of rabbit — striped and with a red rump — found in the Annamite Mountains in Laos and Vietnam. Three of the striped rabbits were found, freshly hunted, in a meat market in Laos by a British biologist. Samples from these animals were sent for identification to one of the world experts on rabbits. Researchers extracted DNA from the Laos rabbits and also from 100-year-old museum specimens of the only other known species of striped rabbit, the critically endangered Sumatran rabbit, endemic to mountain forests in Sumatra. The Annamite rabbit, which has since been seen in a nature reserve in neighboring Vietnam, closely resembles the Sumatran rabbit, both possessing black/dark brown stripes on the face and back, a red rump and short tails and ears. However, despite the striking external similarity, genetic analysis reveals significant differences between the two. The genetic data suggests that these two species may have diverged about eight million years ago. The Sumatran rabbit had been feared extinct as there had only been one sighting since 1916. But, in early 1998, a team from Fauna and Flora International captured automatic camera-trap photos of the species in Mt. Kerinci National Park, in Sumatra. Only 15 specimens of the Sumatran rabbit had ever been collected, all at the turn of the century, and the species remains critically endangered due to the destruction of its mountain forest habitat.

Eukaryotes developed membrane-enclosed organelles and a nucleus. Predation soon evolved, with larger prokaryotic cells engulfing bacteria. About 1.7 billion years ago, eukaryotic cells having membrane-bound nuclei and cytoplasmic organelles evolved from predatory bacteria. According to Lynn Margulis' **endosymbiont hypothesis**, primitive cells acquired the precursors of mitochondria and chloroplasts by engulfing certain types of bacteria and forming a symbiotic (mutually supportive) relationship with them. The fact that these organelles retain their own bacterial-like DNA supports the hypothesis. Cilia, flagella, centrioles, and microtubules may have evolved from a symbiosis between spiral-shaped bacteria and a primitive eukaryotic cell. The origin of the nucleus is more obscure.

3) How Did Multicellularity Arise?

Increased size was an advantage, but large unicellular organisms could not survive due to the slowness of diffusion. Multicellular organisms evolved about one billion years ago. Multicellular algae developed specialized rootlike and leaflike structures that facilitated their invasion of diverse habitats.

Multicellular animals developed specializations to help them capture prey and feed. They evolved muscular movement so that predators could chase prey and prey could escape. Hydrostatic skeletons (water-filled tubes) for locomotion evolved in some worms and then external skeletons evolved in the arthropods. Finally, internal skeletons in the vertebrates developed. Additionally, greater sensory capabilities and more-sophisticated nervous systems evolved.

4) How Did Life Invade the Land?

Terrestrial organisms must find adequate water, protect their gametes from drying out, and resist the effects of gravity without a buoyant watery environment. The plants that first colonized the land, however, had ample sunlight, rich nutrient sources in the soil, and no predators. Some plants developed specialized structures that adapted them to dry land. Waterproof coatings on the aboveground parts reduced water loss, rootlike structures were anchored in the soil, mining water and nutrients, and extra-thick cell walls enabled stems to stand erect.

Primitive land plants (mosses and ferns) retained swimming sperm and required water to reproduce, but the **conifers** (cone-bearing plants) retained their eggs internally and encased sperm within pollen grains blown around by the wind, allowing the conifers to flourish in dry habitats. Landing on a female cone near the egg, the pollen released sperm cells directly into living tissue, eliminating the need for a surface film of water. As the moist climate dried up, conifers flourished. Flowering plants enticed animals (mainly insects) to carry pollen from flower to flower, thus wasting much less pollen than conifers. Flowering plants also reproduced more rapidly and grew more quickly than conifers.

Some animals evolved specialized structures that adapted them to life on dry land. Some animals were **preadapted** for land life: they already had structures suitable for life on land, such as **exoskeletons** in the arthropods. Amphibians evolved from lobefin fishes. Lobefins had two preadaptations for land: stout fleshy fins for crawling and a pouch off their digestive tract that acted as a primitive lung. With these improvements, lobefins evolved into amphibians. But amphibians still depended on water for egg laying and to keep their skin moist for gas exchange.

Reptiles, which evolved from amphibians, developed several adaptations to dry land: internal fertilization; shelled, waterproof eggs containing a supply of water and food; scaly, waterproof skin; and improved lungs. Two groups of smaller reptiles developed insulation to retain body heat. Reptiles gave rise to both birds (with feathers) and mammals (with hair). Unlike birds which lay eggs, mammals evolved live birth and mammary (milk-producing) glands to feed the young. When the reptilian dinosaurs became extinct 65 million years ago, the mammals adaptively radiated out into the vast array of modern forms.

5) What Role Has Extinction Played in the History of Life?

In the history of life, nothing lasts forever. The upward trend in species diversity and the slow, steady turnover of species have been interrupted by episodes of **mass extinction**. These episodes are characterized by the disappearances of many varied species in a relatively short time over a large area. The worst episode occurred about 245 million years ago at the end of the Permian period, when 90% of the world's species became extinct.

Mass extinctions may be caused by climate changes. Organisms that are adapted for survival under one set of environmental conditions may be unable to survive under a drastically different set of conditions. One cause of climate change is plate tectonics (movement of the Earth's plates resulting in changes in latitude). More sudden events also play a role in mass extinctions, such as massive volcanic eruptions and the effects of the impact of a large meteorite, causing an "impact winter" that severely lowered the temperature by blocking out sunlight for a period of years.

6) How Did Humans Evolve?

Regarding human evolution, paleontologists disagree about the interpretation of the skimpy fossil evidence and many ideas may have to be revised as new fossils are found. **Primates** are lemurs, monkeys, apes, and humans. The most likely primate ancestors were probably insect-eating tree shrews, small nocturnal mammals whose fossils are 80 million years old. Early primates ate fruits and leaves and evolved several adaptations for life in the trees. Primate evolution has been linked to: (1) grasping hands for powerful (club swinging) and precise (writing, sewing) manipulations; (2) binocular vision (forward-looking eyes with overlapping fields of vision) for accurate depth perception and color vision for finding ripe fruit; and (3) a large brain with high intelligence that facilitated hand-eye coordination and complex social interactions.

Between 20-30 million years ago, in the tropical forests of Africa, the *dryopithecine* primates diverged from the monkey line. *Dryopithecines* evolved into the **hominids** (humans) and pongids (great apes) some 5 to 8 million years ago, perhaps from a hominid with ape-like traits like *Ardipithecus ramidus*. Early hominids, called the *australopithecines* (southern apes of Africa) which lived about 4 million years ago, could stand and walk upright. Upright posture freed the hands to carry weapons and manipulate tools.

The genus *Homo* diverged from the australopithecines about 2.5 million years ago. The evolution of *Homo* was accompanied by advances in tool technology. *Homo neanderthalensis* (Neanderthals) appeared about 150,000 years ago and had large brains and ritualistic behaviors but did not lead to modern humans based on DNA analysis. Modern humans (*Homo sapiens*) evolved about 150,000 years ago in Africa, perhaps from *Homo heidelbergensis*, which had developed earlier from *Homo ergaster*. *Homo sapiens* spread into the Near East, Europe, and Asia, supplanting all other hominids. The evolution of Homo was accompanied by advances in tool technology. Cro-Magnons (humans from Europe and the Middle East, beginning about 90,000 years ago) had domed heads, smooth brows, and prominent chins, just like us. Humans and Neanderthals coexisted in Europe until humans overran and displaced the Neanderthals.

The evolution of human behavior is highly speculative. Human **cultural evolution** (learned behavior passed down from previous generations) now far out-paces biological evolution. There have been three major surges of human population growth, each associated with a cultural revolution: (1) development of tools (ending 10,000 years ago, with 5 million humans worldwide); (2) agricultural revolution (the past 8000 years, with 750 million humans worldwide in 1750); and (3) industrial revolution (the past 250 years, with over 6 billion humans worldwide at the present time).

Case study revisited. If liquid water does exist under the frozen ice of Europa, what sort of life might exist there? On Earth, a similar situation exists with Lake Vostok, a huge lake the size of Lake Ontario buried more than two miles beneath the Antarctic ice pack. Efforts are underway to devise methods to drill into Lake Vostok without the risk of cross contamination of life forms. In addition to water, what other conditions would be necessary for life to have arisen on Europa?

KEY TERMS AND CONCEPTS

Fill-In: From the following list of terms, fill in the following statements.

aquatic	endosymbiont hypothesis	preadapted
conifers	hominids	ribozymes
Cro-Magnon	microspheres	spontaneous generation
cultural evolution	Neanderthals	terrestrial

1. In the 1600s, biologists thought life arose through _____ from nonliving matter.

2. Certain small RNA molecules called _____ act as enzymes to make more RNA. Possibly, molecular evolution began in the primordial soup when they began to copy themselves and make other molecules.

3. If water containing proteins and lipids is agitated, hollow membrane-like balls called _____ form.

4. According to Lynn Margulis' _____, primitive cells acquired the precursors of mitochondria and chloroplasts by engulfing certain types of bacteria and forming a symbiotic (mutually supportive) relationship with them.

5. _____ organisms must find adequate water, protect their gametes from drying out, and resist the effects of gravity without a buoyant watery environment. Primitive land plants (mosses and ferns) have retained swimming sperm and require water to reproduce, but the _____ retain their eggs internally within cones and encased sperm within pollen grains blown around by the wind, allowing them to flourish in dry habitats. However, some animals were _____ for land life since they already had structures suitable for life on land, such as exoskeletons in the arthropods.

6. Dryopithecine primates evolved into the _____ (humans) and the pongids (great apes) about 5 to 8 million years ago. _____ appeared about 150,000 years ago and had large brains and ritualistic behaviors, but did not lead to modern humans based on DNA analysis.

7. Human _____ (learned behavior passed down from previous generations) now far out-paces biological evolution.

Key Terms and Definitions

conifer (kon´-eh-fer): a member of a class of tracheophytes (Coniferophyta) that reproduces by means of seeds formed inside cones and that retains its leaves throughout the year.

cultural evolution: changes in the behavior of a population of animals, especially humans, by learning behaviors acquired by members of previous generations.

endosymbiont hypothesis: the hypothesis that certain organelles, especially chloroplasts and mitochondria, arose as mutually beneficial associations between the ancestors of eukaryotic cells and captured bacteria that lived within the cytoplasm of the pre-eukaryotic cell.

exoskeleton (ex´-ō-skel´-uh-tun): a rigid external skeleton that supports the body, protects the internal organs, and has flexible joints that allow for movement.

hominid: a human or a prehistoric relative of humans, beginning with the Australopithecines, whose fossils date back at least 4.4 million years.

mass extinction: the extinction of an extraordinarily large number of species in a short period of geologic time. Mass extinctions have recurred periodically throughout the history of life.

microsphere: a small, hollow sphere formed from proteins or proteins complexed with other compounds.

preadaptation: a feature evolved under one set of environmental conditions that, purely by chance, helps an organism adapt to new environmental conditions.

prebiotic evolution: evolution before life existed; especially, the abiotic synthesis of organic molecules.

primate: a mammal characterized by the presence of an opposable thumb, forward-facing eyes, and a well-developed cerebral cortex; includes lemurs, monkeys, apes, and humans.

protocell: the hypothetical evolutionary precursor of living cells, consisting of a mixture of organic molecules within a membrane.

ribozyme: an RNA molecule that can catalyze certain chemical reactions, especially those involved in the synthesis and processing of RNA itself.

spontaneous generation: the proposal that living organisms can arise from nonliving matter.

THINKING THROUGH THE CONCEPTS

True or False: Determine if the statement given is true or false. If it is false, change the underlined word(s) so that the statement reads true.

8. _____ Primitive Earth was characterized by an abundance of free oxygen.
9. _____ The first living organisms were most likely prokaryotic.
10. _____ Mitochondria, chloroplasts, and centrioles have their own DNA.
11. _____ Diffusion occurs quickly and efficiently in large cells.
12. _____ Coal, mined today, is made of fossilized plants.
13. _____ Conifers, as a rule, produce more pollen than flowering plants.
14. _____ Animals with exoskeletons were preadapted to life in the water.
15. _____ Amphibians are fully adapted to life on land.
16. _____ Feathers evolved for insulation.
17. _____ The most severe mass extinction wiped out 50% of the species on Earth.

18. Arrange the following events into the sequence that scientists assert occurred during the history of Earth.
    a. evolution of terrestrial organisms
    b. oxygen gas begins to accumulate in the atmosphere
    c. spontaneous formation of simple organic molecules which, in the absence of O_2, accumulated in the seas
    d. evolution of anaerobic prokaryotic cells
    e. evolution of mitochondria and chloroplasts (the Endosymbiont hypothesis)
    f. chance formation of ribozymes with the ability to make accurate and inaccurate copies of itself
    g. evolution of aerobic prokaryotic cells
    h. evolution of multicellular eukaryotic organisms
    i. evolution of primitive photosynthetic anaerobic cells
    j. by chance, primitive microspheres surround the proper mix of organic molecules and form primitive living cells

Identify: Determine whether the following statements refer to **club mosses and tree ferns**, **conifers**, or **flowering plants**.

19. _____ better adapted to colder climates
20. _____ use insects to transport pollen
21. _____ need water for sexual reproduction since sperm must swim to the eggs
22. _____ primarily use wind to passively transport pollen
23. _____ evolved from conifer-like ancestors
24. _____ dominant plants today
25. _____ dominant plants 250 million years ago
26. _____ dominant plants 325 million years ago

Matching: Terrestrial animals. Some questions may have more than one correct answer.

27. _____ evolved from reptilian ancestors
28. _____ evolved from lobefins whose fins evolved into limbs for crawling
29. _____ dinosaurs
30. _____ use their lungs and moist skin to exchange gases with the air
31. _____ first land animals to evolve waterproof eggs
32. _____ humans
33. _____ first land animals
34. _____ evolved with feathers for insulation
35. _____ land animals that shed their eggs and sperm into the water
36. _____ were preadapted to life on land due to their exoskeletons
37. _____ directly evolved from amphibian-like ancestors

Choices:

a. reptiles
b. amphibians
c. mammals
d. arthropods
e. birds

Multiple Choice: Pick the most correct choice for each question.

38. It is proposed that the primitive atmosphere contained all of the following except
    a. CO_2
    b. O_2
    c. NH_2
    d. H_2O

39. The first living "cells" probably were hollow, ball-shaped structures called
    a. microspheres
    b. protenoids
    c. polypeptides
    d. ribozymes
    e. bacteria

40. The first organisms probably were primitive
    a. photosynthetic bacteria
    b. cyanobacteria
    c. anaerobic bacteria
    d. aerobic microbes
    e. viruses

41. The first cells probably
    a. produced their own food
    b. absorbed food from the environment
    c. engulfed food from the environment
    d. did not require food
    e. underwent sexual reproduction

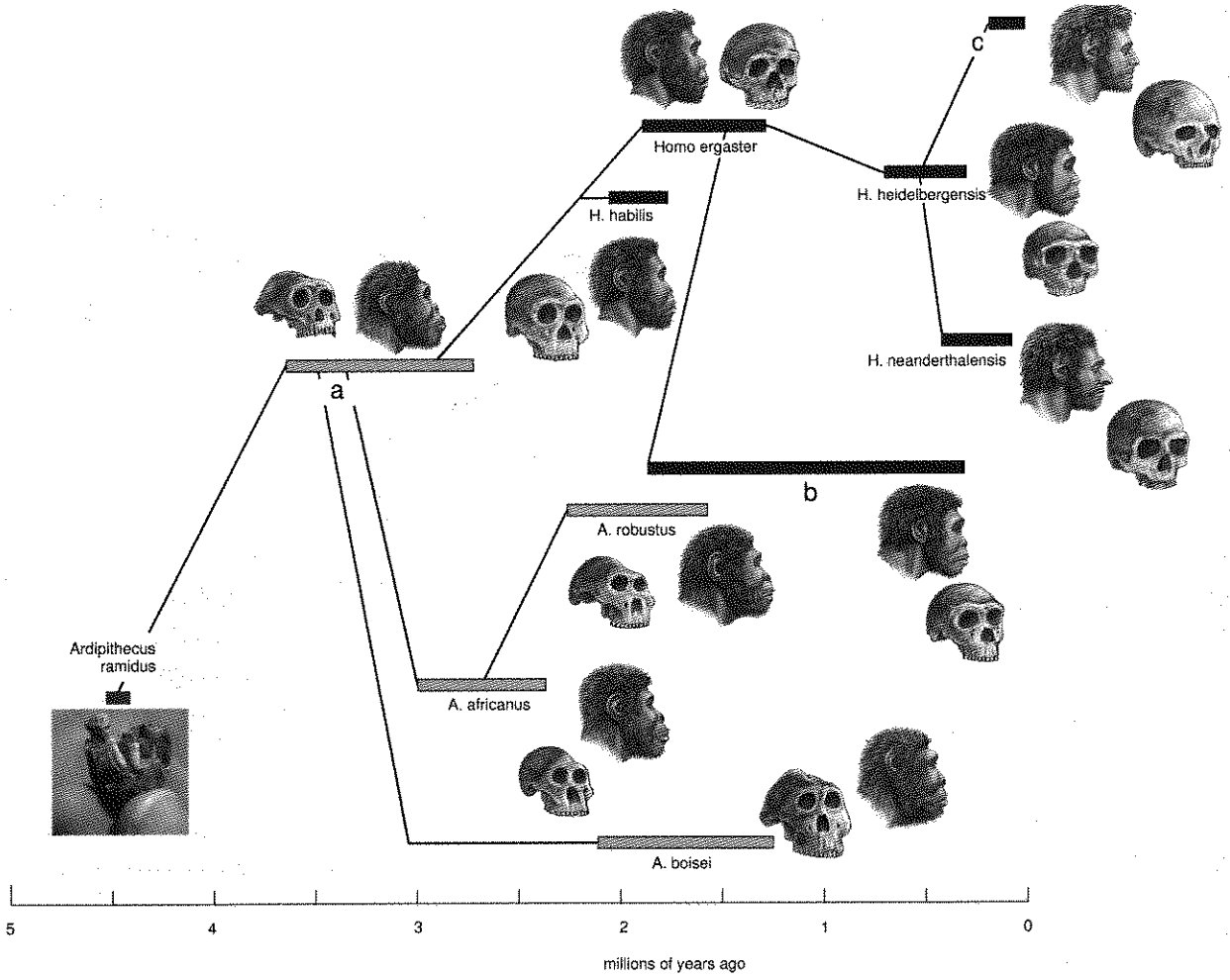
42. Reptiles are more advanced than amphibians because of
    a. internal fertilization
    b. eggs with shells
    c. scaly skin
    d. improved lungs
    e. all of the choices are correct

43. Why are scientists so excited about studying one of the moons of Jupiter, named Europa?
    a. it is about the size of Europe
    b. it is about the same size of Earth's moon
    c. it may have water beneath its frozen surface
    d. it may actually be a small planet
    e. it appears to be younger in origin than Jupiter itself

44. Lake Vostok, a huge body of water buried two miles beneath the Antarctic ice pack, is being studied by scientists because
    a. it is similar to how water may exist on Jupiter's moon Europa
    b. it may contain a large oil deposit
    c. it could solve the world's water shortage
    d. it appears to be contaminated
    e. its temperature is much lower than the ice above it.

45. What is the main problem keeping scientists from examining the contents of Lake Vostok?
    a. fear of a cave-in
    b. fear of contaminating the water with surface bacteria
    c. the lake is too deep to reach with known drilling technology
    d. the region is too cold to work in
    e. the weather is so unpredictable that workers may be stranded there

Short Answer: Based on the following figure, answer the questions below.



46. Identify member "a" of the human family tree: _____

47. Identify member "b" of the human family tree: _____

48. Identify member "c" of the human family tree: _____

APPLYING THE CONCEPTS

These practice questions are intended to sharpen your ability to apply critical thinking and analysis to biological concepts covered in this chapter.

49. Scientists have evidence that life developed from non-living chemicals over 3 billion years ago (spontaneous generation). Define spontaneous generation and explain why scientists assert that it cannot happen today. Also, explain why scientists say that it probably happened many years ago.

_____

_____

_____