CHAPTER 1 Study Guide: Science of Zoology & Evolution of Animal Diversity

1.1 A Legacy of Change

Major feature of life's history is a legacy of perpetual change.

1. Fossil record is imperfect, but records the broken history of evolution.
2. Organic evolution is the major feature of life.

Theory of perpetual change is evolution**.**

1. Zoology is the scientific study of animals.
2. Life's multicellular animal history began more than 600 million years ago.
3. **Phylogeny** is the branching sequence of evolution.
4. Newly formed species gain their characteristics and modifications from previous species.
5. Two major goals: 1) Reconstruct phylogeny of animal life, and 2) Understand historical processes that generate and maintain diverse species and adaptations throughout evolutionary history.
6. Significant steps in evolutionary origins include multicellularity, a coelom, spiral cleavage, vertebra, and homeothermy.

1.2 Principles of Science

1. Science is a way of asking about the natural world to obtain precise answers.
2. On Jan 5, 1982, Judge Overton prohibited Arkansas from enforcing Act 590.
3. Science is separate from activities such as art and religion.
4. The trial over creation science provided a definition of science.
   a. Science is guided by natural law.
   b. Science has to be explanatory by reference to natural law.
   c. Science is testable against the observable world.
   d. Science conclusions are tentative; they are not necessarily the final word.
   e. Science is **falsifiable**.
5. Science is neutral regarding religion and does not favor one religious position over another.

B. Scientific Method

1. Criteria for science form a **hypothetico-deductive method**.
2. **Hypotheses** are based on prior observations of nature or derived from theories based on nature.
3. Testable predictions are made based on hypotheses.
4. A hypothesis powerful in explaining a wide variety of related phenomena becomes a **theory**.
5. The null hypothesis cannot be proved correct.
6. The most useful theories explain the largest array of different natural phenomena.
7. Scientific meaning of "theory" is not the same as common usage of theory as "mere speculation."

C. Experimental and Evolutionary Sciences

1. Questions can be divided into those that seek to understand **proximate** versus **ultimate** causes.
2. Studies that explore proximate causes are **experimental sciences** using **experimental methods** that:
   a. predict how a system being studied will respond to disturbance or treatment,
   b. make the disturbance, and then
   c. compare the observed results with predicted ones.
3. **Controls** are repetitions of an experiment that lack disturbance or treatment.
4. The sub-fields of molecular biology, cell biology, endocrinology, developmental biology and community ecology rely heavily on experimental scientific methods (Figure 1.1).
5. **Ultimate causes** are addressed by questions involving long-term time spans.
   a. **Evolutionary sciences** address ultimate causes.
   b. Evolutionary questions are often explored using a comparative method.
   c. Patterns of modern similarities are used to establish hypotheses on evolutionary origins.
   d. Sub-fields include **comparative methods** in the following areas: biochemistry, molecular evolution, comparative cell biology, comparative anatomy, immunology, comparative physiology and phylogenetic systematics.

1.6 Origins of Darwinian Evolutionary Theory (Figure 1.2)

A. Darwin's theory helps us understand both the genetics of populations and long term trends in the fossil record.

B. Darwin and Wallace were the first to establish evolution as a powerful scientific theory.

(BOX: The Animal Rights Controversy)

A. Pre-Darwinian Evolutionary Ideas

1. Before the 18^{th} century, speculation on origin of species was not scientific.

2. Creation myths portrayed a constant world after a creation event.
3. Early Greek philosophers considered some ideas of evolutionary change.
   a. Xenophanes, Empedocles and Aristotle developed early ideas about evolution.
   b. Fossils were recognized as former life destroyed by natural catastrophe.
   c. Lacking a full evolutionary concept, the idea faded before the rise of Christianity.
4. Biblical account of creation became a tenet of faith.
   a. Evolutionary views were heretical.
   b. **Archbishop Ussher** calculated 4004 BC as date of life's creation.
5. French naturalist Georges Louis **Buffon** suggested that environment modified animal types; set age of earth at 70,000 years.

B. Lamarckism

1. French biologist Jean Baptiste de **Lamarck** offered first complete explanation in 1809 (Figure 1.3).
   a. He convincingly argued that fossils were remains of extinct animals.
   b. Lamarck's mechanism was **inheritance of acquired characteristics**.
   c. He explained long necks of giraffes to stretching efforts of ancestral giraffes.
   d. Lamarck's concept is **transformational**; individuals transform their own traits to evolve.
   e. In contrast, Darwin's theory is **variational** or due to differential survival among offspring. heredity.

C. Charles Lyell

1. Geologist Sir Charles Lyell established the **principle of uniformitarianism** (Figure 1.4).
   a. Uniformitarianism consists of two important principles:
      1) Laws of physics and chemistry remain the same throughout earth's history.
      2) Past geological events occurred by natural processes similar to those observed today.
   b. Natural forces acting over long periods could explain formation of fossil-bearing rocks.
   c. Earth's age must be measured in millions of years.
   d. Geological changes are natural and without direction; both concepts underpinned Darwin.

D. Darwin's Great Voyage of Discovery (1831-1836)

1. In 1831, Charles Darwin (almost 23) sailed aboard the small survey ship HMS *Beagle.*
2. Darwin made extensive observations in the five-year voyage (Figure 1.5; Figure 1.6A,B).
   a. Darwin collected the fauna and flora of South America and adjacent regions.
   b. He unearthed long extinct fossils and associated fossils of South and North America.
   c. He saw fossil seashells embedded in the Andes rocks at 13,000 feet altitude.
   d. Observing earthquakes and severe erosion confirmed his views of geological ages.
3. The Galápagos Islands provided unique observations.
   a. These volcanic islands are on the equator 600 miles west of Ecuador (Figure 1.7).
   b. Galápagos means "tortoise"; the giant reptiles were exploited for food.
   c. Each island varied in tortoises, iguanas, mockingbirds and ground finches.
   d. The islands had similar climate but varied vegetation.
   e. Island species therefore originated from South America and were modified under the varying conditions of different islands.
   f. He wrote that these unique animals and plants were the "origin of all my views."
4. Darwin conducted the remainder of his work at home in England (Figure 1.8).
   a. His collections and notebooks had been sent back before his return in October 2, 1836.
   b. His popular travel journal, *The Voyage of the Beagle*, was published three years later.
   c. In 1838, Darwin read an essay on population by Thomas R. Malthus.
   d. Having studied *artificial selection*, a "struggle for existence" because of overpopulation, gave him a mechanism for evolution of wild species by *natural selection*.
   e. He presented his ideas in a paper in 1844 and began work on a larger volume in 1856.
   f. In 1858, he received a manuscript from a young naturalist, Alfred Russel Wallace, summarizing the main points of natural selection.
   g. Geologist Lyell and botanist Hooker persuaded Darwin to publish a paper jointly with Wallace's paper.
   h. Darwin published a book in 1859: *On the Origin of Species by Means of Natural Selection.*
   i. 1250 copies of first printing sold in one day.
   j. Darwin wrote a series of important additional books in the next 23 years.
   k. An early tree of life is drawn by Ernst Haeckel, who was greatly influenced by Darwin's theory of common descent. (Figure 1.9)

1.7 Darwinian Theory of Evolution

A. Darwin's Theory of Evolution is over 140 years old.

B. Five theories have somewhat different origins and fates and cannot be discussed accurately as only a single hypothesis: **1) perpetual change, 2) common descent, 3) multiplication of species, 4) gradualism, 5) natural selection.**

1. Perpetual change is the basic theory of evolution on which the others are based—the world is constantly changing, as documented by the fossil record that refutes Creationists' claims.
2. Common descent—all forms of life descended from a common ancestor.
3. Multiplication of Species—Species divide and split into different species, which are generally termed to be reproductively separated populations no longer capable of interbreeding.
4. Gradualism—large differences in anatomical traits that characterize different species originate by accumulation of many small incremental changes over very long periods of time.
5. Natural selection—explains the selective processes of the environment, through a phenomenon called **adaptation.**
6. Thomas Henry Huxley is one of Darwin's greatest defenders (Darwin's "bulldog"—Figure , page 10).

C. Darwin's Explanatory Model of Evolution by Natural Selection (BOX)

1. **Observation 1: Organisms have great potential fertility**
2. **Observation 2—Natural populations normally remain constant in size, except for minor fluctuations**
3. **Observation 3—Natural resources are limited**
   a. **Inference 1—A continuing *struggle for existence* occurs among members of a population.**
4. **Observation 4—All organisms show *variation*.**
5. **Observation 5—Variation is heritable.**
   a. **Inference 2—*Differential survival and reproduction* occur among varying organisms in a population.**
   b. **Inference 3—Over many generations, differential survival and reproduction generate new adaptations and new species. Sorting should not be equated with natural selection.**

1.8 Evidence for Darwin's Five Theories of Evolution

A. Perpetual Change

1. The living world is constantly changing in form and diversity.
2. Change in animal life is directly seen in the 600-700 million-year animal fossil history.
3. A **fossil** is a remnant of past life (Figure 1.10A, B, C, D).
   a. Insects in amber and frozen mammoths are actual remains.
   b. Teeth and bones can petrify or become infiltrated with silica and other minerals.
   c. Molds, casts, impressions and fossil excrement are also fossils.
4. Most organisms leave no fossils; the record is always incomplete and requires interpretation.

B. Interpreting the Fossil Record

1. The fossil record is biased because preservation is selective.
2. Vertebrate skeletons and invertebrates with shells provide more records.
3. Soft-bodied animals leave fossils only in exceptional conditions such as the Burgess Shale (Figure 1.11A,B, C).
4. Fine fossil sites also include South Australia, Rancho La Brea, the Olduvai Gorge of Tanzania and dinosaur beds in Alberta, Canada and Utah (Figure 1.12).
5. Fossils occur in stratified layers; new deposits are on top of older material.
6. "Index" or "guide" fossils are "indicators" of specific geological periods.
7. Layers often tilt and crack, and can erode or be covered with new deposits.
8. Under heat and pressure, rock becomes metamorphic and fossils are destroyed.

C. Geological Time

1. Sedimentary Rock Layers
   a. The **law of stratigraphy** dates oldest layers at the bottom and youngest at the top.
   b. Time is divided into eons, eras, periods and epochs. (See inside back cover.)
2. Radiometric Dating
   a. In the late 1940s, this dating method was developed that determines age of rocks.
   b. Radioactive decay of naturally occurring elements is independent of heat and pressure.
   c. Potassium-Argon Dating
      1) Potassium-40 (^{40}K) decays to Argon-40 (^{40}Ar) and Calcium-40 (^{40}Ca).

        2) Half-life of potassium-40 is 1.3 billion years; half of remainder will be gone at end of next 1.3 billion years, etc.
        3) Calculating the ratio of remaining potassium-40 to amount originally there provides mathematically close estimate of age of deposit.
    d. Rate of decay of uranium into lead can date age of earth itself; error is less than 1% over 2 billion years.
3. Fossil Record of Macroscopic Organisms
    a. The Cambrian period of Paleozoic era began about 600 million years ago.
    b. Previous Precambrian era occupies 85% of geological time on earth.
    c. Little research occurred on Precambrian rocks because they have few oil deposits.
    d. Precambrian contains well-preserved fossils of bacteria and algae, casts of lower invertebrates and many microscopic fossils.

D. Evolutionary Trends

1. Fossil record allows observation of evolutionary change over broad periods of time.
2. Animals species arise and go extinct repeatedly.
3. Animal species typically survive 1-10 million years; there is much variability.
4. Trends are directional changes in features and diversity of organisms.
5. Horse Evolution Shows Clear Trend (Figure 1.13).
    a. From Eocene to Recent periods, genera and species of horses were replaced.
    b. Earlier horses had smaller sized and fewer grinding teeth, and more toes.
    c. Change occurred in both features of horses and numbers of species.
6. Trends in fossil diversity are due to different rates of species formation and extinction.
7. Lineages vary in producing new species or suffering extinction; Darwin provided explanations for this phenomenon.

E. Common Descent

1. Darwin proposed that all plants and animals descended from a common ancestor.
2. A history of life forms a branching tree called a **phylogeny**.
3. This theory allows us to trace backward to determine converging lineages.
4. All forms of life, including extinct branches, connect to this tree somewhere.
3. Phylogenetic research is successful at reconstructing this history of life.
4. Diversity profiles can be reconstructed from fossil record (Figure 1.14).

F. Homology and Phylogenetic Reconstruction

1. Darwin saw homology as major evidence for common descent.
2. Richard Owen described homology as "the same organ in different organisms under every variety of form and function."
3. Vertebrate limbs show the same basic structures modified for different functions (Figure 1.15).
4. Darwin's central idea that apes and humans have a common ancestor was explained by anatomical homologies (this was often ridiculed by the media: Figure 1.16).
5. Ground-dwelling birds illustrate homologies (Figure 1.17).
    a. A new skeletal homology arises on each lineage shown.
    b. Different groups located at tips of branches contain homologies that reflect ancestry.
    c. Branches of the tree combine species into **nested hierarchies** of groups within groups.
    d. Analysis of the living species alone can reconstruct the branching pattern.
    e. The pattern of nested hierarchies forms the basis for classification of all forms of life.
    f. Structural, molecular, and chromosomal homologies are all combined to reconstruct evolutionary trees.
    g. Older theories that life arose many times forming unbranched lineages fails to predict the nested hierarchies of lineages; creationism fails to provide testable predictions; all fail as scientific hypotheses.

G. Ontogeny, Phylogeny and Recapitulation

1. **Ontogeny** is the history of development of an organism throughout its lifetime.
2. Evolutionary alteration of developmental timing generates new traits allowing divergence among lineages.
3. German zoologist **Ernst Haeckel** stated stages of development represented adult forms from evolutionary history.
4. "Ontogeny recapitulates phylogeny" also became known as recapitulation or the biogenetic law.
5. Homoeotic genes guide development of anterior versus posterior body segments.
6. Homebox genes encode a protein sequence that bonds to other genes and alters their expression.

7. Haeckel, Darwin's contemporary, thought that this change was caused by adding new features onto the end of ancestral ontogeny; but this idea is Lamarckian.
8. Embryologist **K.E. von Baer** showed early developmental features were simply more widely shared among different animals groups (Figure 1.18).
9. However, early development can undergo divergence among lineages too.
10. Evolutionary change in timing of development is called **heterochrony**.
11. Characteristics can be added late in development and features are then moved to an earlier stage.
12. Ontogeny can be shortened in evolution; terminal stages may be deleted causing adults of descendants to resemble youthful ancestors.
13. Organisms are a mosaic of both; ontogeny rarely completely recapitulates phylogeny.

H. Multiplication of Species

1. **Evolution as a Branching Process**
   a. A branch point occurs where an ancestral species splits into two different species.
   b. Darwin's theory is based on genetic variation.
   c. Total number of species increases in time; most species eventually become extinct.
   d. Much evolutionary research centers on mechanisms causing branching.
2. **Definition of species** varies and may include several criteria.
   a. Members descend from a common ancestral population.
   b. Interbreeding occurs within a species but not among different species.
   c. Genotype and phenotype within a species is similar; abrupt differences occur between species.
3. **Reproductive Barriers**
   a. Reproductive barriers are central to forming new species.
   b. If diverging populations reunite, before they are isolated, interbreeding maintains one species.
   c. Evolution of diverging populations requires they be kept physically separate a long time.
   d. Geographical isolation with gradual divergence provides chance for reproductive barriers to form (Figure 1.19).
4. **Allopatric Speciation (Figure 1.20)**
   a. Allopatric populations occupy separate geographical areas.
   b. They cannot interbreed because they are separated, but could do so if barriers were removed.
   c. Separated populations evolve independently and adapt to different environments.
   d. Eventually they are distinct enough that they cannot interbreed when reunited.
   e. Sympatric speciation denotes species formation not involving geographic isolation.
6. **Adaptive Radiation (Figure 1.21)**
   a. Adaptive radiation produces diverse species from common ancestral stock.
   b. New lakes and islands provide new opportunities for organisms to evolve.
   c. Founders who were under heavy competition are now free to colonize the new habitat.
   d. The Galápagos Islands provided excellent isolation from mainland and each other.
   e. Darwin's finches are example of adaptive radiation from ancestral finch; finches varied to assume characteristics of missing warblers, woodpeckers, etc.

I. Gradualism

1. Darwin's theory of gradualism is based on accumulation of small changes over time.
2. He agreed with Lyell; past changes do not depend on catastrophes not seen today.
3. We observe small, continuous changes; major differences therefore require thousands of years.
4. Accumulation of quantitative changes leads to qualitative change.
5. Ernst Mayr distinguishes between populational gradualism and phenotypic gradualism.
6. **Phenotypic Gradualism**
   a. This theory states that strikingly different traits are produced in a series of small steps.
   b. It remains controversial ever since Darwin proposed it.
   c. Mutations that cause substantial phenotypic change are called "sports" (Figure 1.22).
   d. Animal breeding has used sports to produce short-legged sheep, etc.
   e. Opponents of phenotypic gradualism contend such mutations would be selected against.
   f. A gradualist model is presented in Figure 1.23.
7. **Punctuated Equilibrium** (Figure 1.24)
   a. **Phyletic gradualism** predicts that fossils would show a long series of intermediate forms.
   b. Fossil record does not show the predicted continuous series of fossils.
   c. Some Darwinists contend that fossilization is haphazard and slow compared to speciation.

d. Niles Eldridge and Stephen Jay Gould proposed punctuated equilibrium.
e. This theory contends phenotypic evolution is concentrated in brief events of speciation followed by long intervals of evolutionary stasis.
f. Speciation is episodic with a duration of 10,000 to 100,000 years.
g. Species survive for 5-10 million years; speciation may be less than 1% of species life span.
h. Peter Williamson's Freshwater Snails
   1) Fossil beds in Lake Turkana had a history of earthquakes, eruptions and climate changes.
   2) Thirteen lineages of snails show long periods of stability, brief periods of rapid change when populations were fragmented by receding waters.
   3) Transitions occurred within 5000 to 50,000 years matching punctuated equilibrium.

J. Natural Selection (Figure 1.25 A,B,C)

1. Natural selection gives a natural explanation for origins of adaptation.
2. Rapid evolution by natural selection is found in pepper moths affected by industrial melanism.
3. Birds are able to locate and eat moths that do not match their surroundings.
4. With increasing industrialization, white pepper moths were conspicuous against dark backgrounds.
5. Birds foraged selectively on white pepper moths, black pepper moths thrived and reproduced.
6. Evolutionists proposed that many structures evolved initially for purposes from the uses they have today such as feathers and thermoregulation.

1.9 Revisions of Darwin's Theory

A. Neo-Darwinism

1. Darwin did not know the mechanism of inheritance.
   a. Darwin saw inheritance as a blending of parental traits.
   b. He also considered an organism could alter its heredity through use and disuse of parts.
2. August Weismann's experiments showed an organism could not modify its heredity.
3. Neo-Darwinism is Darwin's theory as revised by Weismann
4. Mendel's work provided linkage through inheritance that Darwin's theory required.
5. The genetic basis of neo-Darwinism is termed the chromosomal theory.

B. Emergence of Modern Darwinism: The Synthetic Theory

1. In 1930s, a synthesis occurred that tied together population genetics, paleontology, biogeography, embryology, systematics and animal behavior.
2. Population genetics studies evolution as change in gene frequencies in populations.
3. Microevolution is change of gene frequency over a short time within a population.
4. Macroevolution is evolution on a grand scale, originating new structures and designs, trends, mass extinctions, etc.
5. The synthesis combines micro- and macroevolution and expands Darwinian theory.

1.10 Microevolution: Genetic Variation and Change Within Species

A. Definitions

1. Different allelic forms of a gene constitute **polymorphism**.
2. All alleles of all genes that exist in a population are collectively the **gene pool**.
3. **Allelic frequency** is the frequency of a particular allelic form in a population (Figure 1.26)
   a. Blood types are coded at codominant alleles I^A (type A) and I^B (type B) and recessive type i (O).
   b. Since each person carries two alleles; the total numbers of alleles is twice the population size.
   c. Dominance describes the phenotypic effect of an allele only, not its relative abundance.

BOX: Hardy-Weinberg Equilibrium: Why Mendelian Heredity Does Not Change Allelic Frequencies.

B. Genetic Equilibrium

1. Whether a gene is dominant or recessive does not affect its frequency; dominant genes do not supplant recessive genes.
2. In large two-parent populations, genotypic ratios remain in balance unless disturbed.
3. This is called the **Hardy-Weinberg equilibrium**.
4. It accounts for the persistence of rare traits such as albinism and cystic fibrosis caused by recessive alleles.
5. Genotype frequency can be calculated by expanding the binomial $(p - q)^2$ where p and q are allele frequencies.

6. For example, an albino is homozygous recessive and the trait is represented by q^2 in the formula: $p^2 + 2pq + q^2 = 1$.
7. Albinos (homozygous recessive) occur in one in 20,000; therefore $q^2 = 1/20{,}000$ and $q = 1/141$.
8. Non-albino (p) is $1 - q = 140/141$.
9. Carriers would be 2pq or $2 \times 140/141 \times 1/141 = 1/70$; one person in 70 is a carrier.
10. Eliminating a "disadvantageous" recessive allele is nearly impossible.
11. Selection can only act when it is expressed; it will continue through heterozygous carriers.

C. Process of Evolution: How Genetic Equilibrium is Upset

1. In natural populations, Hardy-Weinberg equilibrium is disturbed by one or more of five factors.
2. **Genetic Drift**
   a. A small population does not contain much genetic variation (Figure 1.27).
   b. Each individual contains at most two alleles at a single locus; a mating pair has a maximum of four alleles to contribute for a trait.
   c. By chance alone, one or two of the alleles may not be passed on.
   d. Chance fluctuation from generation to generation, including loss of alleles, is genetic drift.
   e. There is no force causing perfect constancy in allelic frequencies.
   f. The smaller the population, the greater the effect of drift.
   g. If a population is small for a long time, alleles are lost and response to change is restricted.
   h. A bottleneck is a large reduction in the size of a population. It is a form of genetic drift that increases the rate of evolutionary change.
3. **Nonrandom Mating**
   a. If two alleles are equally frequent, one half of the population will be heterozygous and one quarter will be homozygous for each allele.
   b. In **positive assortative mating**, individuals mate with others of the same genotype.
      1) This increases homozygous and decreases heterozygous genotypes.
      2) It does not change allelic frequencies.
   c. **Inbreeding** is preferential mating among close relatives.
      1) Inbreeding increases homozygosity.
      2) While positive assortative mating affects one or a few traits, inbreeding affects all variable traits.
      3) Inbreeding increases the chance that recessive alleles will become homozygous and expressed.
4. **Migration**
   a. Migration prevents different populations from diverging.
   b. Continued migration between Russia and France keeps the ABO allele frequencies from becoming completely distinct.
5. **Natural Selection**
   a. Natural selection changes both allelic frequencies and genotypic frequencies.
   b. An organism that possesses a superior combination of traits has a higher **relative fitness**.
   c. Some traits are advantageous for certain aspects of survival or reproduction and disadvantageous for others.
   d. **Sexual selection** is selection for traits that obtain a mate but may be harmful for survival (Figure 1.28).
   e. Changes in environment alter selective value of traits making fitness a complex problem.
   f. Quantitative traits show continuous variation with no Mendelian segregation pattern.
      1) Such traits are influenced by variation at many genes.
      2) Such traits show a bell-shaped frequency distribution.
   g. **Stabilizing selection** favors the average and trims the extreme.
   h. **Directional selection** favors an extreme value to one side.
   i. **Disruptive selection** favors the extremes to both sides and disfavors the average.
6. **Interactions of Selection, Drift and Migration (Figure 1.29)**
   a. Subdivision of a species into small populations that exchange migrants promotes rapid evolution.
   b. Genetic drift and selection allow many combinations of many genes to be tested.
   c. Migration allows favorable new combinations to spread.
   d. Interactions of all factors produce change different from what would result from one alone.
   e. Perpetual stability almost never occurs across any significant amount of evolutionary time.

1.11 Macroevolution: Major Evolutionary Events

A. Speciation and Extinction Through Geological Time

1. A species has two possible fates: become extinct or give rise to new species.
2. Rates of speciation and extinction vary among species.
3. Lineages with high speciation and low extinction produce the greatest diversity.
4. Lineages whose characteristics increase probability of speciation and confer resistance to extinction should come to dominate.
5. Species selection is differential survival and multiplication of species based on variation among lineages.
6. Species-level properties include mating rituals, social structuring, migration patterns, geographic distribution, etc.
7. Some mammalian lineages have a "harem" system, others do not.

B. Mass Extinctions (Figure 1.30).

1. Periodic events where huge numbers of taxa go extinct simultaneously are **mass extinctions**.
2. The **Permian extinction** occurred 225 million years ago; half of the families of shallow water invertebrates and 90% of marine invertebrates disappeared.
3. The Cretaceous extinction occurred 65 million years ago and marked the end of the dinosaurs and many other taxa.
4. Mass extinctions appear to occur at intervals of 26 million years.
   a. Some consider them artifacts of statistical or taxonomic analysis.
   b. Walter Alvarez proposed that asteroids periodically bombard the earth (Figure 1.31).
   c. Catastrophic species selection would result from selection by these events; for instance, mammals were able to use resources due to dinosaur extinction.