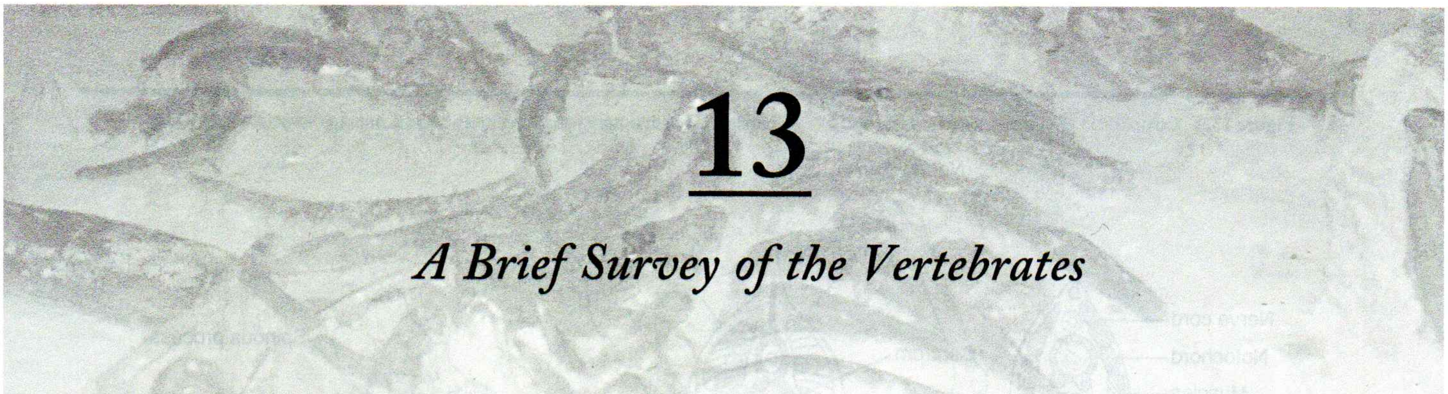


13

A Brief Survey of the Vertebrates

MATERIALS LIST

1. 1000-ml beaker.
2. 100-ml graduated beaker.
3. Plastic dinosaur model.
4. Millimeter scale ruler.
5. Masking tape.
6. Modeling clay (optioal).

INTRODUCTION

Because we ourselves are vertebrates, animals with backbones seem to hold particular interest. Vertebrates are a subphylum of the Phylum Chordata. All members of the Phylum Chordata have some sort of longitudinal supportive structure. In you and me it is our vertebral column. In chordates like **tunicate** larvae and **lancelets,** that structure is a flexible rod or *notochord.* In addition to the notochord, a distinguishing feature of chordates, at least at some stage in their development, is a hollow, nerve cord that extends above (dorsal) and parallel to the notochord (Fig. 13.1). Other characteristics include gill slits in the **pharynx,** a post-anal tail, and blood that moves forward in the primary ventral blood vessel and backward in the dorsal.

In chordates belonging to the Subphylum Vertebrata, the longitudinal supportive structure consists of a series of bony segments **(vertebrae)** that form the **vertebral column** or "backbone." The vertebral column in fishes functions in much the same way as a notochord by resisting shortening of the body as muscles acting against it alternately contract in succession so as to provide the sinous motion needed for swimming. In contrast to the notochord with its simple structure, vertebrae offer greater strength and a variety of attachment points for muscles and other skeletal components. Vertebrae alternate with flexible disks made of cartilage. These **intervertebral disks** are partly remnants of the notochord and are held in place by muscles and ligaments extending from vertebra to vertebra. The vertebral column is **homologous** with the notochord. Structures of different organisms that appear to have a common evolutionary origin are termed homologous. In general, homologous structures in different organisms show a correspondence in location and form.

Study Questions

1. On Figure 13.1, connect by lines the nerve cord in the lancelet, fish, and vertebra. Similarly, connect by lines the notochord or its homologous structure in the fish and the human vertebra. With what feature of the fish skeleton is the human "spinose process" homologous?

____

2. If you were to drop a small goldfish and an earthworm into a bucket of water, which would swim more efficiently? Why?

____

____

____

FISHES

The first fishes to appear on earth were jawless fishes belonging to the Class **Agnatha.** Their earliest remains are Cambrian in age. The Cambrian fossils are identified predominantly on the basis of the microstructure seen in fragments of hard tissue. By Ordovician, however, fossils of jawless fishes are more abundant and often well preserved. The jawless fishes were followed during the Silurian by the first fish with jaws. The appearance of bone-supported true jaws was a milestone in the evolution of vertebrates. The ability to grasp, cut, and hold food led to new and more active ways of life and resulted in many new lineages of fishes. There are not fossils that directly show how the jaws may have evolved from structures in jawless fishes, but a traditional view is that jaws formed from modified, anterior gill supports. The evolutionary history of vertebrates reveals many other examples where a structure having one function is changed to perform a quite different function.

Study Questions

1. In Figure 13.2, what skeletal structures behind the mandibular arch in the dogfish appear to be homologous with the **mandibular arch?**

____

____

Figure 13.1 Comparison of lancelet transverse section (A), with that of an actinopterygian bony fish (B), and a human thoracic vertebra (C).

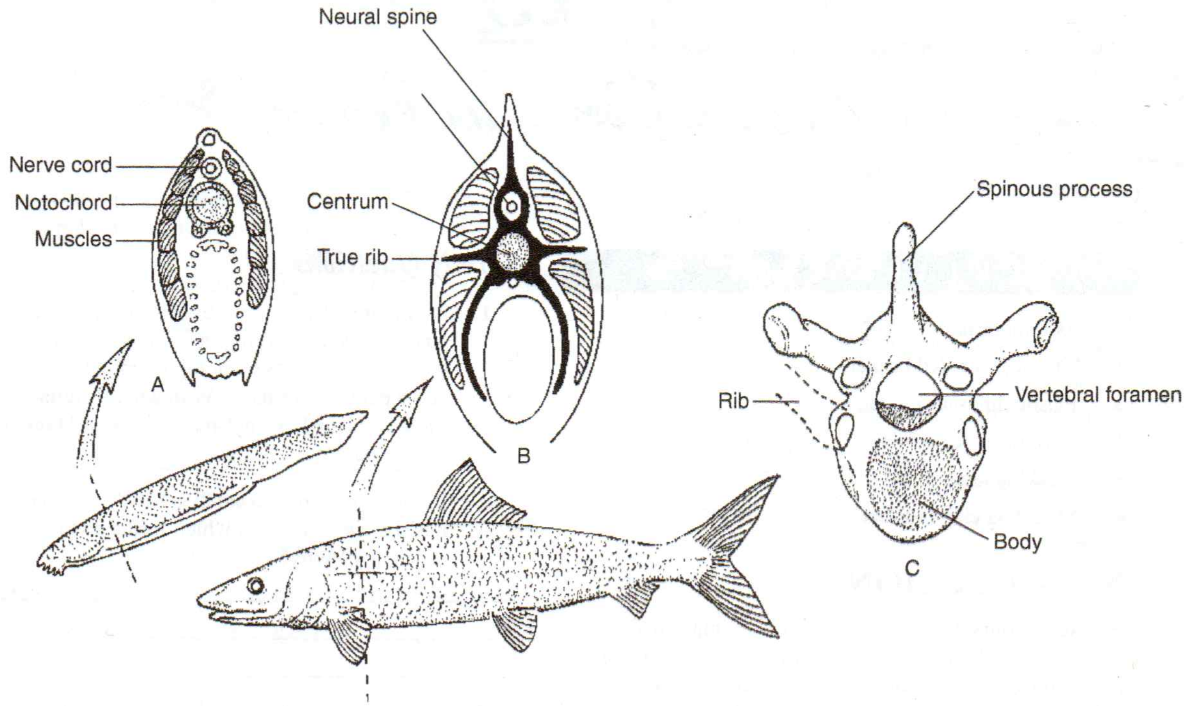
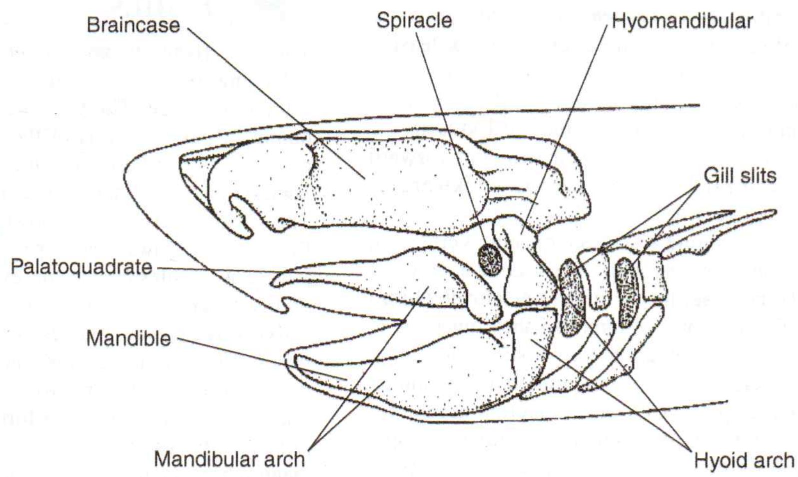


Figure 13.2 Basic skeletal structures of the head of a small shark known as a dogfish.

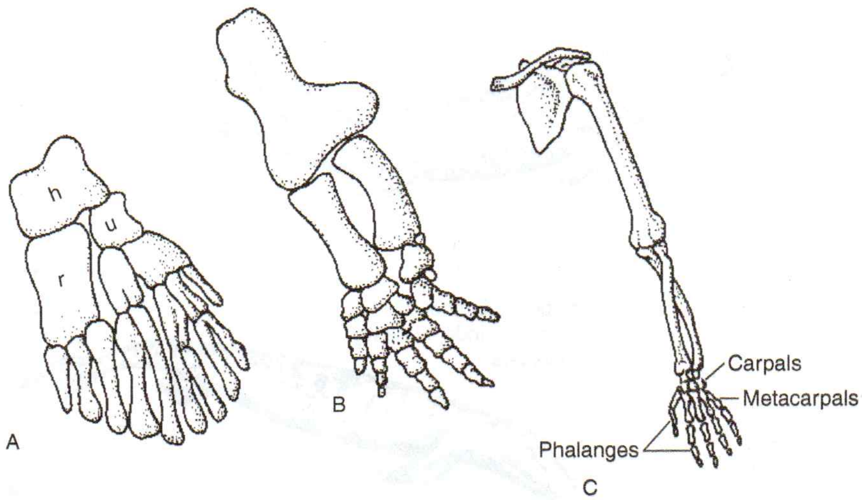


2. What features of the dogfish appear to be homologous with the **spiracle?**

3. What supportive function does the **hyomandibular** have in the dogfish?

By Late Silurian time, fishes with jaws had branched into two large classes: the **Chondricthyes** (sharks and other fishes with cartilagenous skeletons) and the **Osteichthyes** (fishes with bony skeletons). The Osteichthyes have been the most successful in terms of abundance and diversity. The most numerous bony fishes today are those in the subclass **Actinopterygii.** In these fishes the fins are supported by parallel cartilagenous rods called radials. Another subclass, the **Sarcopterygii,** includes a group of fishes called **crossopterygians.** Crossopterygians had muscular robust "lobe fins" supported by a single basal bone.

Figure 13.3 Anterior appendage of a crossopterygian fish (A), an early amphibian (B), and a human (C).



Study Question

On Figure 13.3, label the humerus, ulna, and radius on the amphibian and human.

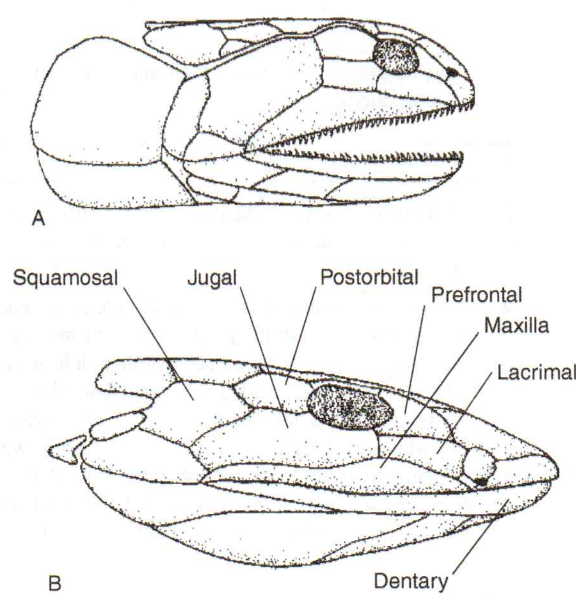
Amphibians

Vertebrates are a diverse group that include both water-dwelling fishes and land animals that walk on all four legs and are therefore called **tetrapods.** It was during the Devonian Period that tetrapods made their appearance. These early tetrapods were **amphibians.** Prominent among the Devonian amphibians were a group known as **ichthyostegans** because of the many fishlike characteristics they retained. In fact, many skeletal features of earliest amphibians and crossopterygian fishes are strikingly similar (Fig. 13.4). The skull depicted in Figure 13.4A is of a 38-million-year-old Devonian crossopterygian fish named *Eusthenopteron.* For many years *Eusthenopteron* seemed the ideal "transition" creature between fish and tetrapods. However, an even better candidate was discovered in Arctic Canada in 2004. The creature had true forelimbs, complete with the beginnings of fingers, wrist bones, and shoulder bones. In honor of the Nunavut natives of the region in which it was discovered, it was named *Tiktaalik* (Tik-TAH-lic), meaning "big shallow-water fish." Because *Tiktaalik* (Fig. 13.5) was part fish and part tetrapod, its discoverers jokingly dubbed it a "fishapod."

Study Questions

1. Many problems had to be solved in making the transition from life in the water to life on land. What changes do you think were made in the way vertebrates:

Figure 13.4 Lateral views of the skull of a crossopterygian fish (A), and *Ichthyostega*, a Devonian amphibian (B).



a. obtained oxygen?

____

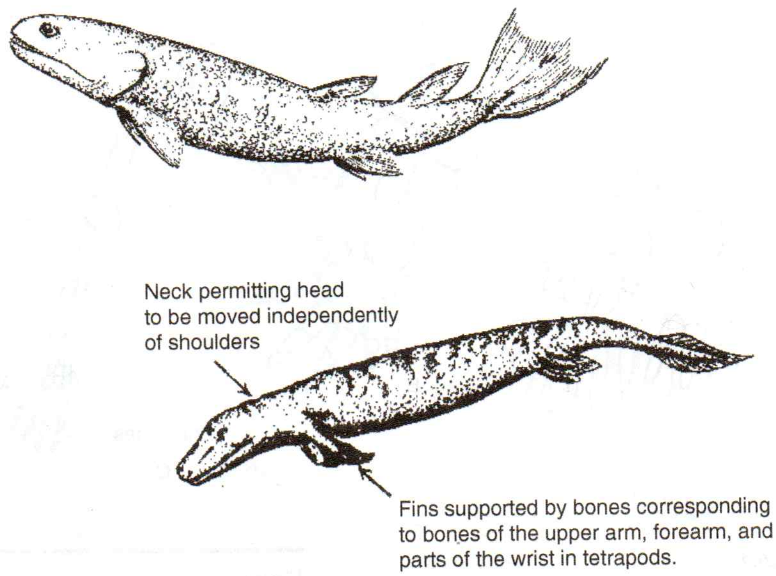
____

b. supported their bodies?

____

____

Figure 13.5 (A) The crossopterygian fish *Eusthenopteron*, a Devonian fish averaging about four feet in length. (B) *Tiktaalik* ranged from four to nine feet in length.



2. How do amphibians betray their ancestry in their mode of reproduction?

____

____

3. On Figure 13.4, label the bones on the crossopterygian that are equivalent to those on the Devonian amphibian *Ichthyostega*.
4. Note the prominent notch on either side of the back of the ichthyostegan skull. The tympanic membrane ("eardrum") was stretched across this notch. An ear bone, the **stapes,** extended from the tympanic membrane into a hole on the side of the braincase. Sound waves striking the tympanic membrane were transmitted by the stapes to the inner ear. What bone, formerly serving as a prop to support the braincase (see Fig. 13.2) was transformed to form the stapes?

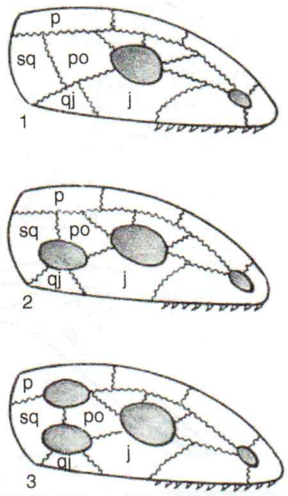
AMNIOTES

Many millions of generations were required before tetrapods evolved from crossopterygian fishes. Even so, the conversion was not complete, for the amphibians that were the first tetrapods needed to return to water bodies in order to lay fishlike, naked eggs that developed into fishlike larvae (tadpoles). In contrast to the fishlike eggs of the amphibians, more advanced tetrapods had evolved an egg called an **amniotic egg.** Within the protective outer covering of this egg, a membrane, the **amnion,** retains water and protects the developing embryo from drying out. Vertebrates having such an egg are termed **amniotes.** Because they do not require standing bodies of water for reproduction, amniotes have been able to roam freely across the lands.

During the Carboniferous Period, amniotes diverged into two branches. The first can be termed the **Reptilia.** This branch includes the **Anapsida** (e.g., turtles), **Diapsida** (e.g., lizards and snakes), and **Archosauria** (e.g., crocodiles, dinosaurs, and birds). The second branch consists of the **Synapsida.** The anapsids, synapsids, and diapsids can be recognized by the positions and number of openings (temporal fenestra) on the sides of their skulls (Fig. 13.6). Anapsids lack such openings, whereas diapsids have two on each side of the skull. A single opening bordered above by the squamosal and postorbital bones identify the synapsids.

The synapsids were particularly abundant and widespread during the Permian Period. The most important synapsid groups were the **therapsids** and the **pelycosaurs.** The therapsids are particularly interesting because they possessed several mammalian skeletal traits. Pelycosaurs are recognized by the distinctive erect sail along their backs (Fig. 13.7). The sail was supported by greatly elongated bones extending vertically from the vertebrae, called the **neural spine.** It is likely that the sail acted as a heat receptor and at other times as a radiator.

Figure 13.6 The three major skull types in tetrapods. **1.** anapsid; **2.** synapsid; and **3.** diapsid. (p, *parietal;* sq, *squamosal;* po, *postorbital;* j, *jugal;* qj, *quadratojugal*)



Study Questions

1. What element of the fish skeleton in Figure 13.1 corresponds to the greatly lengthened bone that supports the sail on a pelycosaur's vertebra?

____

____

2. The amniotic egg provides for limited exchange of gases necessary for the survival of the embryo. Based on knowledge of your own respiration, which gases are taken into the egg and which are expelled?

____

____

Dinosaurs

Dinosaurs are extinct archosaurians with legs that extend directly under their bodies so as to provide an upright stance. That upright stance differed from the sprawling posture characteristic of more primitive tetrapods like amphibians. Dinosaurs dominated the landscapes of the Mesozoic Era for about 180 million years. From relatively small *bipedal* (running on two legs) forms, dinosaurs branched into two great groups: the **Ornithischia,** recognized by their birdlike pelvic skeletal structure, and the **Saurischia,** with pelvic structure more closely resembling the structure in reptiles.

The Ornithischia were all plant-eaters. They included the fierce-looking ceratopsians (like the famous *Triceratops*), the heavily armored ankylosaurs, the stegosaurs, and the so-called duckbill dinosaurs. The Saurischia had a plant-eating branch that included the immense sauropods like *Apatosaurus* (once called *Brontosaurus*), and meat-eaters like the theropods. *Tyrannosaurus rex,* probably the most famous of all ancient beasts, was a saurischian theropod. *T. rex* was huge, but there were many smaller theropods that populated Mesozoic forests (Fig. 13.8).

In both the Ornithischia and Saurischia, the pelvic structure is composed of three *pairs* of bones fused together (Fig. 13.9). Viewed from the side of a mounted skeleton, one would see one bone of each pair or three in all. The uppermost of these bones is the *ilium.* It is firmly attached to the vertebral column. The bone extending downward and toward the rear is the *ischium.* The remaining *pubis* joins the other two and projects downward and forward to help support the visceral mass. Where the three bones come together, there is a hollow area that affords a socket for the rounded end of the upper leg bone or femur.

It is important to note that, although the term *Ornithischia* means "bird-hipped," birds are actually descendents of the Saurischian theropod group. Both birds and theropods are similar in their bipedal stance, as well as the structure of their

Figure 13.7 *Dimetrodon,* a Permian reptile having a sail-like structure along its back. *Dimetrodon* was one of a group of reptiles termed *pelycosaurs.*

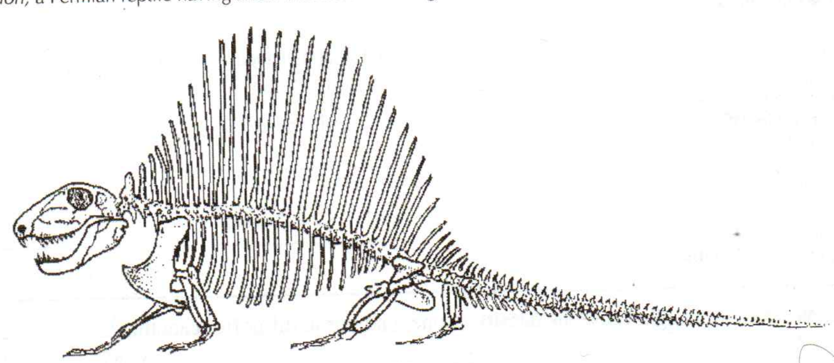
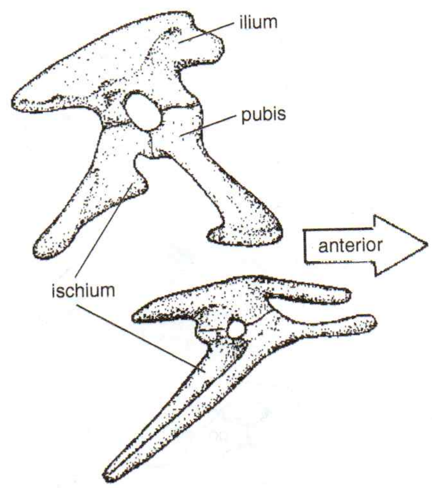


Figure 13.8 A relatively small Late Triassic theropod dinosaur (*Coelophysis*) about to make a meal of a smaller theropod. From front of snout to end of tail, *Coelophysis* was about eight feet (223 cm) in length.

Figure 13.9 Pelvic structures in dinosaurs. Saurischian (above) and ornithischian (below).



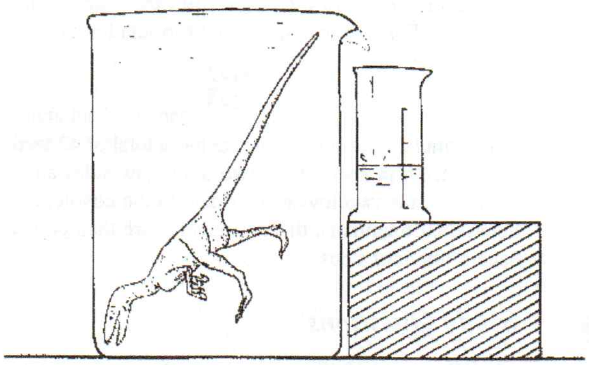
Exercise: Estimating the Weight of a Dinosaur

Study Model		Utahraptor	
1. Begin with length of actual dinosaur in centimeters (provided by instructor).	______	Length of actual *Utahraptor*	*650 cm*
2. Find length of model in centimeters. Cut masking tape into 3-mm-wide strips and extend tape along length of the model. Cut or mark tape at total length, remove, place on flat surface, and measure.	______	Length of model of *Utahraptor*	*16.2 cm*
3. Divide length of actual dinosaur by length of model.	______	650 cm divided by 16.2 cm. Thus the model is about 1/40th the size of the actual *Utahraptor*.	*40.12 cm*
4. Determine volume of the model (Fig. 13.10). Submerge model in a graduated beaker filled to a set level with water and measure the amount of water displaced. Alternatively, fill the beaker brimful. Place a graduated 100-ml cylinder beneath pour-spout, and measure "spill-over" when model is submerged.	______	Volume of *Utahraptor* model	*20.0 ml*
5. Cube the scale of the model.	______	Cube of the scale of the model. *Utahraptor* model is 1/40th the size of actual *Utahraptor*. Thus, 1/40 × 40 × 40 (or 40^3)	*1/64,000*
6. Find volume of the actual dinosaur. Otained by multiplying the inverse of the above value times the volume of the model.	______	64,000 × 20 ml	*1,280,000 ml*
7. Convert milliliters to liters.	______	1,280,000 divided by 1,000	*1,280 liters*
8. Determine weight of actual dinosaur. A liter of water weighs 1 kg. An average-size crocodile weighs 0.9 kg/L. Thus, 0.9 kg/L times the volume of actual dinosaur gives the weight of the dinosaur.	______	0.9 kg/L × 1,280 L	*1,115 kilograms*
9. Convert kilograms to pounds. To convert kilograms to pounds multiply kilograms by 2.205 lbs/kg.	______	1,115 × 2.205 lbs/kg	*2,458 pounds* or 2.46 metric tons

Question... What factors might cause the density of one dinosaur to differ from another? ______________________

Figure 13.10 Setup for measuring the volume of water displaced by a dinosaur model. It is helpful if the spout on the large beaker is enlarged with plastic modeling clay or putty so that water pours directly into measuring cylinder.

Dinosaur model. The model used here, *Utahraptor*, is one of many in "The Carnegie Collection" produced by Safari Ltd., P.O. Box 63085, Miami, Florida 33163. These models were sculpted under the guidance of paleontologists at the Carnegie Museum of Natural History. They are often available in the shops of science museums.



limbs, shoulder girdle, and skull. Feathers, once considered the defining characteristic of birds, are now known to have adorned certain theropods.

Although dinosaurs are widely marveled for the immense size some attained, many of them were as small or smaller than a chicken. Paleontologists can sometimes infer the approximate weight of a dinosaur by the thickness of its bones and other characteristics of the skeleton. Spencer Lucas (1944)* described how approximate weight estimates of dinosaurs might be determined. His method is explained in "Exercise: Estimating the Weight of a Dinosaur" (see also Fig. 13.10).

Study Questions

1. What types of ancient environments of deposition would be likely places in which dinosaurs may have lived?

____

____

____

2. A geologic map (described fully in the next chapter) shows the age and kind of rocks that lie at the earth's surface. Would such a map be useful in a hunt for dinosaur fossils? ______________. Explain why.

____

____

____

*Lucas, S.G. (1994). *Dinosaurs: The Textbook.* Dubuque, IA, Wm C. Brown Publishers.

3. What characteristics of theropods are birdlike?

____

____

____

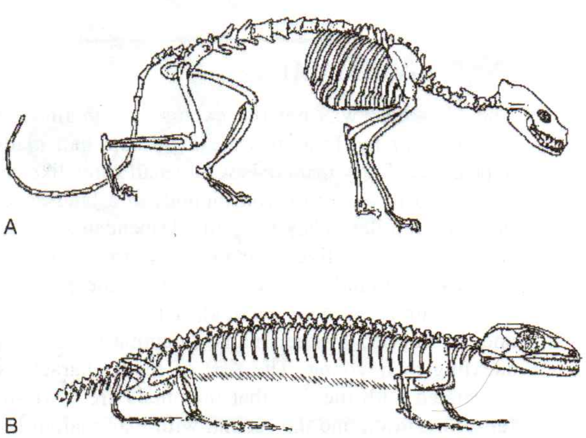
Mammals

The Mesozoic was not the exclusive domain of the dinosaurs, for by Triassic time mammals had made their appearance. Early mammals were small shrewlike creatures that might have been inconspicuous in a landscape dominated by reptiles. They were the descendants of mammal-like reptiles that lived during the Permian and Triassic periods. Mammals are recognized by the possession of fur or hair (except in whales), a four-chambered heart, and, as implied by their name, mammary glands used in suckling their young. The first of these characteristics is associated with the fact that mammals are warm-blooded **(endothermic),** and the second with mammalian postnatal care of their young. Neither characteristic, however, is very useful to the paleontologist, who must differentiate mammals from reptiles on the basis of skeletal characteristics. Fortunately, there are several characteristics of the mammalian skeleton that are diagnostic. One of these is the presence of a single bone, the **dentary,** in the lower jaw. In mammals, the old reptilian **quadrate** and **articular** jaw hingement has been modified to the mammalian **squamosal**-to-dentary type of hinge. In the process, the articular became the **malleus** and the [quadrate] became the mammalian incus. Thus, once again, bones serving one function (hingement) are transformed and pressed into service for a different function (transmitting sound vibrations). Other skeletal characteristics of mammals include a braincase considerably larger than that in reptiles and a double knob of bone (double **occipital condyle**) that forms the articulation between the skull and first cervical (neck) vertebra.

There is ordinarily a functional differentiation of teeth in mammals. In human dentition, this differentiation consists of incisors, canines, molars, and premolars. Other differences in the mammalian skeleton are found below or posterior to the skull. Ribs are usually absent on neck vertebrae. The posterior lumbar region is also ribless and forms a contrast to the great rib basket of the thorax, and in all but four genera of living mammals, the number of cervical vertebrae is seven. The breastbone **(sternum),** which was relatively unimportant in reptiles, becomes an important base of attachment for the longer ribs. In mammals, one also finds a strong ridge (the *scapular spine*) extending down the middle of the shoulder blades. This feature provided a place for attachment of muscles from the upper forelimb and is related to the mammalian trait of positioning the legs more directly under the body. Bones of the pelvis **(ilium, ischium,** and **pubis)** are fused into a single sturdy structure.

Figure 13.11 Skeletons of the Oligocene dog *Hesperocyon* (A) and the Carboniferous reptile *Hylonomus* (B). The drawings are not at the same scale.

Hesperocyon after Matthew, W. D., 1909, The Carnivora and Insectivora of the Bridger Basin, Middle Eocene, *Mem. Amer. Mus. Natu'l. Hist.* **9**:291–576. *Hylonomus* after Carroll, R. L. and Baird, D., 1972. Carboniferous Stem Reptiles of the Family Romeriidae. *Bull. Mus. of Comparative Zoology* **143**:321–363. President and Fellows of Harvard College. Reprinted by permission.



Study Questions

1. Examine the skeletons depicted in Figure 13.11. Which of the figures represents the skeleton of a mammal?

2. List below four features of the skeleton you have selected, that are more mammal-like than reptile-like.
   a.
   b.
   c.
   d.

The Teeth of Mammals

Upon finding the jaw or skull of an extinct mammal, the paleontologist immediately examines the teeth, for these give direct evidence of the kind of food the animal ate as well as certain other information about the animal's behavior. Unlike the teeth of fish, amphibians, and reptiles, the teeth of all but a few mammalian groups are differentiated, or *heterodont.* This means that the teeth in the forward part of the jaws differ in shape and function from those farther to the rear. Typically, these differentiated teeth consist of *incisors* at the front, followed by *canines, premolars,* and *molars.* An expression termed the *dental formula* describes the number of teeth of each type. For example, the dental formula for a coyote is:

$$\frac{3142}{3143}$$

The formula indicates the coyote has a total of 42 teeth. There are ten teeth in *each* of the two upper jaw sides and 11 teeth in *each* of the two lower jaw sides. In the coyote, as in other heterodont mammals, there is never more than one canine in each of the four sides.

Study Questions

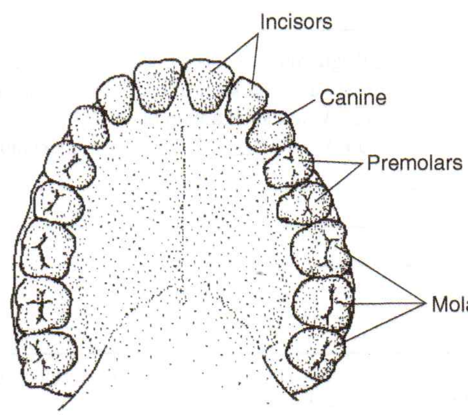
1. Figure 13.12 illustrates the teeth in an adult human. What is the dental formula for *Homo sapiens?*

2. How many permanent teeth are there in the entire mouth of *Homo sapiens?*

The incisor teeth of mammals function in cutting, grasping, and gnawing. In large grazing animals like horses, they are flat and chisel-like so as to effectively bite and crop grasses and associated plants. Incisors occur in both the upper jaw and the lower jaw in horses, with upper incisors anchored in the premaxilla bones. Those in the lower jaw have their roots in the large dentary bone. Upper incisors are not present in deer and cattle. Instead, these animals cut plant food by pinching it off between the lower incisors and a horny plate on the upper jaw.

The incisor teeth in rodents are wonderfully suited for gnawing. They have the form of curved, keen-edged chisels.

Figure 13.12 Permanent human dentition.



Hard enamel covers the front or convex surface of the tooth, whereas softer dentine lies behind the enamel. Because of the difference in hardness between the enamel and the dentine, the enamel layer is able to maintain a razor-sharp edge. In rodents, lateral incisors and canines are missing, leaving a gap or *diastema* between the remaining incisors and the cheek teeth.

The most spectacular of all incisor teeth occur in elephants and their tusked ancestors the mastodonts and mammoths. The immense tusks of these *proboscideans* are actually enormously enlarged and modified second incisors.

Behind the incisors lie the canines. Although many plant-eaters have canines that are used in fighting and defense, these teeth are particulary prominent among the flesh-eaters. In the famous saber-toothed cat *Smilodon,* the upper canines have the shape of huge daggers and were apparently very effective in cutting out chunks of flesh from the large herbivores on which they preyed. The great tusks of walruses are also canines used for pulling the animal up onto the ice and also for dislodging shellfish from hard surfaces on the ocean floor. In the insect-eating bats, canines help to snare insects, whereas in vampire bats they are used to pierce skin and release a small flow of blood.

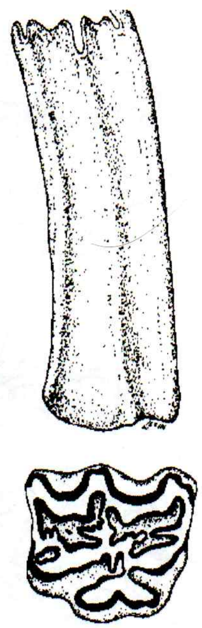
The cheek teeth (premolars and molars) have the important function of breaking food apart into small particles, thereby increasing the total surface area that can be coated with digestive enzymes. The flesh-eaters (carnivores) possess laterally compressed cheek teeth with sharp, bladelike cutting edges. They are called *carnassials.* Carnassials in the lower jaw shear like scissor blades across those in the upper jaw to efficiently cut flesh and sinew.

Mammals that feed on the coarse and gritty vegetation of grasslands require cheek teeth that can both withstand wear and serve as grinding mills. To accomplish the grinding, the occlusal surfaces of the premolars and molars are broad and flat. Grinding, however, could not be accomplished if the surfaces were smooth. To provide the necessary roughness, the hard enamel is folded up and down in the softer cement and dentine (Fig. 13.13). Because of enamel's greater resistance to wear, the layers of enamel form ridges, whereas the softer dentine and enamel wear down as troughs between the ridges.

To provide for the long wear required for a diet of harsh vegetation, the roots of the molars in large grazing animals like cattle, camels, deer, and horses extend deep into the jaws. In addition, the crown (that part of the tooth above the root) is exceptionally long. As the wear surface of the tooth is gradually reduced, the roots rise to compensate for the wear, and thereby expose more of the crown. Bone fills the space vacated by the rising root. By the time most of the crown has been worn away so that the roots can be seen at the gum line, the animal has reached old age. Malnutrition often follows. Deep-rooted, high-crowned teeth such as those described here are termed *hypsodont.*

Many mammals, including pigs and humans, are capable of eating both plant and animal food. They are omnivorous. In most omnivores, the incisors are bladelike. Canines tend to be less prominent except where they are used in defense or have a secondary sexual function. The cheek teeth have low cusps, short crowns, and well-developed roots. They are spoken of as *bunodont.*

Figure 13.13 Side view (A) and view of the occlusional surface (B) of a molar tooth from the upper jaw of a modern horse. The black areas are ridges developed on the occlusional surface (grinding surface) and are composed of wear-resistant enamel. Less durable dentin and cementum occurs between and around the enamel.



As noted earlier, most mammals are *heterodont* in that their teeth can be divided into functional types, such as the incisors, canines, premolars, and molars. A few groups, including porpoises and armadillos, have reverted to the *homodont* condition, in which all the teeth have a more or less similar appearance. Also, teeth may not be present at all in some mammals, as seen in baleen whales and South American anteaters.

Study Questions

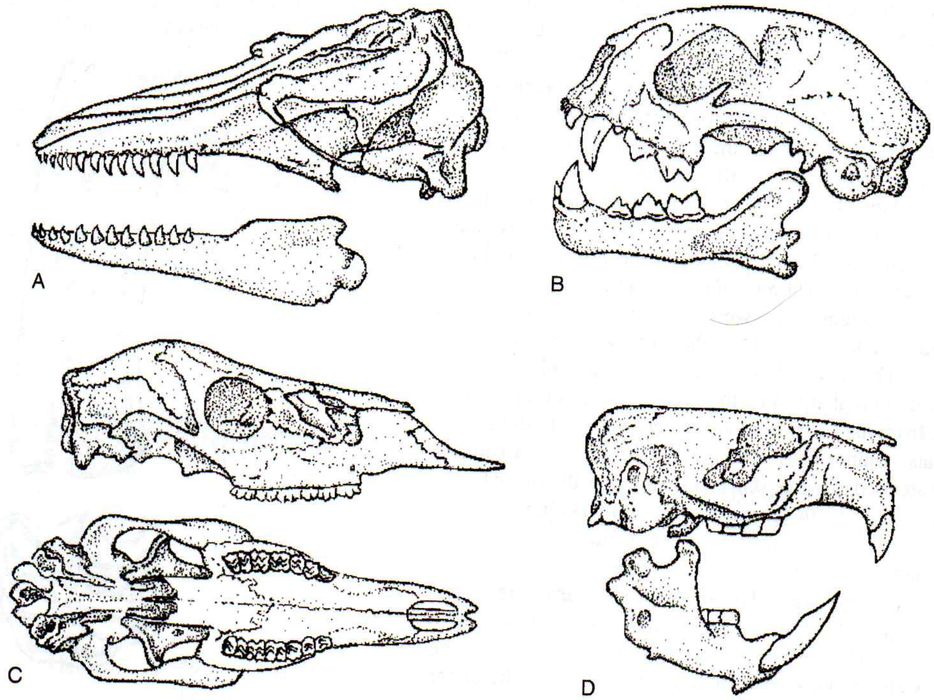
1. Which of the drawings in Figure 13.14 depict the following:
   _____a. Molars characteristic of a flesh-eating mammal.
   _____b. Incisors specialized for efficiency in gnawing.
   _____c. Hypsodont molars with selenodont patterns.
   _____d. Homodont dentition.
2. Among the choices *deer, beaver, cat,* and *porpoise,* what is the most likely animal depicted in figure:
   A. __________ C. __________
   B. __________ D. __________
3. Refer to Figure 13.12. Are the molars depicted in this figure carnassial, hypsodont, or bunodont?

____

____

Figure 13.14 Examples of mammal dentition.

Redrawn from Lawlor, T. E. *Handbook to the Orders and Families of Living Mammals.* Eureka, California: Mad River Press, 1979.



BIRDS

The final group of vertebrates to be visited in this exercise are the birds. Like the mammals, birds are endothermic or "warm blooded." Feathers, a distinctive feature of birds, not only provide for flight but also are an ideal insulation to help maintain high avian body temperature. Birds have been fashioned by nature for high power and low weight. Feathers, hollow bones, efficient wings powered by sturdy breast muscles, a large robust heart, and an efficient respiratory system all combine to produce a remarkable flying machine.

From the time of Charles Darwin, naturalists have been aware of the skeletal similarities between birds and reptiles. These similarities prompted a remark from Thomas Huxley that "birds are only glorified reptiles." Indeed, birds appear to be related to a subgroup of theropod dinosaurs known as coelurosaurs (the familiar flesh-eater *Velociraptor* is a coelurosaur). These reptiles were already birdlike in their bipedal stance and in the structure of the forelimbs, hindlimbs, shoulder girdle, and skull. In fact, a new classification of vertebrates has been proposed in which the close relationship between dinosaurs and birds is indicated by the inclusion of both groups within the Archosauria.

Study Questions

1. Figure 13.15 is a depiction of the skeleton of the Jurassic bird *Archaeopteryx* and a modern pigeon.

   Name three skeletal features of *Archaeopteryx* that are more characteristic of reptiles than of birds.

   a. ______________________________

   b. ______________________________

   c. ______________________________

2. Describe the differences in the following features between the two skeletons.

   skull ______________________

   forelimbs ______________________

   tail ______________________

   pelvic structure ______________________

3. What is the function of the sternum in modern birds?

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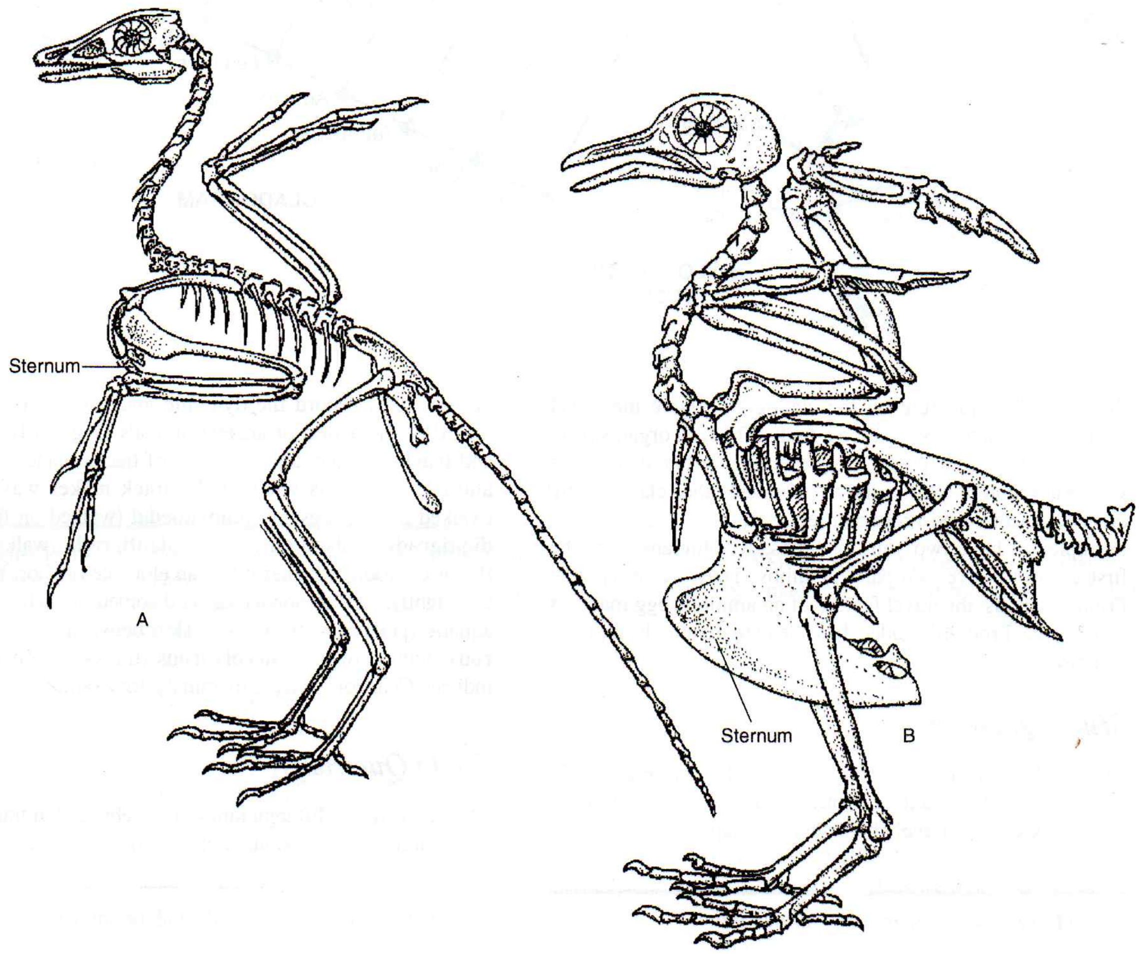
Figure 13.15 Skeletons of *Archaeopteryx* (A) and a pigeon (B). The drawings are not at the same scale. *Archaeopteryx* measured about 50 cm (20 inches) from head to tail.

After Heilmann, G., *The Origin of Birds*, New York. Appleton-Century-Crofts Inc., 1927.



4. What features of the pigeon skeleton indicate greater capability as a flyer?

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Vertebrate Phylogeny: Depicting Relationships

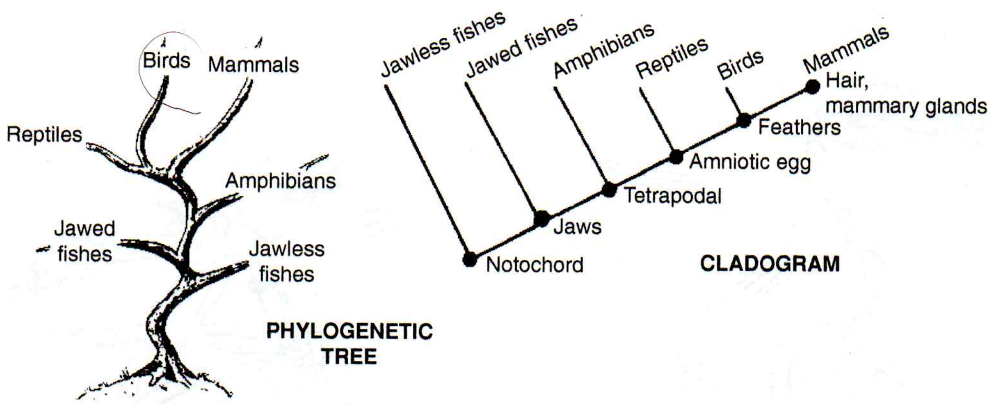
Phylogeny refers to the sequence of changes involved in the evolutionary history of a group of organisms. Phylogeny can be depicted on a treelike diagram called a **phylogenetic tree** or as a **cladogram** (Fig. 13.16).

In a phylogenetic tree, the most recently evolved species or groups are on the upper branches, and the older, ancestral species or groups are on the lower branches. A phylogenetic tree depicts change through time.

A cladogram is a diagram that shows the evolutionary relationships among a group of organisms. A cladogram shows closeness of relationship by the arrangement of groups. The shorter the links between groups, the closer the evolutionary relationship. The cladogram does not incorporate information about the time ranges of organisms. Its sole purpose is to depict relationships.

As shown in Figure 13.16, a cladogram resembles a series of junctions leading to branches that are called **clades.** A clade begins with the first appearance of a new (*novel*) characteristic (also termed a *shared derived characteristic* or an *evolutionary novelty*). The animal or plant having that novel characteristic is the ancestor of all the descendents farther up

Figure 13.16 Phylogenetic tree and cladogram for depicting evolutionary relationships.

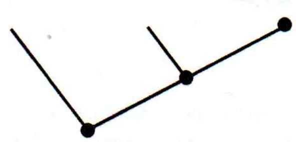


the clade. The juncture on the cladogram where the novel character first appears is called a **node.** Thus, all organisms in Figure 13.16 above the node representing vertebrates have a vertebral column. Within the vertebrates, other clades share other characteristics. Frogs, turtles, mammals, and birds, for example, all have two pairs of limbs. Amphibians were the first group to have two pairs of limbs. They are tetrapodal. From tetrapods, the novel feature of an amniotic egg made its appearance. From this node, clades lead to mammals, reptiles, and birds.

Study Questions

1. In the space below, complete the cladogram (Fig. 13.17) so as to depict a tuna, giraffe, and dolphin. Label the nodes where novel characters first appear.

Figure 13.17 Framework for Study Question 1.



2. Other than the fact that the giraffe and dolphin are amniotes (eggs have an extra-embryonic membrane), name three other evolutionary novelties that these animals have in common.

Vertebrate Ichnology

The tracks and other traces of vertebrate animals are no less interesting and useful than those of the invertebrates discussed earlier in this chapter. They are often particularly fascinating because they record the dynamic and sometimes dramatic record of the action of ancient animals (Fig. 13.18). **Tracks** and **trackways** (continuous series of tracks made by a single animal) inform us whether the track maker was **bipedal** (walked on two legs) or **quadrupedal** (walked on four legs), **digitigrade** (walked on toes) or **plantigrade** (walked on the flat of the foot); whether it had an elongate or short body; if it was lightly built or ponderous; and sometimes whether it was aquatic (perhaps with webs of skin between toes), **carnivorous** (with claws), or **herbivorous** (tracks of hooves would indicate Cenozoic grazing mammals, for example).

Study Questions

1. How many different kinds of vertebrates left tracks in the large slab of siltstone (Fig. 13.18)?
2. In what chronological order did the animals cross the area?
3. Draw circles around the tracks of the plantigrade quadruped.
4. Draw squares around the tracks of a digitigrade biped.
5. What event is recorded by the tracks in the center of the slab?
6. Figure 13.19 is a sketch of vertebrate tracks discovered in Germany in 1834. The tracks occur in a Triassic red sandstone. The smaller tracks are about 10 cm long, and the larger about twice that length. They occur along a single line, with what *appear* to be the thumb impressions directed alternately to the left and right of each pair. The following hypotheses were advanced as interpretations of these tracks:

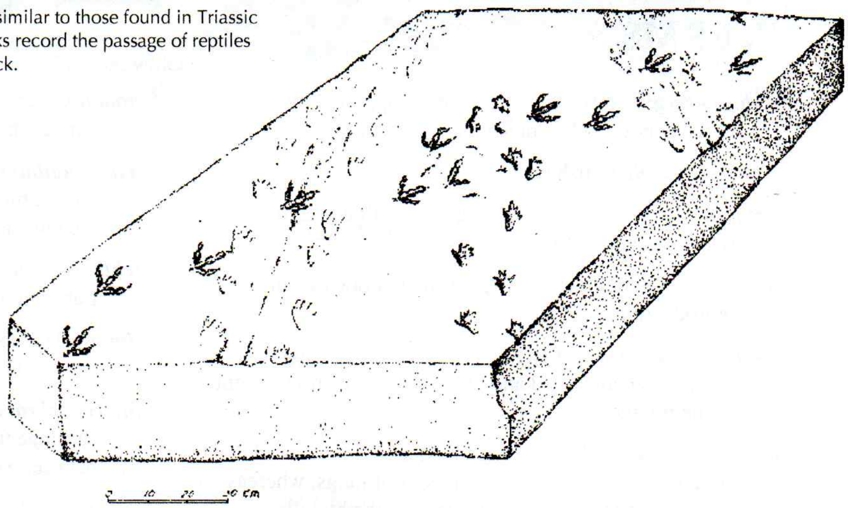
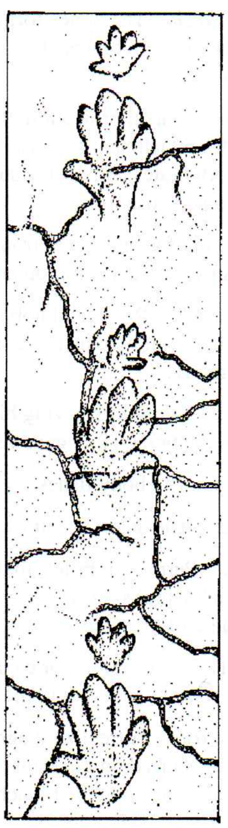


Figure 13.18 Vertebrate tracks in siltstone, similar to those found in Triassic sedimentary rocks of Connecticut. These tracks record the passage of reptiles across soft, wet sediment before it became rock.

Figure 13.19 Sketch of footmarks discovered in 1834 in a Triassic red sandstone in Germany. The animal presumed to have made the tracks was named *Cheirotherium,* meaning "hand beast."

After a drawing in Sir Richard Owen's book, *Paleontology*, published in 1861.



a. The larger tracks were made by a cave bear, and the smaller by a monkey, which followed the bear about.

b. In 1851, Sir Richard Owen proposed that the tracks were made by a large amphibian or reptile having larger rear than front feet, and that the unusual location of the thumb resulted from the animal's gait, which consisted of crossing one leg over the other. Thus, at each step the left foot was placed to the right of the right foot, followed by the right foot being advanced to the left of the left foot.

c. In 1925, Wolfgang Soergel proposed that the tracks were made by a bipedal reptile that occasionally walked on all four legs. Professor Soergel stated that the presumed impression of a thumb was not that of a thumb at all but a finger pointed outward and away from the other fingers.

Discuss the three hypotheses, providing arguments against those you consider untenable. (Also, on your next visit to the zoo, examine the toes of lizards.) Was Professor Soergel correct in stating that the position of the presumed thumb impression was an unnecessary cause of confusion?