The development of paleoecology, the study of relationships among ancient animals and plants, has intensified the demand for paleontological reconstructions in the form of dynamic illustrations, sculpture, and films that re-create the appearance, habits, and often the habitats of prehistoric animals and plants. To the illustrator of prehistoric subjects, reconstructions are illustrations, models, and sculptures that reproduce the appearance of an extinct animal’s bones, skeleton, habitus, and often the habitat in which it lived. For more than a century, reconstructions have been used for murals and models in museum galleries as well as for illustrations in popular books on paleontology. Only recently, however, has there been substantial demand in the scientific literature for paleontological reconstruction, usually in the form of block diagrams showing fossil communities or as illustrations of individual organisms that show the function of skeletal anatomy, soft anatomy, life habits, and growth forms. This chapter will discuss the various kinds of useful information available from the fossil record and some procedures for gathering and translating these data directly into a vertebrate paleoreconstruction.

To prepare a paleoreconstruction, the artist must be able to synthesize basic scientific data. A thorough knowledge of the form and function of the paleontological subject, as well as familiarity with the anatomy and ecology of its living relatives, is usually essential. It is also important to understand the progression of geologic time. The artist who is not a paleontologist or biologist ought to be able to communicate and work closely with those scientists who can supply the basic information needed to reconstruct a fossil organism accurately. The ability to gather much of this information independently could be a significant advantage to any artist. Courses in comparative anatomy, vertebrate and invertebrate zoology, paleontology, and botany are helpful, as are apprenticeships. Independent study is important.

Dissection and study of various modern animals will help the artist to build an understanding and appreciation of body structure. Familiarity with relationships among organs, skeletal structure, muscles, fat deposits, and skin can be applied judiciously to reconstruction of extinct forms. It is further important to know where muscles are attached, how they change shape when body parts move, and how thick they are (when probed with a needle). Specimens for dissection can be obtained from biological supply houses, zoos, and animal laboratories. For reference, observations should be recorded with drawings and photographs during several steps of dissection—for instance, when the skin is pulled back, when muscles are cleaned of fat, as certain muscles are removed, and when bones and organs are exposed. If reconstruction will involve plants, modern and fossil plant structure should be studied. The accuracy of observations and reconstructions based on dissections or other information should be checked with a paleontologist, anatomist, or other specialist in the pertinent field. Especially important to restoring extinct vertebrates is the use of modern analogues, living animals that are most like the extinct subject. These can be relatively close relatives—such as modern horses when restoring fossil horses—or they can be animals of similar form—such as elephants when working on a giant brontosaurus.

Although the illustrator is seldom responsible for preparation of the skeletal reconstruction from which the rendering is to be made, it is important to understand how errors can arise. Errors in a finished reconstruction resulting from inaccuracies in the prepared skeleton or a misinterpretation of the skeleton occur for at least three basic reasons:

1. The reconstruction was based on an incomplete or deformed skeleton.
2. The original interpretations of the skeletal reconstruction were in error but became so ingrained in scientific thought that they were perpetuated long after new evidence indicated that they were wrong.
3. The fossils were assembled erroneously.

There are many cases in which errors in assembling vertebrate skeletons have led to persistently inaccurate reconstructions.

The artist not only must be able to interpret paleontological and biological evidence, but also must possess the imagination to visualize the fossil as a living organism and the technical and artistic skills to translate this mental image into graphic form accurately and convincingly. Whereas the rendering techniques used to prepare paleoreconstructions are the same as those used to produce other forms of scientific illustrations, the pro-
PROCEDURES used to produce the preliminary drawing are quite different. Frequently a sculptured three-dimensional model is created as a guide for the two-dimensional rendering (see figs. 14-19 through 14-22). Creating a reconstruction is, in some ways, similar to preparing a scientific research paper (which it may accompany), except that the results are expressed in pictorial rather than written form.

Renderings can be done in any medium and on any surface, although pen-and-ink is used most commonly. Because reconstructions sometimes are done in mural form, they present the opportunity to work in media such as oils or acrylics on a larger scale than is customary in other fields.

**INSTRUMENTS AND MATERIALS**

In addition to the art materials used for the chosen media and technique, the reconstruction of extinct vertebrates will require the use of some of the following items. (There is some overlap with the list of Instruments and Materials in chapter 13, and reference should be made to that chapter.)

**Surfaces**

Tracing paper, drafting film: inexpensive for early rough drawings and better quality for later stages.

Graph paper: various scales such as 8/inch, 10/inch, to compute enlargements and reductions.

**Optical Devices**

Stereoscopic microscope: for very small fossils.

Reducing objective.

Camera lucida.

Reticule with grid: used when camera lucida is not available.

Opaque projector: indirect for enlargement and reduction of drawings or of the actual fossil; direct for projection of drawings, but can be used backward to draw some fossils (see fig. 2-34).

Camera: 35mm single-lens reflex, with slide and print film.

Lenses: telephoto and macro, for camera.

Slide projector: to enlarge slides of specimens for tracing and study.

**Measuring Devices**

Proportional dividers: large and small sizes, depending on the sizes of the fossils likely to be drawn—8-inch (20cm) will accommodate most small fossils.

Metric measurers: for measuring specimens and drawings—tape measures for curved surfaces, rulers from 15cm (6 inches) to a yardstick or one-meter stick. Rulers should be both clear plastic for use in drawing and white opaque plastic with black markings to be placed next to specimens for photography.

Protractor.

90-degree triangle.

**Specimen-handling Tools**

For very small specimens that require microscopy, the same instruments listed in chapter 13 are needed.

**Specimen Props**

Sandbox: in which to articulate bones.

Microcrystalline (dental wax) (petroleum based and somewhat sticky): for holding bones together or to support them in position; available from dental suppliers. Plasticine also may be used (see Clay, Wax in chapter 2, and Appendix).

Soft cloth fabric: to place under specimens for protection.

Cushions of foam or folded cloth, Styrofoam, large sponges, wooden blocks and wedges and pegs, shot-filled bags.

**Containers**

Boxes: cardboard, for carrying smaller specimens. These can be padded with cloth, cotton, or sponge for delicate specimens. Very large specimens are moved in wooden crates and on dollies, usually handled by museum technicians.

**Miscellaneous**

Scissors: large; for cutting paper pieces as they are taped together. A paper cutter also is handy.

Calculator: for computing relationships among bones.

Plasticine or Klean Klay: for modeling three-dimensional reconstructions; for building muscle layers as guides for the reconstruction. Klean Klay is less oily than plasticine but also does not dry out (see Appendix for source for Klean Klay).

Index cards: Three by five inch or larger; to be used as identification labels placed next to specimens for photography.

Felt-tipped pen: broad; for lettering cards.

Transparent tape: with matte finish that accepts pencil, Scotch no. 810, for example; for holding tracing paper together.

**PROCEDURE FOR RECONSTRUCTING A SKELETON**

After a discovery, bones must be carefully extracted, mended, and treated with a hardening agent to prevent disintegration. Such procedures are best left to a competent preparator. However, the combined efforts of the artist, preparator, and paleontologist are
necessary for full reconstruction of the animal from the skeleton embedded at the discovery site to an illustration or model of the animal's appearance in life.

Even though the illustration techniques apply to all land vertebrates, including early hominids, the large predatory tyrannosaur dinosaurs of the group Theropoda will be used here as the primary example in an outline of basic procedures for preparing a paleoreconstruction. Such features as the relationship of bones to each other, evidence of muscle attachments, and fossil footprints are all clues to an animal's anatomy, life-style, and habitat. This kind of information should be sought whenever an animal is to be reconstructed. The same principles of interpretation apply to invertebrate animals and plants.

Fieldwork

When a large skeleton or bone bed is uncovered in the field, a quarry map or chart of the remains is often prepared, documenting the position of the bones as found (in situ) (figs. 14-1, 14-2). Such drawings and supporting photographs help in reassembling the skeleton in the laboratory and are critically important for understanding how and why the specimens came to be preserved. Photographs should be made of the exposed fossil using the archaeological-type grid system with a camera suspended over the quarry. The grid allows for correction of parallax in the subsequent drawing. (See chapter 21 for a description of quarry mapping.)

Illustrating Related Bones

After fossils have been excavated and then cleaned in the lab, they may be illustrated as either isolated bones or an articulated skeleton left half-buried in the matrix (death pose) (see fig. 14-2). Because these bones or skeletons may be massive or may be stored in some remote location, camera lucida and other reproduction tools may not be practical or available. Slides (35mm) of the specimen in several standard views (lateral, dorsal, ventral)—shot with a telephoto lens to reduce parallax and with a metric scale next to the specimen—can be projected and the specimen's outline and gross characters traced. The subject may photograph more clearly if it is evenly white. To that end and with the permission of the scientist, some specimens can be coated with chemical powders (see chapter 13). Sometimes, to minimize handling of a fragile specimen, a cast is made for illustration or photography. Additional details are drawn from the specimen or, if the specimen is not available, from photographs. Standard views facilitate comparative study. Additional views may be necessary for some purposes. The scientist may also require more complex drawings showing such features as the functioning of various joints and cross sections through elements.

Skeletal Restoration

A full skeletal restoration is the next step in the reconstruction of an animal. If a good freestanding skeletal mount of the animal is not already available, this stage can be accomplished by a series of studies. It now becomes essential to understand the anatomy of the animal being drawn. The most reliable way for the artist to develop a reconstruction is to build up on paper from bones or photographs a pencil reconstruction, preferably in multiple (lateral, top, front) views. Reconstructing an animal from several angles forces the illustrator to examine how various elements relate to one another in three dimensions and may reveal errors that are not apparent in reconstructing the skeleton in lateral view alone. Each of these views shows the full extent of certain bones, depending on the angle, and they may be combined to make a full and accurate analysis of the animal. Restorations that depict a living animal in its habitat may require more complicated poses with foreshortening. Here artistic experience and knowledge help the illustrator estimate what each part of the organism should look like and what its size should be when seen from various angles. When the skeletal reconstruction is complete, a separate drawing is made of muscle and fat layers attached properly to this skeleton. In a third drawing, skin is added and, finally, any cuticular details such as hair and texture.

Sometimes changes are required after the final rendering is done. If the final drawing is to be inked, it should be on good tracing paper or thin film so that it can be changed if necessary by cutting and repiecing. A line reproduction will not show the cut edges.

A Bone Library

Reconstruction begins with a series of tracings that constitute a "library" of skeletal parts, a disarticulated paper skeleton that will be used to reconstruct the whole skeleton. First determine the scale to be used. For example, if the length of the original bone was 1300mm and it is drawn at 130mm, the scale is 1/10. Next calculate the length of the other skeletal elements at that same scale. On a sheet of tracing paper, mark the dimension for any given element and use an opaque projector, grids, or proportional dividers to achieve the desired size of that element for tracing (see chapter 2). If the skeleton is to be restored in multiple views, select and draw the elements in those views that will be reconstructed. Only the overall outline of each bone and a few major topographical contours should be drawn. Details clutter and confuse the already complex skeletal reconstruction.

Combining Unequal Skeletons

A problem that frequently arises is that no single complete skeleton exists for reference and assorted partial skeletons of the same or similar species differ in size. Sometimes what is missing on one side of a specimen can be found on its other side. Elements from various individuals must be scaled to a common size by comparing the dimensions of those bones that are found in more than one skeleton and scaling up or down the associated remains. Caution is necessary here: the proportions of the reconstruction will be accurate only if the size differences of various individual elements are not too great, because body proportions may change radically as size changes during growth. On the other hand, a skeletal reconstruction that shows the overall design of a fossil with only approximate proportions may be useful.

Reconstructing the proportions of a species from multiple fragmentary specimens requires a calculator and a list of measurements of the specimens’ bones. First, choose the most complete adult specimen available to form the core or primary specimen for the reconstruction. Then select sections or parts from the other specimens, and rescale and compile them to make a complete individual. Some elements often are shared between the primary and secondary specimens, facilitating this kind of assembly.

To start the reconstruction, take measurements of long limb bones if possible; if not, girdle bones and sections of the vertebral column will suffice. Calculate the ratio between lengths of an element shared between the primary and secondary specimens. If the primary specimen has a femur 1300mm long and the length of the femur of a secondary specimen is 1000mm, the ratio is 1.3:1. Do the same for some other elements shared between the two skeletons and, with the scientist’s guidance, decide which ratio is best or whether an average of the various ratios is more suitable. If the ratio is as above (1.3:1), all parts from the secondary specimen should be scaled up, that is, multiplied by 1.3, to fit into the primary specimen. If the elements are absent from both the primary and the secondary specimens, find a third specimen and repeat the process.

The task becomes more difficult when, for example, elements are missing from the primary specimen and are present in a secondary specimen, but the two specimens lack shared elements, and a third specimen shares some elements with each, but not the ones the primary specimen is missing. Such complicated situations are common. In this case the size ratio between the second and third specimens must be calculated. Then the elements of the secondary specimen that are absent in the primary one must be scaled to the size of the tertiary specimen. The size ratio between the tertiary and primary specimens is calculated, and the elements scaled into the tertiary specimen. The elements from the secondary specimen are again rescaled, this time from the tertiary to the primary specimen. This procedure may have to be repeated with other specimens to complete the primary specimen’s proportions. If changes in bone size are great, some adjustments to the proportions of the bones themselves may be necessary. For instance, bones from larger individuals tend to be, but are not always, more stoutly constructed than those of smaller juvenile specimens of the same taxon.

If more than one specimen is needed to restore a single individual, but no parts are shared among the specimens, careful guesses must be made of the animal’s proportions. These should be checked by the scientist.

ARTICULATING AND RESTORING THE SKELETON

Although other species are shown here to illustrate certain principles, Tyrannosaurus rex is used to illustrate the basic reconstruction process. Tyrannosaurus rex presents relatively few problems. An almost complete specimen with skull is known. Only part of the tail, some ribs, shoulder girdle, forelimb, and hindlimb are missing. Fortunately, another specimen identical in size is known from a nearby location; this specimen provides the shoulder girdle, humerus, and hindlimb. The missing tail, lower forelimb, and toe bones are reconstructed and scaled in from other tyrannosaurs. Modern analogues provide clues to probable structure. In the case of tyrannosaurs, the best modern analogues are birds, both because of their similar form and because birds are direct descendants of small theropods related to tyrannosaurs.

Lateral View

Vertebral Column

Because the vertebral column is the axial element on which the other bones are attached, it is a logical point to begin the reconstruction. To illustrate a vertebral column, one of two basic approaches can be used: each vertebra can be drawn separately to scale and articulated on paper; or the vertebrae themselves can be articulated in a sandbox or on the framework of a mount as it is being constructed, then photographed or sketched in sections (fig. 14-3a). When some vertebrae are missing, as is commonly the case, the original number must be estimated. The appearance and size of the missing vertebrae can be extrapolated from the vertebrae that are present directly behind or in front of them (fig. 14-4). When the end of the tail is missing, as in the Tyr-
14-3. (a) To determine the posture of the vertebral column of the dinosaur *Allosaurus*, the vertebral centra have been aligned face to face, separated slightly to allow room for the cartilaginous intervertebral discs (not preserved) and the zygapophyses. (b) Schematic drawings of *Camptosaurus* vertebræ to show the positions of the zygapophyses. Left: anterior view; center: side view; right: posterior view. Pen-and-ink on Cronaflex film, by Karen Klitz.
A study of the articulated vertebral column of a *Tyrannosaurus rex* specimen upon which the final reconstruction is based. Note the curvature of the neck and back. Two vertebrae (D7 and D8) in the back have fused together, a pathological condition. One error has been made: the tail, incomplete, has too many vertebrae added to it. More complete tails show a total count of fewer than forty. The neural spines on the back show remnants of ossified interspinal ligaments, evidence of a rigidly braced trunk. Pen-and-ink on Bristol board, by E. S. Christman (*Bulletin of the American Museum of Natural History*, 1916).

244. *Anatosaurus* specimen, estimating the original length can be a problem.

To connect the vertebrae, articulate the zygapophyses (the small interlocking articular surfaces on each vertebra, shown in fig. 14-3b) and align the face of each centrum parallel to the next. Keep the centra separated from one another by about 10 percent of the average length of either adjacent centrum. In life, this space was filled by a flexible intervertebral cartilaginous disc. Broad zygaphyses and the curvature suggest that the neck was very flexible. Small zygaphyses and ossified interspinal ligaments indicate a very rigid trunk column, as in birds. The vertebrae in the pelvic region are rigidly fused to one another. The tail emerges either straight from the pelvic region or, more commonly in tyrannosaurs, with a slight upward bend given by the upturned faces of the last few pelvic centra. If drawings of a portion of the vertebral column seem unsatisfactory, they can be cut apart and rearticulated. This is true for any stage of the penciled reconstruction. The final pencil reconstruction may consist of many pieces of paper fastened together with transparent tape.

**Rib Cage**

The rib cage is important to restoring the shape of the subject, but a crushed specimen rib cage, which is quite common, makes the work difficult. In the tyrannosaurid dinosaurs, the ribs sweep down and backward from the vertebrae as they do in other dinosaurs, birds, and crocodiles. The varying shape and direction of each rib are to be noted. The rib-to-rib connections and some of the sternals, which were cartilaginous and usually not preserved, can be reconstructed by analogy with living vertebrates, in this case birds.
14-5. Pelvis (a) and hip vertebrae (b) of the two *Tyrannosaurus rex* specimens used in the final reconstruction. These drawings illustrate a problem of paleobiology: the pelvis was unnaturally crushed and narrowed by the weight of thousands of feet of overlaying sediments. Pen-and-ink on Bristol board, by E. S. Christman (*Bulletin of the American Museum of Natural History*, 1916).
RECONSTRUCTING EXTINCT VERTEBRATES 1247

The placement of the shoulder girdle upon the rib cage is a most difficult point in reconstructing fossil skeletons because the girdle is a free-floating system attached to the ribs only by muscles and cartilaginous sternal elements, neither of which are preserved. The position of the shoulder girdle is best estimated by noting its placement in well-articulated specimens, by estimating the most plausible position of the girdle and the sternal elements relative to the first dorsal ribs, and by comparison with the similar shoulder girdles of related taxa. In quadrupeds, shoulder girdle position is a major determinant of overall body posture, an important point for the illustrator to remember. Much extra work can be avoided by accurately locating the shoulder girdle in the lateral reconstruction so that subsequently prepared views, based on the lateral, will not require repositioning. It may be worthwhile to do a preliminary reconstruction of the anterior rib cage and the shoulder girdle, following the directions for reconstructing the front view outlined below.

It is easy to locate the placement of the pelvic girdle and hindlimbs on the skeleton. The pelvis attaches directly to the sacral vertebrae through massive buttressing ribs (fig. 14-5).

Function and movement, as well as construction, of the fore- and hindlimbs must be understood to restore an animal as a moving dynamic being. Careful study of the limb joints provides information for accurate reconstruction. Comparative studies (fig. 14-6) show little change in body and limb design from half a ton to ten tons; only the proportions changed. Tyrannosaurs have limbs very like those of birds, and as in birds, the restricted action of cylindrical hindlimb joints limited tyrannosaurs to a fully erect gait in which the limbs were always held directly under the body. This is confirmed by the narrow, slightly sinuous fossil trackways made by predatory dinosaurs.

Measurements of the articular surfaces of the knee suggest that *Tyrannosaurus* had highly flexed knees like those of horses and ostriches rather than the straight knees of elephants (figs. 14-6, 14-7, 14-8). The extensive hip-joint articular surfaces suggest that the femur swung from about 30 degrees below horizontal to just past vertical during fast locomotion (less at slower speeds) and that the ankle was fairly straight, as it is in big ground birds. All of this data can be used to reconstruct the limb action in a motion series study (fig. 14-9).

To finish the penciled skeletal reconstruction in side view, select a reconstructed limb posture that allows both limbs and the pelvis to be seen. Drawing the limbs on separate pieces of tracing paper and taping them to the skeleton drawing makes it possible to try various poses without having to erase and redraw the limbs repeatedly.

Animals with limbs held directly beneath their bodies are relatively easy to draw in lateral view. Drawing the limbs of sprawling gait animals, such as lizards and salamanders, in which the limbs splay out from the body, may be more difficult. This requires a good eye for freehand sketching of oblique (foreshortened) views of limb bones, guided by some pertinent measurements in the proper positions. For some examples of and solutions to the problem, read the chapters on reptilian fossils in *Vertebrate Paleontology* by A. S. Romer (see Bibliography).

Top left:
14-7. Diagram illustrating how knee flexion is estimated in (a) tyrannosaurs and (b) horses by measuring the angle of the articular condyles relative to the main shaft of the femur, and how this compares to actual knee flexion in a locomoting (c) elephant and (d) horse. The same reconstructed in a (e) tyrannosaur. China marker, Stabilo pencil, and ink on coquille board, by Gregory S. Paul.

Bottom left:
14-9. From trackways, stress analysis of limbs, measurements of joint action and flexion, and comparison with modern vertebrates such as the ostrich, a conception of how tyrannosaur limbs worked can be reconstructed and illustrated—as in this stop-action diagram of a running tyrannosaur (not to scale). Pen-and-ink on tracing paper, by Gregory S. Paul.
**Top and Front Views**

Having completed the penciled sketch of the side view, the artist must next restore the skeleton in top and front views. A back view is also useful, but since this is done with the same techniques as the front view, it will not be discussed in depth here.

Figures 14-11, 14-12, and 14-13 show a blueprintlike plan of the skeleton in three nonperspective views—from directly above (perpendicular to the ground), from directly forward of the skeleton (line-of-sight parallel to the ground), and in the direct side view (lateral)—already reconstructed. In effect, each part of the skeleton is triangulated and plotted on the top and front views. It is not a perfect blueprint; some leeway will be allowed in posing the different views (The process of triangulation is explained in chapter 16 and in figs. 16-9 and 21-23.)

To start, cut out two sheets of tracing paper large enough to hold the skeleton drawing in top and front views. Draw in the baselines shown in figure 14-10. These are the ground lines in front and side view, lines describing a transverse plane cutting through the base of the tail (posterior face of the last sacral centrum) in side and top views, and lines representing the vertical body midplane that splits the animal into left and right halves (sagittal section) from front and top views. These baselines describe the three basic planes—ground, body sagittal (midplane), and a transverse plane—needed to triangulate the skeletal elements. Note that the line marking the body midline in top view may be either perfectly straight or slightly curved to re-create the flexion of a vertebral column in a moving animal. The former is a little easier to do and slightly more accurate in measurements; the latter is more realistic. Do not attempt to show curvature of the vertebral column in front and back views; it is difficult and unnecessary.

Complete the reconstruction of the trunk in the multiple views before restoring the skull, neck, and tail in those views. Restore the vertebral column in front view first. Do this by placing the tracing paper with the front view over the lateral view reconstruction. Referring to figures 14-10 and 14-11b, align the ground lines with one another. Then slide the front-view sheet until the body midline runs across the top of the first dorsal’s neural spine. Mark off the very top of the neural spine on the body midline. Using this reference point, take the front-view sketch of the first dorsal vertebra from the “bone library” and draw it in place, taking care to adjust for any tilt of the vertebra. Do the same for each succeeding dorsal vertebra that can be seen in front view, drawing in only those parts not obscured by the vertebra before. After this, restore the dorsal column in top view (fig. 14-11c). Follow the same method used for the front view. Overlay the top-view sheet on the side-view reconstruction, aligning the transverse plane lines with one another. Mark out the positions of tips of the neural spines and transverse processes relative to the body midline. Then use the front view of the vertebral column to mark out where the tips of the transverse processes are astride the body mid-
Plot out the positions of each zygapophysis in top view, then draw in each vertebra in top view. Use these same basic procedures to plot out and draw in the dorsal centra, the sacrals, pelvis, ribs, and limb elements in front and top views (figs. 14-11, 14-12, 14-13). Do one side only, the same shown in the lateral view. Since vertebrate animals are basically bilaterally symmetrical, the half drawings can be flipped over for the final inking.

The rib cage and shoulder girdle present the greatest problem because their circumference and articulation must be restored, a difficult three-dimensional problem that requires the guidance of an expert. They are difficult to reconstruct in two dimensions. Articulating a few sample ribs with the vertebrae and studying articulated specimens with intact rib cages aids in their reconstruction. It is best to restore the rib cage in front view first, then use it and the lateral view to triangulate and

Top left:
14-11. The initial steps in restoring the top and front views of a skeleton. The penciled lateral view (a) is finished, and a ground line and vertical line indicating a plane cutting transversely through the tail have been added. (b) Front view: a ground line and vertical line indicating the body midplane (sagittal line) are drawn in. The baselines have been used, as outlined in the text, to plot on and pencil in the dorsal vertebrae. (c) Top view: a flexed line indicating the sagittal plane and a transverse line indicating a plane cutting transversely through the tail have been drawn in. In these three views, the artist has used triangulation from the baselines to add the neural spines, transverse processes, zygapophyses, sacrum, and pelvis. (Scale bar equals 1 meter.) Pencil on tracing paper, by Gregory S. Paul.

Bottom left:
14-12. The rib cage restored, first in front view (b). Then, triangulating from the front and lateral (a) views, the rib cage has been restored and checked in top view (c). Pencil on tracing paper, by Gregory S. Paul.
check its appearance in top view (see fig. 14-12). Sometimes the top view will show that the front and lateral views are restored incorrectly. For clarity, draw in only those parts of the ribs not obscured by other ribs. Next restore the shoulder girdle front and top views (see fig. 14-13). Further alterations to the rib cage may be required. This is a potential point of crisis in reconstructing a quadrupedal animal since the front and top views of the shoulder girdle may reveal that the lateral reconstruction of the girdle is in error. If so, the shoulder girdle may have to be shifted upon the rib cage, changing the whole posture of the animal relative to the ground. In turn, the top and front views may have to be redone completely. But such errors will occur. Note that the shoulder girdle was shifted posteriorly in the restoration in figures 14-11 and 14-12 from figure 14-13; however, since the tyrannosaur is a biped, the posture of the body and hindlimbs was unaffected.

Once the dorsal-sacral column, rib cage, shoulder girdle, and pelvis are properly restored in top view, the limb elements can be triangulated into the front and top views (see fig. 14-13). Use the elements from the “bone library” as guides to trace or sketch in the limbs, showing only the parts that would be visible from whichever view is being drawn.

Having finished the trunk and limbs, restore the neck and tail in top view with the same basic methods used for the dorsal column. It is best not to restore the neck in the front view or the tail in a back view, however, since doing so is inordinately difficult and will obscure the trunk and limbs. Although a back-view restoration of the skeleton follows the same methodology as the front view, it is easier because the pelvis is usually a solidly built structure that is fairly simple to reconstruct.

**The Skull**

The last part of the skeleton to be considered is the skull. In a sense the skull is a separate entity from the rest of the skeleton. Skulls are very complex structures; the relationship of the mouth roof elements to one another, in particular, may not be as obvious as, for example, the relationship of each vertebra to another, so the skull may require as much effort to reconstruct as the entire rest of the skeleton.

If the skull being restored is partial and disarticulated but the missing parts are duplicated from other individuals or closely related species, use the techniques outlined above for the rest of the skeleton. The individual bones of the skull may be illustrated separately. It is useful to do skull reconstructions simultaneously in multiple views, side and top at least, in order to avoid serious errors that may occur if the skull is reconstructed in one view only. In addition to the standard lateral, posterior, and dorsal views of a completed skull, a three-quarter view is invaluable for explaining the complex structure of a skull to the reader (fig. 14-14).

To add the skull to the skeletal reconstruction, prepare a simplified pencil sketch of the outer skull and jaws showing the suture lines in lateral and top views at the proper scale. In tyrannosaurs, a spherical “condyle” of the skull’s braincase articulates with a cup that is formed by the first, or atlas, vertebra. This is a simple ball-and-socket joint and permits the head to revolve. Pick a suitable pose for the skull and jaws and add them to the top and lateral skeletal reconstructions.
OTHER ELEMENTS IN RECONSTRUCTION

Musculature

Once the reconstruction of the skeleton is complete, the contours of the head and body may be reconstructed with the addition of appropriate soft parts, primarily the muscles. There are two basic types of muscle restorations. One consists of detailed, muscle-by-muscle restoration for specific scientific purposes. Only a few specific muscles may be restored, or the animal's whole musculature may be built up in detail by the illustrator. To do so requires examination of the bones for muscle scars that mark points of insertion, for important processes that anchor or guide certain muscles, and extrapolation from the musculature of analogous living vertebrates. Estimating the bulk of specific muscles depends on the size of insertions and the probable power requirements. The process of interpreting clues from bones for reconstruction of soft parts should not be represented as a hard science. Sometimes definite statements can be made; in other instances, only guesses are possible.

The other type of muscle restoration is for artistic purposes. Here the principles are the same as those just outlined, but the artist is concerned only with the contour muscles, which determine the external shape of the live animal. These restorations can be quite informal but can and must be functional and reflect the animal's shape in a realistic manner (fig. 14-15).

Body Covering

The scientist decides how the skin pattern, texture, and color will be depicted, based on whatever evidence exists. Nonetheless, illustrators may have considerable input or independence because skin patterns are not known for many fossil animals. Skin impressions have, however, been found for all of the large-bodied dinosaur groups, including a tyrannosaur. Some skin impressions show mosaic patterns of nonoverlapping scales and others a pattern of variously sized, nonoverlapping, horny tubercles. Some impressions of small theropods resting in mud appear to record feathers. But big endotherms, including elephants, rhinos, and also other big dinosaurs, are naked-skinned for thermoregulatory reasons. Perhaps Tyrannosaurus was naked-skinned as an adult but down-insulated as a hatchling. Horn (a fingernail-like substance) probably covered the rough areas on top of the snout and over the eyes on the tyrannosaur skull (see fig. 14-15). The details of the foot pads often can be recon-

14-15. Muscle restoration of the tyrannosaur *Albertosaurus libratus*, with superficial and major contour muscles shown. (Scale bar equals 1 meter.) China marker and Stabilo pencil on coquille board, by Gregory S. Paul.


structured with confidence from fossil trackways.

Color is the least knowable and also the least important aspect of dinosaur reconstruction. Nonetheless, the question most frequently asked an illustrator is how he or she knew the animal's color. Large dinosaurs, like most large modern-day animals, may have been dun, earth, or green colored; small dinosaurs, like modern-day small mammals, reptiles, and birds, may have been brightly colored. It is probable that camouflage patterns, sometimes bold, were often present. Like their reptile ancestors and probable bird descendants, dinosaurs likely had color vision. Special color patterns concentrated around the head and neck may have been important as display devices. The designs and variations in color may have been arranged symmetrically with relation to the whole body, analogous to most animals of today.

**Representation**

The final reconstructions may be depicted as drawings, paintings, or diagrams. The form of representation is determined by what most clearly communicates the concept being illustrated, and this is best decided by the scientist and illustrator together. In order to show the relationship between the skeleton and the reconstructed flesh, a drawing of the skeleton surrounded by an outline of the body may be prepared. One way to clarify and dramatize such illustrations is to draw white bones against a solid black background of flesh (fig. 14-16). When this is done, it is best to
keep detail on individual bones to a minimum. The skeletons can be drawn to a standard size (the length of the femur is a good constant), and all animals of similar form can be posed in the same manner. If carefully done, such skeletal restorations are valuable comparative tools for examining differences and similarities. A scale bar may or may not be included. Occasionally the artist has the opportunity to prepare a painting or drawing of the subject against a reconstructed landscape (fig. 14-17).

Any rendering technique that suits the purpose of the drawing can be used. Reconstructions for scientific journals are usually prepared in one of the various black-and-white drawing media to illustrate a particular technical feature. The form of representation may determine the technique chosen—for instance, pen-and-ink to represent white bones on a black background. Pencil on coquille board was chosen for several of the illustrations in this chapter largely because it is a fast way to shade and it effectively conveys the feeling of bone texture.

Behavior

In order to achieve a convincing realism, the artist must know something about the animal's behavior and be conscious of the relationship of the animal to its surroundings. It is not enough to render faithfully the detailed shape of the animal, although this is essential; the spirit of the animal in a lifelike pose also should be captured. Using a combination of technical information, imagination, and common sense, the artist should attempt to express the reactions of the subject by means of the pose of the limbs, the slant of the head, a cast of the eye. To capture this realism, the artist must find out as much as possible about the animal's environment, its probable food and feeding habits, its predators or prey, its relation to other animals of the same species, and its demeanor. Much of this information can be reconstructed or suggested by evidence from the fossil record.

The teeth in particular provide a wealth of information that is useful in reconstructing the animal's food and feeding habits. Herbivorous mammals have a need for crushing and grinding teeth. In contrast, the teeth of carnivorous mammals are adapted for cutting and tearing; the incisors are greatly reduced and the canines are highly developed. (Chapter 19 discusses teeth in detail.)

FINAL STEPS

In consultation with the scientist and by synthesizing as much physical and circumstantial evidence as

14-17. Reconstruction from skeleton to habitat illustration. Barylambda, from the Paleocene: (a) skeleton; (b) charcoal on illustration board, by R. Bruce Horsefall. Courtesy of Field Museum of Natural History and Donald Baird, Princeton University. From A History of Land Mammals of the U.S., by Wm. B. Scott (American Philosophical Society, 1937).
can be gathered, a plausible conception of the appearance and behavior of the extinct animal can be imagined by the illustrator and the final steps in the preparation of a reconstruction may be attempted (fig. 14-18).

First, it is good practice to sketch the animal in a variety of positions and activities before deciding on the final pose. While drafting these initial sketches, the artist should be mindful of the presumed or probable habits and temperament of the animal. The reconstruction may be blocked out by preparing a drawing of the skeleton in the desired position, then making a series of tracing-paper overlays of the muscle structure and skin.

Whatever techniques are employed, the successful completion of any paleoreconstruction utilizes the skill and knowledge of both the artist and the scientist, a mutual effort that can result in paleobiological reconstructions that are both technically as accurate as the state of the science allows and artistically pleasing to the eye.

14-18. Reconstruction of the 2.5-ton duckbill dinosaur Hypacrosaurus casuarius. This reconstruction is uniquely accurate because it is based upon a virtually complete skeleton found in a very lifelike pose similar to that shown here; much of the skin and body profile, the frill along the back, the long vertical shoulder skin folds, the ossicles beneath the hips, and the skin texture were preserved as impressions. China marker and Stabilo pencil on coquille board, by Gregory S. Paul.