# ON A NEWLY MOUNTED SKELETON OF DIPLODOCUS IN THE UNITED STATES NATIONAL MUSEUM

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## INTRODUCTION

Eight years after the exhumation from its resting place in the Dinosaur National Monument in northeastern Utah an articulated skeleton of *Diplodocus* is now on display in the United States National Museum.

The quarrying of these bones was a slow and tedious process, involving the skill of both the miner and the stone cutter, but the magnitude of the task, by a small force, of preparing one of these huge skeletons for public exhibition can be fully appreciated only by those who have passed through such an experience. The extraction of the bones, especially the vertebrae, from huge blocks of refractory sandstone, the restoration of missing parts, and the shaping of the necessary irons to support the skeleton are all arduous, time-consuming operations. It is therefore not surprising that so much time has been required for the completion of this work.

The skeleton has been given an upright quadrupedal pose, with the head uplifted as if scanning its surroundings. It is thought that the entire ensemble portrays this giant reptile more accurately than any previous mount. The missing bones were, for the most part, replaced by casts from the *Diplodocus* specimen in the Carnegie Museum in Pittsburgh, all of the replaced parts being colored to harmonize with the actual bones but with sufficient difference as at once to be distinguished from the originals.

The bones were prepared by Norman H. Boss, Thomas J. Horne, and John M. Barrett; the mounting was done by Messrs. Boss and Horne, but I alone am responsible for any anatomical inaccuracies that may be detected in the reconstruction.

The method of mounting adopted is, with some modifications, that first devised by Arthur Coggeshall in mounting the skeleton of *Diplodocus carnegii* in the Carnegie Museum at Pittsburgh—that is, the vertebral column is supported by a linear series of steel castings, which conform to the shape of the underside of the vertebrae, these in turn being supported by a number of pipe uprights securely anchored in the base. The vertebral supports were cast in 6-foot lengths and after being placed in final position were welded together into one continuous piece. The limbs and other bones are supported by half-round irons with the flat side fitted to the inequalities of the bones. All the ironwork is camouflaged to the variegated color of the specimen so as to render the supporting work as inconspicuous as possible.

The present specimen is a fully adult animal and, except for the missing portions, is an excellent example of its kind.

## COLLECTING THE SPECIMEN IN THE DINOSAUR NATIONAL MONUMENT

In the Uinta Basin in northeastern Utah, near Jensen, Uinta County, an 80-acre tract of land has been set aside as a part of the national park system under the name of Dinosaur National Monument. This reservation, as may be inferred, contains an extensive and important deposit of dinosaurian fossils.

The history of the Dinosaur National Monument had its beginning in 1909 with the discovery of dinosaurian fossils by Earl Douglass, of the Carnegie Museum. During the first six years of work there such an abundance of well-preserved specimens was found that in 1915, at the instigation of Dr. W. J. Holland, then director of the Carnegie Museum, the Secretary of the Interior withdrew this area from the public domain as a national monument in order to conserve this important deposit of fossils. Governmental permission to continue their excavations, however, was granted from year to year up to the close of 1922, when the quarry was abandoned. In the 13 consecutive years that operations were carried on there by the Carnegie Museum, a great mass of material, some 300 tons in all, I am told, was collected. In those collections were many articulated skeletons of both large and small dinosaurs, and especially important was the recovery of a considerable series of well-preserved skulls, the rarest and most sought for part of the dinosaurian skeleton. The great diversity of forms represented, together with their unusually perfect and excellent preservation, marks this as the most remarkable deposit of Morrison fossils ever discovered.

The principal fossil-bearing horizon is a heavy, greenish, conglomeratic, cross-bedded sandstone that occurs in the upper half of the Morrison formation. The Morrison in this section, according to measurements made by Dr. J. B. Reeside, jr.,[1] has a total thickness of 795 feet, made up of the usual alternating beds of shale and sand-

[1] U. S. Geol. Surv. Prof. Paper 132C, pp. 44–45, 1923.

stone. The whole geological section, beginning with the Triassic and extending upward successively through the marine Sundance, Beckwith (Morrison), Dakota, Mowry shales, and Frontier formation, is steeply tilted with a strong dip to the south. The dip reaches an angle of 60° or more above the horizontal.

Although fossil bones have been found at several other levels, nowhere are they so abundant or so well preserved as in the sandstones previously mentioned. The outcropping ledge formed by this layer of fossil-bearing sandstone, which weathers brown, can be easily traced for a mile or more both east and west from the quarry, and fossil bones are evident everywhere.

In the quarry there is a veritable Noah's Ark of the animals of this period. Here was found the largest of the giant sauropodous dinosaurs closely mingled with remains of the smaller but powerful carnivorous forms and those of the slow and heavy-armored *Stegosaurus*, as well as the lightest and most birdlike dinosaurs. Intermingled with these are occasionally found turtle shells, crocodile remains, and fossil wood.

Some of the skeletons are essentially complete, with most of the bones properly articulated, but more frequently only a third or a fourth of a skeleton remains, such as a complete tail, a section of the back, a neck, or a complete limb or foot. Some few of the bones are badly crushed, but on the whole they are quite free from distortion.

The character of the sediments appears to represent the area of an old river bar, which in its shallow waters arrested the more or less decomposed carcasses collected from many points upstream as they drifted down toward it. Thus were brought together the animals of a whole region—a fact which vastly enhances the interest of this deposit. The final part of the story necessitates a rapid covering of the stranded carcasses by sand and other river sediments in order that the bones of the skeletons should become fixed in their relative positions before decomposition of the ligamentary attachments allowed them to shift out of position. That many of the larger skeletons were not completely covered immediately is shown by the fact that the bones of the lower side remain undisturbed while those of the upper or exposed side often show much displacement of parts. That this scattering of the bones was due to current action is indicated by the fact that wherever shifting has taken place they will invariably be found to the eastward of the main portion of the skeleton. In other words, the direction of the current was from the west toward the east. Current action is further indicated by the character of the sediments in which the bones are embedded; that is, by the strong cross-bedding and the assorting of the fine and coarse materials of which the sandstone is composed.

In their final excavating work before abandoning operations, the Carnegie Museum collectors uncovered two partially articulated sauropod skeletons. When these facts were communicated to the officials of the Smithsonian Institution, plans were immediately made to take up the work in order to secure a mountable skeleton of one of these huge reptiles for the national collections. It was my privilege to be placed in charge of this expedition.

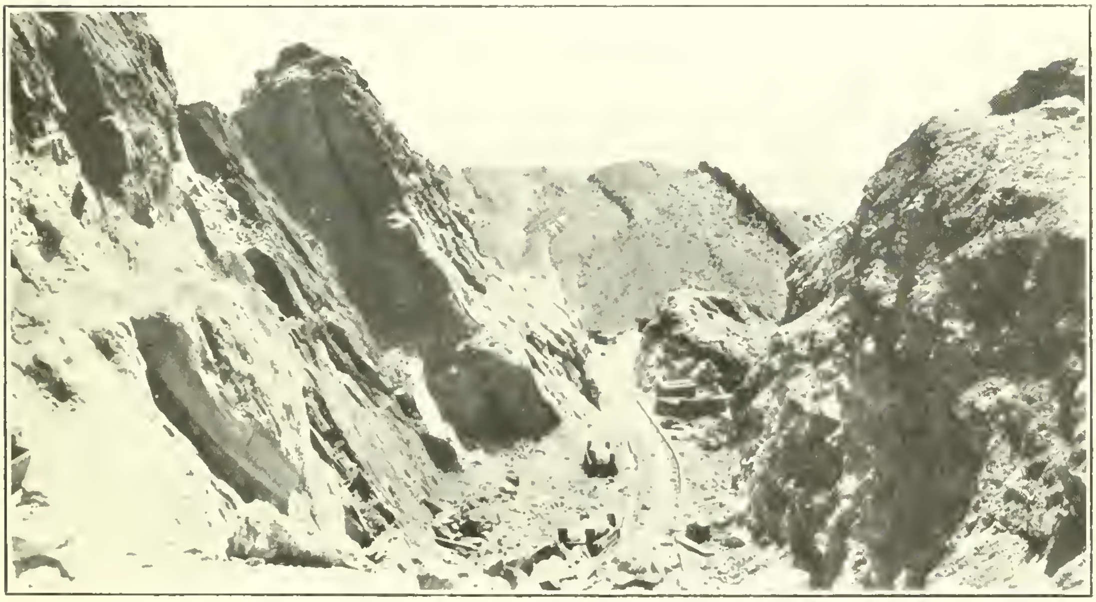
I arrived at the quarry about the middle of May, 1923, and a preliminary survey showed that of the two skeletons partly worked out in relief (see fig. 1) the one bearing the field designation No. 355, although lacking the neck, appeared to offer the best basis for an exhibition skeleton. At the time it appeared to be beautifully supplemented by a second specimen with the cervicals present and of approximately the same size, but later, after preparation in the laboratory, this neck was found to pertain to the genus *Barosaurus* and therefore was no longer available for our purposes.

Regular work in the quarry was begun during the latter part of May and proceeded continuously up to August 8, in which time all of No. 355 and the parts needed of the second individual, were collected and packed for shipment. The three men employed—J. T. Kay, E. M. York, and Golden York—all with experience in this kind of collecting, together with the skillful assistance of N. H. Boss from the National Museum, were largely responsible for the successful outcome of the operations. Difficulty was encountered in handling by primitive methods and in the subsequent arduous work of boxing and transporting the immense blocks of stone inclosing the bones. The largest block quarried containing the sacrum with attached hip bones weighed nearly 6,000 pounds when ready for shipment. The transportation of the boxes to the railroad involved a haul by teams of 150 miles across country and over a range of mountains 9,000 feet above sea level. However, 34 large boxes, having a combined weight of 25 tons, were safely transported to the Museum.

*Position of the skeleton in the ground.*—The specimen lay on its left side. The vertebral column was articulated beginning with the fragmentary centrum of the fifteenth cervical back to and including the fifth caudal. The cervical end of the column was protruding from the outcropping ledge of rock, and if the anterior cervical vertebrae were originally present, they had long since been eroded away and destroyed. The remaining part of the tail had been carried to the eastward and lay extended at right angles to the thoracic part of the skeleton, as clearly shown in the quarry diagram. (See fig. 1.) In all, 32 caudal vertebrae were recovered, all being in articulated sequence except for the dislocation between the fifth and

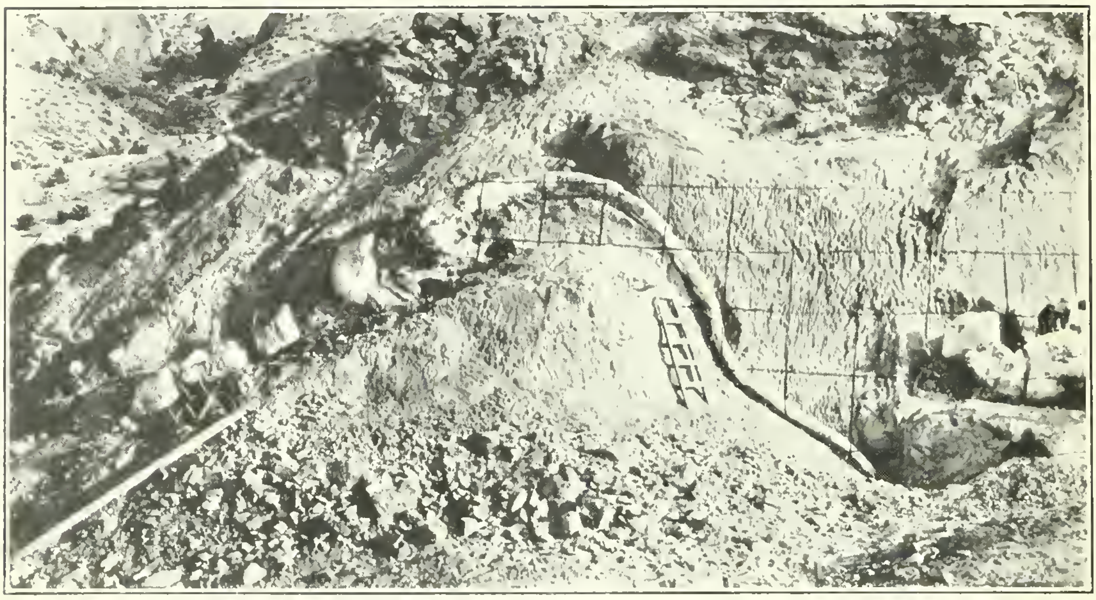
DINOSAUR NATIONAL MONUMENT

The caudal vertebrae of *Apatosaurus* in the middle foreground was the initial discovery that led to the development of this great quarry. In uncovering this skeleton other specimens were found, and so it continued to develop during the entire 15 years that work was carried on there. From a photograph by Earl Douglass.



DINOSAUR NATIONAL MONUMENT

Quarry viewed from the west end of the Carnegie Museum excavation. The fossil-bearing layer has been largely removed from the uptilted rocks on the left of the picture. The track was used for a small mine car on which the débris was removed to the dump. From a photograph by Earl Douglass.



DINOSAUR NATIONAL MONUMENT

A large dinosaur skeleton in process of exhumation by Carnegie Museum collectors. The squares outlined on the rock face are for use in accurately plotting the fossils on a quarry map. From a photograph by Earl Douglass.

DINOSAUR NATIONAL MONUMENT QUARRY

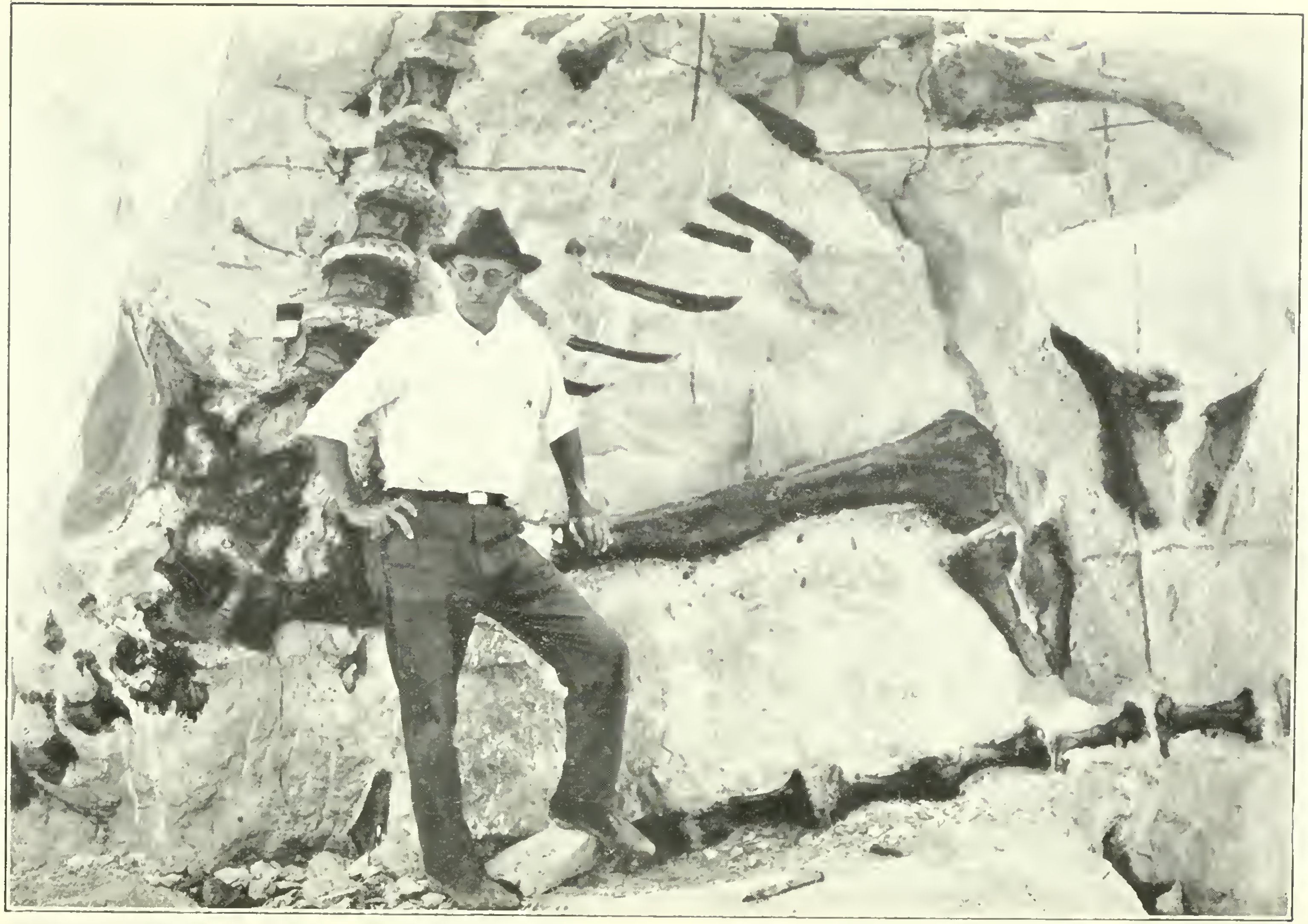
Face of quarry showing a dinosaur skeleton partly uncovered. The large size of the bones is indicated by comparison with a man seated in the right foreground. From a photograph by Earl Douglass.

DINOSAUR NATIONAL MONUMENT QUARRY

Showing the method used in lowering large bones from the steeply inclined face of the quarry. From a photograph by Earl Douglass.

DINOSAUR NATIONAL MONUMENT QUARRY

Showing the method of removing large blocks of plaster-incased bones from the quarry to a point accessible to wagons. From a photograph by Dr. R. C. Max.



The *Diplodocus* skeleton (U.S.N.M. No. 10865) as it was partly uncovered in the face of the quarry. The sacrum with attached ilia is to the left of the man, whose hand is resting on the left femur. The tibia may be seen extending directly downward from the knee joint; the fibula and the complete articulated foot were in correct relationship. At the right of the knee joint are the articulated pubes. The articulated caudal series may be seen at the man's feet. The ends of the articulated thoracic ribs of the left side are protruding from the rock. The articulated dorsal vertebrae extend upward from the sacrum to the top of the picture. On the extreme upper right border are the bones of the fore limbs, the right humerus being articulated with the radius and ulna

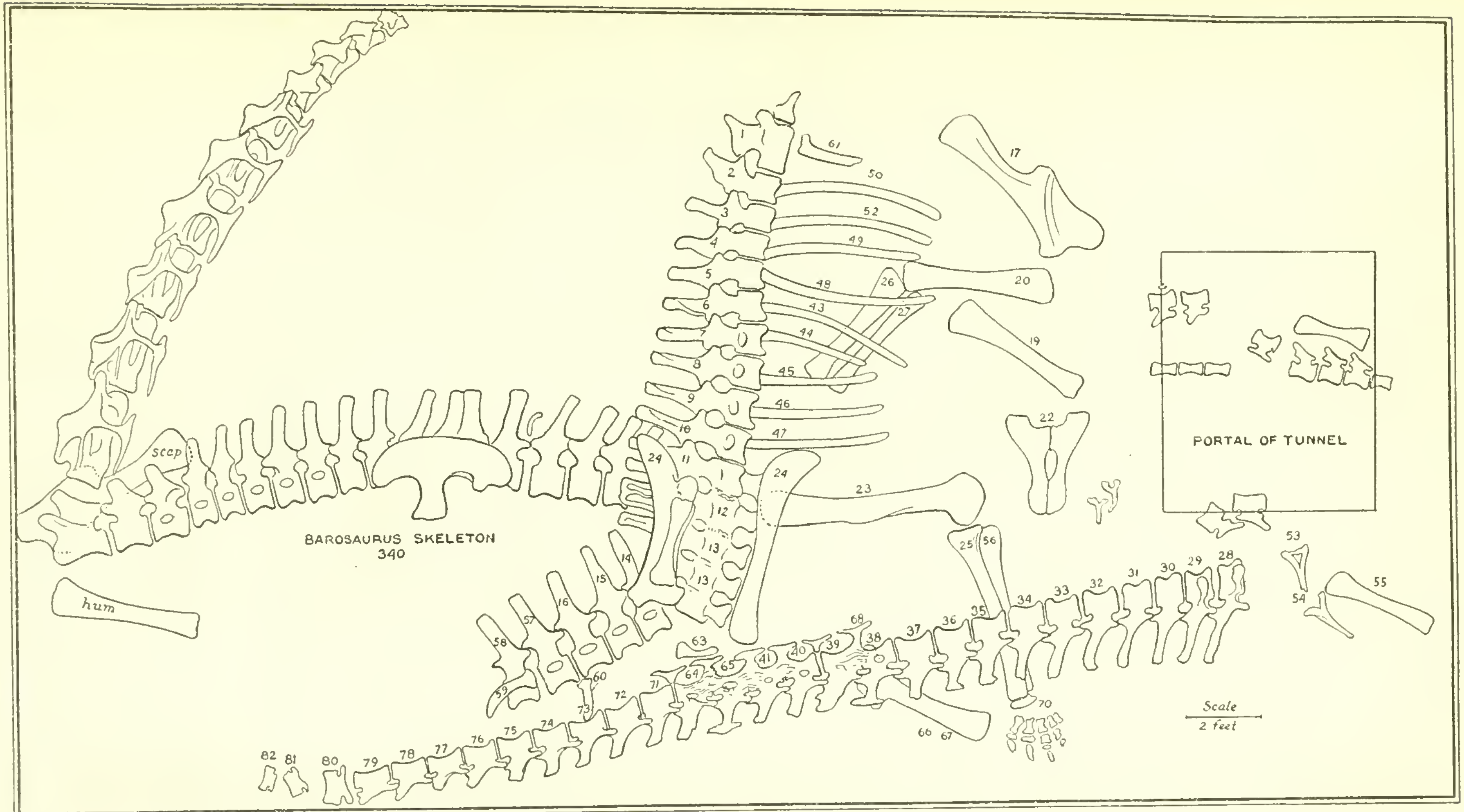



FIGURE 1.—Diagram or quarry map showing the relative positions of the bones of the *Diplodocus* skeleton as it was embedded in the sandstone. Nos. 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10, dorsals 1 to 10, respectively; 11, 12, and 13, sacral vertebrae; 14, 15, and 16, caudal vertebrae 1, 2, and 3; 17, right scapula and coracoid; 19, left humerus; 20, right humerus; 22, pubes; 23, left femur; 24, ilia; 25, left tibia; 26, right ulna; 27, right radius; 28, sixth caudal vertebra; 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, seventh to nineteenth caudal vertebrae; 43, 44, 45, 46, 47, sixth to tenth ribs of the left side; 48, fifth rib of left side; 49, fourth rib of left side; 50, third rib of left side; 52, second rib of left side; 53, fourth chevron; 55, left ulna; 56, left fibula; 57, fourth caudal vertebra; 58, fifth caudal vertebra; 59, chevron; 60, third chevron; 63, metatarsal; 64, twenty-first caudal vertebra; 65, twentieth caudal vertebra; 66, 67, ischia; 68, chevron; 70, left hind foot; 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, caudal vertebrae; 82, caudal vertebra not used in mounted skeleton

sixth mentioned above, and three distal ones displaced at the end. The thoracic ribs of the lower or left side, except the first, were all present and articulated with their respective vertebrae; those of the upper or right side, except one found out of position, were all missing. The left hind leg and foot remained articulated but stretched out in a sprawling position, as shown in Plate 4. The pubes, ischia, bones of the pectoral girdle, and fore-limb bones were found to the east of the main portion of the skeleton. The detailed list of the skeletal parts found is as follows: 10 dorsal vertebrae; 5 sacral vertebrae; 32 caudal vertebrae; 9 ribs (left), 1 (right); both ilia; pubes and ischia; right scapula and coracoid; both humeri; both ulnae; one radius; left hind leg and foot complete; 18 chevron bones.

In the accompanying diagram (fig. 1) made at the time of collecting the specimen the bones of the skeleton are represented in the position in which they were found embedded in the sandstone.

The destructive work of wind, water, and frost in breaking down fossil bones exposed to their action is well illustrated by certain elements of this skeleton.

Collectors from the Carnegie Museum had partially worked out the skeleton from the conglomeratic sandstone in which it was embedded, as shown in Plate 4. The bones thus uncovered remained exposed to the action of the elements for nearly two years before recovery, and in that time many of them were considerably damaged. When first uncovered the preservation was almost perfect and the bones were dark colored, but with exposure they whitened and became much checked and broken, in several instances considerable parts being lost. While some of the missing portions may perhaps be attributed to vandalism, much of the loss is directly due to erosive disintegration, that is, breaking up into such small particles made it no longer possible to preserve the parts affected. On the other hand, undisturbed bones were found to be dark in color and perfectly preserved. This is an interesting example of the rapidity of the disintegration of fully mineralized bones when exposed to the elements.

The vertebrate fauna of the Dinosaur National Monument as known at the present time is as follows:

Dinosauria:
- Saurischia:
  - *Apatosaurus louisae* Holland.
  - *Barosaurus* sp.
  - *Camarasaurus lentus* (Marsh).
  - *Diplodocus* sp.
  - *Pleurocoelus* sp.
  - *Uintasaurus douglassi* Holland.
  - *Antrodemus* (*Allosaurus*) sp.

Ornithischia:
*Camptosaurus medius* Marsh.
*Dryosaurus altus* Marsh.
*Laosaurus gracilis* Marsh.
*Stegosaurus* sp.
Crocodilomorphi:
*Goniopholis* sp.
Chelonia:
*Glyptops utahensis* Gilmore.
Phytosauromorphi:
*Hoplosuchus kayi* Gilmore.

That this preliminary list will be greatly augmented by the study of material already in hand, there is no doubt.

## THE SPECIES OF DIPLODOCUS

Four species of *Diplodocus* have been proposed. Named in chronological order these are: *Diplodocus longus* Marsh, *D. lacustris* Marsh, *D. carnegii* Hatcher, and *D. hayi* Holland.

*Diplodocus longus*, the genotype, was established in 1878 [2] on caudal vertebrae from the midcaudal region. Hatcher [3] has shown that a hind limb and foot mentioned in the original description pertain to the genus *Apatosaurus* (*Brontosaurus*) and can therefore no longer be considered diagnostic of *Diplodocus*. The type specimen is from the Morrison formation near Canon City, Colo.

In 1884 Marsh [4] described *D. lacustris* from the same formation near Morrison, Colo. In the original description a maxillary, teeth, and lower jaws only are mentioned. This was distinguished from *D. longus* by its smaller size and "the much more slender jaws."

In 1901 Hatcher [5] added a third species, *D. carnegii*, based on a well-preserved skeleton, lacking the skull, from Sheep Creek, Albany County, Wyo.

In 1924 Dr. W. J. Holland [6] described *D. hayi* based on the posterior part of a cranium from Wyoming, chiefly distinguished by the absence of a pineal fontanelle in the parietal.

This brief review of the specimens upon which the four species of *Diplodocus* were based shows at once the impossibility of properly contrasting their essential specific differences, and the specific identification of the National Museum specimen is therefore rendered difficult, if not impossible, until there has been a thorough revision of the genus.

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[2] Marsh, O. C., Amer. Journ. Sci., vol. 16, p. 414, 1878.
[3] Hatcher, J. B., Mem. Carnegie Mus., vol. 1, p. 55, 1901.
[4] Marsh, O. C., Amer. Journ. Sci., vol. 27, p. 166, 1884.
[5] Hatcher, J. B., Mem. Carnegie Mus., vol. 1, p. 57, 1901.
[6] Holland, W. J., Mem. Carnegie Mus., vol. 9, p. 399, 1924.

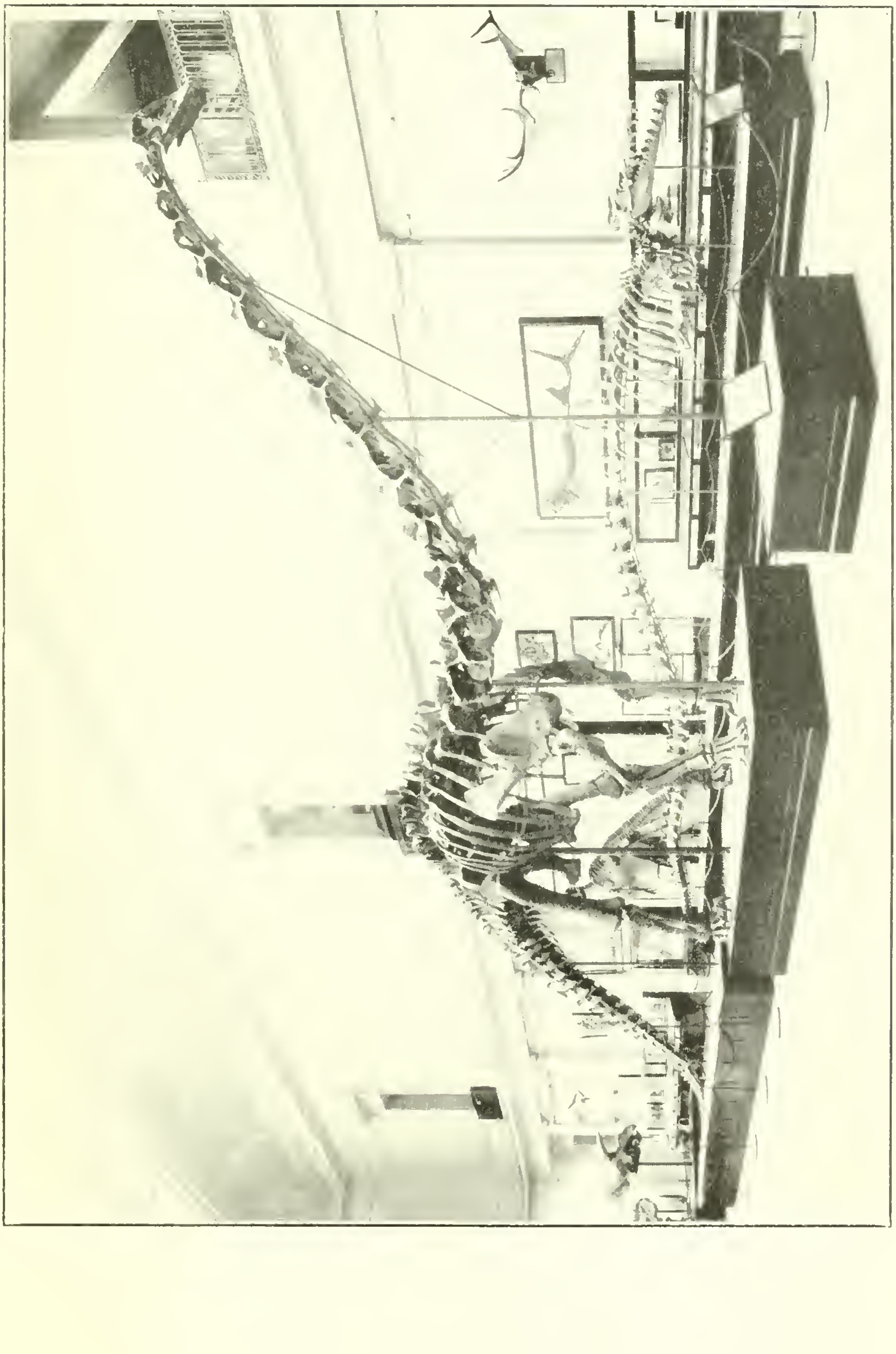
In establishing *D. carnegii*, Hatcher used the more backward inclination of the caudal spines as one of the principal characters for distinguishing it from *D. longus*. The unstableness of this as a distinguishing characteristic is indicated in the present specimen where many of the spinous processes are as much inclined as in *D. carnegii*, while others stand as erect as those of *D. longus*, and is therefore not to be depended upon for distinguishing these two species. Attention is also directed to the fact that since the cervical vertebra originally regarded by Marsh as pertaining to *D. longus* has been shown by Hatcher to pertain to *Apatosaurus* (*Brontosaurus*), the disparity in size of the *D. carnegii* cervical ribs no longer obtains. Thus the species *D. carnegii* is now without specific characterization. Whether the species can be satisfactorily maintained, only a restudy of the original materials can determine. The lack of the skull in the present specimen renders impossible necessary comparisons with the type materials of either *D. lacustris* or *D. hayi*. Under present conditions, therefore, it is practically impossible to identify the specimen under discussion, but in order to avoid further complications in the synonomy I shall tentatively refer it to the species *longus* until a thorough study of the type materials shall disclose the standing of the four species already established.

## POSE OF THE SKELETON

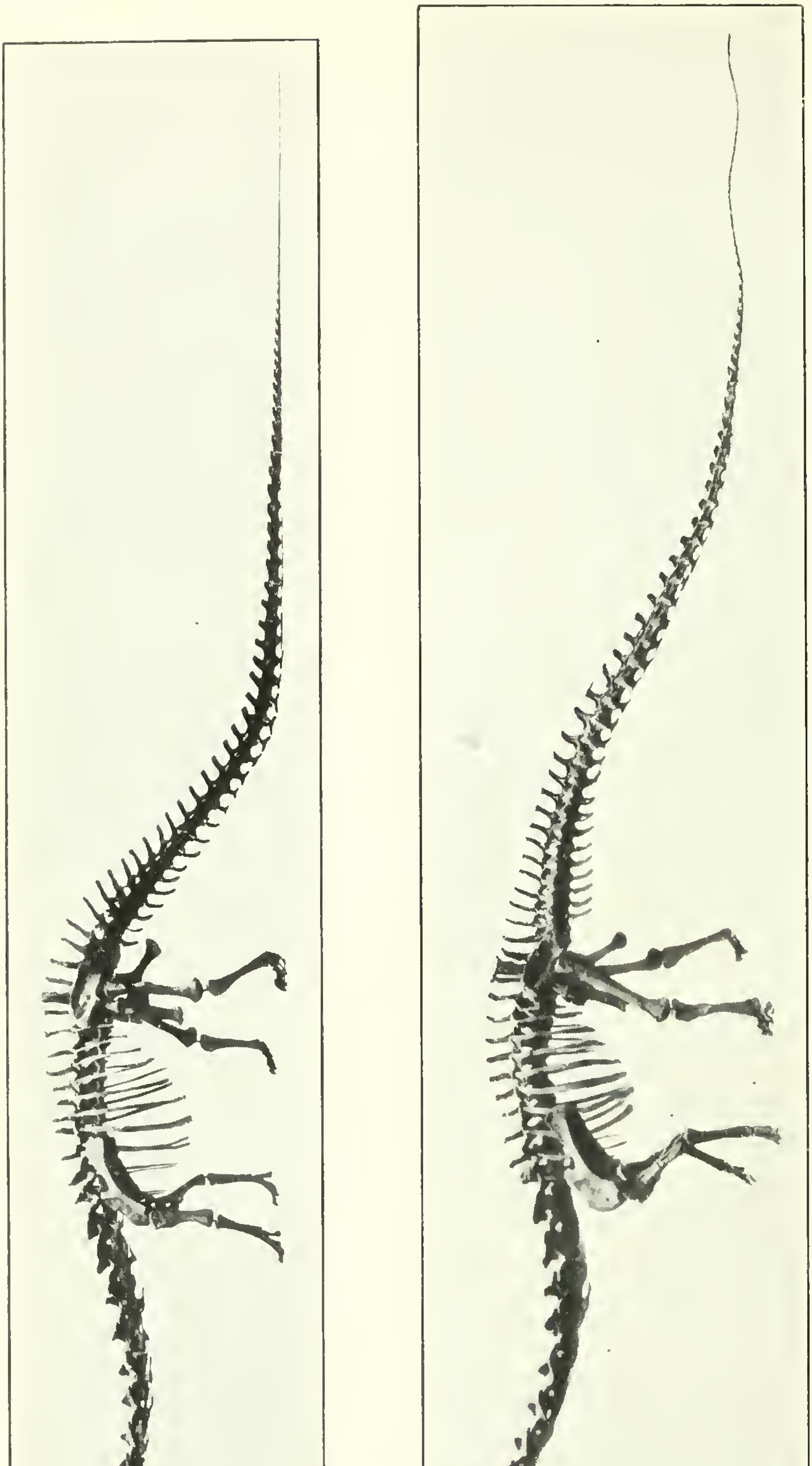
Probably no other extinct animal has been subjected to more intensive study or searching criticism as to the proper pose of a skeleton than has *Diplodocus*. Eminent authorities are divided in their opinion as to whether this animal walked about in a normal upright quadrupedal position or habitually assumed a more prone attitude like the crocodile. Those contending for the first mentioned pose are Hatcher,[7] Osborn,[8] Holland,[9] Abel,[10] and Matthew,[11] while those for the latter are Tornier,[12] Hay,[13] and Hutchinson.[14]

I have in the present mount adopted the quadrupedal pose, and my experience in supervising the articulation of the skeleton has fully convinced me that the crocodilian attitude for *Diplodocus* involves anatomical impossibilities. Nevertheless, the actual articulation of the bones has brought out some points in the anatomy of *Diplodocus* that otherwise would have passed unnoticed. I refer especially to

[7] Mem. Carnegie Mus., vol. 1, no. 1, pp. 57–59, 1901.
[8] Mem. Amer. Mus. Nat. Hist., vol. 1, pp. 191–214, 1899.
[9] Amer. Nat., vol. 44, pp. 259–283, 1910.
[10] Abh. k. k. zool.-bot. Ges. in Wien, vol. 5, pp. 1–60, 1909–10.
[11] Amer. Nat., vol. 44, pp. 547–560, 1910.
[12] Sitz.-Ber. Ges. Naturf. Freunde Berlin, 1909, pp. 193–209.
[13] Amer. Nat., vol. 42, pp. 672–681, 1908; Proc. Washington Acad. Sci., vol. 12, pp. 1–25, 1910.
[14] Geol. Mag. London, vol. 4, pp. 356–370, 1917.



Skeleton of *Diplodocus longus* Marsh (U.S.N.M. No. 10865) as exhibited in the hall of vertebrate paleontology in the United States National Museum



COMPARATIVE VIEWS OF THE MOUNTED SKELETONS OF DIPLODOCUS CARNEGII AND D. LONGUS

Upper figure: Mounted skeleton of *Diplodocus carnegii* in the Carnegie Museum, Pittsburgh, Pa. Lower figure: Mounted skeleton of *Diplodocus longus* in the United States National Museum. Both views are from the left side, and both are about 1/120 natural size.

the upward curvature of the vertebral column both before and behind the sacral region. In previous restorations of *Diplodocus* the presacral region is depicted as extending nearly straight out from the sacrum, the caudals forming a rapidly drooping tail. This idea was carried out in the mounting of the original skeleton of *D. carnegii* and its many replicas distributed over the world. The present specimen shows an error in both of these respects. The articulated presacrals in our specimen have a decided upward arcuation of the column beginning with the vertebrae immediately in front of the sacrum. That this is a natural arrangement seems to be indicated by the peculiar character of the most posterior dorsals, which have the tall spinous processes strongly inclined forward of the vertical axis of the vertebrae as a whole. In other words, when the tenth dorsal vertebra is in position the lower half is inclined backward, which brings the forward leaning spine into a nearly vertical position and thus the spines are evenly spaced; whereas in both the Carnegie Museum and American Museum specimens there are wide gaps between the sacrodorsal and the first free dorsal in front of it. In the Carnegie specimen the spine was detached when found and in restoring it was placed in a vertical position. Similarly in the American Museum specimen the first free dorsal in front of the sacrum which lacked the centrum was restored with the spine in a vertical position. In both instances the wide gap between the tops of the spines resulted when the bones were articulated.

Forward of the mid-thoracic region the column starts the reverse curve downward; thus this part of the backbone has a more natural arched curvature than has previously been given it. This upward curve of the presacral region makes the mid dorsals the highest point above the ground, whereas in the *Diplodocus carnegii* specimen the sacral region is highest.

In so far as the pose of the tail is concerned, the Pittsburgh authorities now recognize the incorrectness of the *D. carnegii* specimen, and in the mounted skeleton of *Apatosaurus* in this same institution the tail is carried far out from the sacrum before beginning to droop toward the ground. This same result was attained by the articulation of the actual bones in the present skeleton, brought about by the decided V-shaped centrum of caudal 3, which is much shorter above than below, and Lull [15] found that the same condition obtains in *Camarasaurus* and *Brontosaurus*. The upward curvature of the tail in the sauropodous dinosaurs bears a striking resemblance to that of the large extant lizard *Varanus komodoensis*.

It would thus seem that all the Sauropoda are so constituted. The elevation of this part of the tail well outward above the posteriorly

[15] Amer. Journ. Sci., vol. 19, pp. 1–5, 1930.

directed ischia gives plenty of room for the extrusion of the egg, a question raised by the late Dr. S. W. Williston upon viewing the rapidly drooping tail of *D. carnegii* for the first time.

The National Museum skeleton as restored has a greatest length between perpendiculars of 70 feet 2 inches, and in front of the hips the tops of the spinous processes of the vertebrae are 12 feet 5 inches above the ground. The head in the pose adopted is 14 feet 6 inches high, but it is clearly apparent that in life it could have been elevated still higher.

The skeleton of *D. carnegii* is said to be 84½ feet in length (probably measured over the curve of the backbone) and 14½ feet high at the hips. I am at a loss to explain the difference in height between the two skeletons, especially since the individual limb bones of the two specimens have practically the same linear dimensions. The difference in length may be accounted for by the slightly greater length of the individual vertebrae of *D. carnegii* and by the omission in the present skeleton of four caudal vertebrae as mentioned elsewhere.

## NOTES ON THE DETAILED SKELETAL ANATOMY OF DIPLODOCUS

Since the skeletal parts of *Diplodocus* have been described in great detail by Marsh, Osborn, Hatcher, and Holland, it is now only necessary to call attention to certain anatomical details displayed for the first time by the specimen here described.

*Dorsal vertebrae.*—The complete dorsal series of 10 vertebrae was found in articulated sequence with the sacrum completely interlocked by their zygapophyses. This specimen thus positively confirms Hatcher's serial determination of the dorsals in *D. carnegii*, some of which were originally found displaced. Comparison of the dorsal vertebrae of the present specimen with the illustrations and descriptions [16] of these bones of *D. carnegii* shows them to be in accord in all important particulars, any differences being confined chiefly to the position and direction of the various buttressing laminae; but since no two vertebrae in the series are alike, and since great dissimilarities often exist on opposite sides of the same vertebra, the differences noted between the dorsals of these two specimens are not considered of much import.

Viewed antero-posteriorly the spines of the vertebrae of the posterior half of the column are relatively wider than in *D. carnegii*, on account of a widening of the lateral laminae. The tall simple spines of the posterior dorsals are succeeded anteriorly by emarginate spines at the apex that become progressively cleft deeper and deeper until in the anterior dorsals there are two distinct parallel

[16] Mem. Carnegie Mus., vol. 1, no. 1, 1901.

spines. The sixth vertebra is the first to show a decided cleft, but in the present specimen it is considerably shallower than in the homologous vertebra of the *D. carnegii* skeleton.

The relative position of the rib articulations, the size of the pleurocels, and the shape and extent of the transverse processes are all in accord with *D. carnegii*. The tenth dorsal is of interest in having the spine intact, the first specimen found showing its true relationship to the lower half of the vertebra. The spine is strongly inclined forward of the vertical axis of the vertebra as a whole. In other words, when the vertebra is placed in an articulated position the lower half is inclined backward (see fig. 2), which brings the forwardly inclined spine into a nearly vertical position. Especial mention is made of this feature for the reason that in previous restorations the tenth vertebral spine has been either restored or replaced in the vertical axis, and when articulated a faulty spacing of the spine top in relation to others of the series has resulted. This forward angulation in the present specimen brings about a fairly uniform spacing of the spines, as would be expected.

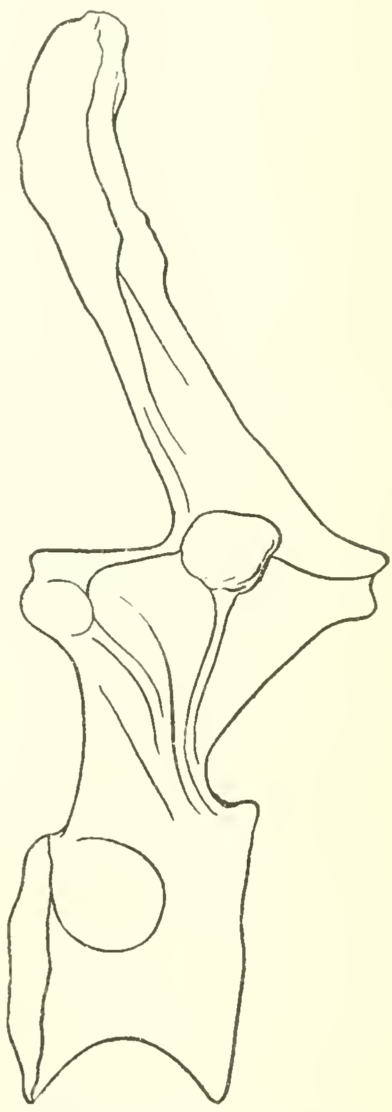


FIGURE 2.—Outline of tenth dorsal vertebra, U.S.N.M. No. 10865, to show forward inclination of the spinous process. About one-sixth natural size

Mention should also be made of the extreme closeness of the articulations of the vertebral centra, indicating a very thin disk of cartilage between their ends. The evidence afforded by this articulated series, and it applies equally well to the caudal vertebrae, refutes the more or less prevalent idea that in articulating dinosaur skeletons the vertebrae should be perceptibly drawn apart to allow for a thick disk of intercentral cartilage.

On account of the vicissitudes of fossilization the transverse processes of the right side of the dorsal vertebrae have been crushed upward somewhat above their natural position, so that with the ribs articulated the contour of the thorax of the two sides presents slightly different outlines.

The principal dimensions of the dorsal vertebrae are given in Table 1.

TABLE 1.—*Comparative measurements of dorsal vertebrae of* Diplodocus

| Vertebra No. | Greatest length of centrum | | Greatest transverse diameter of centra, posterior end | | Greatest height of vertebrae | |
|---|---|---|---|---|---|---|
| | U.S.N.M. No. 10865 | C. M. No. 84 | U.S.N.M. No. 10865 | C. M. No. 84 | U.S.N.M. No. 10865 | C. M. No. 84 |
| | *Mm* | *Mm* | *Mm* | *Mm* | *Mm* | *Mm* |
| 1 | 460 | 510 | 270 | 255 | 650 | 614 |
| 2 | 376 | 416 | 250 | 233 | 740 | 691 |
| 3 | 340 | 326 | 270 | 311 | 775 | 722 |
| 4 | 275 | 318 | 283 | 343 | 750 | 718 |
| 5 | 253 | 255 | 283 | 300 | 765 | 781 |
| 6 | 260 | 255 | 270 | 280 | 800 | 793 |
| 7 | 280 | 264 | 275 | 280 | 835 | 810 |
| 8 | 243 | 275 | 280 | 309 | 874 | 847 |
| 9 | 230 | 290 | 295 | 288 | 900 | 946 |
| 10 | 200 | 267 | 340 | 313 | 936 | 966 |

*Sacral vertebrae.*—The complete sacrum is present with both ilia in position. It consists of five ankylosed vertebrae, all of which are coossified with and give support to the ilia. The conditions found to obtain in the sacral region are very similar to those described by Hatcher [17] in *Diplodocus carnegii*, differing only in minor details. The neural spines of the three middle sacrals have coalesced into a single spine, which in this individual is especially massive, being subequally expanded transversely and anteroposteriorly. The presence of three separate bony ossicles interposed between the tops of the spines is unique, as but a single one has previously been found. The most anterior of these ossicles lies between dorsal 10 and sacral 1; the second between sacrals 1 and 2, and the third between sacrals 4 and 5.

These ossicles are massive, subtriangular in shape, and conform nicely to the interspace between the spines. Their rugose surfaces indicate their inclusion in cartilage, as there is no indication of actual contact of the bone surfaces. It seems quite probable that similar ossicles were present between the spines of the three now coossified, but all trace of their union is obliterated, so that one can not be sure of the condition suggested.

*Caudal vertebrae.*—The caudal region has been fully described by previous authors, and at this time it appears only necessary to call attention to certain details displayed for the first time in *Diplodocus* by this particular individual.

In their general proportions, development of laminae, and progressive structural changes, the caudal vertebrae of this specimen agree very closely with the American Museum specimen of *Diplo-*

[17] Mem. Carnegie Mus., vol. 1, p. 30, 1901.

*docus longus* as described by Osborn.[18] The vertebrae steadily increase in length from the first to the eighteenth and then diminish to the last of the series; the median cleft on the summit of the spines disappears posterior to caudal 8, the diapophyses reduce in size posteriorly, and the lateral cavities extend as far back as the nineteenth vertebra.

An interesting feature of this tail is the complete coossification of the seventeenth, eighteenth, nineteenth, and twentieth vertebrae into a solid rigid section (see fig. 3); and in front of this section caudals 15 and 16 are similarly but less fully united. Coossification of the caudal vertebrae in *Diplodocus* has been previously noted by Hatcher [19] in specimen No. 94 of the Carnegie Museum, where the seventeenth and eighteenth are coossified, and again in Carnegie Museum specimen No. 84, of caudals 2 and 3. Holland [20] in a later communication points out that more careful study indicates that the coossified vertebrae designated the seventeenth and eighteenth by Hatcher in specimen No. 94 are Nos. 20 and 21 of the series, and he adds the information that Nos. 24 and 25 of this same specimen are also coossified.

The coossification of these tail vertebrae in *Diplodocus* has been directly attributed to traumatic causes, but in the National

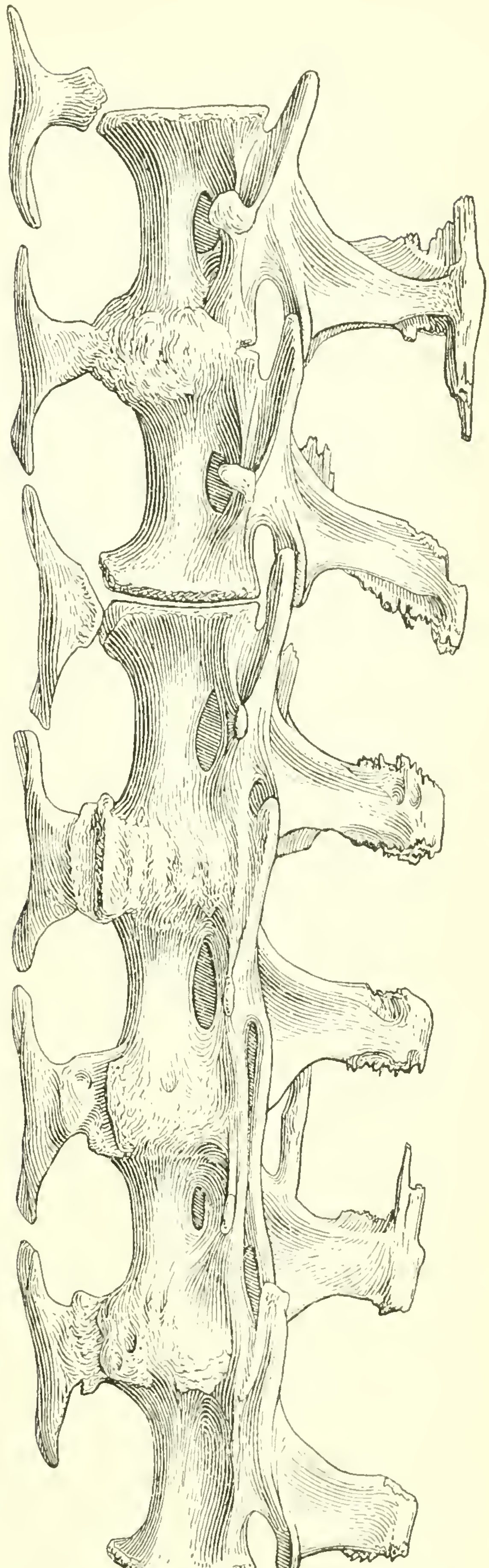


FIGURE 3.—Coossified caudal vertebrae (fifteenth to the twentieth) of *Diplodocus longus*. About one-eleventh natural size

[18] Mem. Amer. Mus. Nat. Hist., vol. 1, pp. 204–209, 1899.

[19] Mem. Carnegie Mus., vol. 1, no. 1, p. 36, 1901.

[20] Amer. Nat., vol. 44, p. 255, 1910.

Museum specimen there are reasons for believing they may be due to senility. In the first place there is no distortion of the bones, and while there is a small excess of extraneous bony matter extending over the joints, it is in no way comparable to the lesion on sauropod caudals described and illustrated by Moodie.[21]

Secondly, the ligaments connecting the spines have also ossified to some extent in this solid section as well as in front of it, as is clearly shown in Figure 3. Between the spines of Nos. 18 and 19 at their bases a completely ossified ligamentary bar joins the two, as shown in Figure 3.

Why coossification of the vertebra should take place in this particular section of the tail is difficult of explanation. Hatcher explained it as being the point where the tail first touched the ground and for that reason was more susceptible to injury. With the dorsal elevation of the tail, it no longer touches the ground in this region but posterior to it, and thus this explanation no longer obtains.

The tail as reconstructed in the present skeleton consists of 31 original caudal vertebrae, 29 of which form a continuous series with the sacrals. The other two vertebrae were found disarticulated, but not far removed from the end of the above-mentioned series. These are thought to represent the thirty-third and thirty-fifth, respectively. The missing vertebrae, including the long whiplike extremity, have been replaced by casts made from the composite tail of the *Diplodocus* skeleton in the Carnegie Museum.

In introducing these casts considerable disparity in size between caudals of the same serial position in the two specimens was found, and we were obliged to omit four vertebrae from the Pittsburgh series on account of their larger size. In other words, the thirtieth as used in the present skeleton is the thirty-fourth of the Carnegie Museum specimen. This omission shortens the tail by 3 feet, as contrasted with the Pittsburgh caudal series.

A distal caudal centrum (Qu. No. 82) with some of the neural arch found with the other scattered caudals at the end of the articulated series could not be used because of its reduced length, being considerably shorter than any of the casts of this section of the tail. Whether this abbreviated caudal indicates a shorter tail in this individual, or whether it does not pertain to the present specimen, is a question that can not be determined until a complete articulated caudal series of *Diplodocus* is discovered in the Dinosaur National Monument area. At this time it seems best to omit it and complete the whiplike portion with the casts of the Pittsburgh specimen which formed an articulated [22] series.

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[21] Amer. Journ. Sci., vol. 41, pp. 530–531, fig. 1, 1916.

[22] Holland, W. J., Mem. Carnegie Mus., vol. 2, no. 6, p. 253, 1906.

TABLE 2.—*Comparative measurements of caudal vertebrae of* Diplodocus

| Vertebra No. | Greatest length of centrum | | | Greatest diameter of centrum, posterior end | | Greatest height of vertebra, above middle of inferior border | |
|---|---|---|---|---|---|---|---|
| | U.S.N.M. No. 10865 | C. M. No. 84 | A. M. N. H. No. 223 | U. S. N. M. No. 10865 | C. M. No. 84 | U.S.N.M. No. 10865 | C. M. No. 84 |
| | *Mm* | *Mm* | *Mm* | *Mm* | *Mm* | *Mm* | *Mm* |
| 1 | 160 | 183 | 152 | 354 | 334 | 917 | 1,049 |
| 2 | 190 | | 163 | 360 | | 827 | 995 |
| 3 | 210 | | 182 | 332 | 332 | 800 | 897 |
| 4 | 230 | 250 | 193 | 312 | 330 | 761 | 830 |
| 5 | 240 | 250 | 205 | 299 | 325 | 702 | 777 |
| 6 | 240 | 237 | 210 | 327 | 309 | 680 | 744 |
| 7 | 245 | 237 | 216 | 327 | 317 | 665 | 690 |
| 8 | 240 | 246 | 215 | 325 | 309 | 586 | 675 |
| 9 | 240 | 270 | 214 | 318 | 300 | 570 | 651 |
| 10 | 250 | 269 | 241 | 302 | 295 | 555 | 610 |
| 11 | 260 | 269 | 267 | 288 | 285 | 530 | 610 |
| 12 | 280 | 295 | 277 | 265 | 272 | 523 | 576 |
| 13 | 290 | | 270 | 260 | | 507 | |
| 14 | 300 | | 305 | 252 | | 480 | |
| 15 | 305 | | 290 | 248 | | 435 | |
| 16 | 310 | | 318 | 228 | | 427 | |
| 17 | 320 | | 300 | | | 400 | |
| 18 | 325 | | 320 | | | 397 | |
| 19 | 310 | | 310 | | | 378 | |
| 20 | 305 | | 300 | 186 | | 340 | |
| 21 | 298 | | 297 | 171 | | 302 | |
| 22 | 288 | | 296 | 164 | | 269 | |
| 23 | 280 | | 285 | 147 | | | |
| 24 | 272 | | 272 | 143 | | 229 | |
| 25 | 265 | | 255 | 132 | | 225 | |
| 26 | 253 | | 242 | 124 | | 188 | |
| 27 | 235 | | 225 | 112 | | 178 | |
| 28 | 223 | | 212 | 93 | | 175 | |
| 29 | 205 | | 201 | 88 | | 167 | |
| 30 | | | | | | | |
| 31 | | | | | | | |
| 32 | | | | | | | |
| 33 | 163 | | | 74 | | 160 | |
| 34 | | | | | | | |
| 35 | 155 | | | 68 | | 128 | |

*Chevrons.*—The total number of chevron bones in *Diplodocus* is unknown at this time. In the specimen described by Osborn [23] there were 26, and this number has been followed in later restorations of the tail. I am inclined to the opinion that a still greater number will eventually be found. In the present specimen 18 chevron bones are represented wholly or in part. Six of these were found articulated, one between caudals 4 and 5, and the remaining 5 from near the middle of the tail were coossified with their respective vertebrae.

For the sake of clearness the chevrons are enumerated with the vertebrae; that is, the first chevron which occurs between the

[23] Mem. Amer. Mus. Nat. Hist., vol. 1, pt. 5, p. 200, 1899.

second and third caudals is designated the third. Thus numbered, the fourth, sixteenth, eighteenth, nineteenth, twentieth, and twenty-first were found articulated. From these fixed points the other more or less scattered elements have been allocated.

A large chevron bone found near the proximal caudals was at first thought to belong to the present specimen, but its very large size with an open haemal canal was not in accord with the known chevron of this region in *Diplodocus*, and it therefore has been omitted from the skeleton.

The twelfth chevron, arbitrarily placed in the series, is unlike any known chevron of *Diplodocus* either in shape or position in the series, but its occurrence in relation to the tail and its general features both suggest relationship with the present specimen. This bone is open above the haemal arch, expanded at its base with an elongated extension that turns posteriorly nearly at right angles to the articular portion. In the specimen described by Osborn all chevrons are closed above the haemal canal as far posterior as the thirteenth chevron. With the few exceptions briefly discussed, all the other chevron bones are in accord with previously known specimens, which have been fully described by Osborn and Hatcher.

*Ribs.*—Of the 20 thoracic ribs that form the complete series in *Diplodocus*, 10 are preserved in the present specimen. The first is missing from the left side, but the other nine were found articulated with their respective vertebrae. The remaining rib, the third of the right side, was found disarticulated but not far removed from the vertebral column. The ninth and tenth ribs were fully coalesced with the diapophyses of the vertebrae and the eighth partially so, thus giving additional evidence of the senile character of the individual. Riggs[24] has observed a somewhat similar condition in *Apatosaurus* in that the last rib was fully ankylosed with the transverse process.

The ribs, except for the loss of minor portions, are in a splendid state of preservation, and having suffered but little distortion from post-mortem causes they display for the first time the true shape of the thorax.

The ribs as articulated differ from previous reconstructions in two important particulars—first, a decided backward sweep of the lower portion of the shafts of the third and fourth; and second, the strong inward curvature of the distal portion of the posterior members of the series. In both of these respects they are in striking contrast to the more or less straight ribs in the *Diplodocus carnegii* skeleton in Pittsburgh. Critical examination of the plaster ribs

[24] Field Columbian Mus. Publ. 82, vol. 2, p. 177, 1903.

cast from the above-mentioned specimen, which were used to replace those missing, seems to show that the originals had been somewhat straightened, probably to conform to some preconceived notion. This backward curvature of the heavier ribs is not a feature new to sauropodous dinosaurs, as evidenced by mounted skeletons of *Apatosaurus* (*Brontosaurus*) in the Field Museum of Natural History, Chicago, and the American Museum of Natural History, New York. It therefore should occasion no especial comment that a somewhat similar condition is now found to exist in *Diplodocus*.

The body proper is short and deep as indicated by the ribs, some of which are more than 5 feet in length. The five posterior ribs, however, all of which are completely preserved, have a decided inward curvature beginning a foot or more above their distal ends. This inward deflection outlines the body as passing smoothly inward to form the flank, which in turn coincides with the form of the lower pelvic bones.

As mentioned previously the tenth rib was fully coalesced with the diapophyses, and it shows this rib as bending forward from the transverse process far enough to clear fully the anterior end of the ilium. In the Pittsburgh and American Museum specimens as articulated it extends downward inside the blade of the ilium. From the evidence of the present specimen it would seem that the position of this rib varies with the individual.

The position of the scapula along the anterior ribs seems to be indicated by a flattening of their upper halves on the outside, which could be of no other use than that mentioned.

Measured over the curve, the complete ribs of this specimen have the lengths given in Table 3.

TABLE 3.—*Comparative measurements of ribs of* Diplodocus

| Rib No. | U.S.N.M. No. 10865 | C. M. No. 84 | A. M. N. H. No. 223 | Rib No. | U.S.N.M. No. 10865 | C. M. No. 84 | A. M. N. H. No. 223 |
|---|---|---|---|---|---|---|---|
| | *Mm* | *Mm* | *Mm* | | *Mm* | *Mm* | *Mm* |
| 1 | | 1,057 | | 6 | 1,680 | 1,680 | |
| 2 | [1] 1,205 | 1,300 | | 7 | 1,515 | 1,580 | |
| 3 | | 1,590 | | 8 | 1,325 | 1,330 | 1,320 |
| 4 | | 1,710 | | 9 | 1,207 | 1,140 | 1,100 |
| 5 | [1] 1,632 | 1,727 | | 10 | [1] 870 | 795 | 794 |

[1] Estimated.

*Scapula*.—There has been the greatest diversity of opinion among paleontologists as to the proper position of the scapula in the skeletons of sauropodous dinosaurs.

Scapulae have been articulated high up on the ribs, in an inclined position, nearly vertical, and low down in a horizontal pose. Perhaps the most radical departure from previously held views is that of Osborn and Mook in a reconstruction of *Camarasaurus supremus* in which the shoulder blade is placed in a nearly vertical position that brought about a great elevation of the shoulders, making this the highest point in the vertebral column. The natural downward curve of the anterior dorsal vertebrae in the present skeleton renders this pose impossible in *Diplodocus.* There seems to be further objection on account of the fact that with the scapula in a nearly vertical pose the coalesced coracoid has its lowermost extremity thrown in so close to the front of the humerus as seriously to interfere with its movement, whereas a more horizontal position at once relieves this condition.

In the present skeleton the scapula has been posed in a more inclined position for the reason that the anterior ribs have flattened external surfaces that seem adapted to the purpose of providing a surface over which the elongated blade of the scapula could play. Furthermore, an articulated skeleton of *Camarasaurus lentus* [25] in the Carnegie Museum gives first-hand evidence that the scapula in sauropodous dinosaurs occupied a more horizontal position. In this connection it is of interest to note that Prof. R. S. Lull has reached the same conclusion as illustrated by the skeleton of *Camarasaurus lentus* and *Brontosaurus excelsus* recently mounted under his direction.[26]

TABLE 4.—*Comparative measurements of scapula and coracoid of* Diplodocus

| Measurement | U.S.N.M. No. 10865 | C. M. No. 84 |
|---|---|---|
| | *Mm* | *Mm* |
| Combined length of scapula and coracoid | 1,508 | 1,600 |
| Greatest length of scapula | 1,153 | 1,240 |
| Greatest breadth of scapula | 602 | 605 |
| Least breadth of scapula | 228 | 204 |
| Length of coracoid | 355 | 512 |
| Greatest expanse of glenoid cavity | 320 | 274 |

*Pelvis.*—The complete pelvic arch was recovered. The ilia were found attached to the sacrum, but the pubes and ischia, though each pair remains articulated, had been shifted to the eastward of the main part of the skeleton. These bones are in full accord with Hatcher's description of the pelvis of *Diplodocus* and call for no special comment here. Their principal dimensions are given in Table 5.

[25] Gilmore, C. W., Mem. Carnegie Mus., vol. 10, p. 376, pls. 14, 17, 1925.
[26] Amer. Journ. Sci., vol. 19, p. 3, fig. 1, 1930.

TABLE 5.—*Measurements of pelvic bones of* Diplodocus

| Measurement | U.S.N.M. No. 10865 | C. M. No. 84 |
|---|---|---|
| | *Mm* | *Mm* |
| Greatest length of ilium | 945 | 1,089 |
| Greatest width of pelvis across the posterior end | 920 | |
| Greatest depth of ilium through greater peduncle | 635 | |
| Greatest width of acetabulum | 380 | |
| Greatest width of centrum of fifth sacral | 384 | |
| Greatest length of pubes | 820 | 1,000 |
| Greatest breadth of proximal end | 410 | 400 |
| Greatest length of ischium | 870 | 940 |
| Greatest breadth of proximal end | 515 | 435 |

*Fore limb.*—The preservation of both humeri, the ulnae, and the right radius with this specimen makes these, so far as I can learn, the most complete fore limbs yet found in definite association with so complete a skeleton of *Diplodocus.* Furthermore, the right limb was found articulated at the elbow, and it gave proof of the correctness of Hatcher's observations [27] as to the proper articulation of these bones at this joint. Reference is especially made to the position of the proximal end of the ulna, which almost entirely incloses the radius and has its articular surface opposed to that of the humerus throughout its entire breadth. The radius articulates with the median anterior surface of the humerus only.

The most striking feature of the *Diplodocus* humerus is the strong angulation of the two ends in relation to each other. In other words, planes passed through their greatest diameters would bisect one another at an angle of 45°. When placed in position in the articulated limb this torque throws the deltoid crest far in under the main axis of the bone. The head is situated in about the middle of the proximal end and is not produced backward beyond the posterior border. At the distal end the ulnar and radial condyles are feebly developed in front and separated by a longitudinal groove. The anconeal fossa is moderate in depth.

The radius and ulna have been illustrated and described by Hatcher [28] so that it is needless to mention them further here.

The restriction of the articular surface of the two extremities of the humerus entirely to the ends and the almost total absence of an olecranon process on the ulna are both features indicating that the limb was not greatly flexed at the elbow in a standing position, a fact that is quite in keeping with the great weight to which they gave support. These features are in striking contrast to the robust olecranon and extensive articular surface of the humerus in such strongly flexed limbs as are found in *Stegosaurus* and *Triceratops.*

[27] Mem. Carnegie Mus., vol. 2, no. 1, pp. 72, 73, 1903.
[28] Loc. cit. pp. 72–73.

The principal measurements of the fore limb are as follows:

| | Mm |
|---|---|
| Humerus, length | 1,010 |
| Humerus, least circumference | 440 |
| Ulna, length | 740 |
| Ulna, least circumference | 295 |
| Radius, length | 690 |
| Radius, least circumference | 244 |

The missing fore feet have been replaced by casts furnished by the Carnegie Museum, whose composition is based, according to Hatcher, upon specimens and descriptions kindly furnished by Dr. H. F. Osborn, of the American Museum of Natural History.

Positive determination of their correctness is still wanting, for these elements are missing in the five more or less complete skeletons of *Diplodocus* now known. The feet as they came to us were provided with three terminal phalanges, but in the present mount all but the first have been omitted for the reason that on the many articulated fore feet now known of sauropodous dinosaurs never has more than one clawlike ungual been found and that on Digit I. It therefore seems reasonable to suppose that *Diplodocus* had a similarly constructed manus. In fact, in a foot attributed to *Diplodocus* described by Osborn [29] mention is made of a single terminal phalanx only.

*Hind limb.*—The right hind limb, including the tarsus and pes, was found complete and articulated. The femur when compared with that of *D. carnegii* (C. M. No. 84) is relatively slenderer, and the two ends are much less expanded, as is clearly indicated in the table of comparative measurements. Otherwise the two bones are in accord. Although the present femur is slightly longer than either of those of the Carnegie Museum specimen, the tibia is slightly shorter. However, these differences in length are so slight as to be readily accounted for by individual variation, or perhaps they are due to elongation through pressure from the weight of superimposed strata. The tibia and fibulae are of the elongated type typical of the relatively slender-limbed *Diplodocus*.

The osseous portion of the tarsus consists of the astragulus only. The pes is complete and displays the digital formula 2, 3, 3, 2, 2. Digits I, II, and III are terminated by clawlike unguals that progressively decrease in size toward the outer side of the foot. The ungual of Digit I has much of the tip missing, probably on account of an injury during life, since the end is rounded and healed. The presence of a small clawed ungual on the third toe fully confirms Hatcher's surmise that such a bone existed, although it was missing from the specimen studied by him.

[29] Bull. Amer. Mus. Nat. Hist., vol. 14, p. 205, 1901.

There was no evidence of a third phalanx on Digit III, although the *D. carnegii* pes shows four. There was a single atrophied phalanx on Digit V. The absence of this bone in the foot of *D. carnegii* suggests that it may have entirely disappeared in some individuals of *Diplodocus*, although present in *Brontosaurus*. Metatarsal V is much stouter and has a wider and more robust proximal end than the corresponding element of the *D. carnegii* pes, but the proportions of the other bones are remarkably similar.

TABLE 6.—*Comparative measurements of hind limbs of* Diplodocus

| Measurement | U.S.N.M. No. 10865 | C. M. No. 84 | C. M. No. 94 |
|---|---|---|---|
| FEMUR: | *Mm* | *Mm* | *Mm* |
| Greatest length | 1,600 | 1,542 | 1,470 |
| Breadth, proximal end | 349 | 500 | 390 |
| Breadth, distal end | 298 | 412 | 365 |
| TIBIA: | | | |
| Greatest length | 960 | | 1,006 |
| Breadth, proximal end | 363 | | 274 |
| Breadth, distal end | 240 | | 195 |
| FIBULA: | | | |
| Greatest length | 1,055 | | 1,050 |
| Breadth, proximal end | 216 | | 213 |
| Breadth, distal end | 175 | | 155 |

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