The skeletal reconstruction of *Barosaurus lentus* in the American Museum of Natural History

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**Abstract**

XXX to follow

**Keywords:** *Barosaurus*, sauropod, neck, rearing, skeletal mount

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# Introduction

*Barosaurus* is a diplodocid sauropod from the Late Jurassic of North America, found in the extensive Morrison Formation of the western states. It closely resembles its relative *Diplodocus* in most respects but is characterised by an extremely long neck, even by sauropod standards. In the popular imagination, it is typified by the iconic rearing mount in the rotunda of the American Museum of Natural History (Figure A).

Although the material that the mount is based on (the partial skeleton AMNH 6341) has never been described in detail, the mounted skeleton has been enormously significant culturally, and it is due to this that *Barosaurus* is universally recognised as proportionally long necked in popular books (e.g. Bartram et al. 1983, Lindsay 1992, Lambert 2000). Along with the Carnegie *Diplodocus* CM 84 and *Apatosaurus* CM 3018, and the Berlin *Giraffatitan* MB.R.2181, it has been one of the keystone specimens in establishing the perception of sauropods by the general public.

There are two popular accounts of the *Barosaurus* mount (Norell et al. 1991, Dingus 1996:21–26) but as yet no scientific account has been published. In this paper, we will review the history of *Barosaurus*, and consider composition of the mounted *Barosaurus* skeleton in the spirit of Janensch’s (1950) review of the original Berlin mounting of *Giraffatitan* (= “*Brachiosaurus*” of his usage) *brancai*. We will determine which parts are cast from the main specimen AMNH 6341, which from other specimens, which sculpted, etc. We will discuss how scaling was calculated and how the pose was decided on, and discuss the controversy generated by the mount.

## Anatomical nomenclature

C*n* indicates the *n*th cervical vertebra, Ca*n* indicates the *n*th caudal vertebra.

## Institutional abbreviations

* AMNH — American Museum of Natural History, New York, New York, USA.
* CM — Carnegie Museum of Natural History, Pittsburgh, Pennsylvania, USA.
* HMNS — Houston Museum of Nature and Science, Houston, Texas, USA.
* MB — Museum für Naturkunde Berlin, Berlin, Germany; specimen numbers for fossil reptiles take the form MB.R.*nnnn*.
* USNM – United States National Museum, Washington DC, USA.
* YPM — Yale Peabody Museum, New Haven, Connecticut, USA.

# Historical background

## Early discoveries of *Barosaurus*

As recounted in McIntosh (2005:40–41), the first fossils of what is now *Barosaurus* were discovered in the 1880s by Mrs. E. R. Ellerman on land owned by Mrs. Rachel Hatch half a mile east of Piedmont on the eastern rim of the Black Hills of South Dakota. In the summer of 1189, O. C. Marsh visited the site with J. B. Hatcher, and collected part of the tail, obtaining a promise from Ellerman and Hatch that they would protect the rest of the specimen until it could be collected. Based on six caudal vertebrae and a chevron from this initial excavation, Marsh (1890) very briefly described and named the new genus and species *Barosaurus lentus* in a six-page paper in which he also cursorily described the theropod *Ornithomimus* and two new species of *Triceratops*. The only *Barosaurus* elements mentioned in Marsh’s description were caudal vertebrae, and a single mid-caudal centrum was illustrated (Marsh 1890: figures 1–2). Marsh’s diagnosis noted only that the caudals resembled those of *Diplodocus* but varied from them in several ways that subsequently turned out to be errors brought about by comparing more anterior *Barosaurus* caudals with more posterior *Diplodocus* caudals.

It was not until eight years later that Marsh attempted to have the rest of the skeleton collected, sending George Wieland in late August 1898. In the intervening time, Mrs. Ellerman had died and parts of the skeleton had been taken by locals, but Wieland was able to reunite much of this material and excavate what remained underground, apparently working alone (Wieland 1920:529). All the material was shipped to Yale and added to the holotype under the specimen number YPM 429.

However, Marsh died the next year, and work on the specimen stalled. Almost two further decades passed before YPM 429 was fully prepared and Richard S. Lull was able to make a presentation of the specimen at the end of 1916 at the eighth annual meeting of the Paleontological Society in Albany, NY. Unfortunately, his abstract (Lull 1917), at only 74 in length, is largely uninformative. More happily he described the specimen in detail in a significant monograph (Lull 1919), which remained the definitive publication on *Barosaurus* until McIntosh’s (2005) revision.

Since Lull’s monograph, *Barosaurus* has become known from several additional specimens. These include several excavated by Earl Douglass, working for the Carnegie Museum, at what is now Dinosaur National Monument, north of Jensen, Utah. One of these specimens was broken up into a cervical sequence CM 1198 (consisting of cervicals ?12, ?13 and ?16) and the postcervical skeleton ROM 3670 — now reunited at the Royal Ontario Museum in Canada under the specimen number ROM 3670. Also excavated by Douglass from Dinosaur National Monument is CM 11984, another partial cervical sequence consisting of C7–C15 but still not fully prepared, residing the collections of the Carnegie Museum.

Diplodocid material from the Tendaguru Formation of Tanzania was rather casually referred to the new species *Barosaurus africanus* by Janensch (1922:464), but the complex nomenclatural history of this species can be ignored for our present purposes as it is now regarded as belonging to the separate genus *Tornieria* as the species *Tornieria africana*.

The most complete and informative *Barosaurus* specimen to date is AMNH 6341, the individual that provided most of the material for the AMNH rotunda mount. It was briefly described as part of McIntosh’s (2005) revision of the genus *Barosaurus*, but has yet to be described in detail. For the remainder of this paper, we will focus on this specimen.

## The AMNH specimen of *Barosaurus*

Earl Douglass had first discovered dinosaur fossils at Dinosaur National Monument in 1909 (Gilmore 1932:2), and so had been working the area for a full decade by 1919, when the expedition sponsor Andrew Carnegie died at the age of 83. It was apparent that work at the quarry would soon end without his funding, and Douglass joined the staff of the University of Utah. Beginning in 1922, two fine diplodocine skeletons where partially excavated from the easternmost part of the quarry (McIntosh 2005:42). One of these, designated #355 In the field, was a *Diplodocus* that was collected by Gilmore for the National Museum of Natural History in Washington DC (USNM 10865) The other, designated #340 and thought at that time also to be *Diplodocus,* was destined to go with Douglass to the University of Utah, though to further complicate matters nine or ten caudal vertebrae were sent to the Carnegie Museum. However, when it became clear that the USNM *Diplodocus* lacked a neck, it was arranged to supplement this material with the neck, anterior dorsals and scapulocoracoid and humerus from the University of Utah specimen. This left the skeleton now spread across three institutions in Salt Lake City, Washington DC and Utah. It is perhaps for this reason that, although the rest of this specimen was excavated, sent to the University of Utah and prepared, it was never mounted. Meanwhile, the neck that had been sent to Washington D.C. proved when prepared not to belong to *Diplodocus* after all but to *Barosaurus*. It was therefore not used after all in the mount of USNM 10865, which was instead completed with casts of the Carnegie *Diplodocus* CM 82 and unveiled in 1932 (Gilmore 1932).

In 1929, Barnum Brown, acting for the American Museum of Natural History, visited most of the nation’s major natural history museums to assess their collections. He realised that the neck, anterior torso, scapulocoracoid and humerus at the USNM, and the tail segment at the Carnegie, belonged to the same individual as the partial skeleton at the University of Utah. Brown negotiated separately with representatives of all three museums to acquire the three portions of this skeleton, and was able to reunite the whole of Douglass’s skeleton in New York at the AMNH, a museum that had had no part in its excavation or early history. Brown arranged complex multipart deals: while the USNM accepted a straight swap for their part of the *Barosaurus* with a skeleton of the tyrannosaurid *Gorgosaurus*, the University of Utah made a cash-plus-fossils deal in which they were paid $2,500 cash plus the equivalent value in fossil mammal specimens (Brown 1929). The reunited skeleton was given the specimen number AMNH 6341. (See Norell et al. 1991:36–38, Dingus 1996:21–22, McIntosh 2005:42–43).

# The AMNH mounted *Barosaurus*

## The conception of the mount

The three parts of AMNH 6341 were reunited from their layovers in the USNM, Utah University and Carnegie Museum by 1930 or shortly thereafter. However, having acquired their *Barosaurus* skeleton, the museum seemed at a loss to know what to do with it. It lay dormant for a decade until the presacral vertebrae were exhibited in glass cabinets alongside the mounted *Apatosaurus* in the Hall of Early Dinosaurs on 17 April 1939 (Figure D.A). They remained here until the renovation supervised by Edwin H. Colbert in the early 1950s. At this point, tentative plans were made in the to mount the *Barosaurus* skeleton in the dinosaur gallery, but it was felt that the mount would take up too much space and these plans were abandoned. Instead, the entire specimen was moved into collections. Four more decades were to pass before the skeleton (or at least a cast based on it) was finally mounted.

In 1986, the museum began planning what would become an extensive renovation of its fossil halls, which had become significantly outdated since the previous update more than thirty years previously. The initial plan was to renovate only the Osborn Hall of Late Mammals, but a change of museum leadership meant that by 1988 the project had become much more extensive, now encompassing all four existing vertebrate fossil halls and expanding into new spaces.

As part of this broader initiative, paleontological staff were asked whether they had any specimens suitable for mounting not in the Roosevelt Memorial Hall that is the main entrance to the museum on Central Park West. The hall, begun in 1931 and completed in 1936 is a majestic space in its own right, but was puzzlingly empty in 1990 (see illustration in Dingus 1996:20). It was the perfect space for a truly spectacular dinosaur mount that could introduce new visitors to dinosaurs, draw them in to the main galleries, and provoke them to think about paleobiological issues.

It occurred to Lowell Dingus, then project director of the fossil halls renovation project, that the most spectacular exhibit would be a gigantic sauropod rearing up on its hind legs. But he thought there was little change of persuading Eugene S. Gaffney, then the curator in charge of the dinosaur collections in the Department of Vertebrate Paleontology, to undertake such a project. In fact, both Dingus and Gaffney were known for their disdain of such speculative “dinomania”: the possibility of both consenting to a rearing mount would have been considered very unlikely.

The iconoclastic palaeontogist Robert T. Bakker had in 1971 included a skeletal reconstruction of a rearing *Apatosaurus* in an entry in the *McGraw-Hill Yearbook of Science and Technology* (Bakker 1971:figure 7f). This was provocative to the palaeoartist Gregory S. Paul, who incorporated the idea in his 1978 painting *Ambush at Como Creek*. In this, only his third dinosaur painting (Gregory S. Paul, pers. comm. 2022), he depicted a herd of *Diplodocus* surprised by an *Allosaurus*. As the carnivore attacks, one *Diplodocus* provides cover for its retreating allies by facing down the pack in a rearing threat display. This initial version of the painting was reproduced in Bird (1985:59), but Paul became dissatisfied with it and painted over parts of the original in 1983 and 1985 to produce the better known final version (Figure E) in which the attack is by a whole pack of *Allosaurus*. This version was reproduced in the influential book *Dinosaurs Past and Present* as Paul (1987:figure 16).

Knowing nothing of Dingus’s independently arrived-at plan, Gaffney found Paul’s painting intriguing. Inspired by this artwork, he conceived for the Roosevelt Hall exhibit the very ambitious idea of mounting a group of *Barosaurus* skeletons under attack from a group of *Allosaurus*. Dingus was astonished to discover that Gaffney had conceived essentially the same plan as himself — and both were further astonished when incoming dinosaur curator Mark Norrell also approved of the proposal, despite his own distaste for behavioural speculation about dinosaurs.

The original suggestion, using half a dozen or more skeletal casts, was deemed impractical, in part because it would have taken up too much space even in the huge Roosevelt Hall. So while the basic idea was adopted, it was scaled back to one erect *Barosaurus* adult and one juvenile, under attack from a single *Allosaurus* — ironically, a scene corresponding more nearly to the original version of Paul’s painting.

Dr. John (Jack) S. McIntosh, a professor of theoretical physics at Wesleyan University in Connecticut, was an avocational paleontologist specialising in sauropods, and became the world’s expert on the group. Gaffney knew him from his undergraduate days and when he succeeded Colbert as curator of the AMNH fossil reptile collection in 1970, McIntosh provided a great deal of information about the AMNH dinosaurs. He told Gaffney that the museum had one of the best known sauropod skeletons in its collection and that he thought it was the then poorly known *Barosaurus*. It would be the perfect specimen to use as the basis of the rearing mount. Early in the design of the exhibit, Dingus and Gaffney asked McIntosh what he thought about the pose. When he gave an enthusiastic “yes, I do think it was possible”, the die was cast. Against their usual inclinations, Dingus and Gaffney had become accomplices in the perpetuation of speculative dinosaur paleobiology. McIntosh would have second thoughts about the rearing pose, though. When interviewed a year later he observed “I’ll just say this — I am not responsible for the pose of the *Barosaurus*, and as a matter of fact, I would have been chicken and would never have mounted it that way if it were my responsibility” (Psihoyos 1994:74), although he did go on in the same interview to reaffirm that he thought the posture possible.

## The creation of the mount

Individual fossilized cervical vertebrae of *Barosaurus* can mass well over 100 kg, and supporting them in the rearing pose would have required a prohibitively strong armature. Furthermore, permanently mounting these scientifically significant fossils 10 m above ground level, even if logistically feasible, would effectively make them unavailable for study. For these reasons, while the mounted skeletons in the main Fossil Halls of the AMNH are mostly real bone, the Rotunda display consists entirely of casts.

The bones of AMNH 6341, the *Barosaurus* specimen that was to provide most of the mount, were not in the best condition by 1990. The presacral vertebrae had been in collections for the best part of 40 years, since Colbert’s early-1950s renovation; the rest of the material had been there for 60 years, since being reunited by Barnum Brown in 1930. Bones in collections can degrade with time, especially the complex and delicate presacral vertebrae, and it is not unknown for broken-off parts to become separated from the elements they belong to. A program of repair and cleaning was required. As outlined below, about 80% of the skeleton was present. These elements were cast, and the remainder were either cast from other specimens of closely related dinosaurs or sculpted.

All casting and sculpting was done by Research Casting International (RCI), an organization specializing in mounting prehistoric animals that had then only recently been established. Founder Peter May had started working with fossil mounts at the Royal Ontario Museum, beginning in 1977, where he learned the techniques from paleontology technician Gordon Gyrmov and former WW2 Luftwaffe test pilot Rudy Zimmermann. He rose to became the head technician at the ROM. Having worked for a while at the Royal Tyrrell Paleontology Museum in Alberta, he found on returning to the ROM that his expertise was in demand from other museums. Initially fitting this outside work into his spare time under the banner of RCI, he went full time with his company in 1990, and the AMNH *Barosaurus* was to become their most important early commission.

In the fall 1990, the RCI crew took the repaired and cleaned *Barosaurus* fossils back from New York to Toronto in the semi-truck, where they remained for the best part of a year. There, the bones were duplicated by coating them with latex, then curing the latex to form rubber molds. These molds were then used to cast polyurethane foam into accurate replicas of the original fossils that, when painted, were indistinguishable from real bone, but which weighed only a twentieth as much as the fragile and irreplaceable originals. XXX Peter: Norell et al. (1991:38) says: “Those that would stand near the ground were cast in higher-density and more durable materials, while those higher up were made of lighter substances.” What substances were used?

The missing parts of the skeleton were also fabricated in Toronto. Under May’s direction, RCI’s technicians sculpted missing bones in clay, basing the shapes on bones of the better known *Diplodocus*. XXX Peter, did you use left/right mirroring for those bones that were known from one side? And did you do any “repair” on the casts of the original bones?

In spring of 1991, a test erection of the rearing *Barosaurus* mount was carried out with the aid of a hired crane and 15 m scissor lift. This had to be done in the parking lot behind the RCI workshop, as the completed mount would be too tall to fit inside the workshop. The event was attended by a group from the AMNH, including Jack McIntosh, who had been brought in as a consultant to ensure that the bones were articulated correctly in the mount. Also present were photographers including National Geographic’s Louie Psihoyos, a television crew, at least one observer from another museum, and a crowd of local workers on their lunch-breaks. The skeleton was pieced together from prefabricated sections. The exercise began with the “tripod” of hindlimbs and tail, anchored together at the pelvis, providing a stable base. These were followed by the torso section, then the three sections of the neck and head, and finally the forelimbs. Dingus (1996:25–28) recalls that “the strangest thing was that the mount actually looked rather natural and graceful […] I had always been extremely skeptical about whether sauropods could rear up to such heights, but the grace of the mount almost erased my doubt”. Although the core of the project had proven successful, another six months would be required before the entire exhibit was ready to assemble in New York, as work was required not only on the main *Barosaurus*, but on the juvenile and the *Allosaurus*.

To provide the base that the skeletons would be mounted on, fossil-bearing rock was considered appropriate. During the summer of 1991, Gene Gaffney and Peter May searched for a suitable site, finally finding an area that Gaffney was satisfied with by the road just outside the Fort Peck Reservation in northeastern Montana. May and his crew later returned to the site and created peels by spraying a thin layer of latex rubber across the rocks. They returned these to RCI, and used them to make and paint a cast. Ironically, the exposures in this area are from the early Paleocene Tullock Formation (about 65 Mya), meaning that the ground that the mounted *Barosaurus* stands on dates from after the extinction of the dinosaurs, about 90 million years after the time *Barosaurus* lived.

In November 1991, the work in Toronto was complete, and the completed exhibit was transported to New York in sections for mounting. Unlike the trial mounting on Toronto, when the neck was attached in three sections, in New York the three sections were first joined together and then fitted as a unit. This large unit, about nine meters in length, proved difficult to manoeuvre, and it took nearly two hours to wrestle it into place to fit into place at the front of the rearing torso. Worse, when the mount was finally completed it was imperfect because, when the whole neck had been hanging horizontally, it had bent in the middle at the point of suspension. The resulting kink in the neck can be seen between C10 and C11 in contemporary photos such as that of Dingus (1996:26). It was soon corrected, however, in a near-disastrous late-night operation (Dingus 1996:28), and the line of the neck is smooth and elegant in the mount as it is today (Figure A).

The exhibit — rearing adult and hiding juvenile *Barosaurus*, and running *Allosaurus* — was unveiled in December 1991 XXX Lowell or Gene, do you remember the exact date?, and was at that time the only publicly exhibited *Barosaurus* in the world (Norell et al. 1991:36) (although additional mounts have since been erected at the Royal Ontario Museum in Toronto, Canada, and the Natural History Museum of Utah in Salt Lake City). Also included in the exhibit, in a case next to the mounted skeletons, were the real 13th cervical of AMNH 6341, and the partial skull and neck AMNH 7530, which the juvenile mounted skeleton had been partially based on. Both of these are, at the time of writing, on exhibit in the Miriam and Ira D. Wallach Orientation Hall.

The total budget for the mounting project was $250,000. XXX Peter, is this correct, and are you happy for it to be known or is it commercial-confidential?

## The composition of the mount

### Overview

Norell et al. (1991:38) wrote that “only about a fifth of the skeleton was missing, but each of these pieces, including the skull, several limb bones, and part of the tail, had to be modeled to complete the skeleton […] the technicians at Research Casting sculpted each individual missing bone in clay, basing the shapes on the remains of more completely known close relatives of *Barosaurus*, in particular, its contemporary *Diplodocus*.” However, they did not specify which elements were included in that missing fifth, nor which specific other skeletons the replacements were based on. A certain amount of detective work is therefore required.

There is some evidence that the last ten cervical vertebrae (C7–16) were preserved in the specimen as first excavated: Brown (1929) says that the material then at the USNM included “the last ten cervical vertebrae with ribs”, and the quarry map of Gilmore (1932:figure 1) shows nine dorsals and ten cervicals belonging to the *Barosaurus* skeleton. If this is correct, though, the most anterior of these (C7) seems to have been lost or destroyed, as McIntosh’s unpublished 1962 notes, his published account (McIntosh 2005) and the present fossil display at the AMNH all include only nine cervical vertebrae, C8–16. Carl Mehling (pers. comm., 2022) has searched in collections for the missing C7 and been unable to locate it. In fact, the C7, if it ever existed, was likely lost or destroyed prior to the 1939 renovation: contemporary photographs (Figure D.B) show the anteriormost cervical vertebra on display, and it is recognizable as the C8 that is the anteriormost currently preserved vertebra.

McIntosh’s (2005:43) catalogue of elements in the referred specimen AMNH 6341 is incomplete and contains multiple errors. However, by reading it in context of the more detailed descriptions of the elements later in the same paper, and with his unpublished 1962 notes on the specimen, and with observations of materials on exhibition in the past and present, it is possible to arrive at a complete list of material as follows:

* the posterior part of the neck (cervicals 8–16)
* all nine dorsal vertebrae (dorsals 1–9)
* the complete sacrum (sacral vertebrae 1–5)
* the anterior part of the tail (caudals 1–29)
* six partial ribs, of which one is the first or possibly second on the left side, and another is probably its counterpart
* a single chevron, from further back than Ca13 and likely in the region Ca22–Ca28.
* right (not left as in McIntosh 2005:43) scapulocoracoid, fully fused together; distal end of left scapula; left coracoid
* right (not left as in McIntosh 2005:43) humerus
* largely complete pelvis: right ilium complete except small part of the upper border; acetabular portion and “distal ends” of left ilium; both pubes and ischia complete except parts of the proximal ends of both pubes and the right ischium
* complete right hindlimb (femur, tibia, fibula, astragalus)
* elements of the right pes: metatarsals I, II and V, phalanges I-I and V-I, two 2nd phalanges, one ungual
* three “ossicles” (McIntosh’s unpublished 1962 notes) — the meaning is unclear.

The sternal plates and the lower forelimb (ulna, radius, carpals and manus) are the only parts of the skeleton entirely missing.

This list of material is a superset of that listed as belonging to the USNM’s part of the specimen in Brown’s (1929) account of reuniting the parts of the skeleton, aside from Brown’s statement that “the last ten cervical vertebrae” (not just the last nine) were at that time present. But Brown stated that the left scapulocoracoid and humerus are present (and the material list of McIntosh 2005:43 followed this error, contradicting his description and illustration later in the same chapter). But the element that was on display in 1939 (Figure D.B) is clearly a complete and well preserved *right* scapulocoracoid, based on the location of the glenoid fossa in combination with the curvature of the shaft. Similarly the humerus that was on display in 1939 is the right, not the left, based on the shape of the proximal end and the anterior projections at the distal end. It is possible that Brown carelessly misidentified the elements in his letter and McIntosh transcribed the error.

In preparing the mounted skeleton, casts of all the elements of AMNH 6341 were used. XXX Peter, Lowell and Gene, is this correct? How much “correction” was done to the casts? The missing elements were cast or modelled from specimens of *Diplodocus*. XXX Peter, Lowell and Gene, is this correct? Was no non-6341 *Barosaurus* used at all? Jack McIntosh XXX and Lowell and/or Gene? visited RCI at least twice during the modelling process to help with the restored elements.

We will now consider the source of specific elements of the cast.

### Skull

The skull in the mounted *Barosaurus* skeleton was cast from the corresponding elements in the Carnegie *Diplodocus*. However, CM 84, the specimen from which the Carnegie mount is mostly assembled, does not itself include a skull. Holland (1906:227) explains that the skull supplied to British Museum (now the Natural History Museum) as part of the *Diplodocus* cast presented to it in May 1905 was a composite sculpture based on several specimens.

* The posterior portion was modelled on material from CM 662 (illustrated by Holland 1906:plate XXVII–XXVIII; now HMNS 175). This specimen was initially referred by Holland (1906) to the genus *Diplodocus* and subsequently made by him the holotype of the new species “*Diplodocus*” *hayi* (Holland 1924). The species has since been moved to its own new genus *Galeamopus* by Tschopp et al. (2015:267).
* The remainder of the skull was based on USNM 2673 (illustrated by Holland 1906:plate XXIII–XXV), the skull on which Marsh (1896:175–179) had primarily based his description of the skull of *Diplodocus*. With the USNM’s permission, the Carnegie Museum made a cast of this skull, of which only the left side had been fully prepared. They used this to restore the missing half. Ironically, this skull has since been referred by Tchopp et al. (2015:228) to *Galeamopus*, meaning that both the fossils on which the Carnegie mount’s skull were based are now considered to belong to that genus.

The skull used in the *Barosaurus* mount is shown in a 1991 photograph (Figure C). It can be fairly confidently confirmed as the same composite illustrated by Holland (1906:figure 1) “as placed in the restoration at the British Museum”, and by Nieuwland (2019:figure 5.3) in a photograph of a worker at the Muséum Natonal d’Histoire Naturelle, Paris, France, with the plaster skull of their *Diplodocus* cast in 1908.

### Neck

McIntosh (2005:45) considered the number of cervicals is reckoned to be 16 on the basis that there are only nine dorsals, compared with ten in the closely related *Diplodocus*, and the most likely reason is that the first dorsal was recruited into the neck. McIntosh’s inference has been widely considered correct, and 16 is now the accepted cervical count for *Barosaurus*. Whether or not there may at some point have been a tenth cervical vertebra included in AMNH 6341 , at present it preserves the last nine cervical vertebrae. These are therefore considered to be C8–C16.

The anterior part of neck of the mount was completed using casts of seven anterior vertebrae from the Carnegie *Diplodocus*, but the anteriormost seven cervicals were not used as that would have resulted in an abrupt transition in length between C7 and C8. Instead, a non-contiguous sequence of Carnegie-*Diplodocus* cervicals was used to obtain a smooth transition probably cervicals 10, 8, 6 and 4–1.

CM 84, the specimen that forms most of the Carnegie mount, includes C2–7, but not the atlas (C1). It is not clear which specimen supplied the atlas in the Carnegie mount: Holland (1906), which discusses the composition of the cast sent to the British Museum, discusses two atlases but does not state which (if either) was used in the mount. These are the atlas of AMNH 969, part of a specimen including a skull that is now referred to *Galeamopus* sp. (Tschopp et al. 2015:219); and the unidentified figured by Marsh (1896:plate XXVII:figures 1–2) and reproduced by Hatcher (1901:figures 4–5), but which neither of them identified with a specimen number. Unless further information comes to light, it is not possible to identify the atlas used in the Carnegie *Diplodocus* — nor, therefore, in the *Barosaurus* mount. XXX Am I missing something?

### Torso and sacrum

The complete dorsal sequence (of nine vertebrae) and complete sacrum (of five vertebra) are present in AMNH 6341. However, McIntosh’s (2005:43) account says that only “six ribs and fragments” were included from a total of 18 (two per dorsal vertebra), the missing ribs were supplied by XXX Anyone?

### Tail

AMNH 6341 includes the first 29 caudals but only one chevron. The distal part of the tail was supplied by XXX Anyone?, and the chevrons were taken from XXX Anyone?

### Forelimbs and girdles

XXXXX

### Hindlimbs and girdles

XXX

### Summary

XXX Reference Figure B, with elements greyed out.

# Discussion

## Rearing pose

The mounted *Barosaurus* is in a spectacular rearing pose, as though to defend its offspring against a threatening *Allosaurus* individual.

XXX John Gurche painting

This pose was controversial when the mount was first unveiled

XXX examples include Hicks and Badeer (1992), Taylor (1992), Choy and Altmann (1992), Dennis (1992), Landry (1992), Badeer and Hicks (1996) XXX get these in the right order, add references, see what else they cite that I have missed.

XXX first ever sauropod restoration in Ballou (1897) shows underwater rearing. See Taylor (2010) on sauropod history.

However, the notion of rearing sauropods has a heritage going back at least to Osborn (1899:213), who wrote that the tail of *Diplodocus* “functioned as a lever to balance the weight of the dorsals, anterior limbs, neck, and head, and to raise the entire forward portion of the body upwards. […] Thus the quadrupedal Dinosaurs occasionally assumed the position characteristic of the bipedal Dinosaurs — namely, a tripodal position, the body supported upon the hind feet and the tail”. In his classic monograph of *Diplodocus carnegii*, Hatcher (1901:57–58) strongly implied, without quite explicitly stating, that *Diplodocus* habitually reared, and Charles Knight was painting rearing diplodocids as early as 1907 (see Taylor 2010:figure 6B).

XXX “We may well assume, with other writers, that the heavier forms, such as Apatosaurus and Diplodocus, which are provided with long spines in the sacral and posterior dorsal region, were adapted to rearing up on the hind legs as is represented in the conventional mounted skeleton of Megatherium. In these forms we find that the body is short and therefore well adapted to this habit [while *Brachiosaurus* was] fitted for purely quadrupedal locomotion.” (Riggs 1904:245–246).

From time to time, bipedality has also been proposed for other sauropods, including for example *Opisthocoelicaudia* (Borsuk-Bialynicka 1977:51) and *Cathetosaurus* (Jensen 1988:124–128) as well as diplodocids including *Barosaurus* itself (Bakker 1986:190–192). in more recent times, biomechanical modelling has been used to establish the feasibility of elevated postures such as that of the AMNH *Barosaurus*. Mallison (2011) argued compellingly from kinetic–dynamic modelling that diplodocines such as *Barosaurus* were particularly well adapted to bipedal rearing and sustained tripodal (tail-supported) standing. So the pose selected for the AMNH mount seems fully justified.

XXX Paul in 1984 depicted two rearing Baro individuals reproduced in Bird (1985:14).

XXX Dingus: The most important aspect, and one that often gets overlooked, is the role the mount played in setting the primary theme of the renovation: What can we know about extinct vertebrates vs. what can’t we know, given the nature of the fossils that are available. This was emphasized in the label that accompanied the mounts, which I’ll try to find the text for.

## Size of the AMNH 6341 animal

The exact length of the neck of *Barosaurus* is difficult to determine as no complete neck is known. Only one known specimen referred to *Barosaurus* preserves the anterior cervicals: AMNH 7535 is a juvenile, consisting of cervicals 2–8, referred by Tschopp et al. (2015:220) to *Barosaurus* sp. Wedel (2007:207) scaled these vertebrae up to match those of AMNH 6341 (C8 is preserved in both specimens), to arrive at his total neck length estimate of 8.5 m. It seems that someone performed a similar scaling operation using these vertebrae during the period of the mounting, as shown by notes hand-written around 1990 on a printed draft of what would become the table of measurements in McIntosh’s (2005) *Barosaurus* paper (Peter May, pers. comm. 2022). The identity of the note-taker is not known, but the handwriting does not match that of McIntosh himself. Summing the known centrum lengths of AMNH 6341 cervicals 8–16 from this table (McIntosh 2005:table 2.1) yield a total of 6993 mm. The scaled-up centrum lengths of AMNH 7535 cervicals 2–7 written onto the manuscript are 125, 174, 234, 299, 355 and 467, for a total of 1654 mm. Together these sums add to 8587 mm, a good match for Wedel’s (2007) estimate of 8.5 m, which is currently the generally accepted figure.

The height of the mounted *Barosaurus* is usually given rather inexactly as “fifty feet above the Rotunda floor” (Norell et al. 1991:39), “almost fifty feet” (Dingus 1996:25), “five-storey-high” (Gordy 1991:3) or “over 50 feet (15 m) from ground to head-level” (Lindsay 1992:26). Although vague, these measurements are enough to establish it as the tallest mounted skeleton of any animal anywhere in the world, about two meters taller than the remounted Berlin brachiosaur which has “a skull located more than 13 m above the level of the feet” (Remes et al. 2011:309).

# Acknowledgements

We are grateful to Scott Hartman (University of Wisconsin-Madison) for allowing us to use his *Barosaurus lentus* skeletal reconstruction and to Gregory S. Paul for permission to reproduce his artwork *Ambush at Como Creek*. Gregory S. Paul also allowed us to quote personal communications. Carl Mehling (AMNH) searched collections for the missing C7 and allowed us to cite a personal communication. Mai Reitmeyer (Department of Library Services, AMNH) helped us to obtain historical photographs. Amelia Zietlow (Richard Gilder Graduate School at the AMNH) provided helpful photographs and information about the present public exhibits.

# References

Bakker, Robert T. 1971. Brontosaurs. pp. 178-181 in: *McGraw-Hill Yearbook of Science and Technology*, 1971. McGraw-Hill, New York, New York.

Bakker, Robert T. 1986. *The Dinosaur Heresies: New Theories Unlocking The Mystery of the Dinosaurs and Their Extinction*. Morrow, New York. 481 pages.

Bartram, Alan, B. Booth, M. Chinery, E. N. K. Clarkson, B. Cox, D. Edwards, C. Maynard and W. D. I. Rolfe. 1983. *The Prehistoric World*. Galley Press (London).

Bird, Roland T. 1985. *Bones for Barnum Brown*. Texas Christian University Press, Fort Worth, Texas.

Borsuk-Bialynicka, Magdalena. 1977. A new camarasaurid sauropod *Opisthocoelicaudia skarzynskii* gen. n., sp. n. from the Upper Cretaceous of Mongolia. *Palaeontologica Polonica* **37**:4–64 and plates 1–14.

Brown, 1929. Report on *Barosaurus* (letter to the American Museum of Natural History, 31 December 1929. page 21 in: Dingus, Lowell. 1996. *Next of Kin: Great Fossils at the American Museum of Natural History*. Rizzoli, New York.

Dingus, Lowell. 1996. *Next of Kin: Great Fossils at the American Museum of Natural History*. Rizzoli, New York.

Hatcher, John B. 1901. *Diplodocus* (Marsh): its osteology, taxonomy and probable habits, with a restoration of the skeleton. *Memoirs of the Carnegie Museum* **1**:1–63 and plates I–XIII.

Holland, William J. 1906. Osteology of *Diplodocus* Marsh with special reference to the restoration of the skeleton of *Diplodocus carnegiei* [sic] Hatcher presented by Mr. Andrew Carnegie to the British Museum, May 12 1905. *Memoirs of the Carnegie Museum* **2(6)**:225–278.

Holland, William J. 1924. The skull of *Diplodocus*. *Memoirs of the Carnegie Museum* **9(3)**:379–403.

Janensch, Werner. 1922. Das Handskelett von *Gigantosaurus robustus* u. *Brachiosaurus brancai* aus den Tendaguru-Schichten Deutsch-Ostafrikas. *Centralblatt für Mineralogie, Geologie und Palaontologie* **1922(15)**: 464–480.

Jensen, James A. 1988. A fourth new sauropod dinosaur from the Upper Jurassic of the Colorado Plateau and sauropod bipedalism. *Great Basin Naturalist* **48(2)**:121–145.

Lambert, David. 2000. *DK Guide: Dinosaurs*. Dorling Kindersley (London). 64 pages.

Lindsay, William. 1992. *Barosaurus: on the trail of the gigantic plant-eating dinosaur* (Dinosaur Spotter’s Guides series). Dorling Kindersley (London). 32 pages.

Lull, Richard S. 1917. *Barosaurus*: a gigantic sauropod dinosaur. *Bulletin of the Geological Society of America* **28** (Proceedings of the eigth annual meeting of the Paleontological Society, held at Albany, New York, December 27, 28, and 29, 1916), pages 214–215.

Lull, Richard S. 1919. The sauropod dinosaur *Barosaurus* Marsh. *Memoirs of the Connecticut Academy of Arts and Sciences* **6**:1–42 and plates I–VII.

Mallison, Heinrich. 2011. Rearing giants: kinetic-dynamic modeling of sauropod bipedal and tripodal poses. pp. 237-250 in: Nicole Klein, Kristian Remes, Carole T. Gee and Martin P. Sander (eds.), *Biology of the Sauropod Dinosaurs*. Indiana University Press, Bloomington, Indiana.

Marsh, Othniel C. 1890. Description of new dinosaurian reptiles. *American Journal of Science*, third series, **39**:81–86. doi:10.2475/ajs.s3-39.229.81

Marsh, Othniel C. 1896. The dinosaurs of North America. Extract from the 16th annual report of the U. S. Geological Survey, 1894-95, part I. doi:10.5962/bhl.title.60562

McIntosh, John S. 2005. The Genus *Barosaurus* Marsh (Sauropoda, Diplodocidae). pp. 38–77 in Virginia Tidwell and Ken Carpenter (eds.), *Thunder Lizards: the Sauropodomorph Dinosaurs*. Indiana University Press, Bloomington, Indiana. 495 pp.

Nieuwland, Ilja. 2019. *American dinosaur abroad: a cultural history of Carnegie’s plaster* Diplodocus. University of Pittsburgh Press. ISBN: 978-0822945574. doi:10.2307/j.ctvh4zh5n

Norell, Mark A., Lowell W. Dingus and Eugene S. Gaffney. 1991. *Barosaurus* on Central Park West. *Natural History* **100(12)**:36-41. <http://hdl.handle.net/2246/6497>

Osborn, Henry. F. 1899. A skeleton of *Diplodocus*. *Memoirs of the American Museum of Natural History*, **1**:189–214 and plates 24–28.

Paul, Gregory S. 1987. The science and art of restoring the life appearance of dinosaurs and their relatives. pp. 4–49 in: Sylvia J. Czerkas and Everett C. Olson (eds.), *Dinosaurs Past and Present, Volume II* . Natural History Museum of Los Angeles County in association with University of Washington Press, Los Angeles. 150 pp.

Psihoyos, Louie (with John Knoebber). 1994. *Hunting dinosaurs*. Random House, New York. 267 pp.

Riggs, Elmer S. 1904. Structure and relationships of opisthocoelian dinosaurs. Part II, the Brachiosauridae. *Field Columbian Museum, Geological Series* **2(6)**:229–247, plus plates LXXI–LXXV.

Taylor, Michael P. 2010. Sauropod dinosaur research: a historical review. pp. 361-386 in: Richard T. J. Moody, Eric Buffetaut, Darren Naish and David M. Martill (eds.), *Dinosaurs and Other Extinct Saurians: a Historical Perspective*. Geological Society of London, Special Publication 343. doi: 10.1144/SP343.22

Tschopp, Emanuel, Octávio Mateus and Roger B. J. Benson. 2015. A specimen-level phylogenetic analysis and taxonomic revision of Diplodocidae (Dinosauria, Sauropoda). *PeerJ* **2**:e857. doi:10.7717/peerj.857

Wedel, Mathew J. 2007. *Postcranial pneumaticity in dinosaurs and the origin of the avian lung*. Ph.D dissertation, Integrative Biology, University of California, Berkeley, CA. Advisors: Kevin Padian and Bill Clemens. 290 pages.

Wieland, George R. 1920. The Longneck sauropod *Barosaurus*. *Science*, New Series **51(1326)**:528–530.

# Figure Captions

**Figure A.** The mounted skeleton of *Barosaurus lentus* AMNH 6341 in the Theodore Roosevelt Rotunda of the American Museum of Natural History, New York. Taylor for scale. Photograph by Mathew J. Wedel, 2012.

**Figure B.** Skeletal reconstruction of *Barosaurus lentus* based primarily on AMNH 6341. Modified to show bones preserved in AMNH 6341 in white, and bones absent from this specimen (which had to be cast or modelled from other specimens for the mount) in grey. Some guesswork was involved here: for example, McIntosh (2005:43) says that six ribs are present, but it is not possible to say which six ribs. Base image copyright © 2022 Scott Harman, all rights reserved. Used by kind permission.

**Figure C.** The skull used in the mounted *Barosaurus*, photographed in 1991: cranium to rear, mandible to the front, both in left dorsolateral view. This skull was copied from that of the mounted Carnegie *Diplodocus*. Note its similarity to the skull “as placed in the restoration at the British Museum” in Holland (1906:figure 1).

**Figure D**. The Jurassic Hall in April 1939, photographs taken during or shortly after the renovations. **A.** The mounted skeleton of *Brontosaurus* (now thought to be *Apatosaurus*); in cabinets behind it the presacral vertebrae of *Barosaurus* AMNH 6341 can be seen in right lateral view. Note that the *Brontosaurus* mount has only thirteen cervicals, perhaps following Marsh’s (1991) skeletal reconstruction. **B.** The cabinets from the background of part A, showing the presacral sequence in anterodorsal view. In front of the vertebrae lie the right humerus, its posterior face uppermost and its proximal end facing the camera (left); and the right scapulocoracoid, its lateral face uppermost and its humeral glenoid roughly articulating with the humerus (right). Cropped from photographs 315932 (part A) and 315930 (part B) from the AMNH Research Library Digital Special Collections, by Charles H. Cole.

**Figure E.** *Ambush at Como Creek*, painted by Gregory S. Paul in the late 1970s or early 1980s. In this revised version, a pack of *Allosaurus* menace a herd of *Diplodocus*. While most of them, including a juvenile and two subadults, try to escape, one adult faces the attacking allosaurs in a threatening rearing posture. This painting was part of the inspiration for the AMNH’s rearing *Barosaurus* mount. Copyright © Gregory S. Paul, 2022. Reproduced by kind permission.