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.

## 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. Two fine diplodocine skeletons has at this point been partially excavated from the easternmost part of the quarry (McIntosh 2005:42). One of these was a *Diplodocus* that was collected by Gilmore for the National Museum of Natural History in Washington DC (USNM 10865) The other, 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 left scapula 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 and scapula/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).

# Materials and Methods

## 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). 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 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.

## The creation of the mount

XXX All casts

— May and crew took the fossils back to Toronto in fall 1990 for casting.

— Early 1991: test erection in Toronto parking lot.

— erected in Nov 1991.

— unveiled in December 1991. At that time the only publicly exhibited *Barosaurus* (Norell et al. 1991:36)

— John Gurche painting

## 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 they replacements were based on.

There is some evidence that the last ten cervical vertebrae (C7–16) were preserved: 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) has been lost or destroyed, as both written accounts (McIntosh 2005) and the present fossil display at the AMNH include only nine cervical vertebrae, C8–16.

XXX Dingus: Gene, please correct me if I’m wrong, but as I recall cast or sculpted bones of Diplodocus were used to fill in the missing elements of the Barosaurus adult and juvenile. I don’t recall any other taxon being utilized, but I may be incorrect.

XXX Gaffney: This is out of my memory banks now, I do know that McIntosh was the real advisor scientifically and he (and I and you?) went to Pete’s place at least twice (before the parking lot mounting party) to help with the restored elements during the casting. As you say Jack used the similar Diplodocus for restoration of the adult mount. I remember bringing up some material we had for him to use.

McIntosh’s (2005:43) catalogue of element in the referred specimen AMNH 6341 lists the posterior part of the neck (cervicals 10–16), all nine dorsals 1–9, sacrals 1-5, the anterior part of the tail (caudals 1–29), six ribs and fragments, 1 chevron, left scapulocoracoid and part of right scapula, left humerus, complete pelvis, right hindlimb and part of a pes. This is obviously incorrect in at least one respect: the last nine cervicals are preserved (C8–C16) and indeed are figured and briefly described by McIntosh (2005), so this is presumably just a typographical error. 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, apart from Brown’s statement that “the last ten cervical vertebrae” (not just the last nine) were at that time present.

### Skull

The skull in the mounted *Barosaurus* skeleton was cast from the corresponding elements in the Carnegie *Diplodocus*. It is not obvious exactly what skull that is, though, as the skull is not included in CM 84, the specimen from which the Carnegie mount is mostly assembled. 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 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

Whether or not there may at some point have been a tenth, at present AMNH 6341 preserves the last nine cervical vertebrae. McIntosh (2005:45) considered thers to be C8–C16: 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.

The anterior neck of the mount was completed using casts of seven anterior vertebrae from the Carnegie *Diplodocus* — probably cervicals 10, 8, 6 and 4–1 (Peter May, pers. comm., 2022).

XXX what about the atlas?

XXX other parts of the skeleton

# Results

## 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).

XXX comparison with *Diplodocus*.

# Discussion

## Rearing pose

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

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 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.

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# 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.

**Figure B.** Skeletal reconstruction of *Barosaurus lentus* based primarily on AMNH 6341, by kind permission of Scott Hartman. Copyright © 2022 Scott Harman, all rights reserved. Reproduced by kind permission.

**Figure C.** The skull used in the mounted *Barosaurus*, copied from that of the mounted Carnegie *Diplodocus*. Cranium to rear, mandible to the front, both in left dorsolateral view. 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, photograph taken during or shortly after the renovations. The focus is the mounted skeleton of *Brontosaurus* (now thought to be *Apatosaurus*), but in cabinets behind it the presacral vertebrae of *Barosaurus* AMNH 6341 can be seen in right lateral view. Photograph 315932 in 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.