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

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**Abstract**

XXX to follow. Make sure that the purpose of the mount is clearly stated.

**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 Roosevelt Memorial Hall 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 monographic 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 the 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, and which from other specimens. We will discuss how scaling was calculated and how the pose was decided on, and summarize the controversy generated by the mount.

## Anatomical nomenclature

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

We follow McIntosh’s (2005) interpretation of the presacral vertebrae of *Barosaurus* consisting of 16 cervicals and nine dorsals, rather then 15 and 10 as in *Diplodocus*.

## 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.
* MfN — Museum für Naturkunde Berlin, Berlin, Germany; specimen numbers for fossil reptiles take the form MB.R.*nnnn*.
* USNM – United States National Museum, Washington, D.C., 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 1889, 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 words in length, is largely uninformative. Subsequently 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 was 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 diplodocine 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 mount. It was briefly described as part of McIntosh’s (2005) revision of the genus *Barosaurus*, but has yet to be described in monographic 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 were 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 Charles W. Gilmore for the National Museum of Natural History in Washington, D.C. (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, Pittsburgh, and Washington, D.C. 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* (Gilmore 1932:4). It was therefore not used after all in the mount of USNM 10865, which was instead completed with casts of the Carnegie *Diplodocus* CM 84 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).

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 holdings 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.

# The AMNH mounted *Barosaurus*

## The conception of the mount

The three parts of AMNH 6341 had been reunited from their layovers in the USNM, Utah University and Carnegie Museum by 1930 or shortly thereafter. However, having acquired their *Barosaurus* skeleton, the AMNH seemed at a loss to know what to do with it. It lay dormant for a decade until the presacral vertebrae and some limb bones were exhibited in glass cabinets alongside the mounted *Apatosaurus* in the Hall of Early Dinosaurs on 17 April 1939 (Figures D, G). Plans were made at that time to mount the skeleton in place of *Apatosaurus* (Anonymous 1939), but these came to nothing. The *Barosaurus* elements remained here until the renovation supervised by Edwin H. Colbert in the early 1950s. At this point, tentative plans were made once more to mount the *Barosaurus* skeleton in the Hall of Early Dinosaurs, 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 covering 65,000 square feet, and expanding into new spaces at a total cost of $38 million.

As part of this broader initiative, paleontological staff were asked whether they had any specimens suitable for mounting 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, with its impressive, barrel-vaulted ceiling. But it was puzzlingly empty as late as 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 chance 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 Memorial 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 come up with 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 Memorial 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 through work done in his spare time became the world’s leading 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 had 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, albeit for a specifically limited purpose, as discussed in the next section. McIntosh was to 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 purpose of the mount

While providing a breathtaking first impression of the museum for new visitors, the purpose of the mount extended well beyond the visual power of viewing the tallest free-standing dinosaur mount ever constructed. More importantly, the mount would introduce a major scientific theme that would be integrated into all the fossil halls encompassed in the renovation project: what can we actually know about these long-extinct icons of evolution, and what can’t we know based on the limited kinds of data preserved in their fossils? The exhibition label for the mount clearly stated this conundrum in a section entitled “Did this really happen?” (Figure I):

No one knows for sure. Our only evidence of the lives of extinct dinosaurs comes from such fossils as bones and footprints. Fossils tell us about the size and shape of the animals and whether they stood on four legs (like *Barosaurus*) or on their two hind legs (like *Allosaurus*). They do not tell us, however, if *Barosaurus* could rear up or if *Allosaurus* hunted alone or in groups.

## 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 Roosevelt Memorial Hall 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 bones 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 of the skeletal elements 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 in a semi-truck from New York to Toronto, 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. Norell et al. (1991:38) noted that “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.” Specifically, the lower elements were cast in polyester resin and fiberglass with a substantial steel armature, while the dorsal series, ribs and cervicals were cast with a much lighter fiberglass matt and backfilled with polyurethane foam to keep the weight down as low as possible. Due to the lightness of these elevated elements, the steel armature could be reduced too.

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*. Some missing bones, including the left scapula and tibia, were sculpted based on their right-sided counterparts. Records do not show exactly which bones were sculpted. XXX We must be able to do better than this.

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, and 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) recalled 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 initial assembly of the rearing barosaur 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 Fort Union Formation (then the 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 in Toronto, when the head and neck were 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 awkward to manoeuvre, and it was difficult to raise it to a sufficient height to slide into its slot. It took nearly two hours to wrestle it 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) and Lindsay (1992:18–20). It was soon corrected, however, in a near-disastrous but ultimately successful 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 to select guests on Tuesday 3 December 1991 (Anonymous 1991) and opened to the public on Wednesday 4 December 1991 (Gordy 1991, Collins 1991). It 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. (That skull and neck, thought in the 1990s to belong to *Barosaurus*, were referred to the closely related diplodocine *Kaatedocus siberi* by Tschopp et al. (2015:220).) The juvenile skull and neck are, at the time of writing, on exhibit in the Miriam and Ira D. Wallach Orientation Hall.

One of us (Dingus) recalls that the total budget for the mounting project was $250,000. Another of us (May) feels that, including the *Allosaurus*, the baby *Barosaurus* and the mounting of the original fossil neck and skull of the baby diplodocine AMNH 7530, $250,000 seems a little light. We have not been able to locate official records to resolve this question.

Since the mount of *Barosaurus* and *Allosaurus* opened to the public, tens of millions of visitors have begun their visit to AMNH by sizing up this iconic, if somewhat controversial, skeletal scene.

## Photography of the mount

During the mounting process at the AMNH, and after the unveiling, many photographs were taken. But the rearing mount is a very difficult object to photograph well, climbing high into a gloomy hall with bright windows. Among the photographers was Lynton Gardiner, who had been contracted by Dorling Kindersley to provide photographs for the children’s book *Barosaurus: On the Trail of the Gigantic Plant-Eating Dinosaur* (Lindsay 1992) in their Dinosaur Spotter’s Guides series, as part of a broader contract to photograph dinosaurs at the AMNH and the Smithsonian. Gardiner recalls (pers. comm. 2022):

The main hall at the AMNH is huge, unevenly and dimly lit, so to get clear bright shots I placed several 2400 and 5000 watt second Comet strobe packs and bare-bulb heads around the hall, synchronizing them with slaves and an infrared sender on the camera. With ISO 200 film we had a consistent f/11 aperture [enabling fine details to be captured and light/shadow contrasts to be adequately depicted] from any vantage point in the hall. I used a Hasselblad camera with a Distagon lens of about 40 mm. Except for using digital cameras now, if I had the same assignment again I’d use a similar approach with synced strobe packs around the hall. Available light with high ISO recording doesn’t produce the crisp detailed results you get with updated traditional electronic flash lighting.

## 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, this account did not specify which elements were included in that missing fifth, nor which specific other skeletons the replacements were based on, and it has not been possible to recover this information from the McIntosh archives. A certain amount of detective work is therefore required. To summarise: a complete list of the elements of AMNH 6341 itself can be assembled from the published works and notes of McIntosh; Peter May recalls that with some exceptions discussed below, the missing bones were filled in with casts taken from the Utah Field House’s copy of the Carnegie *Diplodocus*; the history of that that copy is known, and so therefore so is the composition of the Carnegie original as it was at that time. The details follow.

### *Barosaurus* material in the mount

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
* 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, clavicles and lower forelimb (ulna, radius, carpals and manus) are the only parts of the skeleton missing from both sides. Figure B shows a skeletal inventory of *Barosaurus lentus* with the portions of the skeleton preserved by AMNH 6341 in white and the missing bones in grey.

This list of material is gratifyingly congruent with that depicted in the 1939 exhibition panel (Figure G). This panel provides the additional detail that the neural spines were missing from all five sacral vertebrae and caudals 1–3 and 26–28, and that only the anterior portion of caudal 21 remains. The panel shows 30 rather than 29 caudals: it is possible that some time after this illustration was prepared, the very fragmentary caudal 21 was lost or discarded, and that the caudals identified as 21–29 by McIntosh (2005) were in fact 22–30. The panel further suggests that two of the six preserved ribs may be those of the right side of dorsals 8 and 9. The only contradiction with the material list above is that the pes elements are interpreted differently: the panel shows metatarsals I, II and III, phalanges I-I, II-I and III-I, and ungual I. We consider McIntosh’s assignment more likely trustworthy.

This list of material of AMNH 6341 is mostly a superset of that listed as belonging to what was then the USNM’s part of the specimen in Brown’s (1929) account of reuniting the parts of the skeleton. The only additional element in Brown’s account is his statement that “the last ten cervical vertebrae” (not just the last nine) were at that time present — see above. But Brown stated wrongly that the left rather than right 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, McIntosh 2005:59–62). The girdle 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 his 2005 paper. McIntosh’s unpublished 1962 notes further confirm the presence of these elements from the right (correct) side.

In preparing the mounted skeleton, casts of all the elements of AMNH 6341 were used. Little or no reconstruction was done, so distortion in the preserved cervical vertebrae is retained in the mounted copies; however, missing cervical ribs were added as necessary to the cervicals (Taylor, pers. obs.). The missing elements were filled in with *Diplodocus* casts that have a curious provenance. As recounted in detail by Taylor et al. (2023), the original Carnegie *Diplodocus* molds, having been used ten times by the Carnegie museum to create plaster casts from museums around the world, were donated in 1952 to the Utah Field House of Natural History in Vernal, Utah, and there used to create a concrete cast that was mounted outdoors (Untermann 1959). In 1989, Jim Madsen’s company Dinolab unmounted this concrete cast and used it to create second-generation molds with the immediate goal of providing the Field House with a new, lightweight cast to be exhibited indoors at its new building. These new molds were then used to create several additional *Diplodocus* casts, and also the elements necessary to complete the AMNH *Barosaurus* cast. XXX Peter, Lowell and Gene, was no non-6341 *Barosaurus* used at all? Jack McIntosh, Lowell Dingus and Gene Gaffney all visited RCI multiple times during the modelling process to provide guidance and monitor progress.

With this in mind, 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. As documented in Taylor et al. (in review.), 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 (now HMNS 175). The remainder of the skull was based on USNM 2673, the skull on which Marsh (1896:175–179) had primarily based his description of the skull of *Diplodocus*.

The skull used in the *Barosaurus* mount, cast from molds taken from this composite, is shown in a 1991 photograph (Figure C). It can be 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 Nationale d’Histoire Naturelle, Paris, France, with the plaster skull of their *Diplodocus* cast in 1908.

### Neck

McIntosh (2005:45) considered the number of cervicals in *Barosaurus* 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 (C7) 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 seven casts of 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 the *Diplodocus* C7 (485 mm, Hatcher 1901:38) and the *Barosaurus* C8 (618 mm, McIntosh 2005:46). Instead, a non-contiguous sequence of Carnegie-*Diplodocus* cervicals was used to obtain a smooth transition: one of us (May) believes they were probably cervicals 10 (595 mm), 8 (512 mm), 6 (442 mm) and 4–1, and the relative sizes of the vertebrae corroborate this identification.

CM 84, the specimen that forms most of the Carnegie mount, includes C2–7, but not the atlas (C1). As discussed by Taylor et al. (in review), it is not clear which specimen supplied the atlas in the Carnegie mount, and it seems most likely that this element was a sculpture not based on any specific fossil specimen.

### Torso, sacrum and tail

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), and as noted above the identification of these ribs is uncertain.

AMNH 6341 includes the first 29 caudals (or perhaps caudals 1–20 and 22–30, see above) but only one chevron.

### Forelimbs and girdles

The bones of the forelimb are not only absent from CM 84 (as noted by Hatcher 1901:45) but were completely unknown in the Carnegie collection at the time the mount was constructed. Holland (1906) made no comment on how the forelimbs were obtained for the skeletal mount sent to England. As detailed by Taylor et al. (in review), both humeri, radii and ulnae of the casts produced by the Carnegie Museum were sculpted based on the slightly smaller diplodocine individual CM 662 (now HMNS 175), which also provided the rear part of the skull (see above). The forefeet however were sculpted from those of AMNH 965, now recognized as camarasaurid, and were given three manual unguals as well as too many phalanges. To correct this error, which was well understood by the 1990s, metacarpals from Dinosaur National Monument were used in place of the camarasaurid metacarpals; and while the other elements of the forefeet were taken from the Carnegie *Diplodocus*, the unguals were removed from digits II and III. XXX Peter, were the metacarpals casts or the original fossils? XXX What was the specimen number?

### Hindlimbs and girdles

As noted by Taylor et al. (in review), the Carnegie Museum’s own mounted *Diplodocus carnegii*, uses the left fibula and partial pes of referred specimen CM 33985, but for unknown reasons the casts do not use this material. No documentation survives indicating what material was used to create the left fibula and metatarsals III–V used in the casts. Most likely, these bones were mirror-imaged sculptures of the right-side elements preserved in the *D*. *carnegii* paratype CM 94 (which also furnished these bones on the right side). And the *Barosaurus* cast probably used second-generation casts of these sculptures.

# Discussion

## Rearing pose

As noted above, the mounted *Barosaurus* is in a spectacular rearing pose, as though to defend its offspring against a threatening *Allosaurus* individual. The exhibit was illustrated by a specially commissioned John Gurche painting (Figure F), which was used in gallery signage and in numerous publications (e.g. the cover of *New York Newsday* for 29 November 1991; the cover of the AMNH’s own magazine *Natural History* for December 1991).

The unveiling of the Berlin cast of the Carnegie *Diplodocus* in 1908 had provoked controversy: Hay (1908, 1910) and Tornier (1909) argued that its erect-legged posture was incorrect, and it should sprawl like a lizard; and Holland (1910) emphatically rebutted these suggestions. In the same way, the AMNH *Barosaurus* mount started discussions. From the moment of its unveiling this exhibit was controversial for two reasons.

First, there is no direct evidence that *Barosaurus*, or any sauropod, practiced parental care. However, it is well established from both trackways (e.g. Day et al. 2004) and death assemblages (e.g. Coria 1994) that sauropods did live and move in herds of different-sized individuals, whether genetically related or not. It is not unreasonable to assume that larger individuals defended the smaller from attack on occasion.

Second, and more seriously, some paleontologists felt that *Barosaurus* could not or would not have adopted the rearing pose — something which, as noted above, Dingus, Gaffney and McIntosh all had their own reservations about. In a newspaper report published five days before the exhibit was publicly unveiled, it was claimed that “of six leading paleontologists interviewed for this article, all but one questioned how a behemoth weighing in excess of 25 tons could be accurately depicted in an upright position. Most thought it physically impossible” (Gordy 1991:3) — although since the article also wrongly claims that the posture was chosen “over the objections of Gene Gaffney”, it should not be assumed to be accurate in other matters. While Kevin Padian was quoted supporting the posture, Paul Sereno, Jack Horner and Phil Currie all expressed reservations — though none of them went on to express their criticisms in scientific publications. Thirty years on, Sereno comments “I still think it's ridiculous” (Paul Sereno, pers. comm., 2022), but Horner has mellowed: “I had opposed the idea originally but have since come to the conclusion that at least the males had to have been able to rear up to at least the back of the female. I think it took me about a decade to figure that out. […] I like the mount now, it may have been the way the males displayed. Would have been spectacular!” (Jack Horner, pers. comm., 2022).

More specific criticisms and comments were to follow in published articles. Surprisingly, much of the published discussion was in the medical journal *The Lancet*. First, provoked by Lillywhite’s (1991) brief account of the high blood pressure required to circulate blood to the head of *Barosaurus*, Choy and Altmann (1992) argued that the great size required of the *Barosaurus* heart to perfuse an erect neck would have meant that it beat very slowly. Check valves would therefore have been necessary in the neck arteries to prevent the column of blood from falling back to the heart during diastole. They suggested that these valves may have been active pumps — three pairs of “secondary hearts — though they admitted that in the absence of soft-tissue fossils this is pure conjecture. Millard et al. (1992) dismissed this proposal as unsupported by evidence, noted the absence of check valves in the neck of the giraffe, and argued that the multiple-heart scheme would probably create non-continuous blood flow at the brain. They considered amphibious habits a more likely adaptation for supporting the neck, despite the discrediting of that notion (e.g. Coombs 1975).

Dennis (1992) claimed to have independently reached the same multiple-hearts conclusion as Choy and Altmann (1992), and noted that hagfish, the giant Brazilian earthworm and some insects have multiple perfusion organs. He also considered and discarded the idea that the blood flow to the head operated as a siphon. In a letter published simultaneously, Taylor (1992) pointed out the evidence for sauropod terrestriality, *contra* Millard et al.’s proposed amphibious habits, and that breathing would have been impossible when the lungs were far below the surface (see Kermack 1951). And in a third letter, Hicks and Badeer (1992) argued that the circulatory system was closed, i.e. not exposed to ambient pressure, reducing the need for high blood pressure. (Badeer and Hicks (1996) would revisit their ideas in more detail four years later, proposing a siphon loop circulating blood to the head and arguing that blood pressure in the head was negative.)

Separately from the *Lancet* discussion, Landry (1992) argued briefly that *Barosaurus* would not have had the necessary muscle mass to rear up, that compressive stresses in a vertical spine would exceed the bending stresses in a horizontal spine, and that dropping down from a rearing posture would create too much kinetic energy to disperse.

All of this discussion was welcome to the AMNH team. As noted above, the most important purpose of the mount as originally conceived was not to argue in favour of rearing as a habitual behaviour, but to set out the issue of what we can and cannot know. Dingus (1996:28) noted that he actively welcomed the controversy — not only because all publicity is good publicity, but because the skeleton’s critics were encouraging the public to think about the controversy for themselves.

## A short history of a rearing sauropods

The notion of rearing sauropods has a long heritage. The first ever life restoration featuring sauropods is Charles R. Knight’s 1897 drawing, created under the supervision of E. D. Cope, appearing in Ballou (1897:20) and reproduced in Osborn and Mook (1921:figure 127). This shows several *Amphicoelias* individuals in mostly submerged rearing postures.

Scientific support for the plausibility of rearing goes 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 (1901:58) strongly implied, without quite explicitly stating, that *Diplodocus* habitually reared: “the modified nature of the chevrons of the mid-caudal region indicate the point of contact of the tail with the earth attending the different positions habitually assumed during the life of the individual”.

Riggs (1904:245–246), contrasting his new dinosaur *Brachiosaurus* with the then-known diplodocids wrote: “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.”

Knight was painting rearing diplodocids as early as 1907 (reproduced in Taylor 2010:figure 6B).

Huene (1929:497) provided what was probably the first life restoration of a titanosaur, “*Titanosaurus*” (= *Neuquensaurus*) *australis*. As well as the foreground individual, depicted in a classic four-square pose, two more individuals are shown fighting in the background, one of them rearing on its hind legs.

Borsuk-Bialynicka (1977:51) proposed that the robust titanosaur *Opisthocoelicaudia* occasionally stood on its hind limbs: “the tail working as a prop seems […] probable. […] Occasional bipedality is therefore strongly suggested. It is, however, not a matter of briefly assuming a bipedal stance as is possible in most of the tetrapods. […] The animal must have been stable in this position; otherwise this posture would not have left such distinct traces in the skeleton architecture.”

In 1984, Gregory S. Paul drew an assemblage of four Jurassic sauropods: *Camarasaurus*, two *Barosaurus* and *Apatosaurus*, all but the first of which were shown rearing to near-vertical postures. This drawing, possibly the first artwork to show rearing *Barosaurus*, was reproduced by Bird (1985:14).

In a landmark paper on dinosaur biomechanics, R. McNeill Alexander (1985:9) took the first steps towards numerically modelling the ability of sauropods, including *Diplodocus*, to rear. These early calculations were concerned only with the location of the centre of mass, and the ability of the dinosaurs in question to shift it backwards to the location of the hips.

In his widely read popular-science book *The Dinosaur Heresies*, Bakker (1986:190–192) reiterated and expanded his own argument that diplodocids, including *Barosaurus* itself, not only could rear but habitually did so when feeding. While the idea of rearing sauropods had been growing among researchers, this probably marked the point where the idea began to impinge on non-specialists.

Jensen (1988) described a new camarasaurid species *Cathetosaurus lewisi* (considered by McIntosh et al. (1996) to be a species of *Camarasaurus* but regarded as its own genus by Tschopp et al. 2014). Jensen (1988:124–128) considered several characters of the *C*. *lewisi* holotype BYU 9047 as specializations for rearing and bipedal locomotion: bifurcated neural spines through the entire presacral series, elongated chevrons, a strong system of ossified diagonal intervertebral ligaments in the dorsal vertebrae, suprapostal plates in the sacral vertebrae, and 20-degree forward rotation of the ilia relative to the sacrum. While some of these features do not seem directly related to rearing and others are likely age-related, the rotation of the ilium remains unique and difficult to interpret at anything other than a bipedalism adaptation.

This was the state of science regarding rearing sauropods at the time the AMNH *Barosaurus* mount was unveiled in 1991. As well as catalyzing a scientific debate on the mechanical difficulties of rearing, the mount likely influenced the depiction of sauropods in popular culture: notably, the rearing *Brachiosaurus* that is the first dinosaur seen in Steven Spielberg’s *Jurassic Park* (1993) and the rearing behaviour seen by some *Diplodocus* individuals in the BBC’s *Walking With Dinosaurs* (1999). (The depiction of *Brachiosaurus* in Jurassic Park is a surprising choice for two reasons: brachiosaurs are the most front-heavy of all sauropods, and so the least well adapted to rearing; and the animal is shown rearing to reach foliage that it could easily have reached without doing so.)

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.

## 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. However, see Taylor and Wedel (in prep.) for alternative estimates.

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).

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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, 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.

**Figure F.** John Gurche’s painting XXX details, including title if any, and attribution.

**Figure G.** Public gallery exhibit panel for AMNH 6341, prepared around 1939 to accompany the vertebral sequence, scapulocoracoid and humerus depicted in Figure D. Photographed by Mick Ellison, AMNH. Original caption reads:

Jurassic Period, Morrison Formation. Dinosaur National Monument, Vernal, Utah. Barosaurus is related to Diplodocus and is characterized by extremely long cervical vertebrae which are more hollow than in other sauropods. Bones of skeleton, colored brown in restoration, are displayed below and in adjoining case; missing parts outlined. Restoration of skeleton, one-twelfth natural size. Dimensions of skeleton as restored – length 78 ft. height 19–1/2 ft. Acquired by purchase and exchange. Amer. Mus. No. 6341.

The representation of which bones are included in the specimen is a good match for our modern reconstruction (Figure B), but there are some differences in the reconstruction. Most notably, only 14 cervical vertebrae are depicted, with the nine preserved cervicals interpreted as C6–C14. This is surprising as the closely related *Diplodocus* had been known with some confidence since Hatcher’s (1901) monograph to have 15 cervicals. Also surprisingly, the 1939 reconstruction shows only nine dorsal vertebrae, compared with the ten described by Holland (1905:251–252) when omitting the dorsosacral. This was likely done to correctly depict the total number of preserved presacrals as 18. While McIntosh’s catalogue of material indicates that the first 29 caudals are preserved, the 1939 diagram shows 30 caudals, of which the neural spines of Ca1–3 and Ca26–28 are absent and Ca21 is represented only by the anterior portion of its centrum. Finally, the 1939 diagram suggests that of the right dorsal ribs, only those of D7 and D8 are present, which contradicts McIntosh’s (2005:57) assessment that two of the six preserved ribs are the left and right ribs of D1 or D2.

**Figure H.** Prototype model of the proposed display. This model is three feet (91 cm) tall from the bottom of the base to the top of the rearing *Barosaurus*, and the base is 44 inches (112 cm) long. XXX say more, including stronger S-curve in neck. Small hands. Chicken bones. Photograph by Mick Ellison (AMNH). XXX reference this in the text.

XXX add many more photos!

XXX Use Peter’s VHS video when we get it!