Giant specimens of the sauropod dinosaur *Barosaurus* from Utah

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**Abstract**

The diplodocid sauropod *Barosaurus* is best known from the spectacular mounted skeleton in the atrium of the American Museum of Natural History (AMNH). Apart from the disproportionately long neck it is similar in size to *Diplodocus* — but did *Barosaurus* get bigger?

BYU field jacket 3GR was collected from the Jensen/Jensen quarry, Utah, in 1966 but only recently prepared. It contains three cervical vertebrae, designated A, B and C, anterior to posterior. They belong to *Barosaurus* based on elongation, broad prezygapophyseal facets, “hinged” prezygapophyseal rami with dorsomedial and dorsolateral faces, narrow, posteriorly set diapophyses bearing posterior tubercles, and wing-like postzygadiapophyseal laminae. Based on spine bifurcation, vertebra C is C9–C11. The centra of the AMNH cervicals C9–11 are 685, 737 and 775 mm long. That of vertebra C measures 1220 mm, making it 1.57–1.78 times longer. This suggests a neck length of 13.3–15.1 m based on the established length of 8.5 m for the AMNH specimen.

BYU 9024 is an even larger cervical vertebra, referred to *Supersaurus* but indistinguishable from C9 of *Barosaurus* based on the characters above. At 1370 mm in total length, it is exactly twice the length of the AMNH C9, suggesting a neck 17 m long.

**Keywords:** *Barosaurus*, *Supersaurus*, cervical vertebra, neck, size

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# Introduction

## Historical background

*Barosaurus* is a diplodocid sauropod from the Late Jurassic of North America, found in the extensive Morrison Formation. It was first described very briefly by Marsh (1890) 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 noted only that the caudals resembled those of *Diplodocus* but were proportionally shorter than in that genus and did not retain pneumatic features so far back along the tail.

The caudal vertebrae described by Marsh (1890) were part of a substantial partial specimen, YPM 492. More of this individual was subsequently excavated and prepared, and Lull (1911) wrote an important monographic description. This specimen includes numerous elements identified by Lull as four posterior cervicals (perhaps C12–15), six dorsal vertebrae (considered to be D1, 4, 5, 7, 9 and 10), a partial sacrum, about 19 caudal vertebrae from different parts of the tail, three chevrons, many ribs and fragments, the left sternal plate, a partial scapula, a partial ilium, partial right pubis, partial left ischium, femur fragments, tibia fragments and the ends of the left fibula. As is apparent, there is no skull and the appendicular material is fragmentary, so diagnosis rested primarily on the axial material. Lull (1919: plate II) illustrated three of the cervical vertebrae, but in monochrome and with only one of them shown in more than one aspect. Taylor and Wedel (2016: figures 3, 6–8) illustrated the same three cervicals in colour, each in four or five different aspects. (The fourth, designated Vertebra T, is too damaged to be informative.)

Since Lull’s monograph, *Barosaurus* has become better known from the more complete and better preserved specimen AMNH 6341. This was briefly described in McIntosh’s (2005) revision of the genus *Barosaurus* but has yet to receive a full monographic description. A cast based primarily on this specimen is mounted in a spectacular rearing posture in the Theodore Roosevelt Rotunda at the Americal Museum of Natural History (Figure B): see Taylor et al. (in prep) for detailed discussion of this mount.

More recently, a rediscovered specimen (ROM 3670) was mounted at the Royal Ontario Museum, having been overlooked in collections for decades. But it is largely uninformative as regards cervical morphology: signage in the public gallery indicates that only three cervicals — probably 12, 13 and 16 — are real fossil material, and they are all badly damaged. Garth Dallman (pers. comm., 2022) confirms that the missing vertebrae were filled in with casts from the Carnegie *Diplodocus* CM 84.

In the public gallery of the Natural History Museum of Utah, there is a *Barosaurus* mount in a crouching pose with a raised neck, based in part on real fossils. But the neck is cast from the ROM material (Randy Irmis and Garth Dallman, pers. comms., 2022), so it offers no new information on the cervical morphology. (The Utah *Barosaurus* mount has no single specimen number of its own, being a composite of many specimens.)

In conclusion, then, almost all understanding of the very distinctive neck of *Barosaurus* rests primarily on AMNH 6341, in which the last nine cervicals are preserved, and to a lesser degree on the holotype YPM 429.

## Institutional Abbreviations

* AMNH — American Museum of Natural History, New York, New York, USA.
* CM — Carnegie Museum of Natural History, Pittsburgh, Pennsylvania, USA.
* ROM — Royal Ontario Museum, Toronto, Canada.
* YPM — Yale Peabody Museum, New Haven, Connecticut, USA.

## Anatomical abbreviations

* PRDL — prezygadiapophyseal lamina
* PODL — postzygadiapophyseal lamina
* SPRL — spinoprezygapophyseal lamina

## Note on privately held material

XXX What to say about Western Paleo Labs?

# Materials and Methods

## Length of the neck of AMNH 6341

AMNH 6341 has the best-preserved neck of any *Barosaurus* specimen, but it suffers from two drawbacks.

First, the vertebrae are presently entombed under a glass walkway in a public gallery of the Museum, where they are effectively unavailable for scientific purposes. The walkway has become scuffed over time, becoming increasingly opaque, so that it is difficult to observe the vertebrae in dorsal view: the illustration in Taylor and Wedel (2016:figure 10) were obtained by shooting down through the translucent glass, and extensively manipulating the resulting photographs digitally, and even then the resolution is poor. Neither can the vertebrae be meaningfully observed in lateral view, as the walkways that runs above them is immediately behind a mounted skeleton of *Apatosaurus* and cannot be approached at ground level.

Second, only the last nine cervicals are preserved (along with the complete dorsal series). McIntosh (2005:45) considers these cervicals 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.) This assignment has been generally accepted, and will be followed here.

The sum of the total lengths of the nine preserved centra (from McIntosh 2005:table 2.1) is 6933 mm. However, since the anterior condyle of each vertebra will have been to come degree buried in the cotyle of its predecessor, it may be more appropriate to sum the “functional lengths” *sensu* Taylor and Wedel (2013:6): the length of the centrum omitting the anterior condyle. Happily, McIntosh (2005:table 2.1) includes this information, and the sum of these lengths is 6166 mm — 89% the length when summing the full centrum lengths. Which of these totals should be used? Evidence is equivocal. As shown by Taylor and Wedel (2013:table 4), the thickness of cartilage on cervical vertebrae relative to the bony centrum varies among sauropods from 4.5% for *Sauroposeidon* to about 20% for a juvenile *Apatosaurus*; and among a sample of extant animals, from 2.6% for the rhea to 24% for a juvenile giraffe. Even in *Sauroposeidon*, which has the least intervertebral cartilage of the sampled sauropods, the condyle of C6 barely penetrates the cotyle of C5 (Taylor and Wedel 2013:figures 11–12) and the condyle of C7 does not quite reach the cotyle lip of C6 (Taylor and Wedel 2013:figure 13). For this reason, we favour the use of total centrum lengths. However, we will make the following calculations on three bases: using total centrum lengths (6933 mm for C8–C16); using functional lengths (6166); and using a half-way compromise measurement (6550 mm).

How, then, can we determine the lengths of the seven missing anterior vertebrae? We will use three methods.

### Method 1. Scaling from juvenile ?*Barosaurus* vertebrae

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 John S. McIntosh independently performed a similar scaling operation using these vertebrae, as shown by notes hand-written around 1990 on a printed draft of what would become the table of measurements in his subsequent *Barosaurus* paper (Peter May, pers. comm. 2022). Summing the known centrum lengths of AMNH 6341 cervicals 8–16 from this table (McIntosh 2005:table 2.1) together with the scaled-up centrum lengths of AMNH 7535 cervicals 2–7 written onto the manuscript yields a total of XXX see email.

### Method 2. Extrapolation from anterior *Diplodocus* vertebrae

XXX

### Method 3. Extension by artistic intuition

XXX

## Diagnostic characters of *Barosaurus* cervicals:

* Elongation of centra
* Low, rounded neural spines
* XXX something about the slope from postzygs to top of cotyle?
* Forward sweep of CRL from diapophysis to paraphophysis
* Narrowness of CRL
* Thumb notch posterolateral to prezyg facet
* U-shaped notch between prezyg rami in dorsal view
* “Hinged” parapophyseal rami, angle between PRDL and SPRL
* Posteriorly directed process on diapophyseal process just above CRL
* Width of prezyg rami
* PRDL sweeps out to diapophysis
* Paired PCDLs radiating backwards and downwards from behind diapophysis

Diagnostic characters of cervicals in Revised Diagnosis of *Barosaurus* in Tschopp et al. (2015:261–262):

* (2) pleurocoel not extending onto parapophysis in anterior cervical vertebrae (158-1\*, unique among Diplodocidae)
* (3) elongation index of posterior cervical vertebrae (without anterior condyle) greater than 2.6 (192-2\*, unique among Diplodocoidea)
* (4) an anterior projection on the prdl of posterior cervical, or anterior and mid-dorsal vertebrae, right lateral to the prezygapophysis (213-1, unique among Diplodocoidea)

And of *Barosaurus lentus* (Tschopp at al. 2015:261–262):

* (1) cervical vertebrae pierced by a foramen on the dorsal side of the postzygodi- apophyseal lamina, just anterior to the base of the neural spine process (137-1, unique among Diplodocoidea, when assuming titanosauriform affinities of Australodocus)
* (2) EI (cervical centrum length, excluding condyle, divided by posterior centrum height) of posterior cervical vertebrae is higher than 2.6 (192-2, unique among Diplodocoidea)
* (3) posterior cervical postzygapophyses terminate in front of the posterior edge of the centrum (200-1, unique within Diplodocinae)

XXX Jensen’s Jensen/Jensen Quarry, Jensen

XXX BYU field jacket 3GR, excavated 1966 from Jensen/Jensen

XXX Contains three ?consecutive *Barosaurus* cervicals, designated A, B and C.

XXX Why this is *Barosaurus*.

XXX Difficulty of photographing large bones. Distance and perspective distortion. Photo of me up the ladder shooting down.

XXX Why BYU 9024 is morphologically indistinguishable from *Barosaurus*.

# Results

XXX Sizes of A, B and C.

XXX Serial position of A, B and C.

XXX Size of the 3BJ animal

XXX Size of BYU 9024

XXX Serial position of BYU 9024

## *Barosaurus* compared with *Diplodocus*

*Barosaurus* closely resembles its near relative *Diplodocus* in its postcervical skeleton, differing primarily in cervical characters. This is most notable in the elongation of the neck: it is 40% longer than the 6.1 m neck of the well known *Diplodocus carnegii* holotype CM 84, casts of which grace a dozen museums around the world. The best known *Barosaurus* specimen and the best known *Diplodocus* specimen (AMNH 6341 and CM 84 respectively) are almost exactly the same size in their torso and limbs, differing only in that the former has a longer neck and the latter a longer tail (Figure A). Otherwise proportional differences are minor: *Barosaurus* is slightly taller at the shoulders and slightly less tall at the hips. Since the neck and tail typically accounts for no more than 20% of the mass of a sauropod (see e.g. Taylor 2009: table 4), these two individuals likely weighed almost exactly the same.

As the well known AMNH 6341 specimen of *Barosaurus* is about the same size as the Carnegie *Diplodocus*, which massed perhaps 12 tonnes (Wedel 2005:220) — as since the ROM and Utah mounts are of comparable size such that AMNH material can be readily incorporated into them — it is generally accepted that all the well-known *Barosaurus* individuals massed on the order of 12 tonnes.

XXX Size of the BYU 9024 animal

XXX Comparison of neck with total height of Berlin brachiosaur

# Discussion

XXX Does this mean that *Supersaurus* is *Barosaurus*? No, it's not that easy.

XXX Ecological implications of rare super-giant individuals

# Acknowledgements

First and most important, we thank Brooks B. Britt (Brigham Young University Museum of Paleontology) for helping us to access the BYU specimens that are at the heart of the present work, and also for taking us to an outstanding Brazilian barbecue lunch in the middle of one of our working days in the BYU collection. We also thank Daniel Brinkman (Yale Peabody Museum) for access to the *Barosaurus* holotype YPM 429.

We are grateful to Rick Hunter (Western Palaeo Labs) for allowing us access to privately owned *Barosaurus* cervicals at the North American Museum of Ancient Life.

Scott Hartman has raised the bar for scientifically accurate skeletal reconstructions of dinosaurs, and we are grateful to him for allowing us to use his *Diplodocus carnegii* and *Barosaurus lentus* reconstructions for the comparison in Figure A., and for permission to cite personal communication.

We thank David Evans (Royal Ontario Museum) for information about the ROM’s mounted *Barosaurus* specimen and Randall B. Irmis for information about the composite mounted skeleton at the Natural History Museum of Utah, and for permission to cite personal communication. We also thank Garth Dallman and Peter May (Research Casting International) for permission to cite personal communications.

# References

XXX Not all of these are cited. Trim once the body of the manuscript is mostly done.

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).

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.

Hatcher, Jonathan 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.

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*. Dorling Kindersley (London). 32 pages.

Lull, R. 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

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.

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

Taylor, Michael P. 2009. A re-evaluation of *Brachiosaurus altithorax* Riggs 1903 (Dinosauria, Sauropoda) and its generic separation from *Giraffatitan brancai* (Janensch 1914). *Journal of Vertebrate Paleontology* **29(3)**:787–806. doi:10.1671/039.029.0309

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

Taylor, Michael P., and Mathew J. Wedel. 2013c. The effect of intervertebral cartilage on neutral posture and range of motion in the necks of sauropod dinosaurs. *PLOS ONE* **8(10)**:e78214. 17 pages. doi:10.1371/journal.pone.0078214

Taylor, Michael P., and Mathew J. Wedel. 2016. The neck of *Barosaurus*: longer, wider and weirder than those of *Diplodocus* and other diplodocines. *PeerJ PrePrints* **1**:e67v2. doi:10.7287/peerj.preprints.67v2

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.

# Figure Captions

**Figure A.** Relative size and proportions of the best known *Barosaurus* and *Diplodocus* specimens. In black, *Barosaurus lentus* AMNH 6341; in grey, *Diplodocus carnegii* CM 84. Skeletal reconstructions by Scott Hartman, used by kind permission. *Barosaurus* has notably longer neck than *Diplodocus* and a shorter tail. It is also somewhat taller at the shoulders and less so at the hips. Otherwise their size and proportions are very similar. XXX how was it reconstructed?

**Figure B.** The mounted skeleton of *Barosaurus lentus* AMNH 6341 in the Theodore Roosevelt Rotunda of the American Museum of Natural History, New York. XXX to be sourced.

**Figure C.** Juvenile *Barosaurus* sp. AMNH 7535, cervical vertebra 9 in left lateral view, red-cyan anaglyph. XXX not yet cited.

**Figure D.** Juvenile *Barosaurus* sp. AMNH 7535, cervical vertebra 7 in left lateral view, red-cyan anaglyph. The vertebra is shown with dorsal to the top, since the available photographs vary slightly in their dorsal-vental perspective, not their anterior-posterior perspective. XXX not yet cited.

**Figure E.** Cervical vertebra 9 of two *Barosaurus* specimens compared in dorsal view (anterior to left). **A.** juvenile *Barosaurus* sp. AMNH 7535. **B.** adult *Barosaurus lentus* AMNH 6341. Note that the latter has features characteristic of *Barosaurus* cervicals, including: broad prezygapophyseal facets set on broad rami; “hinged” prezygapophyseal rami, in which a longitudinal ridge separates two flat laminae, the PRDL laterally and the SPRL medially; “swept-out” lateral processes that project laterally, and which are met anteriorly by an elegantly curved PRDL and posteriorly by an elegantly curved PODL; a “thumb groove” separating the prezygapophyseal facet from a laterally positioned eminence on the prezygapophyseal ramus; a “U”-shaped notch where the two SPRLs meet medially; and flaring postzygapophyseal rami. All these features are absent in AMNH 7535. These missing features can be in part explained by lateral crushing, but the vertebra shows little sign of extensive crushing. Their absence may be due to the juvenile status of the individual: at approximate 330 mm in total centrum length, its C9 is less than half the size of that of AMNH 6341 at 685 mm (McIntosh 2005:table 2.1). Or they may indicate that AMNH 7535 is not in fact *Barosaurus*, or at least not *Barosaurus lentus*.