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 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 known from additional specimens, including several mounted skeletons in public galleries (largely as casts rather than real fossils), although none of these have yet been formally described in any detail.

* The most influential of these is AMNH 6341, the iconic rearing mount in the rotunda of the American Museum of Natural History (Figure B), which was briefly described in McIntosh’s (2005) revision of the genus *Barosaurus*. We will return to this skeleton shortly.
* 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 neck of *Barosaurus* as a functional unit is based on the AMNH specimen, due to crushing of the holotype YPM 429 and the paucity of cervical material in other significant specimens.

## The AMNH mount

XXX This section might get moved to a separate manuscript.

Although the AMNH specimen has not been described in detail, it has been enormously significant culturally, and *Barosaurus* is universally recognised as proportionally long necked, even by sauropod standards (e.g. Bartram et al. 1983, Lindsay 1992, Lambert 2000). The mount was created in 1990 by Research Casting International, using casts rather than original fossils. It 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. 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). 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). 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.

The exact length of the neck of *Barosaurus* is difficult to determine as no complete neck is known. AMNH 6341 preserves the last nine cervical vertebrae, which McIntosh (2005:45) considered 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). The atlas was most likely a cast of the one incorporated into the Carnegie mounted skeleton.

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.

## *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 well known AMNH 6341 specimen of *Barosaurus* is about the same size as the Carnegie *Diplodocus*, which massed perhaps 12 tonnes (Wedel 2005:220) — and 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. In this paper, we will review evidence for significantly larger specimens.

## 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

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

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.

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.

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# 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. 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.

**Figure B.** A photograph of the AMNH mount. 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*.