The composition of the Carnegie *Diplodocus*

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**Abstract**

XXX Mike to write this when everything else has been done.

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# Introduction

*Diplodocus* is a sauropod dinosaur from the Late Jurassic of North America, found in the extensive Morrison Formation of the western states. Although larger and more complete sauropods are now known, *Diplodocus* was the first giant dinosaur known from a substantially complete skeleton: the Carnegie Museum’s iconic specimen CM 84 (Figure A). As explained below, casts of this important specimen were sent all around the globe, and as a result this individual became — and remains — the single best-known dinosaur in the world.

However, although the mounted skeleton is often referred to as CM 84, it is actually a composite containing substantial portions of CM 94 and smaller parts of other specimens, and some sculpted elements. The precise composition of the mount has changed since its initial unveiling, and the eleven casts that were made from its molds used slightly different elements again. Documentation of the choice of elements has not been comprehensive, and as a result most of the museums around the world that are exhibiting a Carnegie *Diplodocus* do not know exactly what bones when into making it up.

In this paper, we will summarise the history of the original Carnegie *Diplodocus*, and determine which fossil elements are included both in the fossil mount at the Carnegie Museum and in the many mounted casts based on this material.

## Nomenclature

The mounted *Diplodocus* skeleton at the Carnegie Museum does not have a specimen number of its own. It is often referred to loosely as CM 84, since that is the specimen that contributes most of the fossil material to the mount; or, more carefully, as CM 84/94/307, since those are the three specimens that currently contribute original fossil material. In this paper, we will refer to it as “the Carnegie mount”; when we refer to CM 84, we mean the particular individual specimen, not the mount. When referring to the various cast mounts, we refer to them by the name of the city that they were originally mounted in, e.g. the London cast, the Berlin cast and the Vernal cast. XXX Mike, make sure this is consistently the case.

The diplodocine specimen initially designated CM 662 was moved to the Cleveland Museum of Natural History in 1956, museum director Graham Netting having told head of vertebrate paleontology J. LeRoy Kay to trade large dinosaur specimens due to lack of storage space. It was there given the specimen number CMNH 10670. Some time later, the specimen was sold for $15,000 to the Houston Museum of Natural History, where it was catalogued as HMNS 175 and mounted in 1975. For simplicity we refer to this specimen throughout by its original designation CM 662, as it was under this specimen number that most of its role in this story was played out.

A distinction is made between molds and casts. A mold is a negative structure made from an original specimen (or, less commonly, a cast), in which the spaces inside the mold match the shapes of the original specimen. A cast is a positive structure, a copy made of a specimen made by filling a mold, and its shape matches that of the original specimen.

Vertebrae are designated as follows, for a vertebra at position *n* in a part of the spinal column: cervical vertebrae C*n*, dorsal vertebrae D*n*, sacral vertebrae S*n* and caudal vertebrae Ca*n*.

## Institutional abbreviations

* AMNH — American Museum of Natural History, New York, New York, USA.
* BMNH — British Museum of Natural History, London, England. (Now the Natural History Museum, using the abbreviation NHMUK.)
* BYU — Brigham Young University, Provo, Utah, USA.
* CM — Carnegie Museum of Natural History, Pittsburgh, Pennsylvania, USA.
* CMNH — Cleveland Museum of Natural History, Cleveland, Ohio, USA.
* HMNS — Houston Museum of Nature and Science, Houston, Texas, USA.
* MNHN — Muséum National d’Histoire Naturelle, Paris, France.
* USNM — United States National Museum, Washington DC, USA.
* WDC — Wyoming Dinosaur Centre, Thermopolis, Wyoming, USA.

# Historical background

On 11 December 1898, the *New York Journal and Advertiser* published an illustrated article about giant dinosaurs (Anonymous 1898), depicting a “Brontosaurus giganteus” in bipedal posture, peering into the an 11th story window. In fact, the dinosaur depicted in this article, “Most colossal animal ever on Earth just found out west”, was extrapolated from a single femur, described as being eight feet long, but shown in a photograph as being the same height as an adult man. Nevertheless, industrialist and philanthropist Andrew Carnegie was inspired by this article, and instructed the Pittsburgh museum that he founded and funded to obtain a giant dinosaur skeleton for exhibit. William J. Holland, director of the Carnegie Museum, used Carnegie’s money to hire experienced field palaeontologists away from other museums and sent them out to hunt sauropods.

On 4 July 1899 — Independence Day — Dr. Jacob L. Wortman, working for the Carnegie Museum, found the first bones of a largely complete sauropod specimen at Sheep Creek in Albany County, Wyoming. He and his team collected it across a period of several months (Hatcher 1901:3–4, Nieuwland 2019:44). This specimen was designated CM 84. It consisted of 14 cervical vertebrae C2–15 (although see Taylor 2022:8–11 on uncertainties about the neck material), all 10 dorsal vertebrae D1–10, sacrum, caudal vertebrae Ca1–12, 18 ribs, both sternal plates, left scapulocoracoid (not right as stated by Hatcher), almost complete pelvis, right femur, and two thin bones of uncertain identity which Hatcher thought might be clavicles (McIntosh 1981:20).

In 1900, Mr. Olof A. Peterson collected another, slightly smaller, specimen of the same species of sauropod from the same quarry (Hatcher 1901:3). This specimen was designated CM 94. It consisted of nine cervical vertebrae, nine dorsal vertebrae, sacrum, 39 caudal vertebrae, fragments of ribs, five chevrons, both sternal plates and scapulocoracoids, the complete pelvis, left femur, and right tibia, fibula, astragalus and pes (McIntosh 1981:20).

Both specimens were prepared out of their matrix by a team led by Mr. Arthur S. Coggleshall.

On 15 May 1901 (Niewland 2019:46), the classic description of both these specimens of *Diplodocus* was published (Hatcher 1901), written by John Bell Hatcher, the Carnegie Museum’s head of palaeontology. This monograph illustrated CM 84 in some detail and named it as the holotype of the new species *Diplodocus carnegii* in honour of the museum’s sponsor. The illustrations included a skeletal reconstruction of *Diplodocus* (Hatcher 1901:plate XIII; Figure B).

At the start of October 1902, King Edward VII of England paid a surprise visit to Carnegie at Skibo Castle in Scotland. Seeing a framed copy of the skeletal reconstruction of *Diplodocus*, he requested a specimen for the British Museum in London, England, of which he was a trustee (Nieuwland 2109:50). Carnegie, keen to gain favour with men of influence, happily promised to provide one as a gift, and on 2nd October wrote to Holland to ask him to excavate another *Diplodocus* for the British Museum.

In late December 1902, when Carnegie had returned to Pittsburgh, Holland explained that finding a comparable specimen was unlikely, and would be expensive even if luck was on their side. He was able to persuade Carnegie that a cast of their existing specimen would be a more practical gift (Nieuwland 2019:58). Holland arranged the details in correspondence with E. Ray Lankester, his counterpart at the British Museum (Natural History).

To defray the high cost of producing the cast, Holland suggested that the molds could be used to create multiple casts which Carnegie could gift to other heads of state — and idea that appealed greatly to Carnegie.

Starting in 1903 and running through into 1904, the Carnegie Museum made molds of the *Diplodocus* bones, and the first set of casts from these molds. (Some bones had to be sculpted, because the originals were either absent or in too poor a condition for the molding process.) The work was led by Arthur Coggeshall, the chief preparator of fossils at the Carnegie Museum, who was also in charge of designing the armature to carry the cast bones. A crew of Italian plasterers led by Serafino Agostini was employed, thanks to their expertise in casting artworks and Agostini’s experience at the AMNH (Nieuwland 2019:71). (Agostini seems to have continued to work for Carnegie Museum for at least another 30 years, as the Annual report for 1934 says that “Mr. Agostini made some excellent moulds and casts of the skulls of *Apatosaurus* and *Diplodocus* during the year and one of these skull casts has been mounted on our great skeleton of *Apatosaurus* which stands in the exhibition hall.” (Carnegie Institute 1934:))

In late June of 1904, the cast created for the British Museum was temporarily mounted as a trial at the Pittsburgh Exposition Society Hall — see photograph in Nieuwland 2019:figure 3.1. The skeleton was shown to an invited party on 29th June, then to the public on the 30th, before being disassembled again on the 2nd July. On the very next day, Hatcher died of typhoid fever at only 42 years of age — but he had at least seen the skeleton that he had described in its mounted state before his death (Holland 1906:226). The Carnegie Museum’s *Diplodocus* cast was therefore (albeit briefly) the first mounted sauropod in the world, six months ahead of the AMNH’s composite *Brontosaurus*, AMNH 460, which was to be unveiled on 16th February 1905 (Brinkman 2010:104).

The casts were shipped from Pittsburgh on 3rd December 1904 and arrived safely at the British Museum on 11 January 1905.

By February 1905, not only were the molds and the BMNH cast complete, but four additional sets of cast elements had been made, all at a total cost of $8,558 (Nieuwland 2019:75). This cost did not include that of shipping and mounting the casts, which was typically rather more expensive than their production had been.

In April 1905, Holland and Coggleshall arrived at South Kensington and supervised the assembly of the first cast skeleton (Holland 1905:443). At 1pm on 12th May 1905, the mount was unveiled at the BMNH — see photographs in Holland 1905:plates XVII and XVIII. Speeches were given by Ray Lankester, Andrew Carnegie, Lord Avebury speaking for the trustees, Holland (including a tribute to the recently deceased Hatcher), Sir George Trevalyan (the longest-serving of the trustees) and Sir Archibald Geikie (representing British geologists). Although the material for the mount had been completed as early as October the previous year, the public unveiling had been delayed until spring of 1905 in the hope that more of London’s dignitaries could be present. The king himself, disappointingly to Lankester and Carnegie, was not among those in attendance. However, the events attracted a great deal of press coverage, not only in London and Pittsburgh but across Britain and America, and even in Canada and Australia. The next day, the exhibit was opened to the general public, and attracted the largest crowds that had ever attended the museum (Holland 1906:264).

After Hatcher’s death, Holland had succeeded him as the scientific leader of the work on *Diplodocus*, even though his principal field of study was lepidoptery. In 1906, his monograph on *Diplodocus* osteology (Holland 1906) was published, using two new specimens to expand on Hatcher’s (1901) description with more detail especially on the skull, atlas, tail, sternal plates and supposed clavicles.

On 11 April 1907, the original *Diplodocus* fossils were mounted at the Carnegie Museum (Nieuwland 2019:92), nearly two years after the London cast. The skeleton was unveiled as part of the opening of a new Carnegie Museum building on Forbes Avenue in the Oakland suburb of Pittsburgh, the original building having quickly been outgrown. As will be discussed in detail, below, this “original material” mount in fact included elements from multiple specimens, cast of several more, and sculpted elements based on yet other specimens. The next day, Carnegie met with the German Theodor von Möller and the Frenchman Paul Doumer, each of whom asked him to gift *Diplodocus* casts to their respective countries. Carnegie agreed, and on the next day — the last of the three-day inaugural festival — Holland announced the gifts to all the guests. Although the *Diplodocus* mount had been only one part of the Carnegie festival, its fame quickly grew with the local population, and it “became increasingly identified with the museum itself to the point where one could wonder whether it contained anything else” (Nieuwland 2019:97).

Holland and Coggleshall worked on the casts destined for Berlin and Paris, hoping initially to install the Paris cast first but finding it difficult to get the necessary arrangements solidified. In the end, both casts were constructed on the same European trip. The German cast was erected at the Humboldt Museum für Naturkunde Berlin beginning on 14 April 2008, and the work was complete by 13 May. The exhibition was opened to little fanfare, with no formal unveiling event, and the mounted skeleton was positioned off to the side of the museum’s main hall, which remained dominated by whale skeletons (Nieuwland 2019:115–118).

On 22 May, Holland and Coggleshall arrived in Paris to erect the third cast at the Muséum National d’Histoire Naturelle (MNHN), to find that the French press were already raising public excitement. The work was completed in time for a lavish public ceremony on 15 June, in the great contrast to the muted launch of the Berlin mount. The Paris unveiling was attended by the French president, prime minister and police prefect, the American Ambassador, and a selection of scientists and artists (Nieuwland 2019:139–140). Carnegie himself was strangely unconcerned, and did not attend the festivities.

The visibility of the Carnegie *Diplodocus* in various locations, in its mammal-like upright posture, provoked some controversy: Hay (1908, 1910, 1911) and independently Tornier (1909) argued that its erect-legged posture was incorrect, and it should sprawl like a lizard. Abel (1910) and Holland (1910) emphatically rebutted these suggestions; Matthew (1910) also disagreed — showing rather more respect to Hay than Holland did, and critical of Holland’s tone, but dismissive enough of Tornier to write that “the subject appears, frankly, to be somewhat outside the range of his studies, and his comparisons are not broad or thorough enough to be at all convincing”.

The donation of a cast to the Kaiserliches und königliches naturhistorisches Hof-Museum in Vienna, Austria was not wholly welcome to the museum director Franz Steindachner. But once emperor Franz Joseph of the Austrian-Hungarian empire had requested the gift from Carnegie, he had little option but to find space for it somewhere. This proved difficult — a mooted new building was cancelled due to lack of funds, and in the end the skeleton was mounted in a three-meter-wide corridor (Nieuwland 2019:216–219). The emperor was present for the unveiling on 24 September, 1909, but the ceremony appears to have been an rather unspectacular affair, lasting only fifteen minutes. The novelty of the Carnegie *Diplodocus* was wearing off, and most of the subsequent gifts would be received with less than extravagant gratitude.

On 27 October 1909, the last of the original batch of five casts was mounted in Bologna, Italy, largely at the instigation of the university museum’s director, Giovanni Capellini — although the name of King Victor Emmanuel III was invoked, gratifying Carnegie’s desire to be seen to be responding to requests from heads of state. (Nieuwland 2019:227–228) Although previously casts had been erected in the capital cities of the countries they were donated to, Bologna was considered an appropriate venue, perhaps partly because the University of Bologna is the oldest continuously operating university in the world.

XXX Ilja, can you please flesh out the remainder of the timeline from here?

1909–1910: five further casts are made from the molds

1910: a cast is mounted in St. Petersburgh (now Leningrad), Russia. Discuss posture.

1912: another cast is mounted in La Plata, on the outskirts of Buenos Aires, Argentina. See Otero and Gasparini 2014 at <https://bioone.org/journals/annals-of-carnegie-museum/volume-82/issue-3/007.082.0301/The-History-of-the-Cast-Skeleton-of-Diplodocus-carnegii-Hatcher/10.2992/007.082.0301.short>

1913: another cast is mounted in Madrid, Spain.

1914: The Great War breaks out, ending Carnegie's arbitration campaign that was the main reason for donating casts, and reducing the pace of creating new casts.

1917 at the latest: the molds went into storage and are not used again, according to Untermann (1959:364).

1919: Carnegie dies, leaving no permanent endowment for vertebrate palaeontology at the Carnegie Museum (Brinkman 2010:109), plunging the department into financial difficulty.

1932: the penultimate cast is mounted in Mexico (with missing/damaged parts produced and added in 1931/2), funded in part by Carnegie’s widow Louise.

1934: the final cast is sent to Munich, but never mounted. “In November and December a replica of the skeleton of *Diplodocus carnegiei* was assembled, repaired, boxed, and shipped to Munich, in completion of an exchange of fossil material received some five years ago” (Carnegie Institute 1934:40).

See Taylor and Sroka in prep. on the Concrete *Diplodocus* of Vernal.

See Taylor et al. In prep. on the AMNH rearing *Barosaurus* mount.

See Table B for a summary of all the Carnegie *Diplodocus* casts.

# Material in the mounted skeleton

## The original mount at the Carnegie Museum

Hatcher’s (1901) descriptive monograph on *Diplodocus carnegii* was written well before any of the material was mounted, and so does not comment on the material of the mount. Hatcher (1901:4) did provide material lists both for CM 84 itself and for the specimen, CM 94, which provided much of the missing material for the mount. But his list contains at least one error — it is the left scapula and coracoid that are preserved, not the right (McIntosh 1981:20).

Hatcher’s (1903) brief further notes of *Diplodocus carnegii* also did not touch on the planned mounting. (He did however revise the interpretation of the manus to be more plantigrade than previously: this was exactly wrong, as would be shown only a year later in Osborn’s (1904) paper beginning “My previous figures and descriptions of the manus are al incorrect” and illustrating the now familiar vertical semicircular arcade of metacarpals. Two years later, Holland (1906:226), either unaware or unconvinced by Osborn’s paper, would claim that the manus should be even more plantigrade that Hatcher had argued.)

Holland (1905) provided an account of the presentation of the first cast to the BMNH, and especially of the speeches given during the presentation ceremony. (In this account, and in subsequent papers, Holland referred to Carnegie’s *Diplodocus* species by the name “*Diplodocus carnegiei*”. Although this spelling of the species name should perhaps have been used in the original description, the fact is that it was not, and Hatcher’s (1901) prior publication of the species name *carnegii* has priority.) Although this account is more political than scientific, it does contain the detail that the proximal end of the right tibia shows theropod tooth marks. (As noted by McIntosh (1981:20), the right tibia is actually from CM 94, not the “core specimen” CM 84.)

Holland’s (1906) follow-up on *Diplodocus carnegii* osteology, while dealing in part with the cast that was mounted at the BMNH in 1905, also predated the 1907 mounting of the original fossil material at the Carnegie Museum. This paper was therefore unable to provide a comprehensive catalogue of which bones from which specimens were used in the mount, but did provide some relevant information especially about the skull. CM 84, the specimen from which the Carnegie mount is mostly assembled, does not itself include a skull. Holland (1906:227) explained that the skull supplied to British 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 sculpted based on material from CM 662, which was described in detail by Holland (1906:230–246) and illustrated by Holland (1906:plates XXVII–XXVIII). This specimen was initially referred by Holland (1906) to the genus *Diplodocus* and subsequently made by him the holotype of the new species “*Diplodocus*” *hayi* (Holland 1924:399). The species has since been moved to its own new genus *Galeamopus* by Tschopp et al. (2015:267).
* The remainder of the skull was based on USNM 2673 (illustrated by Holland 1906:plate XXIII–XXV), the skull on which Marsh (1896:175–179) had primarily based his description of the skull of *Diplodocus*. With the USNM’s permission, the Carnegie Museum made a cast of this skull, of which only the left side had been fully prepared. They used this to restore the missing half. Ironically, this skull has since been referred by Tchopp et al. (2015:228) to *Galeamopus*, meaning that both the fossils on which the Carnegie mount’s skull were based are now considered to belong to that genus rather than to *Diplodocus*.

Holland (1906:228–230) was ahead of his time in determining the orientation of the skull as being strongly inclined relative to the cervical column. Citing Marsh’s (1896:175–176) observation that “the occipital condyle […] is placed nearly at right angles to the long axis of the skull”, Holland (1906:229–230) rightly observed that “to place the skull with its longer axis in a line parallel with that of the cervical vertebrae was a mechanical and anatomical impossibility [and] involves the dislocation of the neck”. Instead he arranged for the skull of the London cast to be strongly inclined downwards. Yet when the Senckenberg Museum in Frankfurt, Germany opened in 1907, displaying a bas-relief half-mounted *Diplodocus* skeleton supplied to it by the AMNH, the skull was oriented incorrectly, with its long axis parallel to the neck (photograph in Anonymous 1907:figure 1), and it remains in this impossible posture even in the recent remount (see e.g. Norman 1985:188-189). Over a century later it is still common to see artwork of *Diplodocus* (and other sauropods) with their heads parallel to their necks, as for example in the cover art of Lindsay (1992) and even the silhouette on the cover of Nieuwland (2019).

Holland (1906:246–249) also described and illustrated in detail the atlas of AMNH 969, but did not specify that it was the one used as the basis for the sculpture used in the mount — and indeed it does not appear to be, as his illustrations of the disarticulated odontoid, atlas intercentrum and neural-arch halves (figures 11–21) do not resemble the fully ossified atlas depicted in his photograph of the mounted skull and anterior neck (figure 1). XXX Matt, do we know more about the atlas in the mount?

Holland (1906:257–264) also discussed the bone that Hatcher (1901:41) tentatively described as a clavicle, but he was unable to reach a conclusion as to its true identity, dismissing the suggestion of Nopcsa (1905) that it was a baculum and suggesting they it could be a sternal rib. A pair of sculpted clavicles based on a similar element from CM 662 were tentatively included in the BMNH cast during the mounting, and photographed (Holland 1906:figures 25–26), but were removed after a few days due to the uncertainty about their true identity (Holland 1906:263–264; see photograph in Holland 1905:plate XVIII). They do not seem ever to have been incorporated in the Carnegie mount, and are not present in the current mount (Figure C). More recently, it has been suggested thst this bone in CM 84 is an interclavicle (Tschopp and Mateus, 2012).

These scraps of information can be found in Hatcher's and Holland's publications. In fact, we have not been able to locate any published detailed account of the material used in the mounted skeletonbefore that of McIntosh’s (1981) catalog of the Carnegie dinosaurs. McIntosh’s account is understandably terse, given that he was writing notes on hundreds of specimens, so we reproduce the relevant sections in full here:

***Diplodocus carnegii*** Hatcher, 1901

Cervicals 2–15, dorsals 1–10, sacrals 1–5, caudals 1–12, 18 ribs, left scapula (not right as stated by Hatcher), left coracoid, right ilium and a fragment of the left, pubes, ischia, right femur, both sternal plates, supposed clavicle.  
[…]  
This specimen forms the core of the skeleton which was mounted and put on display in 1907. The latter was completed by additions from several other individuals as follows: CM 94 (median caudals, right scapula-coracoid, right tibia-fibula-pes), CM 307 (distal caudals). The skull was modelled from the braincase of CM 662 and skull USNM 2673. The right forelimb (and also the left forelimb of the eleven casts of the skeleton sent to museums throughout the world) was accurately modelled from the smaller individual CM 662. The forefeet were modelled from the larger manus AMNH 965 now known to belong to *Camarasaurus*, and too many phalanges were assigned to the manus. In the Carnegie Museum of Natural History original only, the left forelimb CM 21775 now assigned to *Camarasaurus* was used, as were the left fibula and partial pes CM 33985.

Hatcher (1901:) noted that CM 94 “pertained to a somewhat smaller individual” than CM 84. Frustratingly, he gave few measurements of CM 94, and those he did give (e.g. of the ilium, p. 46) mostly do not have corresponding measurements of CM 84. The exception is in the femora, which Hatcher (1901:47) reported as 1542 mm in length for CM 84 and 1470 mm for CM 94. On this basis, CM 94 is 95% as large as CM 94, and including elements from it in the skeletal mount based primarily on CM 84 is warranted. (The CM 94 femur is proportionally less robust than that of CM 84, though, being only 78% as broad across the proximal end and 89% as broad across the distal end.)

CM 662 had not been discovered at the time Hatcher wrote his 1901 monograph. It is described in Holland (1906) but with a strong focus on the skull, and no measurements are given. No subsequent description has been published of this excellent specimen, neither while it was at the Carnegie Museum, nor during its time at the Cleveland Museum of Natural History, nor since its arrival at the Houston Museum of Natural History. McIntosh’s (1981:20) mentioned it being “the smaller individual” compared with CM 84, but did not quantify this. However, McIntosh (2005:68) gives the femur length of CM 662 as 1448 mm. As a cross-check, he also (p61) gives the humerus length as 910 mm (left) and 936 mm (right), and on the previous page gives the humerus:femur ratio as 0.64, implying femur lengths of 1422 mm (left) and 1463 mm (right) — and the given femur length falls close to the middle of this range. Given 1542 mm femur length of CM 84, CM 662 is 94% as large: very similar in size to CM 94, and close enough to CM 84 that inclusion of casts in the mount is justified.

Curtice (1996:72–73) gave a more precise account of the source of the caudal vertebrae: Ca13–31 and 33–36 were from CM 94, while Ca32 and Ca37–73 inclusive were from CM 307. He obtained this information either from Jack McIntosh or from materials found in the Carnegie library (pers. comm., 2022). Curtice (1996:73) believed that the CM 307 caudals were mounted in a position about six places further back than they should have been. (The CM 307 caudals were catalogued by McIntosh (1981:21) as *Diplodocus* sp., not necessarily *D*. *carnegii*, and in fact may not belong to the genus *Diplodocus* at all.)

McIntosh’s account of the mounted skeleton omits the source of several elements, and these omissions have not been remedied by any subsequent publication known to us. The elements of unspecified origin are the atlas (C1), chevrons, and left ilium, femur and tibia. XXX Matt, can we track this information down? The paratype specimen CM 94 includes a left femur, which may have been used. (XXX Matt, was it?) Furthermore, while McIntosh noted that the left fibula and pes of the original mount were taken from CM 33985 and that these were not used in the casts, he did not say how the left fibula and pes were furnished in the casts. XXX Matt, can we find this out?

As noted above while Holland (1906:246–249) described in detail an atlas of *Diplodocus*, that of AMNH 969, he did not say that it was used in the mount; and the atlas shown in his figure 1, a photograph of the mounted cast’s head and anterior neck, does not appear to be it. Disappointingly, Holland (1906) did not comment at all on the hindlimb or girdle.

Hatcher’s (1901:4) list of the material of CM 84 does not mention chevrons at all, and his list for CM 94 says only “these remains were found associated with a few chevrons”, reiterated in his mention on page of 34 that “associated with No. 94 there were found […] several chevrons” — clearly not enough to furnish material for the tail of the mounted skeleton. However, Holland (1906:255) confusingly wrote that “the anterior chevrons used in making the reproduction [i.e. the London cast] were those found with our specimen No. 84”, even though there seem to have been none associated with that specimen. It must be considered possible that this was a typographical error for CM 94: although only more posterior caudals from CM 94 were used in the mount, its vertebral column as found was complete from C7 through to Ca39, and so likely included chevrons for the anterior caudals. Holland (1906:255–256) continued “Many of the chevrons after the first six are reproductions of those found and described by Professor Osborn in his paper on *Diplodocus*”, i.e. AMNH 223, described by Osborn (1899).

Table A summarises the contributions from different specimens to the Carnegie mount (and subsequent modifications, and the casts). Figure D shows graphically the contributions of the different specimens. Figure E shows the original mount as it appeared in 1907, and highlights the difference between humeri, that of the left forelimb having been supplied from the camarasaurus id specimen CM 21775.

[Table A here]

Before the mount was attempted, Hatcher (1901:39) reported that the total length of the *Diplodocus* CM 84/94 composite as reconstructed on paper was 68 feet (≈ 20.7 m). This estimate omitted the distal tail, and would be revised upwards in future publications. By the time Holland described the presentation of the London cast only four years later, he gave the length as 84 feet (Holland 1905:448) (≈ 25.6 m). We have not been able to locate any sourced measurement in any published source subsequent to this.

## Changes made to the mount at the Carnegie Museum

### Replacement of skull with cast of CM 11161

The first known change made to the Carnegie mount was the replacement of the original skull sculpture based on CM 662 and USNM 2673. We have been unable to locate records stating which skull was used in the replacement, but it is still in place today and by inspection it is evidently based on CM 11161. This specimen is a complete and superbly preserved cranium and mandible, described and illustrated in detail by Holland (1924). It was discovered on Thanksgiving Day of 1912 (McIntosh 1980:17).

In the absence of extant records, it cannot be stated when precisely this switch was made, or even whether the new skull is a cast or a sculpture. Carnegie Museum annual reports from 1912 (when CM 11161 was discovered) up until the turn of the millennium make no mention of its use as the basis of a new skull for the mount. It was certainly available for Serafino Agostini to have used when he “made some excellent moulds and casts of the skulls of *Apatosaurus* and *Diplodocus*” in 1934 (Carnegie Institute 1934:40), but since this report mentions that one of those casts was used to provide a skull for the mounted *Apatosaurus* CM 3018 and no mention is made of one used for the *Diplodocus* mount, we can assume this was not done, and that the substitution must have happened later.

The annual report for 1962 says that chief preparator Joseph Yarmer “made several new molds of specimens in the collections, including one of the *Diplodocus* skull from which a number of casts were made.” (Carnegie Institute 1962:16). Unfortunately, the report does not specify which *Diplodocus* skull was used. CM 11161 would certainly have been a strong contender, and it may have been around this time that the new skull was added to the mounted skeleton, but it is impossible to be sure.

We know at least that the skull replacement was done before 1979, when Amy Henrici began working at the museum, as it was already in place at that point. In a personal communication from the Carnegie Museum’s former Exhibits Preparator, who began working there in 1971, he recalls making a model of the *Apatosaurus* skull, but that he never made a model or a cast of the *Diplodocus* skull. This suggests that the replacement of the skull was completed before 1971 – perhaps, then, when Agostini created the *Diplodocus* mold in 1962.

Curiously, the skull replacement it is not mentioned in McIntosh’s (1981) account of all the dinosaur specimens at the Carnegie museum, and in particular not in the section on the mount on page 20. Given McIntosh’s habitual thoroughness, the omission from his account of the mounted skeleton is anomalous.

Regarding whether the present skull is a cast or a sculpture: it preserves bone texture, including damage, very accurately (Figure F). The mounted skull includes the sclerotic ring in the left orbit but omits it from the right orbit. This is the condition in the original CM 11161 fossil (compare Tschopp et al. 2015:figure 1D with figure 3E), and while this asymmetric preservation would be replicated by a cast, it would not likely be included in a sculpture. For these reasons, we believe the skull is a cast.

### Re-pose of neck

In a photograph of the mounted *Diplodocus* taken some time between 1980 and 1999 (Figure G), the neck is shown in a somewhat raised posture and is suspended from the ceiling. This is in contrast to older photos in which it is horizontal and supported from beneath by a pole. However, the tail remained in its old dragging posture. XXX Matt, do you know when this neck elevation was done and by whom?

### 1999 replacement of forefeet with CM 662 sculptures

The forefeet of the original mount were sculpted from those of a *Camarasaurus* specimen AMNH 965, the forefeet of *Diplodocus* being unknown at the time. They were reconstructed in a semi-plantigrade posture now known to be inaccurate, and reconstructed with unguals on each of the first three digits (Figure E.A–B, G), although it was already known at the time of mounting that sauropod forefeet had claws on only the first digit (Osborn 1904:181). Only nearly a century later, in the second quarter of 1999, were these error remedied, when Norman Wuerthele and Amy Henrici made casts of the forefeet of CM 662 (Carnegie Institute 1999), which were installed shortly afterwards. Although this individual was originally a Carnegie Museum specimen, by this point it was at the Houston Museum of Natural Science.

### 2007 refurbishment of the dinosaur exhibition

By the turn of the millennium, the original 1907 Hall of Dinosaurs had been in place for nearly a century with no major renovations. Plans were laid early in the 2000s not just to renovate the hall but to add additional space in a newly constructed atrium, add more mounted skeletons and other specimens, and remount the existing skeletons. The expansion was announced on Thursday 11 April, 2002 (Siemers 2007); architects were hired in 2004 (Hopey and McNulty 2007) and the hall was closed for refurbishment on Friday 11 March 2005 with a special event that evening marking the occasion (Horne 2005).

The new dinosaur exhibition, titled *Dinosaurs in the their world*, was opened in two phases: the Triassic and Jurassic sections in November 2007, and the Cretaceous section in June 2008. The Jurassic section, including *Diplodocus*, was opened for ticketed previews at 6 am on Saturday 17 November 2007 (Roddy 2007) and for general admission on 21 November 2007 (McNulty 2007).

As part of the broader renovation project, the Carnegie *Diplodocus* was remounted in a new, more dynamic posture, and several changes were made to the materials incorporated in the mount, as follows.

### Forefeet WDC-FS001A

As noted above, CM 662 has been recognised since 1924 as representing a different species from CM 82, “*Diplodocus*” *hayi* (Holland 1924:399). It was perhaps for this reason (XXX Matt, was it?) that, unlike their predecessors, the sculptures based on these forefeet remained in the Carnegie mount for less than a decade. During the remount of 2007, the forefeet were replaced once more, this time with scaled-up sculptures based on casts of the putative *Diplodocus carnegii* manus WDC-FS001A described by Bedell and Trexler (2005).

Since the replacement of the CM 662-based forefeet, the species *hayi* has been moved to its own genus *Galeamopus* (Tschopp et al. 2015:267), further justifying the decision to replace these forefeet with those of *Diplodocus* proper.

### Forelimbs from BYU material

Until the 2007 remount, the Carnegie mount had retained the obviously incorrect left forelimb of the *Camarasaurus* specimen CM 21775 (Figure E). XXX Matt, is this true? See email thread and Figure G. (This specimen is described and illustrated by Tschopp et al. 2019:33–37 and referred by them to Camarasauridae indet.) The right forelimb, having been based on the diplodocine CM 622, was a better match for CM 82, but not perfect as discussed above. For this reason, both forelimbs were replaced in the 2007 remount by scaled-up sculptures based on the forelimb bones of a well preserved but smaller specimen of *Diplodocus*, BYU 681: specifically, the humerus BYU 681/4742, the radius BYU 681/4726 and the ulna BYU 681/4708 (Tschopp et al. 2019:33). XXX Matt, who did this work?

Wilhite (2003:33) assigns the humerus BYU 681/4742 to *Diplodocus*, but Bonnan (2007:1111) lists it as belonging to *Camarasaurus.* Hedrick et al. (2012:301), Mitchell and Sander (2014:768) and Dumont et al. (2014:783) all list the femur BYU 681/11940 as belonging to *Apatosaurus*, but it seems from Wilhite (2003:148) that BYU 681 is a composite of elements from different taxa.

The femur of BYU 681/11940 is 1330 mm in length (Klein and Sander 2008:256), compared with 1542 mm for CM 84 (Hatcher 1901:47). If BYU 681 were a single individual, this would indicate that it was 86% as large in linear dimension as CM 84, but the assignment of different parts of BYU 681 to different taxa makes this dubious. At any rate, 86% is too small an individual for casts of its bones to have been incorporated directly into the mount, hence the scaling of the sculptures.

### Distal caudal vertebrae

Also included in the 2007 remount were about ten additional distal “whiplash” caudals, bringing the total number of caudal vertebrae to ~83. The rationale was that the complete tail of the small apatosaurine specimen CM 3378 (probably *Apatosaurus louisae*) contains 82 vertebrae; given that diplodocines are generally more elongate, gracile animals than apatosaurines, it was estimated that *Diplodocus carnegii* would have had at least 83 caudals in life.

XXX Matt, what is the current length of the mount and how was it measured? Photogrammetry, LiDAR scan, string?

## The casts made from the Carnegie molds

As noted above, McIntosh (1981:20) reported that the casts of the Carnegie *Diplodocus*, starting with the BMNH cast in 1905, were different in some details from the original-material mount erected in 1907 at the Carnegie Museum. Specifically, the left forelimb of the casts was sculpted from the slightly smaller diplodocine individual CM 662 rather than from the camarasaurid forelimb CM 21775. Not only was this forelimb inherently more appropriate for *Diplodocus*, it was also a better match for the right forelimb, which in both the Carnegie mount and the casts was based on CM 662. In this respect, the casts were better than the original mount.

As noted above, the referred *Diplodocus carnegii* specimen CM 33985 provided the left fibula and partial pes (metatarsals III, IV and V, see McIntosh 1981:21) of the original mount. For unknown reasons, however, these were not used in the casts. No documentation survives indicating what material was used to create the casts for these elements. XXX Matt: or does it? XXX Mike: perhaps visit the Paris mount and see if they are mirrored?

Since the mounting of the ten original casts, some updates have taken place: for example, the skull of the Madrid cast was replaced by “a new Carnegie replica” when the exhibit was moved to a new hall in 1935 (Nieuwland 2019:247) and the posture of the La Plata cast was updated when it was moved from Hall V to Hall II in 2012 ( Nieuwland 2019:247).

# Discussion

XXX Mike: difficulty of tracking down all this information, importance of records

In working on this paper, it has become apparent how much the work we do now is part of a continuing story. Only six years elapsed from the discovery of CM 84 to the mounting of the London cast; two more years until the Carnegie mount of the original fossil material was erected; only six more years elapsed before the last pre-WWI cast, the eighth, was mounted in Madrid; 21 years after that until the last of the Carnegie Museum’s ten plaster casts was donated to the Munich museum that never mounted it; 18 years until the molds themselves were donated to the Field House museum in Vernal and five more years until the concrete cast was set up outside the Field House (Taylor and Sroka in prep.); 22 years until the original cast in London was moved into its natural home in the main gallery of the Natural History Museum, with the skull of the Carnegie mount being replaced at around the same time; 12 years until a fresh mold made from the concrete cast was used to supply *Diplodocus* parts for the AMNH’s iconic rearing *Barosaurus* mount (Taylor et al. in prep.); eight years until the forefeet of the Carnegie mount were replaced; eight more years until the renovationof the Carnegie mount; ten years until the Natural History Museum removed the first ever *Diplodocus* cast from display to make more room for corporate events. Now, five years on, we hope that in writing up some of this history we are making our own contribution to the ongoing story of this most historic, charismatic and important of fossils.

# Acknowledgements

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# Tables

**Table A.** Source of the skeletal elements of the original Carnegie mount, modifications subsequently made to that mount, and sources of elements of the casts where they differ from the original material mount. (C) indicates that a cast was used for an element rather than real bone; this is omitted in the casts column; (S) indicates that a sculpture was used, based on the named specimen. No attempt is made to track changed made to the casts subsequent to their original erection.

|  |  |  |  |
| --- | --- | --- | --- |
| **Element** | **Original mount** | **Changes to mount** | **Casts** |
| Skull | CM 622 (S) +  USNM 2673 (S) | CM 11161 (C), probably late 1970s. |  |
| Atlas | ? |  |  |
| C2–15 | CM 84 |  |  |
| D1–10 | CM 84 |  |  |
| Sacrum (S1–5) | CM 84 |  |  |
| Caudals 1–12 | CM 84 |  |  |
| Caudals 13–31, 33–36 | CM 94 |  |  |
| Caudals 32, 37–73 | CM 307 |  |  |
| Caudals 74–83 | (omitted) | Sculptures added |  |
| Cervical ribs | CM 84, some sculptures |  |  |
| Dorsal ribs | CM 84, some sculptures |  |  |
| Chevrons 1–6 | CM 94 or possibly CM 84 |  |  |
| Chevrons 7– | AMNH 223 (S) |  |  |
| Sternal plates | CM 84 |  |  |
| Left scapulocoracoid | CM 84 |  |  |
| Right scapulocoracoid | CM 94 |  |  |
| Clavicles | (omitted) |  |  |
| Interclavicle | (omitted) |  |  |
| Left forelimb | CM 21775 |  | CM 662 (S) |
| Right forelimb | CM 662 (S) |  |  |
| Forefeet | AMNH 965 (S) | CM 662 (C); replaced again by  WDC-FS001A (C) |  |
| Left ilium | ? |  |  |
| Right ilium | CM 84 |  |  |
| Pubes | CM 84 |  |  |
| Ischia | CM 84 |  |  |
| Left femur | ? |  |  |
| Right femur | CM 84 |  |  |
| Left tibia | ? |  |  |
| Right tibia | CM 94 |  |  |
| Left fibula | CM 33985 |  | ? |
| Right fibula | CM 94 |  |  |
| Right pes | CM 94 |  |  |
| Left pes | CM 33985 (in part) |  | ? |

**Table B.** The dozen Carnegie *Diplodocus* individuals consisting of the original material mount and all casts made from the original molds, in chronological order of presentation.

|  |  |  |  |
| --- | --- | --- | --- |
| **Mount** | **Museum** | **Presented to** | **Unveiled** |
| London cast | Natural History Museum | King Edward VII | 12th May 1905 |
| Carnegie mount | Carnegie Museum of Natural History | N/A | 11 April 1907 |
| Berlin cast | Museum für Naturkunde Berlin | Kaiser Wilhelm II | 13 May 1908 |
| Paris cast | Muséum National d’Histoire Naturelle | Président Ar- mand Fallières | 15 June 1908 |
| Vienna cast | Kaiserliches und königliches naturhistorisches Hof-Museum | Emperor Franz Joseph | 24 September 1909 |
| Bologna cast | Giovanni Capellini Museum for Paleontology and Geology | King Victor Emmanuel III | 27 October 1909 |
| St. Petersburg cast |  |  |  |
| La Plata cast |  |  |  |
| Madrid cast | Museo Nacional de Ciencias Naturales | King Alfonso XIII | 28 November 1913 |
| Mexico City cast |  |  |  |
| Munich cast |  |  | never |
| Vernal cast | Utah Field House of Natural History | N/A | 6 June 1957 |

# Figure Captions

**Figure A.** The *Diplodocus carnegii* holotype CM 84 as it is today: the original fossil material mounted in the public gallery of the Carnegie Museum. Head, neck, torso and forelimb in left lateral view, with *Homo sapiens* Michael P. Taylor for scale. Photograph by Mathew J. Wedel.

**Figure B.** John Bell Hatcher’s reconstruction of the skeleton of *Diplodocus* (Hatcher 1901:plate XIII). Andrew Carnegie has a framed print of this reconstruction at his home at Skibo Castle, and it was seeing this that provoked King Edward VII of England to ask Carnegie for a Diplodocus for the British Museum — a request that led ultimately to the creation of the concrete *Diplodocus* of Vernal. Hatcher’s reconstruction, now over 120 years old, mostly holds up well: only the forefeet, which were unknown to Hatcher, are badly wrong., with splayed fingers rather then vertical arcade of metacarpals that is now known to make up the sauropod manus. The dragging posture of the tail is also wrong: sauropod tails were held above ground level, and the base of the tail should be distinctly inclined upwards from the sacrum rather than downwards as here. The low posture of the neck illustrated by Hatcher was probably not habitual, but certainly could be attained in order to drink.

**Figure C.** Shoulder and chest region of the mounted skeleton of the Carnegie *Diplodocus* CM 84, s it is today, in left anterolateral view. Highlighted bones: scapulae in blue, coracoids in red and sternal plates in yellow. Note the absence of the putative clavicles that Holland tentatively added to the mounted BMNH cast in May 1905, as shown in his photographs (Holland 1906:figures 25–26), before removing them.

**Figure D.** Skeletal atlas of the Carnegie mount of *Diplodocus carnegii* as originally erected in 1907, with bones color-coded according to the specimen they belonged to or were cast or sculpted from. Modified from a skeletal reconstruction by Scott Hartman, used with permission. Bones are coloured as follows: CM 84 (most of the skeleton), yellow; CM 94 (lower right hindlimb and much of the tail), red; CM 307 (the rest of the tail), blue; CM 662 (sculpted right forelimb), green; AMNH 965 (sculpted forefeet), purple; CM 21775 (left forelimb), cyan; CM 33985 (left hindlimb), orange; CM 662 (sculpted braincase), indigo; USNM 2673 (sculpted remainder of skull), gold. Clavicles, interclavicle, sternal ribs and gastralia were all omitted from the mounted skeleton. See Table A for more detail.

**Figure E.** Two views of the mounted skeleton of *Diplodocus carnegii* as originally exhibited at the Carnegie Museum, highlighting the mismatched humeri. **A.** Skeleton in almost directly anterior view, taken between 1932 and 1936, part of photo used by Gilmore (1936:plate XXXV). **B.** Skeleton in right anterolateral view, taken in 1907, the year of the unveiling. Note that in both A and B, the left humerus is significantly shorter and more robust than the right, and that the forefeet are splayed and carry unguals on all of the first three digits. **C.** Line drawing of right humerus of *Diplodocus* sp. AMNH 5855 in anterior view, modified from Mook (1917:figure 2A). **D.** Right humerus of the Carnegie mount in left anterolateral view, enlarged from part B, sculpted from CM 662, a slightly smaller diplodocine individual then thought to belong to *Diplodocus*, subsequently referred to the new species *Diplodocus hayi* Holland 1924, and now referred to its own genus *Galeamopus* Tschopp et al. 2015. **E.** Left humerus of the Carnegie mount in anterior view, enlarged from part B, CM 21775, assigned by McIntosh (1981:16) to *Camarasaurus*, but considered by Tschopp et al. (2019:29–37) to be Camarasauridae indet. This bone measures 1000 mm in proximodistal length (Tschopp et al. 2019:table 10). **F.** Right humerus of *Camarasaurus supremus* AMNH 5761/H.1 in anterior view, modified from Osborn and Mook (1921:figure 84B). Parts B and E scaled to the same heights as parts C and D respectively.

**Figure F.** The present skull on the mounted skeleton of *Diplodocus carnegii* at the Carnegie Museum, in right anterolateral view. This is believed to be a cast of the complete and largely undistorted *Diplodocus* sp. cranium and mandible CM 11161. Note the realistic bone texture, including damage, especially on the mandible. Photograph by Josh Franzos, used with permission.

**Figure G.** The mounted skeleton of *Diplodocus carnegii* at the Carnegie Museum in left anterolateral view, taken some time between 1980 and 1999. The photograph cannot date from later than 1999 because the old forefeet are still in position, with their splayed metacarpals and unguals on digits 1–3. Note that the neck had by this time been reposed since earlier photographs (Figure E), in a more elevated posture, and was now suspended from the ceiling rather than supported from below by scaffolds.