The history and composition of the Carnegie *Diplodocus*

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**Abstract**

*Diplodocus* is a sauropod dinosaur from the Late Jurassic Morrison Formation of North America. It is known around the world primarily because of a single skeleton, that of the Carnegie *Diplodocus*, because the millionaire industrialist Andrew Carnegie had casts of it mounted in nine prominent cities around the world between 1905 and 1930. As well as these iconic casts, the original fossil material was mounted at the Carnegie Museum in 1907, and underwent a series of minor changes through the years before a major remount as part of the Carnegie's Dinosaur Halls renovation in 2005–2007. The composition of the original mount was never fully described, and the changes made since the initial mount have been poorly documented. The bulk of the skeleton consists of bones from the *Diplodocus carnegii* holotype CM 84. The paratype CM 94, a referred specimen CM 33985, and a specimen of a related species CM 307 all provide additional fossil material. Significant parts of this mount are however casts or sculptures, including the skull, atlas, numerous caudal vertebrae, forelimbs and forefeet, and most of the left hindlimb. The left forelimb and both forefeet used in the original mount were cast from a camarasaurid, and the right forelimb from that of the diplodocine *Galeamopus* (= “*Diplodocus*”) *hayi*. The forelimbs were replaced in the 2007 remount by scaled-up sculptures based on probably diplodocid elements; and the forefeet by scaled-up sculptures of another diplodocine specimen. Numerous divergent length measurements exist for this specimen, but the current mount is about 26.1 m long based on photogrammetric and LIDAR models.

**Keywords:** *Diplodocus*, sauropod, skeletal mount, cast, history, Carnegie

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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 went 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 three of the four specimens that 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; the sole exception is that we refer to the Russian cast, as it was initially installed in St. Petersburg but currently stands in Moscow.

The diplodocine specimen initially designated CM 662 was traded to the Cleveland Museum of Natural History in November 1956, because Carnegie museum director Graham Netting had instructed 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. In 1963, however, the specimen was sold for $15,000 to the Houston Museum of Natural History, where it was catalogued as HMNS 175. (The CMNH’s *Haplocanthosaurus* was excavated between 1954 and 1957 (McIntosh and Williams 1998:4–5) and it is possible that the diplodocine CMNH 10670 was moved on because it became apparent that there was not enough space to mount two large sauropods.) The Houston museum mounted the skeleton in 1975 — ironically filling it out with elements cast from second-generation Carnegie *Diplodocus* molds, supplied by Dinolab (Taylor et al. 2022) — then restored and remounted it between 2013 and 2015. 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, from a cast or a sculpture), 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.)
* BSP — Bayerische Staatssammlung für Paläontologie und Geologie, Munich, Germany.
* 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.
* MfN — Humboldt Museum für Naturkunde, Berlin, Germany (formerly HMN). Fossil reptile specimens are designated MB.R.*nnnn*.
* MNHN — Muséum National d’Histoire Naturelle, Paris, France.
* TAMU — Texas A&M University, College Park, Texas, USA.
* USNM — United States National Museum, Washington DC, USA.
* WDC — Wyoming Dinosaur Centre, Thermopolis, Wyoming, USA.
* YPM — Yale Peabody Museum, New Haven, Connecticut, 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 (Figure J.A) 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 (Figure J.B), 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 (Figure N). He and his team (Figure K) 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, Olaf A. Peterson (Figure J.C) 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 as reported by McIntosh (1981) (but see below), 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 Arthur S. Coggeshall (Figure J.D) and his team (Figure I).

On 15 May 1901 (Nieuwland 2019:46), the classic description of both these specimens of *Diplodocus* was published (Hatcher 1901), written by John Bell Hatcher (Figure J.E), 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. (Hatcher’s (1901:56–57 diagnosis of the new species is arguably rather thin, depending almost entirely on the orientation of the neural spines of proximal caudal vertebrae; but John S. McIntosh considered *D*. *carnegii* legitimately distinct from *D*. *longus* (Rea 2001:ix)) The illustrations included a skeletal reconstruction of *Diplodocus* (Hatcher 1901:plate XIII; Figure B).

Early in October 1902, King Edward VII of England paid a surprise visit to Carnegie at Skibo Castle in Scotland. There, according to most sources, he saw a framed copy of the skeletal reconstruction of *Diplodocus*, from Hatcher’s descriptive monograph. As Coggeshall (1951a:276) told it nearly half a century later, however, what the King saw on his visit to Skibo Castle was a water-colour sketch of the Carnegie *Diplodocus* that had been executed by Holland even before Hatcher’s description was published. Either way, the King was impressed, and requested a specimen for the British Museum (BMNH) 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). That same month, Holland began arranging the details of the donation in correspondence with E. Ray Lankester, his counterpart at the British Museum (Natural History), writing that “the whole [is] to be executed in the very highest style of art”. The offer would be formally accepted by the Trustees on 23 February 1903 (letter from Holland to Lankester, 10 June 1904, reproduced by Barrett et al. 2010:24).

As early as 4 August 1903, Carnegie was thinking bigger than a single cast. In a letter to Holland, he wrote “I think better to make more than one cast of *Diplodocus* — if I visit all the Crowned Heads could send one to their National Museums” (Carnegie 1903). Again, Coggeshall’s (1951a:276) account is slightly different: in his account it was Holland’s foresight, not Carnegie’s that led to multiple copies being made — and Holland’s (1903:2) letter of 31 January 1903 corroborates this interpretation: “The first issue from the molds will be your gift to the British Museum […] Subsequent issues may be employed by you to gratify the scientific acquisitiveness of such men as the Kaiser and the Czar, the President of the French Republic, the King of Belgium, *et id omne genus*”. Whoever originated this idea, it appealed to Carnegie as it allowed him to exploit *Diplodocus* to gain support from those with authority to advance peace arbitration, the main focus of his philanthropy at this time.

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. 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 (Figure J.F) was employed, thanks to their expertise in casting artworks and Agostini’s experience at the AMNH (Nieuwland 2019:71). Other members of the Italian crew included Emile Poli and Manno Fabri (Krishtalka 1988:15). Agostini continued to work for Carnegie Museum for another 44 years until retiring in 1948 (Krishtalka 1988:15), and remained an important part of the operation: 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 1934:40). Although the *Diplodocus* skeleton was made up of about 200 bones (counting the skull as a single unit), the molds consisted of 600 pieces (Madsen 1990:2), as some of the more elaborately constructed vertebrae required up to 30 pieces to capture their complexities (Nieuwland 2019:63).

Although we, and other sources, speak freely of molds and the casts made from them, the reality is rather more complex. As Holland (1903) wrote in a letter to Carnegie, “the condition of our bones […] is such that we cannot without endangering the specimens in some cases pour plaster about them to make piece molds. […] It will become necessary for us to carefully model in sculptor’s clay a number of at least the vertebrae, and then from the models make molds, from which an indefinite number of reproductions can in future be made.” Thus the molds of at least some of the complex cervical and dorsal vertebrae are actually molds of sculptures, not of the original bones; and so the casts created from them do not precisely match the original bones.

In early summer of 1904, the cast created for the British Museum was temporarily mounted as a trial at the Main Hall of the Pittsburgh Exposition Society at The Point in downtown Pittsburgh (Figure L; photograph in Nieuwland 2019:figure 3.1). At this point, it was the only available building in the city big enough to house the skeleton, the museum’s new Dinosaur Hall not yet having been completed. The work was led by Coggeshall, who was responsible not only for executing the mount but also for creating the techniques. At the start of the 20th Century, there was little prior art for mounting large fossil skeletons. The most experienced crew was that responsible for mounting all the Bernissart *Iguanodon* specimens in Brussels, but they maintained little to no contact outside the francophone world, and guarded their secrets. Coggeshall had to work out for himself how the cast bones could be mounted in a lifelike posture, informed by some experience with fossil mounts in his previous post at the AMNH, but nothing on the scale of a complete sauropod. The mounting was carried out by a team of three: Coggeshall himself aided by Agostini and L. S. Coggeshall (Coggeshall 1951a:276), the latter almost certainly Arthur’s brother Louis.

By 4 June, Hatcher (1904a) was able to write that “The *Diplodocus* skeleton is rapidly assuming form in the Exposition building, and we shall, I think, have the mount complete by the 1st of July.”, and on 14 June “The mounting of our skeleton of *Diplodocus* in the Exposition building is rapidly nearing completion and in two weeks more it will be an accomplished fact” (Hatcher 1904b). The work was on the predicted schedule, and 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). Carnegie field worker William H. Utterback (1904) wrote that Hatcher’s sudden death was “a sad blow indeed. Having been the warmest of friends for many years and associated with him in this work under the most trying of circumstances I feel his loss more than words can express […] The loss to science and to our institution will never be fully realized.”

The Carnegie Museum’s *Diplodocus* cast was therefore (albeit briefly) the first mounted sauropod in the world, eight months ahead of the AMNH’s composite *Brontosaurus*, AMNH 460, which was to be unveiled on 16th February 1905 (Brinkman 2010:104).

With limited space at the museum before the completion of the Dinosaur Hall, which by 14 June had only just begun (Hatcher 1904b), the *Diplodocus* molds were stored in a brick horse stable behind 419 Craft Avenue in Oakland (Krishtalka 1988:15). The casts that had been made from them were shipped from Pittsburgh on 3rd December 1904 in a shipment of 36 packing cases, 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. Each cast skeleton weighted 6,000 lb (2.7 tonnes), or 10,900 lb (4.95 tonnes) when packed for shipment.

In April 1905, Holland and Coggeshall arrived at South Kensington and supervised the assembly of the first cast skeleton (Holland 1905:443). At 1pm on 12th May 1905, the mounted cast was unveiled at the BMNH — see photographs in Holland (1905:plates XVII and XVIII). It was placed in the Hall of Reptiles, as the Hall of Palaeontology was full (Rea 2001:ix). At a lavish event, 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 event 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 lepidopterology. 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, casts 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 Coggeshall 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 Berlin Museum für Naturkunde beginning on 14 April 2008, and the work was complete by 13 May. Coggeshall (1951a) claimed that during the trip he was interrogated by the German Secret Service at their headquarters under suspicion of being an English spy, until he was able to produce a card signed by the Kaiser explaining the work that he was doing. The exhibition was opened to disappointingly little fanfare, with no formal unveiling event at the museum, and the mounted cast was positioned off to the side of the main hall, which remained dominated by whale skeletons (Nieuwland 2019:115–118).

On 22 May, Holland and Coggeshall 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. It had been decided beforehand to mount the cast with its tail curled back in a loop, because of space restrictions. The work was completed in time for a lavish public ceremony on 15 June, in great contrast to the muted launch of the Berlin cast. The Paris unveiling was attended by the French president and prime minister, the Parisian 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 multiple locations, in its mammal-like upright posture, provoked some controversy: Hay (1908, 1910, 1911) and Tornier (1909) — independently, so he claimed — argued that its erect-legged posture was incorrect, and it should sprawl like a lizard. Tornier also criticized the position of the neck and tail. Abel (1910) and Holland (1910a) 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 skeletal cast 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 a 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.

The original casts had now all been given away, but requests kept coming in, which led Carnegie and Holland to have another five casts prepared. The first planned donation, to Rio de Janeiro, was thwarted by the tumultuous quagmire of Brazilian politics. However, a Russian cast was installed in St. Petersburg in June and July of 1910, again supervised by Holland, who confided to Carnegie that he was “really getting tired of ‘the old Dip’” (Nieuwland 2019:232), together with Coggeshall. Holland (1910b, 1913:249–50) told colourful and somewhat contradictory tales of the in-progress mount’s catastrophic collapse when visited by a party of officials, and these have been retold (e.g. Krishtalka 1988:15–16). But as Coggeshall’s (1951b:313–314) published reminiscences of his work in Russia with *Diplodocus* made no mention at all of this incident, it must be considered apocryphal.

The precise date of the cast’s completion is impossible to determine, as there was no official opening event. On 5 July 1910, Holland wrote to Carnegie that “work on the St. Petersburg *Diplodocus* is drawing to a close” (Holland 1910d), and he reported getting home on 22 August, so these dates give us bounds on completion of the mount. In an earlier letter to Tschernyschew on January 3rd (Holland 1910c), he had outlined plans to visit the First Entomological Congress in Brussels immediately after setting up the Russian cast. That conference took place from 1–6 August. Assuming that he did in fact attend, the journey from St. Petersburg to Brussels must have taken about a week, so that places the possibility of finishing the work between roughly 7 July and 23 July. He probably spent some time in Berlin before the conference as well, so “early July” is the best estimate available. This particular cast would lead a turbulent life: see below.

Although Holland had by now grown tired of traveling across the Atlantic each summer to set up yet another *Diplodocus* cast, he was persuaded to travel to Argentina for that purpose in 1912 (Otero and Gasparini 2014). The request had come from Argentinian President Sáenz Peña via the American ambassador in Buenos Aires, Charles Sherill. While Carnegie’s efforts had thus far been aimed at European states, by 1911 Argentina was looking as though it could well become the most influential state in the southern hemisphere, and even rival the power of some of Europe’s nations. It was therefore an interesting nation for Carnegie to ply with a *Diplodocus* replica. Carnegie briefly even threatened to send the original *Diplodocus* to the museum in La Plata, but was stopped from doing so by Holland (Nieuwland 2019: 238–239). By this time, *Diplodocus* itself had begun to fade in the light of the German discoveries of huge sauropods in their East African colony (Maier 2003), which in this period began to become the yardstick by which dinosaurian hugeness was measured.

By July of 1912, the Argentinian cast was ready for shipment, and it arrived at the La Plata museum in August; Holland and Coggeshall followed a month later. Constructing the dinosaur itself presented no meaningful challenges to so experienced a team. Of course, the reception of a 26-meter object caused some discussion, mainly about the orientation of the skeleton and the position of the tail. In the end, it was decided to orient *Diplodocus* towards rather than away from the main hall of the building, and to introduce a Parisian-style curl of the tail. By mid-October, the project had been finished. The Argentinian president was unable to conduct an official opening himself, because the departure from Buenos Aires to La Plata would have involved a formal handing over of authority to the vice president (Coggeshall 1951b: 314–315). The donation received very little publicity at the time, although Holland’s memoir of the trip gave it some notoriety afterward (Holland 1913).

Shortly after the preparations for the La Plata cast had begun, in January of 1912, the Spanish ambassador was ordered to request a *Diplodocus* from Carnegie on behalf of King Alfonso XIII (Pérez García and Sánchez Chillón 2009). In marked contrast to Argentina, public interest in the Spanish *Diplodocus* was far greater than it had been in any country since France (Nieuwland 2019: 243–246). The Madrid cast was prepared concurrently with the Argentine one, and sent to Spain in September of 1913. Holland and Coggeshall, who arrived in Madrid on 11 November 1913, were treated as guests of honour, and took longer to complete their work than they had in La Plata due to numerous social obligations (Coggeshall 1951b:314). The cast was complete by 28 November, and donated in absentia to the monarch who was nominally the cast’s recipient. On 2 December 2012, Queen María Cristina and her daughter, the *infanta* Beatriz, opened the new museum hall containing the *Diplodocus*, which was perhaps the closest thing to an official unveiling (Pérez García and Sánchez Chillón 2009:140).

The outbreak of World War One put an end to Carnegie’s arbitration campaign, and affected him heavily as a person: he retreated almost entirely from public life to his New York apartment, where he died in 1919. As a consequence, the *Diplodocus* donation scheme came to a halt. It had been a great success, however: Holland was later to write to Carnegie’s widow Louise that “Your dear husband once said to me: ‘I never got as much pleasure or as much publicity from so small a sum of money as I have through your happy thought of making replicas of the animal, which bears my name’.” (Holland 1928).

By the time of his death, Carnegie had mostly succeeded in giving away his fortune, and it soon became clear that he had allocated no permanent endowment to the various institutions he had created, including the natural history museum in Pittsburgh (Brinkman 2010:109). This meant that its previously luxurious financial circumstances were suddenly exchanged for relatively spartan ones, and the museum had to halt its ambitions to compete with better-funded institutions in New York and Chicago. Work at the Carnegie Quarry in Utah, which was far from exhausted, also had to be abandoned.

Around this time, the molds from which the casts had been made went into storage, and were not used again for forty years (Untermann 1959:364). However, of the ten casts that had been created from them, two still remained, though incomplete.

In 1922 Holland retired from the museum, aged seventy-four, but his involvement with *Diplodocus* would require one last trip. Seemingly unaware of rising political tensions between the United States and Mexico, he supported a request for a *Diplodocus* cast from the Mexican ambassador in a letter to Carnegie’s widow Louise in 1927 (Rea 2001:204–207). She was persuaded to spend part of the money in the *Diplodocus* restoration fund on having the last two casts completed and gifting one of them to Mexico. On 6 April 1930, at the age of 81 (not 80 as stated by Nieuwland 2019:250), Holland arrived in Mexico City together with Coggeshall’s brother Louis, to set up his last *Diplodocus*. He was compelled to return home, frustrated, before the mount was completed (Rea 2001:209), and the task was finished by Louis Coggeshall, but there was no formal unveiling ceremony in Holland’s absence. A year and a half later, Holland died of a stroke on 13 December 1932.

The remaining *Diplodocus* was completed, boxed, and shipped to Munich’s Staatssammlung für Paläontologie und Geologie in November and December of 1934, completing an exchange for fossils received from Germany five years previously (Carnegie Institute 1934:40). On arrival, however, the cast was not mounted, but instead stored in the basement of the Alte Akademie, which also housed the rest of the paleontological collections. The replica was long assumed to have been lost during bombing in 1944, along with the *Spinosaurus aegypticus* holotype BSP 1912 VIII 19. However the cast had been removed from the building before the bombing raid, and while the elements themselves were not destroyed, the record of where they had been moved to was lost. It now seems the cast was taken to an abandoned convent on the outskirts of Munich. It is believed that a group of hippies, holding parties in the convent during the 1960s, found some cast bones, took these home and attracted the attention of the authorities, who then discovered the crates (sources who wish to remain anonymous, pers. comm.). At any rate, the cast was restored to the Munich museum in 1977, but has remained in storage ever since. Calls for it to be mounted as one of the attractions of a new museum at the Nymphenburg castle came to nothing, partly because the museum authorities favoured a lighter and stronger resin cast over the maintenance-intensive plaster one.

Although this was the last of the ten plaster casts created at the Carnegie Museum, the molds were to have at least one more outing. In 1952, J. LeRoy Kay, Carnegie’s curator of vertebrate paleontology, gifted the now decrepit molds to the Utah Field House of Natural History in his home town of Vernal, Utah (Untermann 1952). There they were used to create a concrete cast which was erected outside the Field House in 1957 (Untermann 1959) and stood until 1989 (Taylor et al. 2022) It is not clear what happened to the molds after this: see the extensive discussion in Taylor et al. (Taylor et al. 2022). The concrete cast was then dismounted and repaired and used to create a second-generation set of molds by Dinolab, inc. These molds have been used to create third-generation *Diplodocus* casts, and also to supply missing elements for the AMNH’s rearing *Barosaurus* mount (Taylor et al., in prep.)

See Table 1 for a summary of all the Carnegie *Diplodocus* casts and the original mount, in chronological order.

# 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 all 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 than 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 include any skull material. 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 a subsequent 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). (See below for details.)

Holland (1906:257–264) also discussed the bone that Hatcher (1901:41) had 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 that 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 its 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 that 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 skeleton earlier than 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.

(McIntosh noted that the right “tibia-fibula-pes” of the mounted skeleton was furnished from CM 94, He did not mention the right astragalus, but given that CM 94 included this element it seems reasonable to assume this was also used in the mount.)

Hatcher (1901:4) 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 were given — a distressingly common problem even in modern publications (Wedel 2009). 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 (1981:20) mentioned it being “the smaller individual” compared with CM 84, but did not quantify this. However, McIntosh (2005a: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.

Holland (1906:254) gave a more precise account of the source of the caudal vertebrae in the London cast: Ca1–12 were from CM 84, Ca13–31 and 33–36 were from CM 94, and Ca32 and Ca37–73 inclusive were from CM 307. 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 they may not belong to the genus *Diplodocus* at all. Tschopp et al. (2019:19–21) referred them to Diplodocinae indet.) See below for more details on the caudal vertebrae in the Carnegie mount.

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. 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.

As best as we can determine, the atlas used in the casts and the original Carnegie mounts (Holland 1906:figure 1) was a sculpture rather than a cast of a specific element from another specimen. It does not resemble the atlas illustrated by Marsh (1896:plate XXVII, part 1) as belonging to *Diplodocus longus*, and reproduced by Hatcher (1901:figure 4). Nor, as noted above, do its neural arches resemble those of AMNH 969, illustrated by Holland (1906:figure 14). Furthermore, it seems that the atlas in the present Carnegie mount is different again, having longer and slenderer posterior processes of the neural arch than those in the atlas used for the London cast and presumably for the original Carnegie mount (Figure M). This change may have been made at the same time that the original skull was replaced by a cast of CM 11161 (see below).

The cervical ribs of the atlas present another mystery. Holland’s (1906:figure 1) illustration of the head and anterior neck of the London cast omit these, and they seem to have been absent from the original Carnegie mount itself (see detail in various figures herein). Neither are they present in the current Carnegie mount (detail in Figure A, pers. obs.). However, the Paris mount features a pair of very large atlantal ribs, extending back well past the posterior end of the axis. They resemble the element illustrated by Holland (1906:figure 20) as a “supposed rib of the atlas of *Diplodocus* preserved in the American Museum of Natural History” and may be sculptures based on this element. However, the bone illustrated by Holland (1906:figure 21) as the rib of the axis is not included in the Paris mount. Much atlantal ribs are currently present in the London mount (Taylor, pers. obs., 2022) but are currently absent from the Berlin mount (Daniela Schwarz, pers. comm., 2022) and were absent even before the remount in the 2000s (Taylor, pers. obs.). Why the large atlas ribs were included in the Paris cast and smaller ones in London casts, but omitted from the Carnegie mount and the Berlin, cast is unknown.

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. McIntosh’s (1981:20) catalogue entry for CM 94 says “[other elements] and chevrons were used to complete the mount of CM 84”, though the entry for CM 84 does not mention this. Further confusing matters, 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). Even if the five chevrons of CM 94 accounted for five of the first six chevrons, that still leaves one unaccounted for. At any rate the use of AMNH 223 casts for the rest of the chevrons is corroborated by Brinkman’s (2010:240) observation that the London cast “was also missing a long series of chevrons, casts of which had been urgently requested from the American Museum, which was slow to fill the order”.

Disappointingly, Holland (1906) did not comment at all on the provenance of the left hindlimb or ilium used in the London cast. The paratype specimen CM 94 includes a left femur, and it is tempting to imagine that it may have been used, but as McIntosh (1981:20) points out, the left femur was among the material of CM 94 that was traded to the Cleveland Museum along with CM 662 — and this is confirmed by accession records at CMNH (Amanda McGee, pers. comm., 2022). In an unpublished manuscript, Madsen (1990:5) said of the Carnegie mount that “Sculpted elements include the left femur and tibia”, but gave no further details. Inspection of the current mount shows that the left femur and tibia are indeed sculptures, and so is the left ilium. No records have been located indicating which elements the sculptures were based on, but most likely they mirror their counterpart elements from the other side of CM 84 (for the ilium and femur) and CM 94 (for the tibia).

Table 2 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 camarasaurid specimen CM 21775.

## 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 Yarmer 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.

It is possible that the atlas was replaced at the same time as the skull (see above).

### Re-pose of neck

In a photograph of the mounted *Diplodocus* taken some time between 1985 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 more horizontal and sup

ported from beneath by a pole (Figure E). However, the tail remained in its old dragging posture.

It is possible that the change in neck support was made to free the space under the neck and so make room for the tail of the *Allosaurus* mount CM 11844 that was at some point moved there from its original 1938 position behind and to the right of the *Diplodocus* tail. (The tail of the repositioned *Allosaurus* can be seen in Figure G). But as the date of the *Allosaurus* move is not known, this does not help us determine when the *Diplodocus* neck was raised.

### 1999 replacement of forefeet with CM 662 casts

The forefeet of the original mount were sculpted from those of a camarasaurid 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, Figure H.A), 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 errors remedied, when Norman Wuerthele and Amy Henrici made casts of the forefeet of CM 662 (Carnegie Institute 1999), which were installed shortly afterwards (Figure H.C). 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* and the *Apatosaurus louisae* holotype CM 3018, was opened for ticketed previews at 6 am [sic] 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 by Phil Fraley Productions (Figure P), and several changes were made to the materials incorporated in the mount, detailed in the following sections.

### Forefeet WDC-FS001A

As noted above, CM 662 has been recognised since 1924 as representing a different species from CM 84, “*Diplodocus*” *hayi* (Holland 1924:399). It was for this reason 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) (Figure H.D).

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. However, the phylogenetic analysis of Tschopp et al. (2015:229–230) found WDC-FS001A as a basal diplodocine not included in *Diplodocus*, suggesting that even this third set of forefeet may not be correct.

### Forelimbs from BYU material

The initial version of the Carnegie mount included the obviously incorrect left forelimb of the camarasaurid specimen CM 21775 (Figure E.B, E.E). This remained in place through the 1930s (Figure E.A) and is generally said to have been retained until the 2007 remount (e.g. Tschopp et al. 2019:33). This is most likely correct, but it is notable that in a photograph taken some time between 1985 and 1999 (Figure G) the left humerus appears about as long and as gracile as the right, suggesting the possibility that it may have been replaced some time before then. The apparent difference between forelimb disparity in the 1907 and 1980s/90s mount may however be explainable by the different camera angles and the foreshortening effects produced by their perspectives on the two humeri.

At any rate, the right forelimb, having been based on the diplodocine CM 662, was always a much better match for CM 84, but not perfect as discussed above. For this reason, both forelimbs were slated to be replaced in the 2007 remount. Various enquiries were made, but mostly proved unfruitful:

* The Smithsonian (National Museum of Natural History) has a fine partial skeleton of Diplodocus, USNM V 10865, which includes both humeri and ulnae and the right radius, with the right forelimb having been found in articulation (Gilmore 1932:19–20). However, they had no casts on hand and the undermanned vertebrate palaeontology department did not have the necessary resources to mold and cast replicas of the required limb bones.
* The Sauriermuseum Aathal in Switzerland has several diplodocid specimens. The owner, Kirby Siber, noted that between 1990 and 1995 “we collected seven *Diplodocus* specimens, all partial skeletons and all without forelimbs! It looked to us like *Diplodocus* did not have any!”. Sauropod forelimbs are typically lost early in taphonomy, and this seems to be especially true in *Diplodocus* (Siber, pers. comm., 2022). Siber proposed that limb bones of their specimen XL, about 90% the size of CM 84, might be of use. The cost of purchase for the original fossils proved prohibitive and the option of casting was explored. These plans were abandoned, though, as the specimen XL did not have a radius and its ulna had also been misplaced.
* The Wyoming Dinosaur Centre had relevant elements but they were all too small (about 60% the size of CM 84).
* Enquiries were made about the mounted *Diplodocus* DMNS 1494 at the Denver Museum of Natural History. The specimen had been received from the Carnegie Museum in exchange for fossil mammals, and mounted by Philip Reinheimer during the mid-1930s with a WPA crew, before being remounted more recently by Ken Carpenter and Bryan Small (Ken Carpenter, pers. comm., 2022). This line of enquiry was abandoned when it became apparent that its forelimbs were casts from the Carnegie’s old forelimb material!

The AMNH, Dinosaur National Monument and the Yale Peabody Museum were all also suggested as possible sources, but none was able to help. Sauropod limb specialist Ray Wilhite was consulted, and concluded from his database that the choice was between elements that were the right size but poorly preserved, or well preserved but the wrong size. Since it would be necessary to combine elements from multiple specimens to create complete forelimbs, Scott Lucas of Phil Fraley Productions, in consultation with Wilhite, concluded that the best option was to sculpt forelimb bones based on a small but well-preserved associated specimen from Brigham Young University, scaled up. This specimen was BYU 681: specifically, the humerus BYU 681/4742, the radius BYU 681/4726 and the ulna BYU 681/4708 (Tschopp et al. 2019:33).

The femur 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.

Wilhite (2003:33) assigned the humerus BYU 681/4742 to *Diplodocus*, but Bonnan (2007:1111) listed 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 — in which case the scaling calculation above may be poorly founded.

### Caudal vertebrae

It has been generally assumed that the caudal vertebrae in the Carnegie mount are the original fossils. In truth, the situation is more complex than that. The anteriormost 12 caudals are from the holotype, CM 84, and the elements included in the mount are all the real fossils. But the remainder of the tail includes or has included several plaster replicas.

As noted above, Holland (1906:254) explained that in the London replica, Ca13–31 and 33–36 were cast from CM 94, and Ca32 and Ca37–73 were cast from CM 307. It is natural to assume that the corresponding real fossils were used in the Carnegie mount, but this cannot be so.

Regarding CM 94, Hatcher (1901:4) listed among its bones 20 caudals and 11 vertebrae that were not at that point sufficiently prepared to be identified. He also noted that the caudal “sequence” was found disarticulated, and that the elements catalogued under this specimen number belonged to two or more individuals (Hatcher 1901:34). One of the 11 unprepared vertebrae (field no. 5) was subsequently identified as a cervical but the other 10 are probably all caudals (McIntosh 2005b). This gives us a total of at most 30 caudals from this specimen.

However, McIntosh (1981:20) gave a caudal count of 39 for CM 94. Where can this number have come from? When McIntosh was studying the Carnegie collection in 1969, he found 17 caudals marked CM 94. To these must be added a further six that had been loaned to Cleveland and later Houston to fill out the *Galeamopus* (= “*Diplodocus*”) *hayi* specimen initially numbered CM 622, which became CMNH 10670 in Cleveland, then HMNS 175 in Houston. In the early 1970s, Wann Langston, having made casts of these for the Houston mount, returned the originals to the Carnegie Museum (McIntosh 2005b), at which point there were 23 caudals of CM 94 in the collection. There were also caudals from this specimen in the mount: specifically, 19 from Ca13–Ca31 and another four from Ca33–Ca36, for a total of 23. However, McIntosh (2005b) had determined some time earlier that at least seven of the CM 94 caudals in the mount were plaster casts (but did not say which ones), reducing the number of real CM 94 caudals in the mount to at most 16. (McIntosh (2005b) speculated that Coggeshall used used some of the better preserved caudals of CM 94 and made casts of those that were not in such good condition.) If there were 16 real caudals in the mount plus the 23 in the collection, that would make up the count of 39 caudals given in McIntosh’s (1981) catalog — but it is impossible to reconcile this number with Hatcher’s (1901:4) account of 20 caudals and 11 unidentified vertebrae. XXX how many are in collections right now?

It seems likely, then, that at least seven of the caudals in the ranges 13–31 and 33–36 are probably plaster casts, but it is difficult to determine which ones. McIntosh’s (2005b) stated that the two fused pairs 20–21 and 24–25 are “certainly real”. When Phil Fraley Productions were disassembling the old mount in 2005, they analysed the individual elements, and Scott Lucas sent a list of nine plaster caudals: those in positions 13–16, 31, 32 and 33–35 — which is compatible with the two fused pairs being real bone. Even this list cannot be straightforwardly interpreted, however, as it contains one too many caudals in the range 13–36, including two that are both numbered 32. It is the more anterior of the #32s that is listed as plaster, but it is unclear whether the three plaster caudals numbered 33–35 are really those in the designated positions, or in positions 34–36. Since the list also mentions a #36 that is real bone, this may indicate that one more CM 94 caudal was incorporated into the mount than Holland (1906:254) had indicated.

It might be expected that numerous CM 94 caudals, conserved and stabilized, would have been incorporated into the 2007 remount in place of the plaster casts. However, a database note on this remounting located by Amy Henrici says “One caudal added from CM 94”. No records have been found indicating which caudal this was, nor why only one was used. At any rate, it is is likely that the number of CM 94 caudal plaster casts remaining is eight.

The situation is similarly complex with CM 307. McIntosh (1981:20) credits this specimen as having supplied “distal caudals” and Curtice (1996:73) says “These [CM 307] caudals were used to complete the mount of CM 84, occupying position 32 and 37–73 inclusive”, echoing Holland (1906:254). But there is some evidence that the real fossils may have been incorporated only relatively recently: the database note located by Henrici continues “Caudals 37–73 were casts in original mount and replaced with caudals from CM 307”. Henrici also found a “specimen removed” tag in the CM 307 drawer in collections indicating that at least some elements of the specimen were removed from the drawer for loan to Phil Fraley on 20 November 2006. (None remain there today.)

However, photographs of caudals 37–46 supplied by Phil Fraley, which were taken after they were removed from the old mount for the remounting process, clearly show that these elements were real bone and not casts. (Incidentally, Holland’s (1906:plate XXIX) illustrations of these caudals do not closely resemble the actual fossils.) Adding to the confusion, Harris (2006:figure 18c) included photographs of two whiplash caudals of CM 307, which were likely taken in collections. Another photo taken by Harris some time around 2003 (pers. comm, 2022) shows a drawer of 18 whiplash caudals, one of which is a perfect match for one of those in his (2006:figure 18c) illustration. It therefore seems that shortly before the remount, at least 18 distal caudals of CM 307 were in the Carnegie collections rather than being incorporated into the mounted skeleton, but that these did not include any of 37–46. Correspondence between Matthew Lamanna and John Scott Lucas confirms that in November 2006 Carnegie staff sent an unspecified number of caudal vertebrae from CM 94 and CM 307 to Fraley’s lab — most likely the single vertebra of CM 94 referred to in the database note and the 18 of CM 307 that had been photographed by Harris.

It seems, then, that only the more proximal caudals of CM 307 were included in the mount in 1907. Casts seem to have been used for the more distal elements, replaced with real fossils in 2007, and the accounts of Holland (1906:254), Curtice (1996:73) and Tschopp et al. (2019:20) are all misleading. It must be remembered that Holland’s account was written the year before the real fossil mount was constructed, and was focussed on the 1904–1905 creation of the London cast, so that his account of which caudals were used specifies which were the sources of cast elements for that mount. It is natural to assume, but not necessarily correct, that the real fossil mount used the bones that the casts were taken from. If Curtice (1996) and Tschopp et al. (2019) drew their information from Holland (1906) and made this understandable assumption, that might account for the misreporting.

The most likely conclusion is that only the anteriormost 20 of the CM 207 caudals were included in the 1907 mount, the remaining 18 being provided as casts, with the real material remaining in collections until 2006. But it is also possible that all 38 caudals of CM 307 were indeed incorporated into the original mount, but that the eighteen most distal were subsequently removed and replaced with casts. This may have been due to the risk of theft, as these small bones would have been easy targets for souvenir-hunters in the days when the tail was mounted at ground level. If this was the case, then it would have been natural to return the real caudals to the tail when it was reposed in its present elevated posture, far out of reach of museum visitors.

One further oddity is that Fraley’s photographs show that two separate caudals of CM 307 were labelled 38A and 38B. This would seem to indicate either that the caudals described as 37–73 actually totalled 38 rather than 37; or that a sequence of 37 caudals filling positions 37–73 were actually numbered 37, 38A, 38B and 39–72. Once more, we have not been able to locate records or correspondence that would enable us to settle this point.

Also included in the 2007 remount were about ten additional distal “whiplash” caudals, made by Western Paleontological Laboratories, 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.

It may be that the already very long tail of the Carnegie *Diplodocus* should be rather longer still. Although the taxonomic identity of CM 307, from which the mid-to-distal caudals were taken, is not known with certainty, it does not appear to be *Diplodocus carnegii*. Ken Carpenter (in prep.) has noted that mid-caudals are proportionally about 25% longer in *D*. *carnegii* than those of other diplodocine species (Figure Q). Since about 40% of the tail length is made up of CM 307 vertebrae (Taylor pers. obs.), increasing that portion by 25% would increase the total tail length by about 10%. The present tail is about 15 m long (see caption to Figure O.A), so this would extend the total length of the animal by 1.5 m.

## 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. (McIntosh listed this specimen as belonging to *D*. *carnegii* on page 21 of his catalog, but only as *Diplodocus* sp. in the table on page 59.) For unknown reasons, however, these were not used in the casts. One possible reason would be that CM 33985, which had been excavated in 1900, might not have been prepared out of its matrix at the time the material for casting was being assembled in 1903–1904. This would be reasonable given the extraordinary volume of fossil vertebrate material that was being collected and prepared by Carnegie Museum teams around that time.

No documentation survives indicating what material was used to create the casts for these elements. Most likely, the left fibula and metatarsals III–V used in the casts were mirror-imaged sculptures of the right-side elements preserved in the *D*. *carnegii* paratype CM 94.

## Updates to the casts

Since the mounting of the ten original casts, some updates have taken place:

* The London cast, having been initially mounted in the Reptile Gallery (now the Human Biology Gallery), was moved to the Fossil Reptile Gallery (now the Waterhouse Gallery) in 1931, stored in the basement for safety between in April 1940 (four months before the beginning of the Blitz), returned to the Fossil Reptile Gallery after WWII and moved to the museum’s main hall (now the Hintze Hall) in 1979 (Hendry 2018), before finally being taken down in January 2017 to make more space for corporate events (Steerpike 2015; Nieuwland 2019:260). Changes to the mount have been minimal during this time. Small caudal vertebrae have often been stolen, and the museum kept a box of spares to replace them (Hendry 2018). Two significant changes have made in this time. First, the neck was supposedly raised in the 1960s (Barrett et al. 2010:40), although the then-current posture depicted by Barrett et al. (2010:4–5) does not appear more elevated than in the original pose of 1905 (Barrett et al. 2010:27). Second, the tail was replaced and elevated in 1993 (Lindsay et al. 1996:269; Barrett et al. 2010:43), the dragging paster casts of the original being replaced by lightweight casts in a more dynamic pose that better reflects current understanding of sauropod behaviour. At some point, the London cast was assigned its own specimen number, NHMUK PV R8642 (Natural History Museum 2022). As of the 2022 “Dippy Returns” exhibition, the London mount still has the old three-clawed camarasaurid forefeet in their original splayed posture.
* Some time before 2005, the excess phalanges and unguals were discarded from the forefeet of the Berlin mount, though the plantigrade pose of the forefeet was unchanged (pers. obs., Taylor). The cast was completely remounted in 2006 by Research Casting International, under the supervision of a team led by Kristian Remes, as part of a renovation of the Museum für Naturkunde’s central hall. Among other postural changes, the tail was raised and the forefeet were reconfigured in a digitigrade pose (Figure H.B). Remes no longer remembers whether new and more appropriate forefoot material was used in the remounting (Remes, pers. comm., 2022), but it is most likely that the original casts were used and merely reposed (Wolf-Dieter Heinrich and MfN preparators via Daniela Schwarz, pers. comms., 2022). Peter May of Research Casting International (pers. comm. 2022) also believes, but does not recall with certainty, that the old manus material was reused. However, no left-over casts of manual material can be found in collections (Daniela Schwarz, pers. comm., 2022).
* The Paris mount remains in its original location, and is entirely unchanged since its creation in 1908, with the exception that possibly a few tail vertebrae had to be replaced in the mid 20th Century after a mishap. Coggeshall (1951a:278) claimed that the museum was converted into a hospital during World War I and the skeleton dismantled and later remounted, but this contradicts other accounts: it is not included in lists of temporary hospitals at that time. The preponderance of evidence shows that it was not moved during either World War (Vincent Reneleau, pers. comm., 2022). This makes the Paris mount an important and perhaps unique historical artifact in its own right, and it is to be hoped that the MNHN resists the temptation to modernize it.
* The Vienna mount has been moved twice and undergone a partial remount (with changes to the tail and slight changes to the neck), probably before 1998 judging by photos in Riedl-Dorn (1998)
* The Bologna mount is in original location (although it was possibly relocated to another hall in the museum and then moved back at some point). In 2009, the tail was raised (Sarti 2012:1). The neck has also been placed in a leftward curve, perhaps at the same time — probably to offer visitors a better view.
* The Russian mount has undergone the most adventures of them all. Having been mounted at the The Imperial Museum at St. Petersburg in early July 1910, it was first moved to Moscow in 1934 along with the other collections of the Russian Academy of Sciences. In 1937 it was remounted in the Neshkuchny Palace, an 18th-century complex next to Gorky Park, as part of the XVIIth International Geological Congress, which was held in Moscow in that year (Bodylevskaya 2007). Here it was given a bizarre posture with parasagittal hindlimbs but strongly everted elbows (Taylor 2014), possibly following Abel’s suggestion (Abel 1910). It was next moved to storage in Almaty, Kazakhstan from 1942 to 1944, possibly to avoid war damage. After this, it was returned to the Neshkuchny Palace, but then placed in storage following the Palace’s closure as a museum in 1954. Since 1987 it has been displayed in Moscow’s new Orlov Museum of Natural History, having been remounted in more traditional fashion with erect limbs, but with a dragging tail that was already strikingly old-fashioned by that time. Finally, it was buried in soft peat for three months and recycled as firelighters. So far as we are aware, however, the same original set of casts have remained in use through all these changes.
* The La Plata mount was repaired and repainted a brick-red colour in 1977. It has been moved within the museum on multiple occasions — from Hall III to Hall V in 1987, and to Hall II in 2003 (Otero and Gasparini 2014:300–301), at which time the posture of both the neck and tail was updated and the colour reverted to its original dark grey. The history of this mount is covered in detail by Otero and Gasparini (2014).
* The Madrid mount has been moved within the museum, but in other respects seems to be largely unchanged since the original mounting. The one significant update is that the skull was replaced by “a new Carnegie replica” when the exhibit was moved to a new hall in 1935 (Nieuwland 2019:247)
* The Mexico mount was moved within its museum in 1964, and now resides in the Evolution of Life Gallery. It has recently been remounted, most likely in 2018, though hard information is difficult to come by.

As noted above, the Munich cast was never mounted, and at the time of writing remains in the museum basement.

# Discussion

## The length of the Carnegie *Diplodocus*

The length of the Carnegie *Diplodocus* and its casts has been variously reported in the literature. Hatcher (1901:39), working with the holotype and referred specimens CM 84 and CM 94, but without a complete tail, derived a total length of 68 feet (= 20.7 m) along column from the tip of the snout to the end of caudal 37. This estimate omitted the distal part of the tail, and would be revised upwards in future publications.

Holland’s (1904a) letter to Ray Lankester promised that “the skeleton when mounted will be between 78 and 80 feet in length”, referring to the London mount which included casts of distal caudals from CM 307. In a letter to Carnegie (styled as “My Dear Lord Rector”), apparently written immediately afterwards (Holland 1904b), he explained in more detail:

The beast turns out to be between 84 and 85 feet long from the tip of the nose to the tip of the tail, when the vertebral column is laid down horizontally. When mounted, of course, with the necessary graceful curvature which belongs to the mounted skeleton, the length is diminished, so that it covers on the floor a length of only about 78 or 80 feet. The whipcord tail adds considerably to the length, but Hatcher swears that as three tails have now been found with the bones in position and all tapering out as is the case here, that we are quite right in putting on this long tail.

(Carnegie had an honorary position as the Rector of the University of St. Andrew’s, fifty miles northeast of Edinburgh, and Holland was Chancellor of the University of Pittsburgh. In their correspondence they would occasionally refer to one another jocularly by these titles.)

By the time of Holland’s (1905:448) account of Lord Avebury’s speech at the dedication of the London mount, the reported length had increased to 84 feet (= 25.6 m). When writing to arrange the installation of the Berlin cast, Holland (1907) wrote that “The entire length of the specimen as it stands in our Museum, from the tip of the nose to the end of the tail is approximately [23.94 in German translation] meters in length” (= 78.5 feet).

Untermann (1959:365) gave the length of the Field House’s concrete cast as 76 feet (= 23.2 m). Sarti (2012:14) gave a length of 27 m (= 88.6 feet) for the Bologna mount, and Otero and Gasparini (2014:299) gave the same length for the La Plata mount. This possibly inflated length frequently appears in popular sources, and also (unreferenced) in one of our own earlier papers (Taylor and Naish 2007:1560). David Letasi (pers. comm., 2022), in preparing mounts of second-generation casts for the Museum of Science and Industry in Tampa, Florida, had Jim Madsen of Dinolab lay out the skull and axial skeleton at his lab, and measured it at 75 feet (= 22.9 m). Vincent Reneleau has measured the Paris mount by dropping a plumb line from its snout and measuring in a straight line along the ground until the curve in the distal tail, then measuring around the curve. He found a total length of 23.5 m (= 77 feet), which would increase by 80 cm if the tail were elevated to the height of the pelvis and held straight out (Vincent Reneleau, pers. comm. 2022).

Discounting Hatcher’s initial estimate as based on an incomplete skeleton, we find good agreement between the measurements of Untermann, Letasi and Reneleau. We might write off Avebury’s 84 feet as an exaggeration to amplify the value of Carnegie’s gift, and the two 27-meter estimates as unsourced. Thus the casts likely measure about 76 feet (= 23.2 m). However, as pointed out by Wedel (2019), casts typically come out smaller than the elements they were molded from, by perhaps 2.5% or so. If that was the case with regards to the concrete cast, that suggests that the original skeleton may have been longer by about 2 feet, giving a figure of 78 feet (= 23.8 m), according well with Holland’s (1904a) letter.

The total length of the real skeleton as now mounted at the Carnegie Museum is surprisingly difficult to measure, perhaps casting some light on why published estimates have varied so much. The obvious approach is to run a string from the snout along the curve of the vertebral column to the tip of the tail, then measure the length of the string. But even using lifts it is difficult or impossible to position a string directly along the dorsal midline of the vertebrae. An alternative would be to drop plumb-lines from the midline of the skeleton, and measure between them along the floor: but this too is difficult due to the complex pose with curved neck and tail, which would require many plumb lines, and because of the raised platform on which the legs and torso are mounted, and the display of reconstructed plants on that platform.

Instead, Peter Falkingham measured the length of the current mount (including the ten distal caudals added in 2007) using a photogrammetric model constructed in November 2022 using RealityCapture, from photographs taken by Carnegie Museum volunteer Hannah Smith (now Hannah Rak) in the early to mid 2010s (Figure O.A). Markers were placed along the midline of the *Diplodocus* digital model at the tip of the snout, at mid-neck, at the cervicodorsal junction, on the neural spine of each of the first 33 caudal vertebrae, at the tip of the tail, and at a point midway between Ca 33 and the tail tip. The total length was calculated as the sum of the measurements between consecutive markers, yielding 26.05 m (= 85.5 feet). Corroborating this estimate, another was performed using a LIDAR scan by Dakota Campbell, founder of Eye-Bot Aerial Solutions. Measuring along a sequence of lines connecting the neural spines of short sequences of vertebrae (Figure O.B), he found a total length of 85 feet, 8+11/16 inches (= 26.13 m). The closeness of this estimate to that of Falkingham gives some reassurance that these measurements of slightly over 26 m are correct. Of the two, Campbell’s estimate is perhaps likely to be the more accurate, as the vertebral column was broken into more segments.

This is 2.33 m longer than the likely 23.8 m of the old mount, the extra length presumably being due to the additional caudals inserted in the remount. The last few caudals (70–73) of CM 307 average 110 mm in length (Tschopp et al. 2019:table 3). If the ten sculpted whiplash caudals were of similar length, they would account for 1.1 m of additional length. The other 1.2 m is a mystery: perhaps, as well as CM 307 caudals replacing casts in the tail, some vertebrae of this specimen were also added at that time.

See Table 3 for a summary of the different length estimates in the literature.

The uncertain dimensions of even the best-known dinosaur specimens have uncomfortable ramifications for palaeobiological inference. For example, in chapter 4 of his dissertation, Matt Wedel (2007) included femur measurements of *D*. *carnegii* along with the cervical and dorsal lengths in a database used for statistics, not realizing to what extent that skeleton is a chimaera (Wedel, pers. comm., 2022). Given that the femora of CM 84 and CM 94 vary in length by 5%, in proximal breadth by 28% and in distal breadth by 13%, the conclusions drawn from his analysis could vary considerable depending on which femur is used. Caution is always warranted when making statements about the sizes of dinosaur species, as opposed to specimens.

## Documenting skeletal mounts

The mounted skeleton of *Giraffatitan brancai*, based on its paralectotype specimen MB.R.2181 (then “*Brachiosaurus*” *brancai* HMN S II) was unveiled in August 1937. With understandable delays due to the 2nd World War, Werner Janensch (1950) published his account of the mount 13 years later, specifying which elements were from the paralectotype, which had been filled in from other comparable specimens, and which were sculpted at what scales. The Berlin museum’s atrium was renovated and the skeletons remounted in 2005–2007, and the new *Giraffatitan* mount unveiled in 2007; only four years later Remes et al. (2011) gave a comprehensive account of the remount. Unfortunately, such published documentation is the exception rather than the rule, and the composition of many important sauropod mounts remain essentially undocumented. For example, in Matthew’s (1905) nine-page account of the AMNH’s newly mounted *Brontosaurus*, only half a page is dedicated to summarising the actual fossil material included. Little is known about the Yale Peabody Museum’s *Brontosaurus excelsus* mount based on the holotype YPM 1980, beyond extracts of Lull’s terse account reproduced by Schuchert and LeVene (1940) and then by Padian (1978). Over time, primary documentation is lost, memories fade, and the principals retire or die. There is no way now to ask Hatcher or Holland what was the source of the left ilium, femur and tibia in the Carnegie *Diplodocus* mount; or, in relation to a mounted skeleton erected only 30 years ago, to ask John S. McIntosh about the choices made in creating the rearing *Barosaurus* in the rotunda of the American Museum of Natural History. Every mounted dinosaur skeleton is an important scientific and historical artefact: those of large and generally incomplete dinosaurs such as sauropods arise from complex scientific and political processes involving myriad controversies and decisions. We urge those who have the privilege of working on them to write up their choices for publication before memories fade and records are lost.

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 et al. 2022); 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 renovation of 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. A single narrative thread winds through all these 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.

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# Tables

**Table 1.** 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 Armand 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 |
| Russian cast | The Imperial Museum, St. Petersburg | Tsar Nicholas II (nominally) | Early July 1910 (see text) |
| La Plata cast | Museo de La Plata | President Roque Sáenz Peña Lahitte | 1912; no specific event. |
| Madrid cast | Museo Nacional de Ciencias Naturales | King Alfonso XIII | 2 December 1913 |
| Mexico City cast | Museo de Paleontología (UNAM) | N/A | 1930; no specific event. |
| Munich cast | Staatssammlung für Paläontologie und Geologie | N/A | (Arrived in 1934; never mounted) |
| Vernal cast | Utah Field House of Natural History | N/A | 6 June 1957 |

**Table 2.** 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 changes made to the casts subsequent to their original erection.

|  |  |  |  |
| --- | --- | --- | --- |
| **Element** | **Original mount** | **Changes to mount** | **Casts** |
| Skull | CM 662 (S) +  USNM 2673 (S) | CM 11161 (C), maybe 1962. |  |
| Atlas | Sculpture | New sculpture. | ? |
| C2–15 | CM 84 |  | Some of them cast from sculptures rather than from the original elements. |
| D1–10 | CM 84 |  |  |
| Sacrum (S1–5) | CM 84 |  |  |
| Caudals 1–12 | CM 84 |  |  |
| Caudals 13–31, 33–36 | CM 94, mix of real fossils and casts | One real CM 94 caudal replaced a cast. |  |
| Caudals 32, 37–73 | CM 307, mix of real fossils and casts | Some CM 307 caudals replaced casts. |  |
| Caudals 74–83 | (omitted) | Ten sculptures added to the end of the tail. |  |
| 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) |  |  |
| Sternal ribs | (omitted) |  |  |
| Gastralia | (omitted) |  |  |
| Left forelimb | CM 21775 | BYU 681 (S) | CM 662 (S) |
| Right forelimb | CM 662 (S) | BYU 681 (S) |  |
| Forefeet | AMNH 965 (S) | CM 662 (C); replaced again by  WDC-FS001A (S) |  |
| Left ilium | Sculpture |  |  |
| Right ilium | CM 84 |  |  |
| Pubes | CM 84 |  |  |
| Ischia | CM 84 |  |  |
| Left femur | Sculpture |  |  |
| Right femur | CM 84 |  |  |
| Left tibia | Sculpture |  |  |
| Right tibia | CM 94 |  |  |
| Left fibula | CM 33985 |  | ? |
| Right fibula | CM 94 |  |  |
| Left pes | CM 33985 (in part) |  | ? |
| Right pes | CM 94 |  |  |

**Table 3.** Published length measurements for the Carnegie *Diplodocus* and its various casts. Some were reported in feet, and some in meters. In each case, both measurements are given: the original is marked with \*, the converted measurement is unadorned.

|  |  |  |  |
| --- | --- | --- | --- |
| **Reference** | **Length (feet)** | **Length (m)** | **Notes** |
| Hatcher (1901:39) | 68 feet \* | 20.7 m | Along the column from the tip of the snout to the end of caudal 37. |
| Holland (1904a) | 78–80 feet \* | 21.3–24.4 m | London mount, predicted. |
| Holland (1904b) | 84–85 feet \* | 25.6–25.9 m | London mount, from the tip of the nose to the tip of the tail when the vertebral column is laid down horizontally. |
| Holland (1904b) | 78–80 feet \* | 21.3–24.4 m | London mount, when mounted [...] with the necessary graceful curvature. |
| Holland (1905:448) | 84 feet \* | 25.6 m | London mount |
| Holland (1907) | 78.5 feet | 23.94 m \* | Berlin mount. |
| Untermann (1959:365) | 76 feet \* | 23.2 m | Vernal mount. |
| Sarti (2012:14) | 88.6 feet | 27 m \* | Bologna mount. |
| Otero and Gasparini (2014:299) | 88.6 feet | 27 m \* | La Plata mount. |
| David Letasi (pers. comm., 2022) | 75 feet \* | 22.9 m | Elements used in Lehi mount, laid out in sequence. |
| Vincent Reneleau (pers. comm, 2022) | 77 feet | 23.5 m \* | Distance along floor between a plumb-line dropped from the snout to the tip of the tail. |
| Current Carnegie mount | 85.5 feet | 26.05 m \* | Photogrammetry: see text. |
| Current Carnegie mount | 85 feet, 8+11/16 inches \* | 26.13 m | LIDAR model: see text. |

# Figure Captions

XXX renumber sequentially. Update acknowledgements to match.

**Figure A.** The *Diplodocus carnegii* mounted skeleton as it is today: the original fossil material mounted in the public gallery of the Carnegie Museum. Head, neck, torso and forelimbs 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 had 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. 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 (Taylor et al. 2009), 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, as 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. Photograph by Michael P. Taylor.

**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 (right scapulocoracoid, 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 (lower left hindlimb), orange; CM 662 (sculpted braincase), indigo; USNM 2673 (sculpted remainder of skull), gold. White elements were sculpted, but the models on which the sculptures were based is unknown: most likely the corresponding CM 84 elements from the other side. 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 C and F scaled to the same heights as parts D and E 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, by Melinda McNaugher/Carnegie Museum of Natural History. This photograph was taken some time between 1985, when McNaugher became the exhibit photographer, and 1999. It 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.

**Figure H.** Right forefeet of the Carnegie *Diplodocus* and its casts, all in anterior view. **A.** The feet as originally mounted in 1905 (the London cast), 1907 (the Carnegie Museum original-material mount) and subsequent casts, as supervised by Hatcher and Holland and executed by Coggeshall. This photograph shows the right forefoot of the Paris mount, which is unchanged since its original mounting. This forefoot material, cast from the camarasaurid specimen AMNH 965, has elongate metacarpals splayed in a semi-plantigrade posture, with multiple phalanges on each digit and large unguals on digits I, II and III. Photograph by Vincent Reneleau (MNHN). **B.** The right forefoot of the Berlin mount, as remounted in 2006 by Research Casting International, supervised by Kristian Remes. This consists of the original casts mounted in 1908 by Holland and Coggeshall, reposed in a more modern digitigrade posture, with superfluous phalanges and unguals discarded (see text). Photograph by Verónica Díez Díaz (MfN). **C.** The forefeet of *Galaemopus* (formerly *Diplodocus*) *hayi* HMNS 175 (formerly CM 662), casts of which were used in the Carnegie mount between 1999 and 2007. Note the much shorter metacarpals, the fully digitigrade posture, the reduction in phalangeal count, and the single large manual ungual on digit I. Photograph by Jeremy Huff (TAMU). **D.** The present forefeet of the Carnegie mount, modelled in 2007 after those of WDC-FS001A, then thought to belong to *Diplodocus carnegii* (Bedell and Trexler 2005) but currently thought to belong to an as-yet unnamed basal diplodocine (Tschopp et al. 2015:229–230. Note the resemblance to the diplodocine forefoot in part C, with short metacarpals, digitigrade posture, reduced phalangeal count, and a single large manual ungual. Photograph by Matt Lamanna (CM).

**Figure I.** Carnegie Museum preparation laboratory, with key personnel, in 1903 — probably January 1903, based on the calendar on the right wall. (Carnegie photo library #1010.) Foreground: various fossils still in matrix. Right: a sequence of caudal vertebra, posterior to the front, possibly from the Carnegie *Diplodocus* referred specimen CM 94 (there are too many of them to be from the holotype CM 84) or from the *Apatosaurus excelsus* referred specimen CM 563 (subsequently transferred to UW 15556 and referred to *Brontosaurus parvus* by Tschopp et al. (2015:229) (Anthony Maltese, pers. comm., 2022). People from left to right:

* Far left, mostly cropped from image: field worker William H. Utterback
* Seated, facing right: field worked Olaf A. Peterson
* Standing at back: preparator Louis S. Coggeshall (Arthur’s brother)
* Seated, looking to camera: preparator Charles W. Gilmore
* Seated at far table: field worker Earl Douglass
* Standing behind far table: chief preparator Arthur S. Coggeshall
* Sitting at far table, facing left: preparator Asher W. VanKirk
* Seated: illustrator Sydney Prentice
* Sitting on bench: John Bell Hatcher, whose description of *Diplodocus carnegii* had been published two years previously

**Figure J.** Six of the key players in the story of the Carnegie *Diplodocus* and its casts. **A.** Andrew Carnegie, the millionaire philanthropist who funded the creation of the Carnegie Museum and after whom it is named. **B.** William J. Holland, director of the Carnegie Museum, whom Carnegie tasked with sourcing a giant dinosaur to exhibit. **C.** Olaf A. Peterson, who led the excavation of the paratype specimen CM 94. (See Figure K for those who excavated the holotype specimen CM 84). **D.** Arthur S. Coggeshall, who was the lead preparator of the *Diplodocus* fossils and supervised the subsequent mounting of both the original material and the casts. **E.** John B. Hatcher, who wrote the classic 1901 monograph describing the new species *Diplodocus carnegii* based on CM 84 and CM 94. **F.** Serafino Agostini, leader of the Italian crew that made the plaster molds and sculpted some of the elements that these were taken from.

**Figure K.** The field crew that excavated the Carnegie *Diplodocus* holotype CM 84 at Bonediggers Camp, Sheep Creek, Albany County, Wyoming. From left to right: Paul Miller, Jacob L. Wortman, William H. Reed, and William Reed Jr. Carnegie Museum photograph #37, taken in 1899.

**Figure L.** Trial mount of the first Carnegie *Diplodocus* replica, before it was shipped to London, in the old Exposition Building, downtown Pittsburgh, USA. Seated on the plinths, from left to right: preparators Asher W. VanKirk, Arthur S. Coggeshall, and Louis Coggeshall. Carnegie Museum photograph #620, taken on 1 or 2 July 1904.

**Figure M.** Comparison of atlas (cervical vertebra 1) of various specimens referred to *Diplodocus*, all in left lateral view, scaled to about the same size. **A.** A highly fused atlas illustrated by Marsh (1896:plate XXVII, part 1) and described by him as belonging to *Diplodocus longus*. This was reproduced by Hatcher (1901:figure 4) as the only then-known atlas referred to *Diplodocus*, although the referral must be considered highly uncertain. The specimen number is unknown. As noted by Holland (1906:248), the posterodorsal process of the neural arch is broken off, and Marsh’s restoration of its tip is too short. **B.** The atlas of AMNH 969, showing the neural arch in left lateral view (from Holland 1906:figure 14) with a speculative drawing of the intercentrum (which Holland illustrated in anterior, posterior and ventral views, but not in lateral view). Holland considered this atlas to belong to *Diplodocus*, but Tschopp et al. (2015:219) referred it to *Galeamopus* sp. **C.** The atlas of the Paris mount, unchanged since its original installation. The neural arch appears pale grey in this photograph while the intercentrum is a darker brown. Two areas of the image have been lightened where the atlas is obscured in lateral view by part of the skull and by the atlantal rib (see text). Photograph by Vincent Reneleau (MNHN). This is evidently the same as the atlas used in the original London mount, as illustrated by Holland (1906:figure 1). **D.** The atlas of the current Carnegie mount. Note that this differs from all three of the other specimens, having longer and slenderer posterior processes of the neural arch, and an anteroposteriorly longer intercentrum.

**Figure N.** Jacob L. Wortman, leader of the field team, in Quarry D at Sheep Creek, Albany, Wyoming, in 1899, as the Carnegie *Diplodocus* is being excavated. Before him is the right femur of CM 84 in medial view with the ventral side lying upwards. Closer to the camera is a pelvic girdle bone, probably the right pubis in medial view with proximal to the left. Carnegie photograph #29.

**Figure O.** Digital models used for measuring the total length of the current Carnegie *Diplodocus* mount. **A.** Photogrammetric model created by Peter Falkingham (Liverpool John Moores University) from photographs taken by Carnegie volunteer Hannah Smith (now Hannah Rak). This screenshot, viewing the model as though from above and slightly to the left of the mounted sauropods, shows the *Diplodocus carnegii* mount at top left and the *Apatosaurus louisae* holotype CM 3018 at bottom right. Pale blue dots along the midline of the *Diplodocus* show where markers were placed: at the tip of the snout, at mid-neck, at the cervicodorsal junction, on the neural spine of each of the first 33 caudal vertebrae, at the tip of the tail, and at a point midway between the Ca 33 and the tip. The total length was calculated as the sum of the measurements between consecutive markers: 6.76 m for the head and neck, 3.78 m for the trunk and 15.51 m for the tail, totalling 26.05 m. **B.** LIDAR-based model by Dakota Campbell of Eye-Bot. Blue boxes show lengths of measured segments, in feet and inches. The total of these measurements is 85 feet, 8+11/16 inches (= 26.13 m).

**Figure P.** The Carnegie *Diplodocus* in left posterolateral view, towards the end of the remounting process at Phil Fraley Productions, in 2007. The armature has not yet been painted to match the bone, and the distal segment of the tail has yet to be fitted. Photograph by Phil Fraley.

**Figure Q.** Mid-caudal vertebrae of diplodocines, all from around the same part of the tail, plus or minus two positions. **A.** *D*. *longus* CM 887. **B.** *D*. *carnegii* CM 94; **C.** *Diplodocus* sp. CM 11975. **D.** *Galeamopus* (= “*Diplodocus”*) *hayi* HMNS 175. Scale bar 10 cm. Reproduced by permission of Ken Carpenter.