The composition of the Carnegie *Diplodocus*

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**Abstract**

XXX to follow

**Keywords:** *Diplodocus*, sauropod, skeletal mount, casting, 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 when into making it up.

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

## Nomenclature

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

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

Vertebrae are designated as follows, for a vertebra at position *n* in a part of the spinal column: cervical vertebrae C*n*, dorsal vertebrae D*n*, 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.)
* 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.
* USNM – United States National Museum, Washington DC, USA.

# Historical background

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

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

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

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

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

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

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

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

Starting in 1903 and running through into 1904, the Carnegie Museum made molds of the *Diplodocus* bones, and the first set of casts from these molds. (Some bones had to be sculpted, because the originals were either absent or in too poor a condition for the molding process.) The work was led by Arthur Coggeshall, the chief preparator of fossils at the Carnegie museum, who was also in charge of designing the armature to carry the cast bones. A crew of Italian plasterers led by Serafino Agostini was employed, thanks to their expertise in casting artworks and Agostini’s experience at the AMNH (Nieuwland 2019:71).

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

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

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

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

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

On 11 April 1907, the original *Diplodocus* fossils were mounted at the Carnegie Museum (Nieuwland 2019:92), nearly two years after the London cast. The skeleton was unveiled as part of the opening of a new Carnegie Museum building on Forbes Avenue in the Oakland suburb of Pittsburgh, the original building having quickly been outgrown. As will be discussed in detail, below, this “original material” mount in fact included elements from multiple specimens, cast of several more, and modelled 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).

XXX Written up to here

1908: further casts are erected in Berlin, Germany; and Paris, France. The Berlin cast sparks a debate about posture (Hay 1908, Tornier 1909, Hay 1910, Holland 1910).

1909: the last two casts of the original batch are mounted in Vienna, Austria; and Bologna, Italy.

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

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

1912: another cast is mounted in La Plata, on the outskirts of Buenos Aires, Argentina.

1913: another cast is mounted in Madrid, Spain.

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

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

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

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

1934: the final cast is sent to Munich, but never mounted.

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

# Material in the mounted skeleton

## The original mount at the Carnegie Museum

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

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

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

Holland’s (1906) follow-up on *Diplodocus carnegii* osteology, while dealing in part with the cast that was mounted at the BMNH in 1905, also predated the 1907 mounting of the original fossil material at the Carnegie Museum. This paper was therefore unable to provide a comprehensive catalogue of which bones from which specimens were used in the mount, but did provide some relevant information especially about the skull. CM 84, the specimen from which the Carnegie mount is mostly assembled, does not itself include a skull. Holland (1906:227) explained that the skull supplied to British Museum as part of the *Diplodocus* cast presented to it in May 1905 was a composite sculpture based on several specimens.

* The posterior portion was modelled on material from CM 662, described in detail by Holland (1906:230–246) and illustrated by Holland (1906:plates XXVII–XXVIII). (This specimen was subsequently moved to the Cleveland Museum of Natural History as CMNH 10670; then moved to the Houston Museum of Natural History as HMNS 175). CM 662 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). The species has since been moved to its own new genus *Galeamopus* by Tschopp et al. (2015:267).
* The remainder of the skull was based on USNM 2673 (illustrated by Holland 1906:plate XXIII–XXV), the skull on which Marsh (1896:175–179) had primarily based his description of the skull of *Diplodocus*. With the USNM’s permission, the Carnegie Museum made a cast of this skull, of which only the left side had been fully prepared. They used this to restore the missing half. Ironically, this skull has since been referred by Tchopp et al. (2015:228) to *Galeamopus*, meaning that both the fossils on which the Carnegie mount’s skull were based are now considered to belong to that genus rather than to *Diplodocus*.

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

XXX Atlas of AMNH 969 described and illustrated in detail by Holland (1906:246–249).

XXX Sternal plates and “clavicles” in BMNH mount illustrated by Holland (1906:257), but the “clavicles” were removed from the mount after a few days (Holland 1906:263–264) and have still not been reincorporated (Figure C). But they appear in Holland (1905:plate XVIII).

XXX Furcula is probably a furcula, see <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3582252/>

In fact, we have not been able to locate any published account of the material used in the mounted skeleton before 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.

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

McIntosh’s account of the mounted skeleton omits the source of several elements, and these omissions have not been remedied by any subsequent publication known to us. The elements of unspecific origin are the atlas (C1), and left ilium, femur and tibia. Furthermore, while McIntosh noted that the fibula and left pes of the original mount were taken from CM 33985 and that these were not used in the casts, he did not say how the left fibula and pes were furnished in the casts. XXX find this out!

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

XXX chevron source is not discussed anywhere

XXX length as reported by Holland

XXX Table A here, summarising contributions from different skeletons; cite Figure D. Cite Figure E for CM 21775.

## Changes made to the mount at the Carnegie Museum

XXX Annual report for 1934: “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.” XXX is that the same person as Serafino Agostini who led the casting work in 1904?

XXX Annual report for 1962: “Mr. Yarmer also made several new molds of specimens in the collections, including one of the Diplodocus skull from which a number of casts were made.” XXX but which *Diplodocus* skull?

XXX Amy writes: I talked to Dave yesterday, and he recalls helping Pat Martin make a mold of one of the Diplodocus skulls. He recalls that the palate was "spilling out of the skull," so it might be CM 3452. He also mentioned that they had to fix the mold to account for crushing on one side of the skull and other problems. To me this sounds like Pat made a model of the skull that was used to make a mold and then casts.

XXX When? The skull was replaced with a cast of CM 11161. Done before 1979, when Henrici began working at the museum. Annual reports from 1912 (the date collected for CM 11161 in the database) thru 1999 do not mention the replacement, so the date may have been lost.

XXX In the second quarter of 1999, the manus were replaced with casts of those of the former CM 662 [now the holotype of Galeamopus hayi at the Houston Museum of Natural Science], etc.) — see quarterly report (XXX reference),

Still more changes were made during our remount in the late 2007 (XXXwhen exactly?):

XXX the CM 662 manus casts were replaced with scaled-up replicas of a cast of the putative *Diplodocus carnegii* manus described by Bedell and Trexler [2005]

XXX Ten-ish sculpted posteriormost (‘whiplash’) caudals were added to bring the total number of caudal vertebrae to ~83.

XXX [if memory serves], the humeri, radii, and ulnae were replaced with replicas of cf. *Diplodocus* specimens at Brigham Young University [specifically, I think they’re scaled-up sculptures based on the smaller forelimb bones BYU 4742, BYU 4708, and BYU 4726])

XXX I can't even find a reliable statement of the total length of the Carnegie Diplodocus! Somehow, some time, the figure 27 m settled itself in my mind, but I have no idea where it came from or whether it's accurate! XXX Re: the current length of the mount, we just had it LiDAR-scanned, so if I can get ahold of the results (long story) I should be able to give you a precise number. XXX Also, I think Bates et al. (2016) (https://royalsocietypublishing.org/doi/full/10.1098/rsos.150636) may have made a photogrammetric model using pics a volunteer of mine took in the early-mid 2010s; maybe that'd be useful too?

## The casts made from the Carnegie molds

XXX

# Discussion

XXX Difficulty of tracking down all this information, importance of records

XXX Links to the past: numebr of years between key incidents: we are part of a story

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# Figure Captions

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

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

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

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

**Figure E.** Mounted skeleton of *Diplodocus carnegii* as originally exhibited in 1907 at the Carnegie Museum, highlighting the mismatched humeri. **A.** skeleton in right anterolateral view. **B.** Line drawing of right humerus of *Diplodocus* sp. AMNH 5855 in anterior view, modified from Mook (1917:figure 2A). **C.** Right humerus of the Carnegie mount in left anterolateral view, enlarged from part A, modelled from CM 622, a 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 *Galemopus* Tschopp et al. 2015. **D.** Left humerus of the Carnegie mount in anterior view, enlarged from part A, CM 21775, assigned by McIntosh (1981:16) to *Camarasaurus*, but considered by Tschopp et al. (2019:29–37) to be Camarasauridae indet. **E.** Right humerus of *Camarasaurus supremus* AMNH 5761/H.1 in anterior view, modified from Osborn and Mook (1921:figure 84B). Parts B and E scaled to the same heights as parts C and D respectively.