VOLUME I, PART V.

A Skeleton of Diplodocus.

MEMOIRS

OF THE

AMERICAN MUSEUM OF NATURAL HISTORY.

V.—A SKELETON OF DIPLODOCUS.

By Henry Fairfield Osborn.

Plates XXIV–XXVIII.

In the spring of 1897, one division of the American Museum exploring party was sent by the writer to the Como Bluffs of Wyoming, made famous by numerous discoveries of Dinosaurs. It was believed that this rich locality had been exhausted by the continuous excavations of the U. S. Geological Survey under the direction of Professor Marsh. The first prospecting, however, resulted in the discovery by Mr. Barnum Brown and the writer of a large femur, which guided us to the very remarkable skeleton of *Diplodocus longus* described in this Memoir. Dr. J. L. Wortman joined the party and superintended the work of excavation by Mr. Brown and others, which occupied several months.

At one time strong hopes were aroused that the entire animal would be found together. The long tail stretched off parallel with the cliff, interrupted only by a small gully which had cut through a small section of the caudals. In front of the sacrum the dorsals stretched forwards in a promising way, but the centra were wanting, and finally nothing but the neural arches remained.

The left side was found most deeply imbedded and most completely preserved in the region of the sacrum. The bones recovered are as follows: 8 posterior dorsals lacking the centra; left neural arches of 3 cervicals; sacrum, lacking centra 1 and 2, consisting of 4 vertebræ; caudals 1–21, and 23–27, complete with chevrons; portion of caudals 32, 33, 35 (estimated); ribs of three posterior dorsals; left ilium and ischium; upper three fourths of left femur; right scapula.

Not only the relative completeness of this skeleton, but the highly skilful manner in which it was taken out, render it unique. Not a fragment preserved is missing or out of place. Upon arrival in the Museum, the reconstruction of the pelvis and sacrum proved especially difficult, but was completed successfully by Mr. Brown, under the direction of Mr. Hermann. Mr. Brown worked out the entire tail with great skill. Mr. Hermann has carefully restored the missing dorsal centra, and prepared this superb specimen for exhibition. In course of his work upon the caudals, Mr. Brown made a number of observations which have been of considerable service to the writer. The pen drawings and restoration are by Mr. Rudolph Weber; the photographs by Mr. Abram E. Anderson.

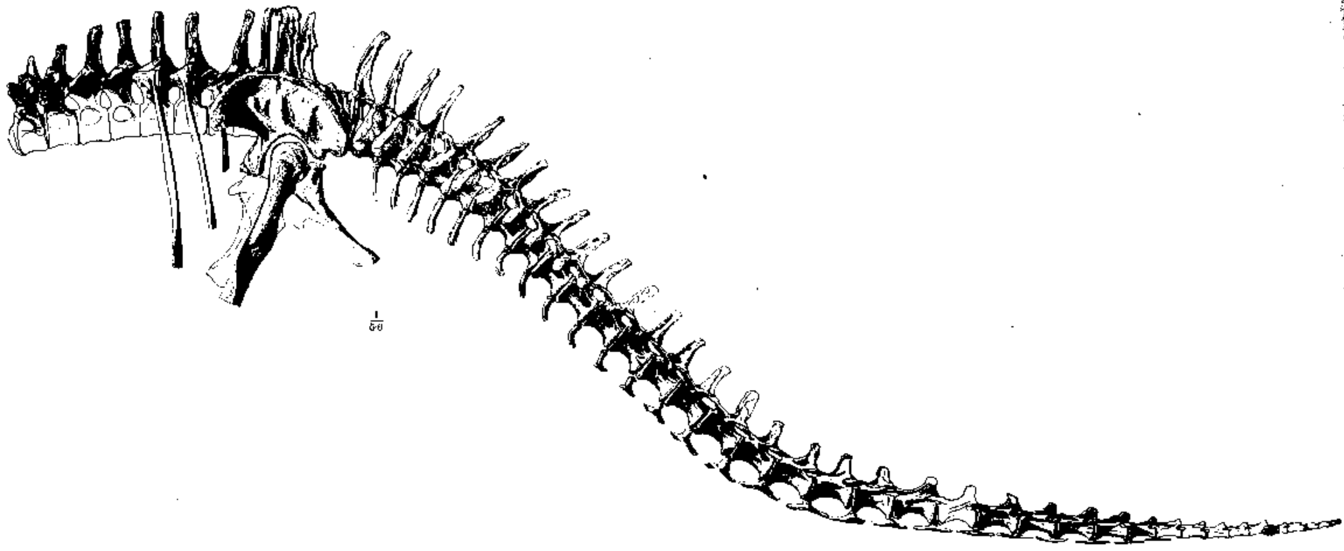

Fig. 1. Restoration Posterior half of vertebral column of the Diplodocus Skeleton with Pelvis and Femur in position. $\frac{1}{60}$ nat. size.

Description of Skeleton.

The points of greatest novelty are found in the vertebral column, since the only portions of this region described by Professor Marsh are a single cervical, an anterior dorsal, three sacral centra, and one caudal with chevrons.

In order to understand the general structure of the posterior half of the column, that is, from the 8th presacral backwards, the reader is at once referred to the above Restoration, Fig. 1.

A remarkable *balance between the opisthocœlous presacrals and procœlous postsacrals* is observed. Vertebra for vertebra they correspond very nearly in size, with a slight advantage in favor of the presacrals.

This balance, which was completed by the ponderous tail stretching out to a length of 30 feet, was probably an adaptation to the power of vertically elevating the anterior portion of the body, certainly while in the water, and quite possibly while on land.

Between these balanced dorsals and caudals are the excessively rigid sacrals, coalesced with each other and with the ilium. Thus a long balanced vertebral lever is established with the acetabulum as a fulcrum; with opisthocœlous vertebræ in front and procœlous vertebræ behind.

The dominating principle in construction of the backbone is maximum strength with minimum weight. The ingenuity of sculpture by which this is brought about, every single vertebra differing from its fellow, baffles the Lamarckian as well as the Darwinian, and tempts us to revive the old teleological explanation.

Cervical Vertebræ.

Portions of three cervical vertebræ are preserved, affording an estimate as to their length. In the most anterior, a part of the centrum, the prezygapophysis, *a.z.*, and diapophysis, *t*, are preserved. In the second we see the prezygapophysis, diapophysis, and postzygapophysis, *p.z.* In the third, only the prezygapophysis and diapophysis are preserved. The centra, *c*, and ribs, *r*, are indicated in outline.

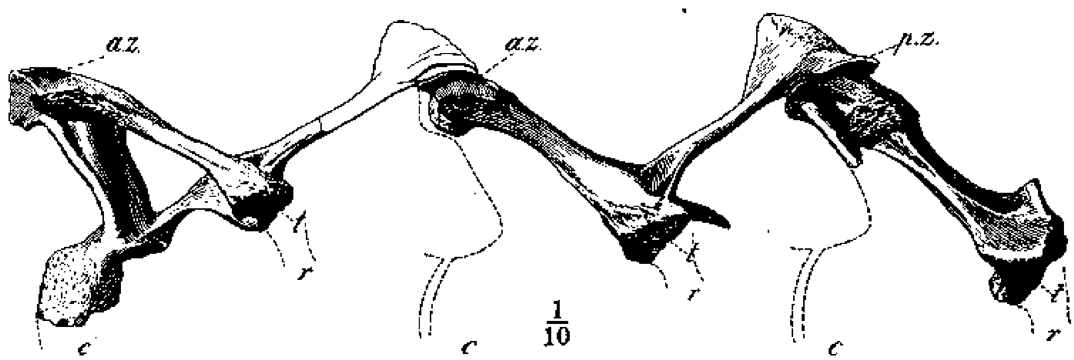

Fig. 2. Portions of three Cervicals. 1/10 nat. size.

Dorsal Vertebræ.

The number of dorsal vertebræ in the Sauropoda is still unknown. Marsh figured it at 14 in *Brontosaurus*. The writer has shown grounds for believing that the number was larger. We may provisionally adopt 15 as the number in *Diplodocus*. According to this estimate the most anterior vertebra preserved would be the eighth dorsal. It is best to enumerate the dorsals also from the sacrum forwards, namely as *presacrals* 1, 2, 3, etc. In the accompanying figures also two sets of numbers are given.

General Characters of Dorsals.

Of the 8 dorsals discovered, the 6 anterior are mounted as found, interlocked by their zygapophyses; the 2 posterior are interlocked with the sacrum.

All the dorsal vertebræ bear ribs, including two ribs which lie beneath the ilium. There are no lumbars.

The spines rise rapidly to the sacrum, which is the highest fixed point in the vertebral column.

Vertebræ without transversely expanded spines; spines paired anteriorly, single posteriorly.

The seven principal characters of the dorsals preserved are the following:

1. *Neural Spines.*—There is no nodal vertebra or sudden transition from paired spines to single spines, such as we observe in *Brontosaurus* (see Osborn, '98, 231). Neither are any of the dorsal spines transversely expanded. On the contrary, the low bifid, or laterally paired spines of the cervicals and anterior dorsals gradually converge and rise until in the 3d, 2d, and 1st presacrals (or 13th, 14th, and 15th dorsals) the spines are lofty and single, expanding into rugosities at the summits.

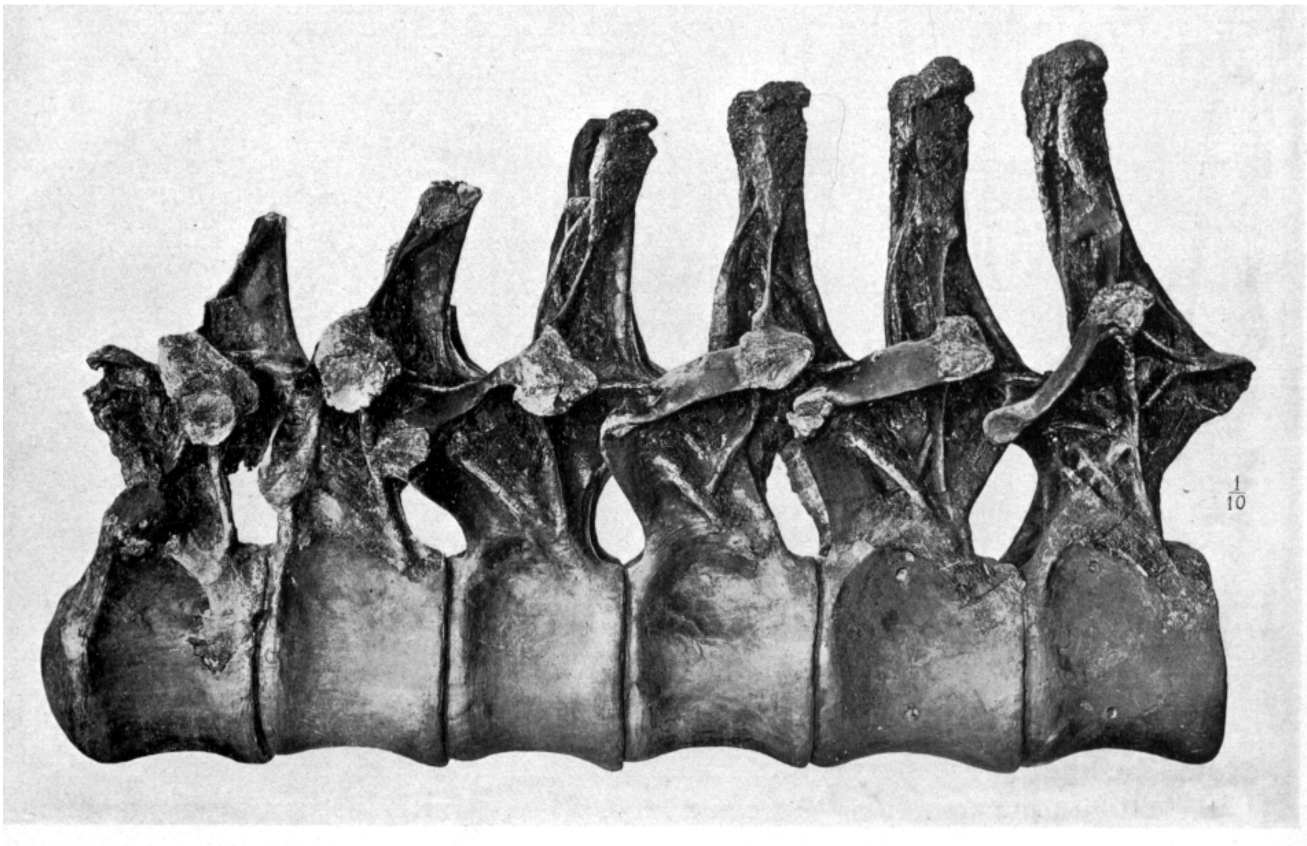

Fig. 3. Lateral view of Dorsals 8–13 (estimated) or Presacrals 8–3. Centra restored, omitting lateral cavities $\frac{1}{10}$ nat. size.

2. *Rib Articulations.*—The diapophysial tubercular articulations, *t*, are very high throughout, while the capitular articulations, *c*, rise suddenly from a point just above the centrum in presacral 8 (see Fig. 7) to a high level in Ps. 5–1. The ribs are thus borne in Ps. 5–1, high above the centrum.
3. *Zygapophyses.*—Ps. 8–1 have very extended zygapophyses extending into the hyposphen-hypantrum articulations below.

4. *Laminar Buttresses.*—The neural arches and spines are sculptured into thin laminar buttresses which reduce the weight to the last degree. As best shown in Figs. 4 and 7, these are ***constructed in such a manner as to connect all the principal points of strain and stress***, as follows :

a. Vertical Median Laminæ of Neural Spine, bracing against antero-posterior strains.

1. *Prespinal lamina, a.s.*, rising upon the inner sides of the prezygapophyses and extending upwards to top of the bifid or single neural spines.

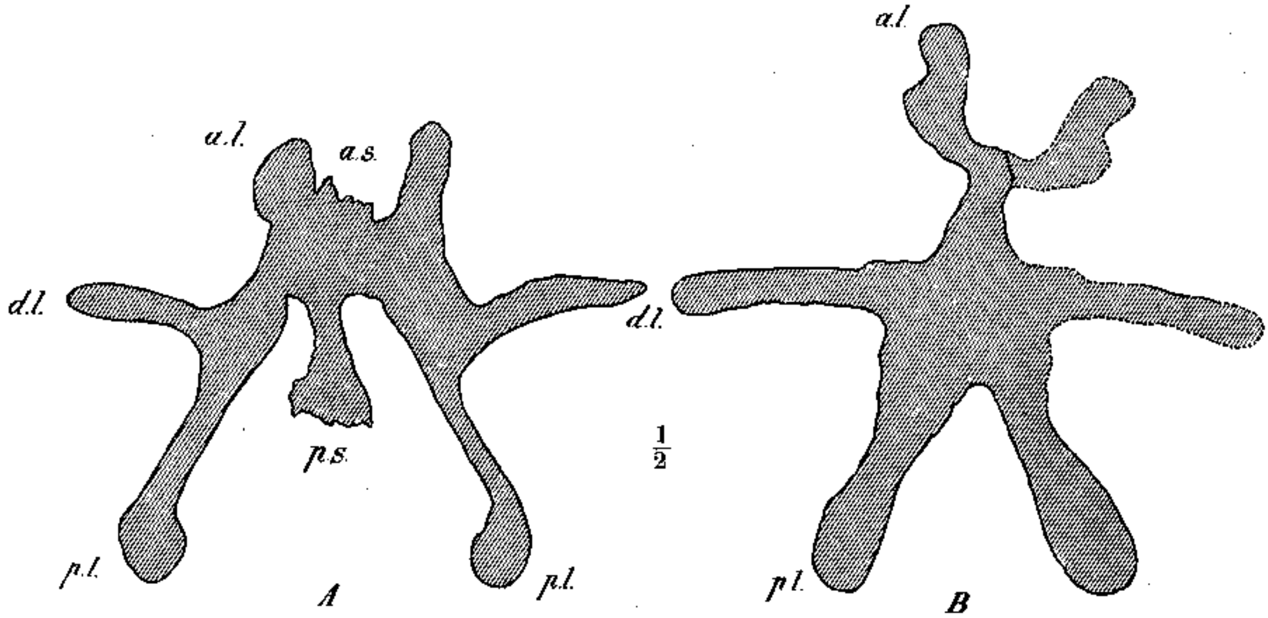

Fig. 4 A. Neural spine of 6th Presacral, transverse section, showing eight laminæ.

Fig. 4 B. Neutal spine of 4th Presacral, transverse section, showing six laminæ.

a.s., prespinal lamina ; *p.s.*, postspinal lamina ; *a.l.*, prezygapophysial lamina ; *p.l.*, postzygapophysial lamina ; *d.l.*, diapophysial lamina.

2. *Postspinal lamina, p.s.*, rising from postzygapophysial lamina and extending upwards to top of spines.

b. Horizontal Laminæ, *h.l.*, between Neural Spine and Neural Arch.

3. *Horizontal lamina*, connecting prezygapophysis with rib capitular, rib tubercular facets, and postzygapophyses.

c. Lateral Vertical Laminæ.

4. *Prezygapophysial lamina, a.l.*, descending vertically from anterior borders of spine above prezygapophyses, through rib capitulum facet to centrum, forming anterior border of neural arch.

5. *Diapophysial lamina, d.l.*, or ***transverse process***, descending from side of spine, through prominent rugosity for tubercle of rib, downwards into neural arch.

6. *Postzygapophysial lamina, p.l.*, descending from posterior borders of spine, through postzygapophyses, to form posterior border of neural arch.

d. Oblique Laminæ.

7. *Oblique and intersecting laminæ.* Extending upon sides of neural arch from prezygapophyses downwards and backwards, and from postzygapophyses downwards and forwards. Also minor laminæ intersecting each other at sides of neural arch, *o.l.* (See Ps. 3.)

The vertebræ are thus reduced in weight and increased in strength in the most effective manner.

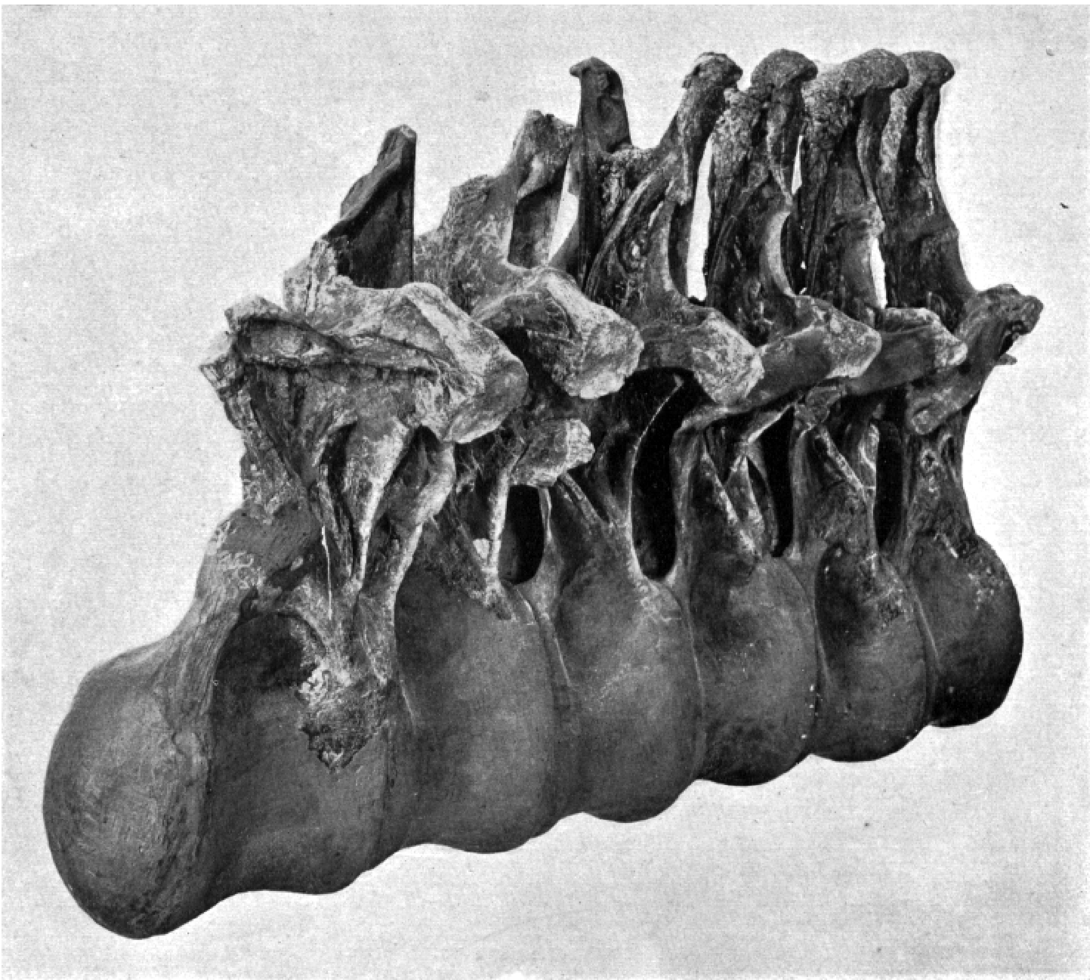

Fig. 5. Oblique anterior view of Presacrals 8-3, showing convergence of Spines, Diapophyses, and Diapophysial Laminæ.

These laminar buttresses are proportioned in the successive vertebræ to meet the peculiar mechanical strains of each, no two vertebræ being alike.

Similar laminæ, differently proportioned and less elaborate, are seen in *Brontosaurus* and other Sauropoda.

5. *Lateral Cavities of Centra.* — The centra are practically destroyed. In Ps. 8 alone is observed the upper border of a lateral excavation which was undoubtedly developed in all the others as in the anterior caudals.

6. *Opisthocœlism.* — All the dorsals are opisthocœlous.

7. *Asymmetry.* — Not only are successive vertebræ unlike but the same vertebræ vary in structure upon opposite sides. In some instances they are decidedly asymmetrical. There is probably much individual

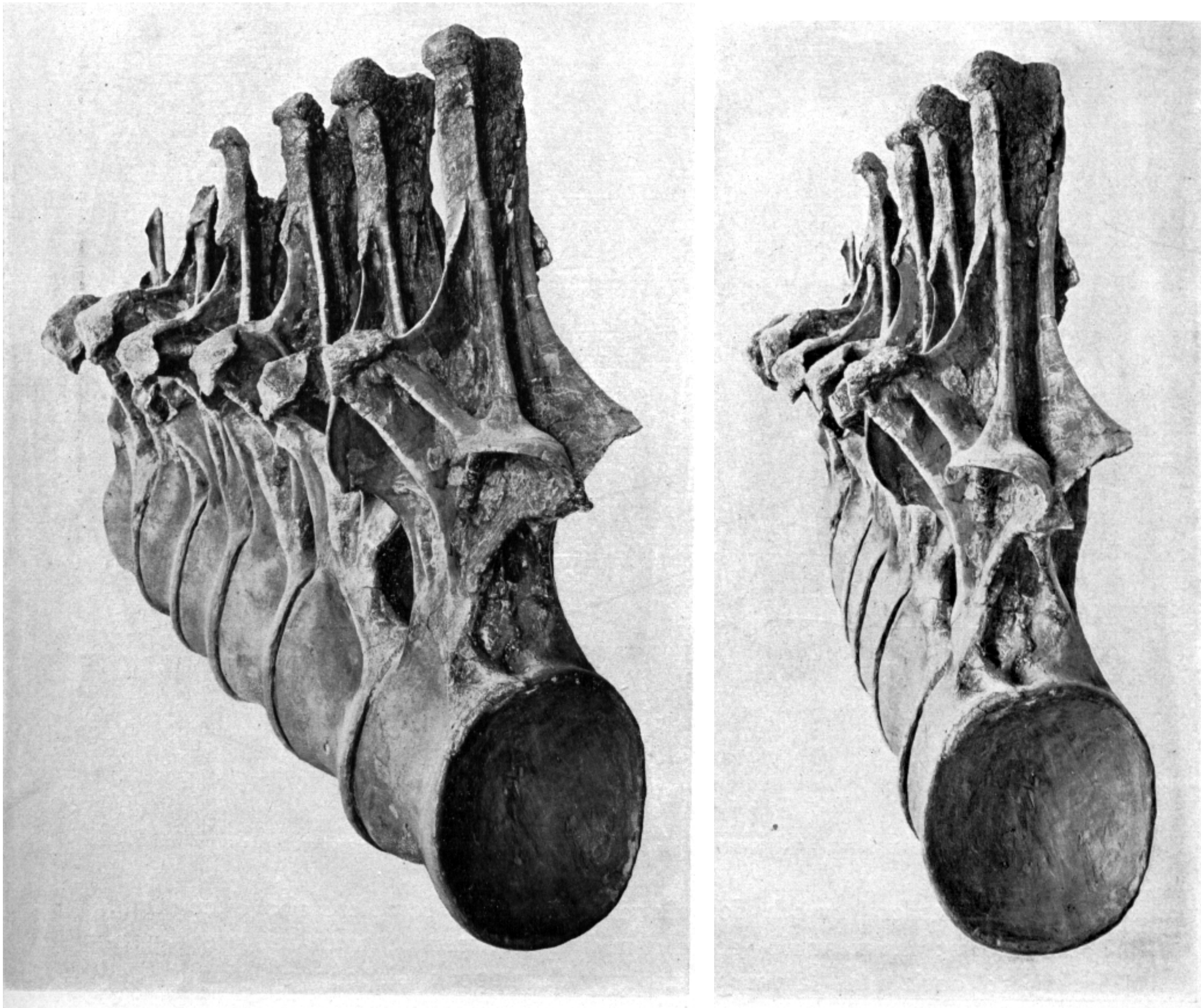

Fig. 6. Posterior oblique views of Presacrals 8–3, showing Postspinal, Postzygapophysial, Horizontal, and Diapophysial Laminæ. Also Hyposphen.

variation in these grotesque forms. As already observed by the writer ('98, p. 227), a marked characteristic of the Sauropoda or Cetiosauria is the sudden form change in the successive dorsal vertebræ. Each bone requires a detailed description.

Special Characters of Dorsals.

8th presacral or 8th dorsal. Condition: the summits of the paired spines broken away; the neural arch crushed posteriorly; prezygapophyses and lower part of arch wanting. Characters: shallow lateral cavity; capitular facet of rib large, on anterior portion of neural arch slightly above level of centrum; rib tubercle facet much more elevated, with its supporting vertical and oblique laminæ placed very far back.

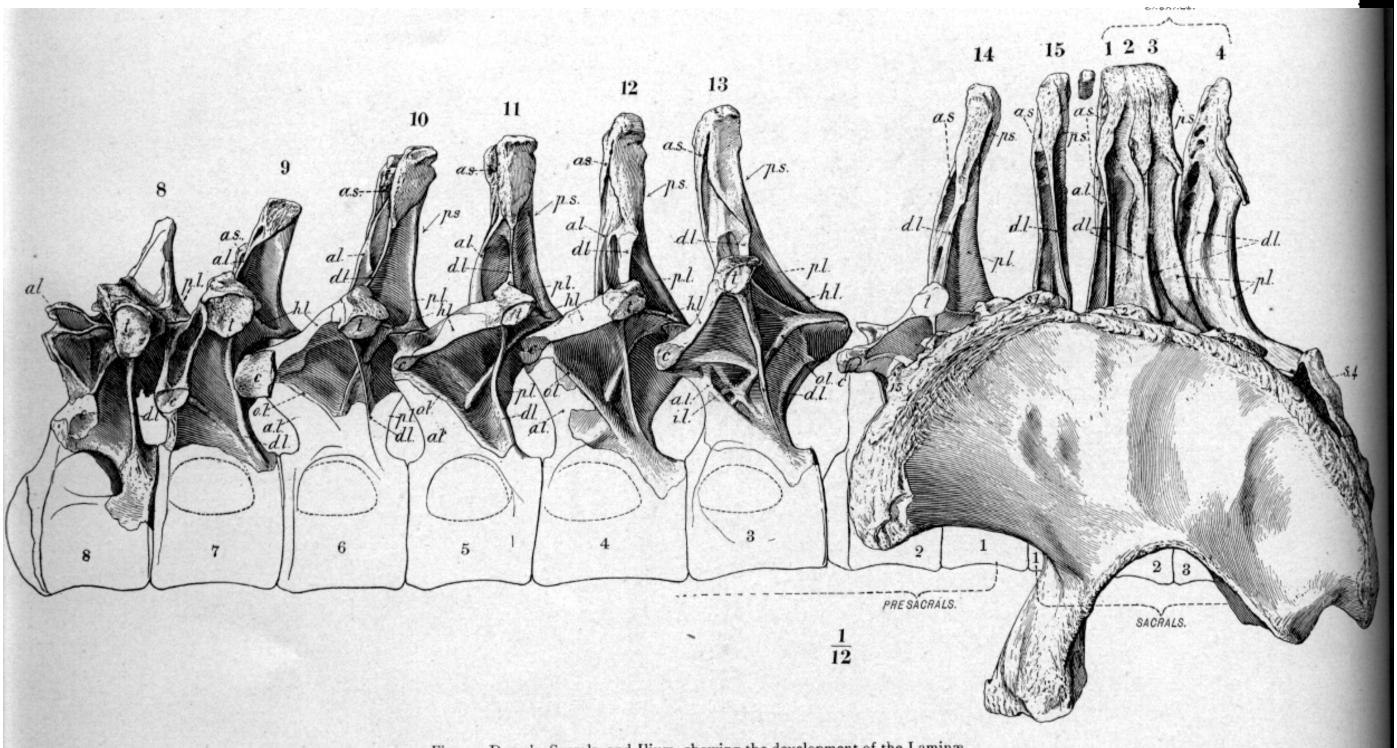

Fig. 7. Dorsals, Sacrals, and Ilium, showing the development of the Laminæ.

a.s., prespinal lamina; *p.s.*, postspinal lamina; *a.l.*, prezygapophysial lamina; *d.l.*, diapophysial lamina; *p.l.*, postzygapophysial lamina; *h.l.*, horizontal lamina; *o.l.*, oblique lamina; *i.l.*, intersecting lamina; *c.*, capitular facet; *t.*, tubercular facet; *s.1–s.4*, diapophysial rugosities.

7th presacral or 9th dorsal. Condition: nearly complete above centrum. Characters: capitular rib facet placed midway between centrum and prezygapophyses; horizontal lamina more strongly developed; diapophysial lamina descending far back upon centrum; paired neural spines forked or bifid at top, with broad connecting lamina between them.

6th presacral or 10th dorsal. Condition: completely preserved above centrum. Characters: paired neural spines united to a point $\frac{1}{3}$ from summit; prominent prezygapophysial laminæ on either side of prespinal lamina diverging at summit into paired spines, with the stout prespinal rugosity between them; postspinal lamina becoming prominent; side of spine with a prominent muscular rugosity which tapers inferiorly into diapophysial lamina, this lamina more slender below and not descending to centrum, postzygapophysial lamina projecting behind it; capitulum of rib attached still higher.

5th presacral or 11th dorsal. Condition: lacking inferior portion of neural arch. As in D. 10, a pair of prezygapophysial laminæ on either side of prespinal lamina. Characters more progressive than preceding, as follows: neural spines early confluent at summit; prespinal laminæ more prominent; postspinal lami-

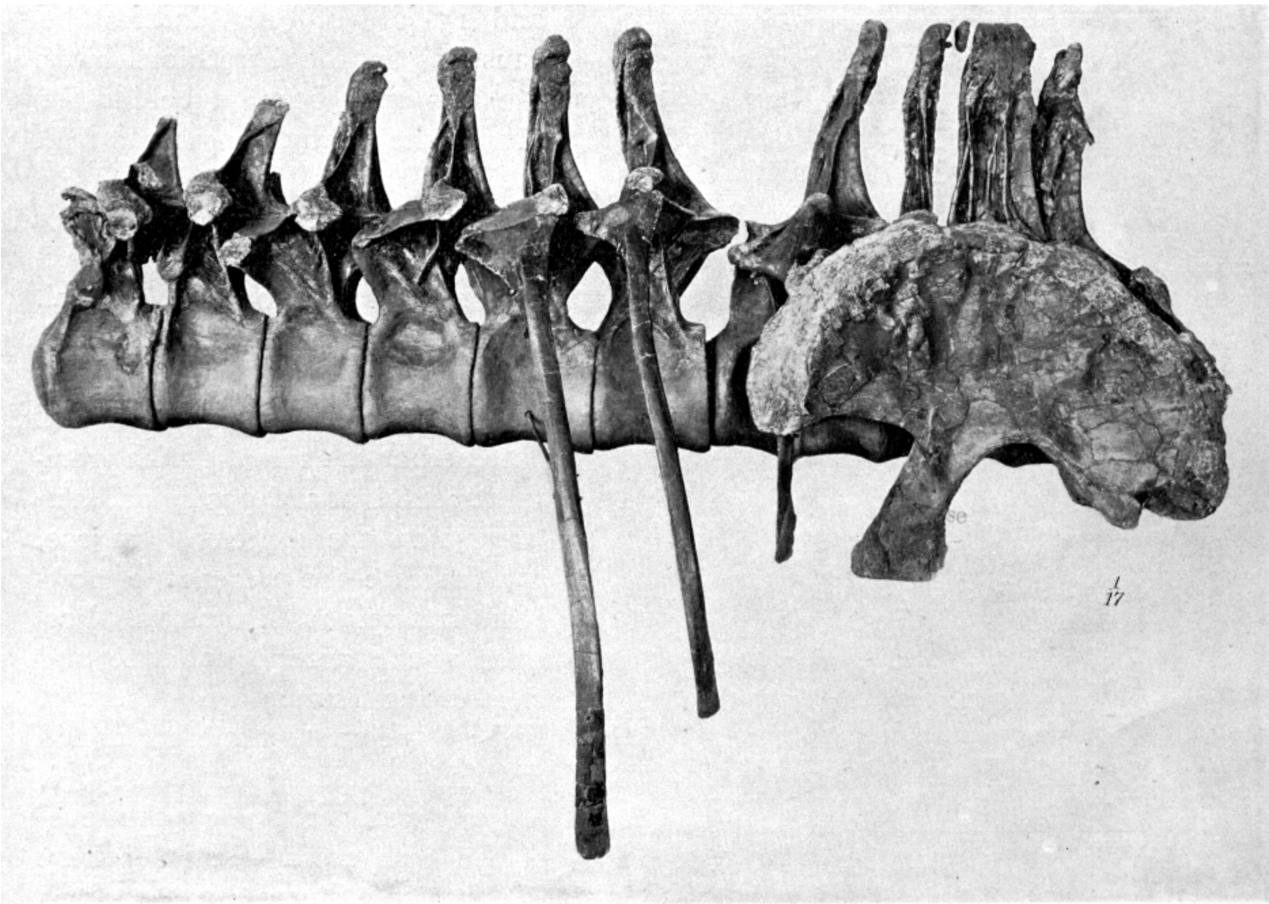

Fig. 6. Dorsals, sacrals, and ilium. 1/17 nat. size.

næ more prominent; capitulum of rib within 4½ cm. of prezygapophysis; diapophysial lamina more prominent above, directed downward and forward below tubercle. Oblique laminæ on neural arch more conspicuous.

4th presacral or 12th dorsal. Condition: complete above centrum with rib attached. Characters: prezygapophysial lamina not rising so high upon spine; all the laminæ (except the intersecting) well developed; capitular facet elevated; neural spine broadened at top, single, with slight median depression. The rib is well preserved, length approximate 130 cm., the capitulum and tuberculum being nearly upon one level and connected by a broad plate which is sculptured upon the inner surface; it passes from the plate into a triangular mid and inferior section.

3d presacral or 13th dorsal. Condition: complete except prezygapophysis and lower portion of centrum. All typical laminæ strongly developed, including the oblique and intersecting laminæ. Neural spine single, with broad rugosity at summit. This is the most elaborately constructed and typical vertebra of the dorsal series. The rib is shorter than the preceding, length approximately 118 cm.

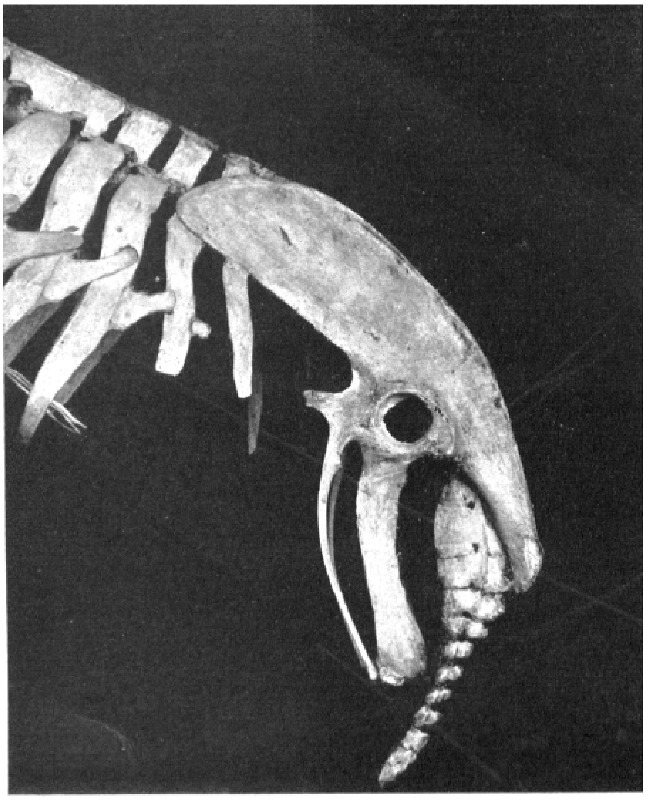

Fig. 9. Posterior Dorsals and Pelvis of *Apteryx*, showing Ilium overlapping two Posterior Ribs.

Presacrals 2 and 1 (dorsals 14 and 15) are of great interest because, as in the Struthious birds, the ribs they bear lie behind the ilium, the 14th being still free, the 15th having coalesced with the ilium. The analogy with *Apteryx* (Fig. 9) is very striking.

2d presacral or 14th dorsal. Condition: portions of neural arch and spine preserved. Characters: The neural spine is expanded and flattened at the summit, with prominent prespinal and postspinal laminæ which are extremely rugose, and indicate the presence of powerful interspinous ligaments. Portions of the anterior oblique and intersecting laminæ are preserved. The rib is complete, measuring 68 cm. (not including curvature); it projects well down below the level of the iliac crest, and is entirely free from the ilium.

1st presacral or 15th dorsal. Condition: upper portion of the neural arch and spine preserved. This vertebra lies distinctly in front of the *neck* of the ilium, with which the first true sacral unites; it also lacks the sacral arcade springing from the centrum. It must therefore be considered the last dorsal.

Nevertheless, it coalesces with the superior border of the ilium by a bar (Fig. 7, R. 15) which *may be considered either a metamorphosed rib* or *an expansion of the metapophysial lamina*. If this element is a rib then *Diplodocus* presents a condition clearly analogous to that in *Struthio* (Fig. 10), in which the last rib all but unites with the ilium.

SACRAL VERTEBRÆ.

PLATES XXV AND XXVI.

A sharp and very ancient or primitive line of demarcation separates the sacral vertebræ from the dorsals, namely:

1. *Sacral ribs.*—The possession of sacral ribs springing directly from the sides of the centra. These are profoundly different from the elevated posterior dorsal ribs which spring from the junction of the neural spine and neural arch. The sacrum therefore does not expand by the addition of posterior dorsals.
2. *Vertical laminar diapophyses.*—The possession of broad, plate-like, transverse processes which consist of the *diapophysial laminæ* above described. These laminæ, as in the dorsals, are connected above with thin plates ascending to the summit rugosity of the neural spines, and descend below to unite with the sacral ribs.

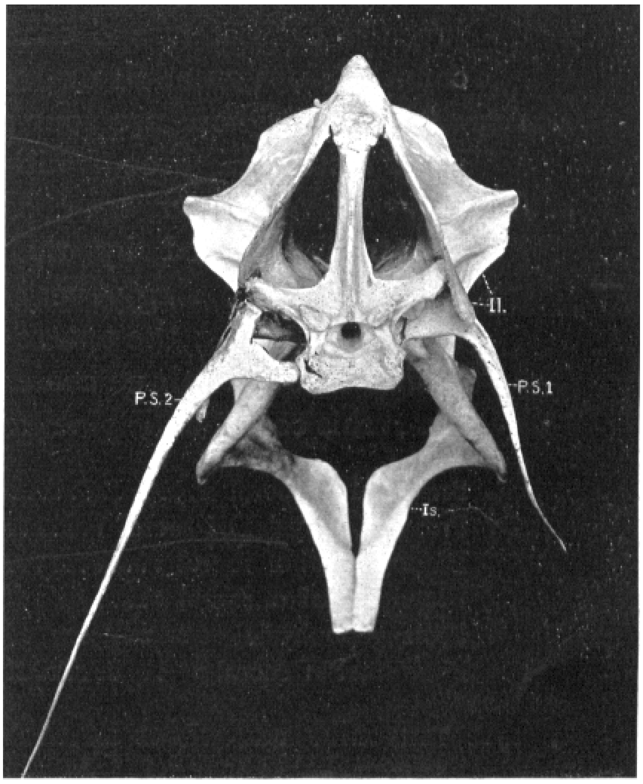

Fig. 10. Anterior view of Sacral Region in *Struthio*, showing two Dorsal Ribs, *P.S.* 1, *P.S.* 2, beneath Ilium. Also union of Ilium with Neural Spines, Diapophyses, and Ribs.

a. Each of these laminæ unites upon its outer side throughout its whole length with the ilium, and each appears above the iliac crest as a diapophysial rugosity homologous or in a continuous series with the rugosities above the rib tubercle facets in the dorsals. (See Fig. 7, s^1, s^2, s^3, s^4.)

b. These laminæ form the boundaries of three pairs of cavities between the sacrals and the ilia. These cavities open above and below. They are partly shut in above by expansions of the horizontal laminæ.

c. This arrangement is wholly dissimilar to that in *Struthio*, as is seen by a comparison of Figures 8 and 10; in *Struthio* there are no laminar plates, the union is by the ribs, diapophyses, and summits of the spines. It is similar to that in *Morosaurus*, as recently described and figured by Williston ('98, p. 175). These sacra (*Morosaurus*, Kansas

Museum, and *Diplodocus*, American Museum) clear up the hitherto incompletely understood relations of the sacrals to the ilia.[1]

d. The sacrum of a supposed young *Morosaurus* figured by Marsh ('96, Plate 33) represents the *sacro-iliac union as exclusively composed of sacral ribs, i. e.*, free elements at junction of centra and neural arches, which are mistakenly termed 'transverse processes' by Marsh. This cannot be the case in *Diplodocus*, because we see the very extensive diapophysial laminæ, arising as outgrowths of the neural arch, and evidently coalescing with the sacral ribs below. These laminæ are serially homologous with the transverse processes of the dorsals, and morphologically are quite distinct from ribs.

It is possible that the simple rib connection of the young *Morosaurus* is a juvenile character, and that the compound, or pleuro-diapophysial connection, is an adult or growth character.

3. *Four sacrals.*—There are four rib-bearing true sacral vertebræ in *Diplodocus* instead of three as hitherto described by Marsh.

a. The *three anterior sacrals*, constituting the primitive Dinosaur sacrum, are firmly united by their neural spines. These three spines coalesce into a single very robust spine, showing the diapophysial laminæ separate; the antero-posterior diameter of this spine is far less than that of the three coalesced spines of *Brontosaurus* or *Morosaurus*; this compound spine exhibits the following laminæ (See Fig. 7):

Prespinal of sacral 1	*a. s.*
Prezygapophysial of sacral 1	*a. l.*
Diapophysial of sacral 1	*d. l.*
Diapophysial of sacral 2	*d. l.*
Postzygapophysial of sacral 3	*p. l.*
Postspinal of sacral 3	*p. s.*

b. The muscular rugosities at the sides of the neural spines descend upon the diapophysial laminæ in the dorsals and in sacrals 1 and 2; in sacrals 3 and 4, and in the caudals, the rugosities descend upon the postzygapophysial laminæ. This difference constitutes evidence that:

4. *Posterior sacral-caudals.*—The sacrum of Cetiosaurs is reinforced by the addition not of dorsals, but of anterior caudals. The third sacral was probably the first of the anterior caudals to be added in an ancestral stage of evolution.

a. The fourth sacral[2] is still more conspicuously a modified caudal. It unites firmly with the third by its centrum, but its neural spine is entirely

[1] In his latest article upon the Sauropoda ('98, p. 487), Marsh states in his definition of the order: "Each sacral vertebra supports its own sacral rib or transverse process; no diapophyses on sacral vertebræ." A sacral rib, however, is not a transverse process, and it is evident that in these animals, as in the birds, both elements constitute the sacral arcade.

[2] This vertebra was broken off in Marsh's specimen (see '96, Plate 28), leading him to describe and figure this animal as possessing only three sacrals.

separate above the level of the prezygapophyses. Its diapophysial lamina unites with the posterior border of the ilium only. This lamina passes downwards and forwards into a very powerful sacral rib which unites with the neck of the ilium.

5. *Double sacro-iliac union.*—The sacral ribs unite with the neck of the ilium; the diapophysial laminæ unite with the plates and crests of the ilium.

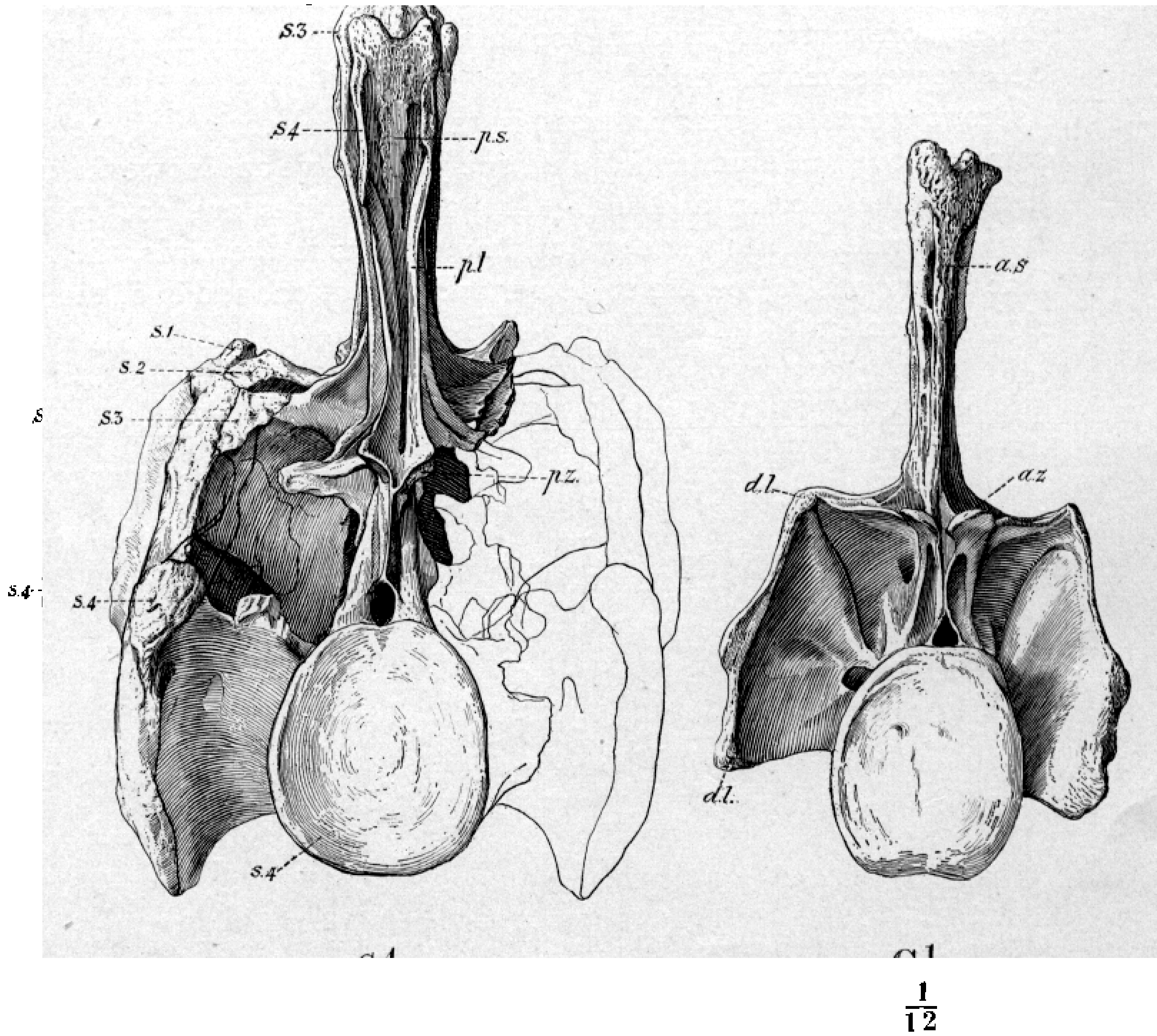

Fig. 11. Posterior view of Sacrum and Ilia; also anterior view of 1st Caudal, showing fundamental similarity between 4th Sacral and 1st Caudal.

Relations of Sacrum and Ilium.

1. This is the first instance among the Sauropoda in which a nearly complete sacrum has been found attached to the ilium.

a. This fortunate circumstance determines *the correct position of the ilium with relation to the sacrum*, and shows that the entire pelvic girdle has been incorrectly placed in all the figures and restorations of Marsh;

his error consisted in his placing the anterior and posterior acetabular borders, or pubic and ischiac peduncles, of the ilium upon the same horizontal plane, thus directing the superior iliac crest backwards, and altering the natural angle of the entire pelvis.

b. The anterior acetabular or pubic peduncle in *Diplodocus* is demonstrated to be far below the level of the posterior acetabular or ischiac peduncle; thus the iliac crest is directed mainly upwards. This position of the ilium is undoubtedly characteristic of all Cetiosaurs; it places the pubes more vertically, and the ischia more horizontally than they have been represented hitherto.

2. The second point of great interest is the great elevation of the sacral spines above the ilium and the uniquely extensive and powerful union between the sacrum and ilia. The sacral spines are not only the highest spines in the vertebral column, but, as in the birds, the sacro-iliac junction is the centre of power and of motion, and is of the most rigid character.

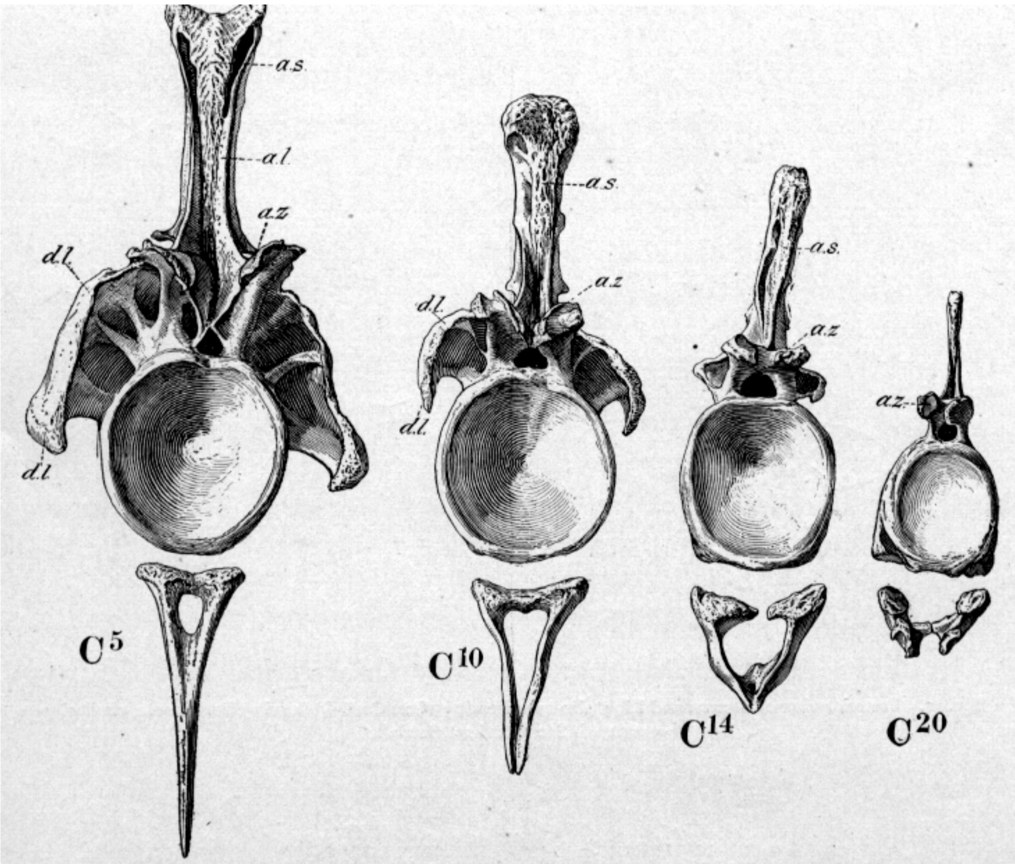

Fig. 12. Anterior view of characteristic Caudals, showing rapid change in the character of spines,
Fig. 12. Anterior view of characteristic Caudals, showing rapid change in the character of spines,
Diapophyses, Centra, and Chevrons, 1/8 nat. size.

Caudal Vertebræ.

The completeness of the tail with its chevrons is of great moment; but few are missing as indicated in the restoration upon page 192.

37 caudals is the number estimated. 29 is the number fully or partly preserved. 26 chevrons are preserved. The length of the tail is estimated at 9 metres, or about 29 feet — this estimate is obtained by the addition of the actual lengths of the centra as follows:

Antero-Posterior Diameter of Centra.

1st Caudal	.152	20th Caudal	.300
2d "	.163	21st "	.297
3d "	.182	22d "	.296
4th "	.193	23d "	.285
5th "	.205	24th "	.272
6th "	.210	25th "	.255
7th "	.216	26th "	.242
8th " (estimated)	.215	27th "	.225
9th " "	.214	28th " (estimated)	.212
10th "	.241	29th " "	.201
11th "	.267	30th " "	.190
12th "	.277	31st " "	.172
13th "	.270	32d " "	.161
14th "	.305	33d " "	.151
15th "	.290	34th " "	.147
16th "	.318	35th " "	.135
17th "	.300	36th " "	.117
18th "	.320	37th " "	.107
19th "	.310		

The caudals thus steadily increase in length from the first to the 18th and then steadily diminish towards the extremity. Sudden contrasts in measurement in the table above are due to distortion.

General Characters of Caudals.

PLATES XXVII AND XXVIII.

Totally dissimilar from the caudals of other reptiles, and even from those of other Dinosaurs, the caudals of Sauropoda or Cetiosauria are distinguished by profound changes in different regions. *Diplodocus*[1] seems to be even more remarkable in this respect than *Brontosaurus*.

1. All the caudals are procœlous.
2. As to chevrons there are four types (compare Figures 12 and 13) which unless found together would not have been considered as belonging to the same animal.
3. *Lateral cavities* of the centra extend from the first to the 18th caudal, gradually diminishing in extent.

An *inferior concavity* characterizes all the centra and sharply distinguishes them from those of *Brontosaurus*.

4. As to proportion the anterior caudals are *short*, relatively *broad*, and spreading with heavy rugosities, as the seat of the powerful muscula-

[1] The latest definition of the Diplodocidæ by Marsh ('98, p. 488) was published after he had examined the tail of the specimen here described. It includes a partial correction of his earlier definition of the caudal characters.

ture of the tail, sacrum, and femur. The median caudals (of the type first described by Marsh) are *long, narrow*, and contracted, as the seat of the propelling fin; the posterior caudals are long, slender cylinders.

5. The neural spines pass from the elevated rugose type (resembling that of the dorsals and sacrals), anteriorly, to a thin, laterally compressed type in the mid or fin region. This is evidence that the anterior caudals were of service in the vertical motions of the sacrum and back (as explained below) as well as in the lateral motions of the tail.
6. *Inferior horizontal lamina.* — The mechanical construction of the anterior caudals is most superb. In addition to the laminæ characteristic of the dorsals we find an *inferior horizontal lamina*. This is designed to brace the diapophysial lamina below against the heavy lateral strains of the femoro-caudal and ischio-caudal muscles; this lamina forms the dorsal wall of the lateral cavity.
7. The prezygapophyses, in caudals 1–12, are braced by two supplementary X laminæ which cross each other above the neural arch in front (see Fig. 12 X, C. 1–C. 5). The postzygapophyses are braced by a median vertical I lamina.

   There are thus upon both sides and in the median line *eleven* laminæ in the caudals, in contrast with *eight* laminæ in the dorsals.
8. There is no hyposphen-hypantrum extension of the zygapophyses as in the dorsals.
9. The neural spines in certain vertebræ are hollow — that is, traversed by vertical tubular cavities.
10. In addition to the laminæ and cavities which are consecutively developed, almost every inch of surface is pocketed and sculptured with secondary hollows, intersecting and oblique bars. The mechanical elaboration is thus even more extreme than in the dorsals. Each of the anterior caudals requires a separate description, which should be followed by the reader in connection with Figs. 11, 12, 13, and Plates XXVII and XXVIII.

Special Characters of Caudals.

1st Caudal. — Summit of neural spine cleft as in posterior sacral and third presacral. Prespinal and postzygapophysial laminæ very strong; postspinal, prezygapophysial and upper portion of diapophysial laminæ very weakly developed.

Winglike diapophysial laminæ opposite neural arch, with a concave anterior surface pocketed at its junction with the centrum, supported or braced above by a horizontal lamina.

Note 1. — *Progressive Changes in Caudals 1–12.*

a. Disappearance of median cleft in summit of spine, in C. 8.

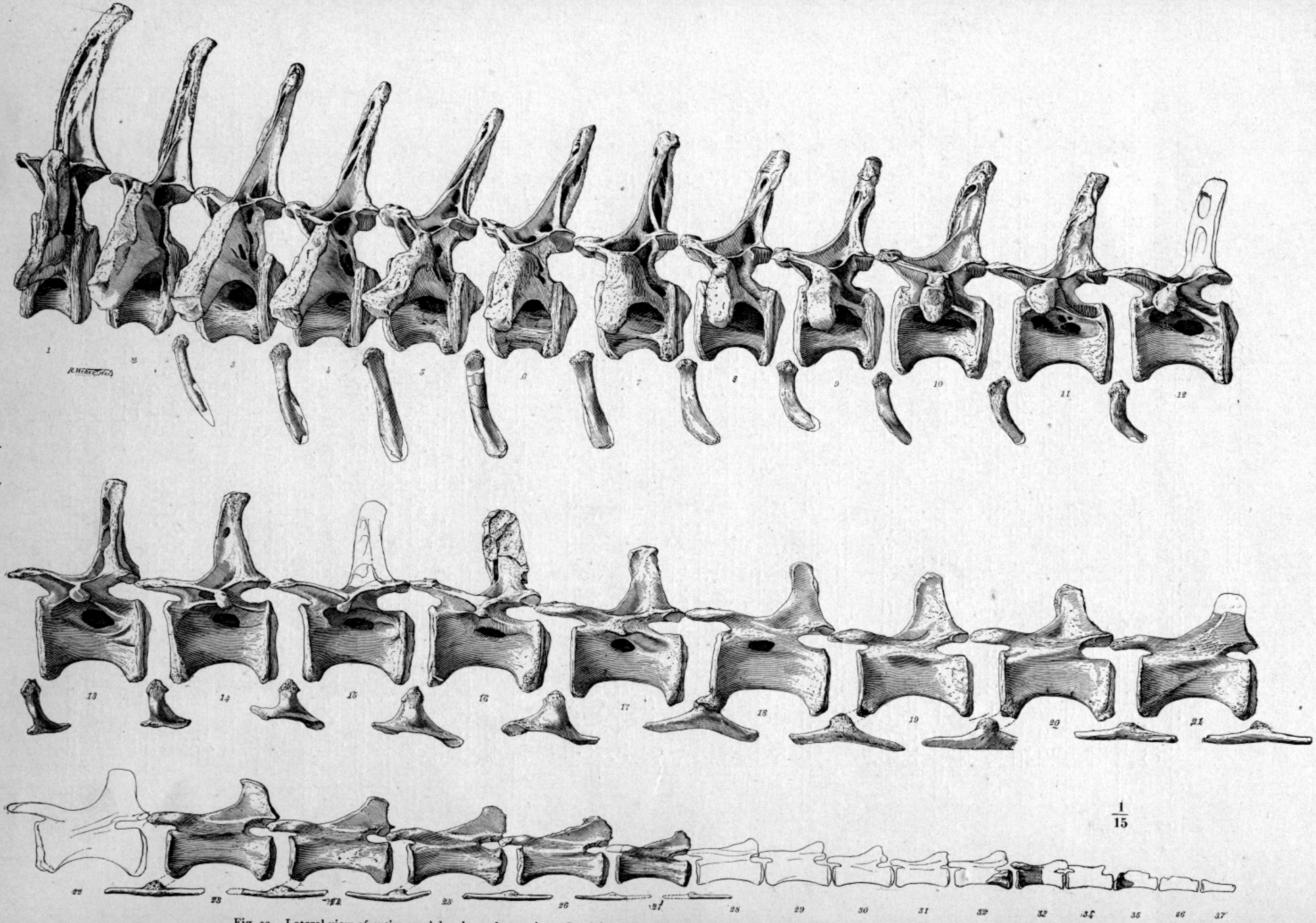

Fig. 13. Lateral view of entire caudal series. $\frac{1}{15}$ nat. size. Caudals connected with Chevrons by dotted lines are those in which a very close union existed.

b. Disappearance of upper or neural spine portion of diapophysial lamina, in C. 3.

c. Gradual decrease of superior horizontal lamina and increase of inferior horizontal lamina.

It thus appears that in addition to the general changes of form, centra, cavities, etc., noted on page 205, each vertebra has a distinctive development of its laminæ in adjustment to its particular stresses and strains.

2d Caudal. — Resembling C. 1 with more concave diapophysial lamina, presenting a broadly rugose outer border, and feebler prespinal lamina.

3d Caudal. — Differing from preceding in absence of upper portion of diapophysial lamina. Prespinal lamina still less prominent, prezygapophysial laminæ more prominent.

Note 2. — *Compensatory Development of Laminæ.*

It is apparent that the prespinal and prezygapophysial, postspinal and postzygapophysial laminæ are *mutually compensatory*, that is: strong prespinal, weak prezygapophysial; weak postspinal, strong postzygapophysial, or *vice versa.* This compensation is especially evident between caudals 4 and 7, 8 and 12, as explained below.

4th to 7th Caudals. — Distinguished by rapid increase of prezygapophysial laminæ with compensatory decrease of prespinal lamina, increase of postspinal lamina, and decrease of postzygapophysial laminæ.

The anterior view (Fig. 12) of caudal 5 gives an exceptionally clear view of the X zygapophysial laminæ, also of the secondary laminæ bracing the diapophysial lamina.

Caudals 8 – 12 exactly reverse the progression shown in C. 4 – 7. They show a decrease of the prezygapophysial laminæ and an increase of the prespinal laminæ; an increase of the postzygapophysial laminæ and a decrease of the postspinal laminæ.

Caudal 8 is the first with an uncleft spine.

All the centra have a long, deep concavity below.

The elongation of the centra and zygapophyses and diminution of the diapophyses becomes very rapid.

Caudals 13 – 16 include the complete transition from the robust anterior type, to which powerful muscles were attached, to the laterally compressed posterior type which supported the caudal fin, and were moved principally by tendinous extensions of the anterior muscles. Between C. 9 and 17 also a complete change in the chevrons occurs. The change is as follows:

The diapophyses and lateral cavities persist into C. 16 on the right side. The cavities persist as far back as C. 18 on the left side.

The pre- and postzygapophysial laminæ become laterally compressed and subside into the spine, which is elongated antero-posteriorly.

Caudals 17–27 exhibit the laterally compressed moderately procœlous character of C. 16 with a gradual diminution in size; all the characteristic features disappear except the form of the centrum with its long inferior concavity. The chevrons undergo a series of changes.

Caudal Chevrons.

The most anterior chevron appears behind the second caudal. The chevrons are chiefly attached, in some cases connected, with the vertebræ behind them. For the sake of clearness the chevrons may be enumerated with the vertebræ, the most anterior chevron being termed chevron 3. Chevron 18 is firmly coalesced with caudal 18, enabling us to positively determine the position of all those in front of it.

There are no less than five types of chevrons:

Chevrons 3–9 are of the typically reptilian form, with a small hæmal canal completely surrounded by bone, extending downwards into a long, laterally compressed spine. (Figs. 12, 13.)

Chevrons 10–12 are shorter, with a large hæmal canal, closed above and open below by a fissure which divides the spine into two halves. These halves are in contact but not actually conjoined. (Figs. 12, 13.)

Chevrons 13–14 are closed below and suddenly expand antero-posteriorly at the base of the hæmal arch. C. 14 is open above the hæmal canal.

All chevrons behind C. 13 are open above the hæmal canal.

Chevrons 15–19. The upper portion of the chevron which unites with the centrum is much reduced. The lower portion expands antero-posteriorly and a long median opening appears between the two halves, which are still connected at the ends.

Chevrons 20–28. The connection of the elongated lower halves disappears and the chevrons consist of a pair of slender parallel rods, wholly separated, and attached upon the outer lower angles of the centra.

Arches.

Of the pelvic girdle the left ilium and ischium were found.

The *ilium* is finely preserved; the superior crest is perfect, but the anterior border is flattened or crushed inwards instead of turning sharply out to allow space for the two posterior ribs which lie in behind it.

The superior crest, as above noted upon page 203, is directed mainly upwards, not backwards as heretofore indicated by Marsh; the rugose border of the crest is surmounted or emphasized by five diapophysial rugosities, that is, those springing from the first presacral vertebra, and from the four sacrals. The anterior border exhibits a thin horizontal portion below the crest and a very heavy pre-acetabular bar or pubic peduncle; this bar connects with the broad supra-acetabular neck of the ilium along which the sacral ribs are attached.

The function of this pre-acetabular bar appears to have been to support the weight of the body when the anterior portion of the trunk was raised and the tail depressed. Then the femur was shifted backwards and the head forwards in its socket, so as to transfer the body weight to the anterior border of the acetabulum. This bar or peduncle then came into service.

The posterior iliac border is extremely short.

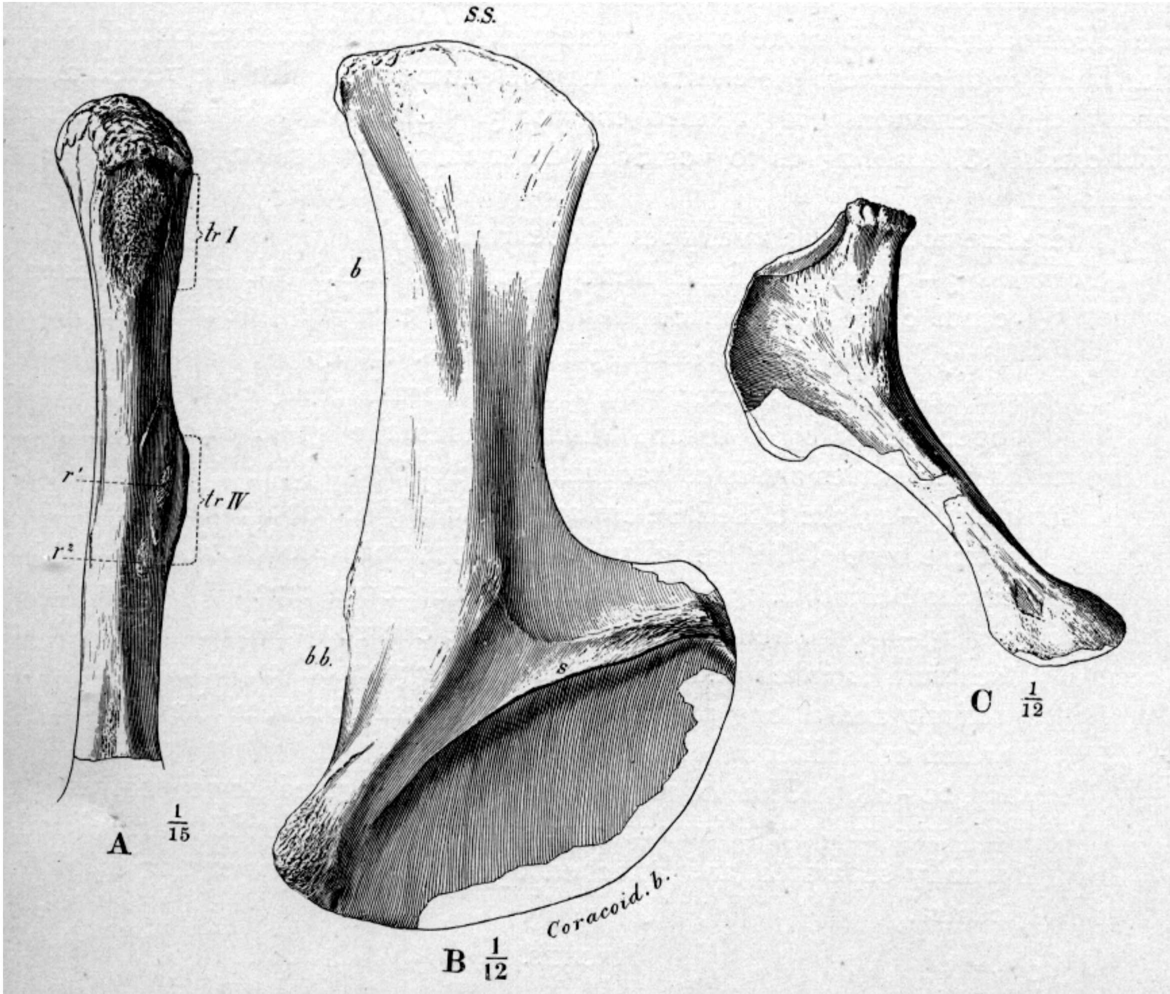

Fig. 14. *A*, External view of Left Femur, $\frac{1}{15}$. *B*, External view of Right Scapula, $\frac{1}{12}$. *C*, External view of Left Ischium, $\frac{1}{12}$.
Fig. 14. *A*, External view of Left Femur, $\frac{1}{15}$. *B*, External view of Right Scapula, $\frac{1}{12}$. *C*, External view of Left Ischium, $\frac{1}{12}$. The anterior border of the Ischium should be produced into a hook below.

The *ischia* of *Diplodocus* are distinguished by their long symphysial union in the median line and coalescence near the extremities. In this specimen the anterior portion of the lower border is restored. Another specimen more recently found in Bone Cabin Quarry, shows that just behind the junction with the pubes the inferior border thins out and terminates in a sharp hook, as represented by Marsh. A similar hook has been observed by us in *Brontosaurus*.

The *pubes* are wanting in this specimen but have been found associated with ischia in Bone Cabin Quarry and will be described subsequently in a paper upon the limbs of *Diplodocus*.

Of the shoulder girdle only the *scapula* is preserved. Singularly enough this is the right scapula, for most of the skeleton represents the left side. It lacks the anterior-inferior border. It is distinguished by the gradual expansion of the blade towards the supra-scapular border, *ss.*, by the subequal dimensions of the blade, *b*, and coracoidal portion or body, *bb*, and by the exceptional prominence of the spine, *s*, which descends obliquely across the body.

LIMBS.

The *femur* is a highly characteristic bone. It is distinguished by a prominent trochanter placed on the posterior border, near the middle of the shaft, which apparently corresponds with the *fourth trochanter*, tr^4, of Dollo.[1] This is for the insertion of the great *femoro-caudal* muscles of birds and Dinosaurs.

This is the most powerful rugosity among a group in this portion of the shaft. Just superior to it upon the inner side is a smaller rugosity; presumably for the *femoro-ischial* muscles. Upon the outer side of the shaft opposite this trochanter are two lesser muscle-insertion areas. The great trochanter tr^1, occupies an extensively rugose area.

This femur is much more slender than that of *Brontosaurus* and has rather the proportions of the *Amphicœlias altus* femur described by Cope. The part preserved measures 1.21 m.; the circumference of the shaft just above the 4th trochanter is .52; just below the 4th trochanter it is .53. The circumference of the femur of a full-grown Brontosaur in our collection is .72, or 2 feet 5 inches. The lower portion of the shaft begins to expand to form the condyles; it hardly appears that this femur could have attained the length assigned by Cope to the *Amphicœlias altus* femur, namely, 1.930.

MEASUREMENTS OF SKELETON.

	Feet.	Metres.
Estimated height of 10th dorsal (from centre of centrum)........	2.7	.80
" " 11th " " " " "	2.9	.844
" " 12th " " " " "	2.10	.880
" " 13th " " " " "	3.	.912
" " 14th " (from edge of centrum)..........	3.3	.986
" " Sacrals 1–4..................................	3.3	.986
Length of 12th rib (from tubercle to extremity)................	4.4	1.320
" 13th "	3.7	1.100
" 14th "	2.7	.794
Ilium, antero-posterior diameter of crest........................	3.3	1.
" vertical diameter above pubic peduncle....................	2.5	.738
Scapula, vertical diameter....................................	4.5	1.360
" tranverse "	1.10	.538
Ischium, from iliac border to extremity.........................	2.10	.851

SUMMARY OF NEW CHARACTERS.

The greatly extended and revised knowledge afforded by this specimen may now be summarized. Most of the observations made by the late Professor O. C.

[1] Note s. l. présence chez les oiseaux du 'troisième trochanter' des dinosauriens et sur la fonction de celui-ci. Bull. d. Mus. Roy. d. Hist. Nat. d. Belgique, Mars, 1883.

Marsh upon this genus are here confirmed; the principal exceptions from his statements relate to (1) the position of the ilium, (2) the number of sacral vertebræ, (3) the structure of the caudal chevrons, (4) the size of the animal.

Dorsals. The neural spines arise from the convergence of paired cervical spines.

There are no nodal or broad-spined dorsals as in *Brontosaurus.*

The rib articulations are greatly elevated in the posterior dorsals.

The two posterior dorsals are placed behind the ilium and bear one free and one coalesced or vestigial rib.

Sacrals. There are four sacrals, three of which exhibit a complete coalescence of the spines, the fourth being more free and like a caudal. The sacro-iliac union is by means of sacral ribs and diapophysial plates.

Additions to the sacrum are made from the caudal series.

Caudals. All the anterior caudals have broad diapophysial laminæ. These plates were first observed by the writer in *Brontosaurus* or *Camarasaurus.* There are five distinct types of chevrons. One of these, belonging to the 18th or 19th caudal, is the type to which Marsh assigned the name *Diplodocus.*

Ilium. The superior crest of the ilium is directed upwards, and the coalesced sacrals form the centre of motion and the highest portion of the vertebral column.

There is a balance of weight between the dorsals and anterior caudals.

The laminar construction of the dorsals, sacrals, and caudals is shown to exhibit a unity of type, with local differences adjusted to special stresses and strains.

Restoration and Habits of Diplodocus.

Figure 1.

We must await the discovery of the complete limbs and neck before *Diplodocus* can be completely restored. Yet a number of important points regarding the general structure of the animal can be established now.

The length of the entire skeleton was considerably greater than estimated by Marsh. The known and estimated linear measurements are as follows:

	Feet.	Metres.
Caudals	30	
Sacrals	2	.60 +
Dorsals (estimated)	12	3.65
Cervicals (estimated)	12	3.65
Skull	2	.61
Total	58	8.51

The animal was about 60 feet in length and relatively more elevated and more slender than *Brontosaurus.* The proportions of the shafts of the femora, namely, *Diplodocus* 5, *Brontosaurus* 7, probably give us an approximate idea of the weight ratio—that is, *Diplodocus* had about five sevenths the bulk of *Brontosaurus.*

We must consider as three of the most important advances in our general knowledge of the structure of these animals : first, the establishment of the sacral spines as the highest point in the backbone ; second, of the sacrum and ilium as a centre of power and motion ; third, of the balance between the dorsals and caudals.

We observe in Marsh's restoration of *Brontosaurus,* a pioneer work of very great difficulty, that the mid-dorsal region is made the highest point in the backbone; that the sacral region is subordinate; that the tail (in which 8 or 10 anterior caudals are now known to be omitted) is an *appendage* of the body instead of an important locomotor organ of the body. In all these points Marsh's restoration is probably incorrect.

Diplodocus gives us a new and different conception of the Cetiosaurs or Sauropoda, one which increases their ability as aquatic reptiles, and specializes the functions of the tail. The tail constituted one half the length of the animal, and was of immense service as a propeller in enabling it to swim rapidly through the water, the broad anterior portion being provided with very powerful lateral muscles, and the compressed posterior portion being controlled by tendons and made effective by a vertical fin.

The tail, secondly, functioned as a lever to balance the weight of the dorsals, anterior limbs, neck, and head, and to raise the entire forward portion of the body upwards. This power was certainly exerted while the animal was in the water, and possibly also while upon land. Thus the quadrupedal Dinosaurs occasionally assumed the position characteristic of the bipedal Dinosaurs—namely, a tripodal position, the body supported upon the hind feet and the tail.

Thirdly, the *supporting function* of the posterior half of the tail is indicated by the sudden change in the shape of the chevrons at the 13th caudal; the chevrons of caudals 13 to 19 indicate the region to which part of the main weight of the body was transmitted ; these chevrons are powerful and broadly spread out at the bottom. The 18th chevron is firmly anchylosed with the centrum ; the 19th, 20th, 21st, 23d, 24th, 25th, are firmly connected with the centra by sutural surfaces, though not anchylosed.

What may be termed the 'supporting and balancing' tail of the Hadrosaurs, Iguanodonts, and Megalosaurs is of a much simpler type than this 'balancing, supporting, and propelling' tail of the Cetiosaurs.

There is a traditional view that these animals were ponderous and sluggish. This view may apply in a measure to *Brontosaurus.* In the case of *Diplodocus* it is certainly unsupported by facts.

As compared with the Crocodilian or Cetacean type, the axial skeleton of *Diplodocus* is a marvel of construction. It is a mechanical triumph of great size, lightness, and strength. Judging by the excessive rugosity of the vertebræ and limbs, the powerful interspinous ligaments attached to the pre- and post-spinal laminæ, the backwardly directed rugosities at the summits of the diapophysial laminæ in the dorsals, and of the postzygapophysial laminæ in the caudals, the animal was capable not only of powerful but of very rapid movements. In contrast with *Brontosaurus* it was essentially long and light-limbed and agile. Its tail was a means of defence upon land and a means of rapid escape by water from its numerous carnivorous foes. Its food probably consisted of some very large and nutritious species of water-plant. The anterior claws may have been used in uprooting such plants, while the delicate anterior teeth were employed for prehensile purposes only. The plants may have been drawn down the throat in large quantities without mastication, since there were no grinding teeth whatever. It is only by some such means as these that these enormous animals could have obtained sufficient food to support their great bulk.

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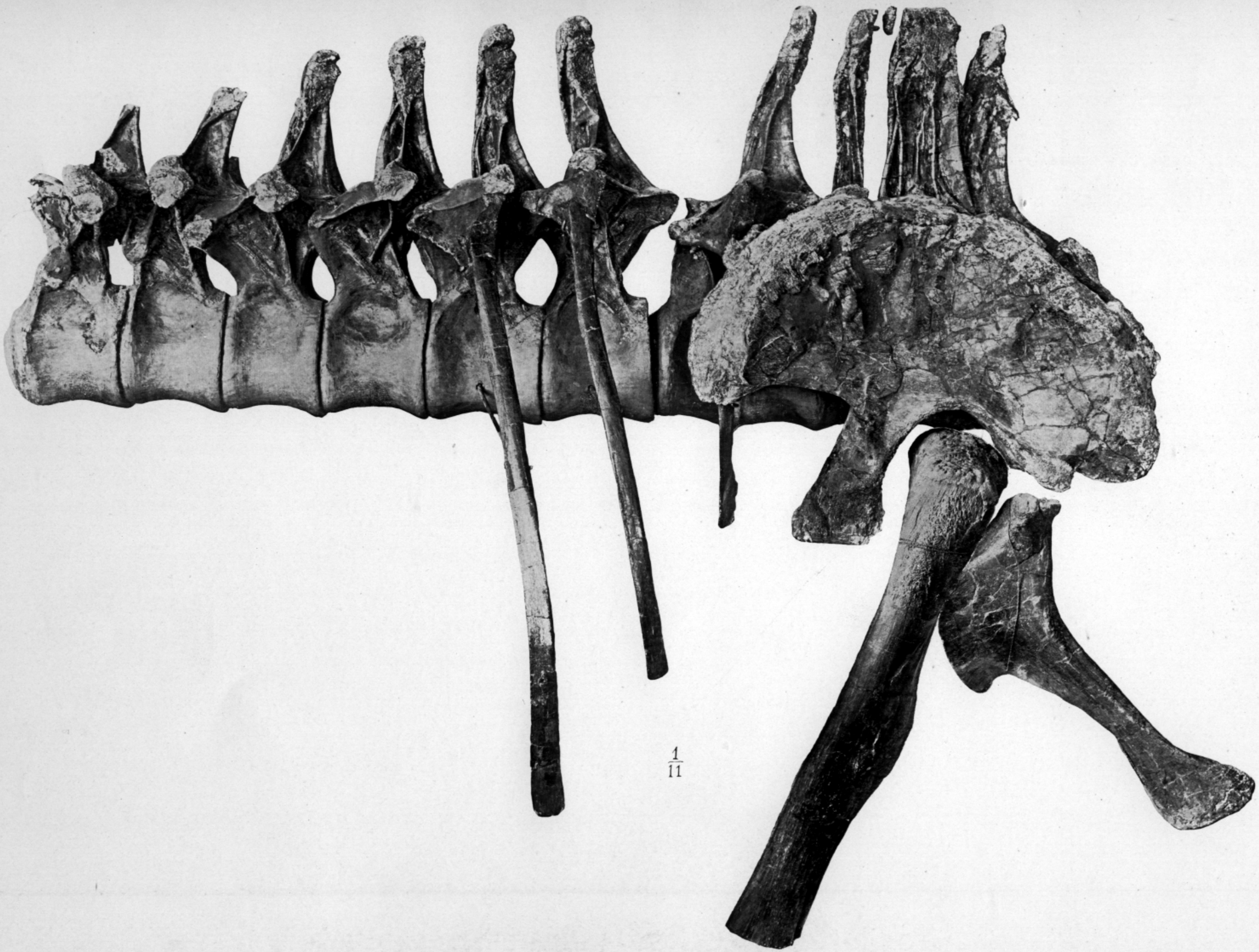
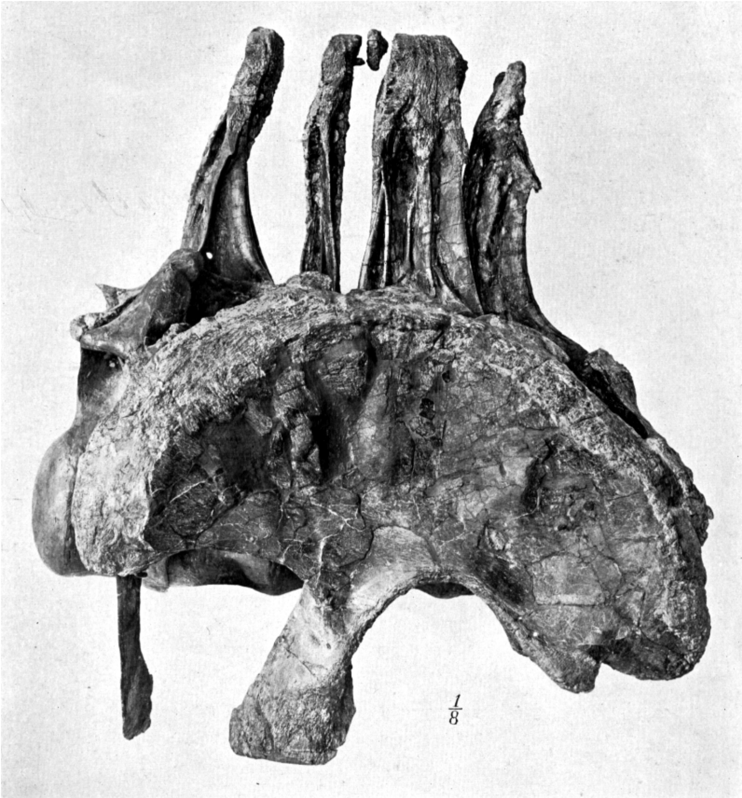
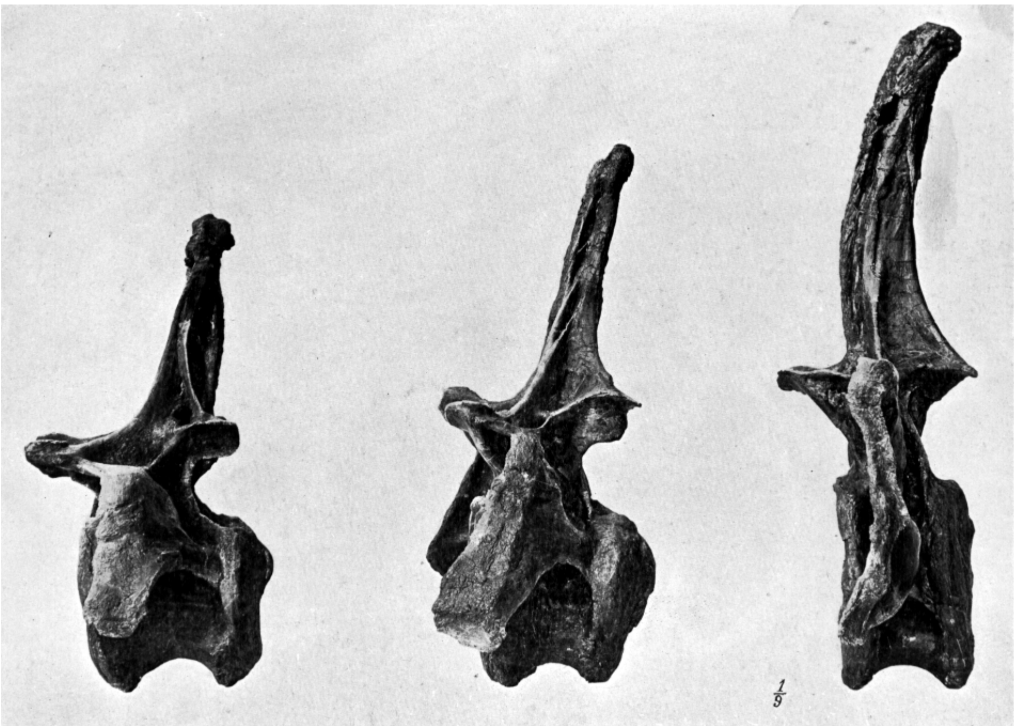


$\frac{1}{11}$

Diplodocus longus.

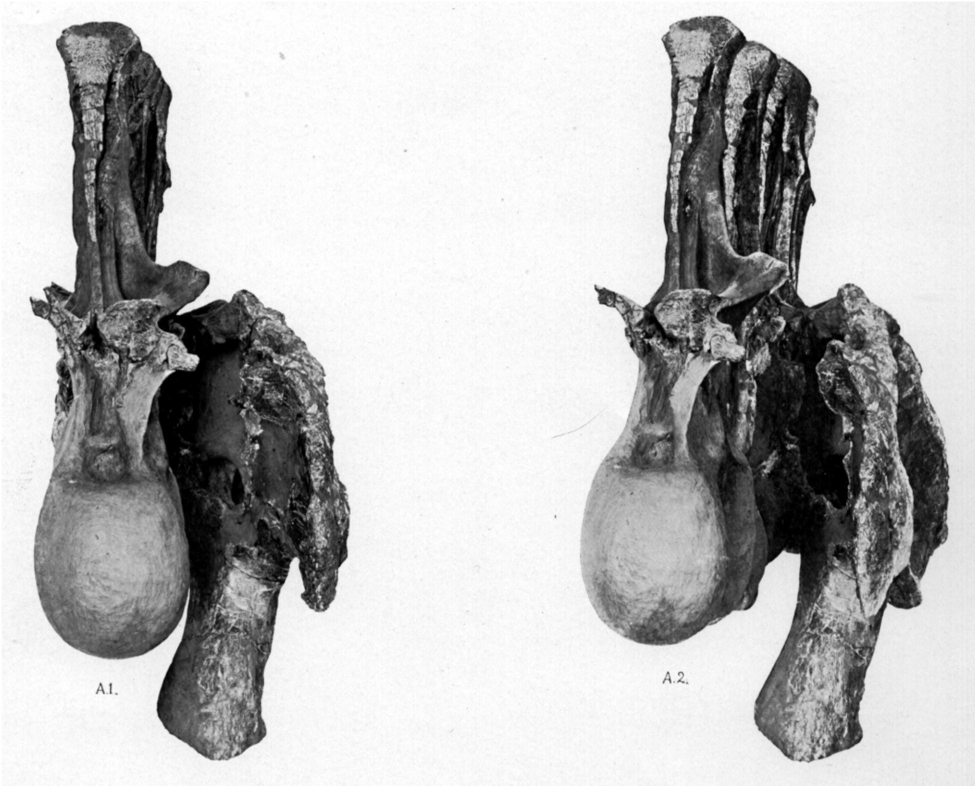
Dorsals, Sacrals, Ilium, Ischium, and Femur, $\frac{1}{11}$ natural size.





DIPLODOCUS LONGUS.

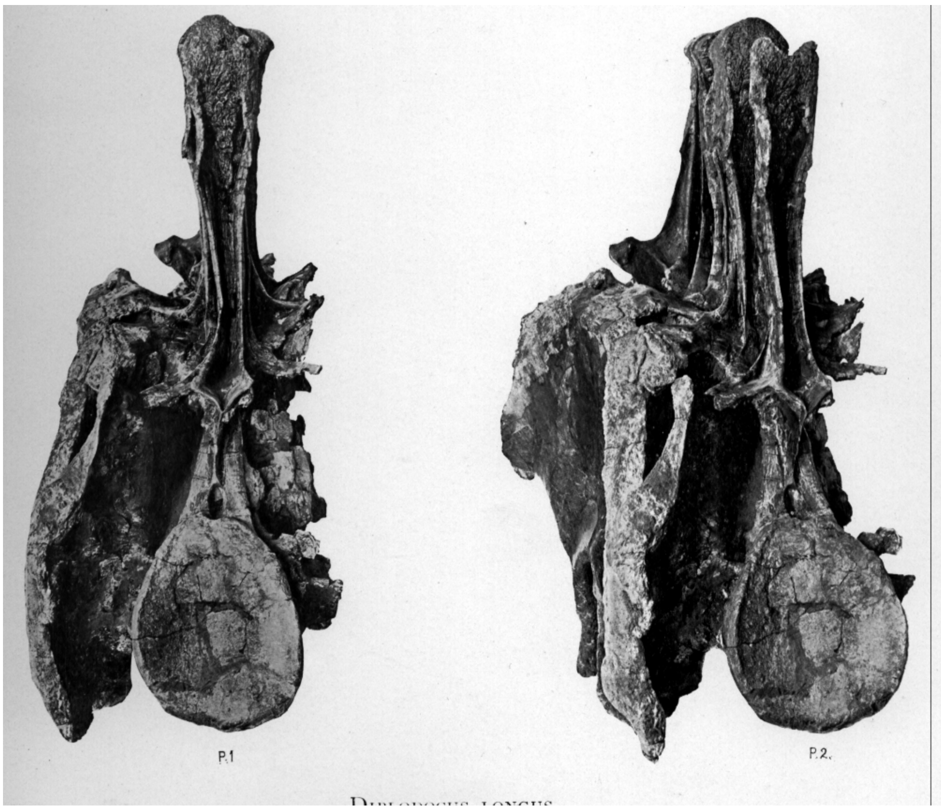
UPPER FIGURE.—Lateral view of posterior Dorsals, Sacrum, and Ilium, $\frac{1}{8}$ natural size.
LOWER FIGURE.—Lateral view of 1st, 4th, and 7th Caudals, $\frac{1}{8}$ natural size.



DIPLODOCUS LONGUS.

Anterior, oblique, and posterior views of Sacrum and Ilium.

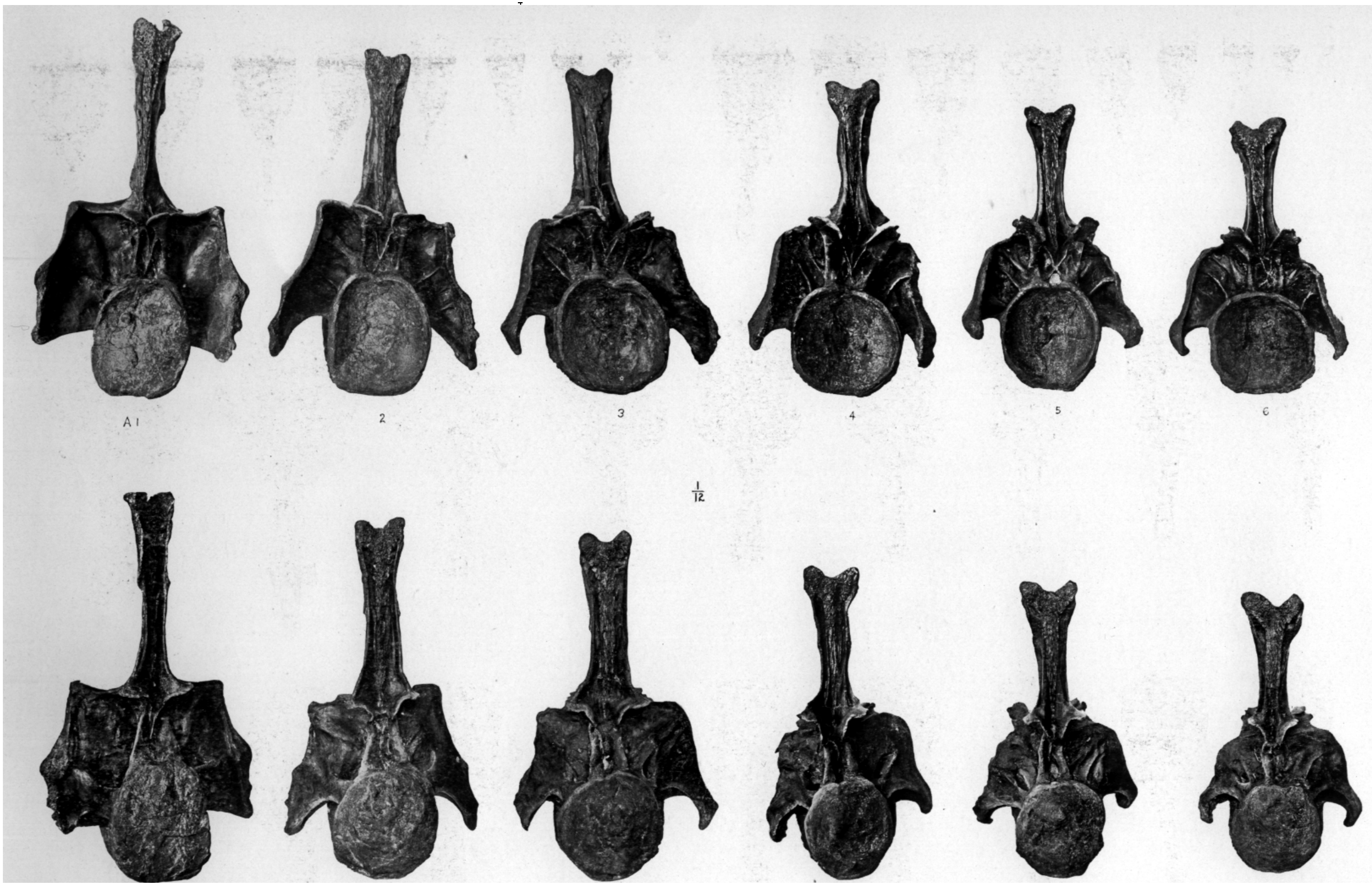
***A1*, anterior direct view, *A2*, oblique ; *P1*, posterior direct, *P2*, oblique.**



Diplodocus longus.

Anterior and posterior views of Caudals 1–6, $\frac{1}{12}$ natural size.

A, anterior view; *P*, posterior view.



DIPLODOCUS LONGUS.

Anterior and posterior views of Caudals 7–35, $\frac{1}{12}$ natural size.

A, anterior; *P*, posterior.