STRUCTURE AND RELATIONSHIPS OF OPISTHOCELIAN DINOSAURS.

PART I.

APATOSAURUS MARSH

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STRUCTURE AND RELATIONSHIPS OF OPISTHOCELIAN
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PART I.

APATOSAURUS* MARSH.

BY E. S. RIGGS.

The genus Breontoaurus Marsh was described† in 1879 from a
well preserved skeleton found near Lake Como, Wyoming. The
completeness of this specimen and the widely published restorations
based upon it have caused this genus to be long regarded as the best
known of all the American Opisthocoelica.‡ However, many questions
of morphology were left in doubt by this famous specimen. No skull
which could be identified with the genus has ever been described; that
figured in Marsh's restoration is based upon a comparison with the
skull of Morosaurus. The structure of the hind feet was not made
clear until figured by Osborn in 1899,§ while the structure of the fore
foot remained a matter of conjecture until figured by Hatcher in 1902.||
The vertebral formula of the dorsal and caudal series, as well as many
skeletal and pelvic characters, has remained to be determined by an
usually well preserved skeleton just placed upon exhibition in the
Field Columbian Museum.

The specimen under consideration (Mus. No. 7163) was collected
by the Museum Paleontological Expedition of 1901, in charge of the
writer, ably assisted by Mr. H. W. Menke. It was found in the Grand
River Valley near Fruitia, Colorado, in a geological horizon ¶ probably
equivalent to the Como Beds of Wyoming. The specimen was discov-
ered in the fall of 1900, but owing to the lateness of the season, its
removal was deferred until the following spring.

When found the last cervical vertebra was projecting from a steep
hillside. The thoracic series led diagonally into the face of the hill,
leaving the distal ends of a number of ribs exposed and partially broken

*Breontoaurus, Marsh, is shown to be a synonym of Apatosaurus.
‡Sauropods and Cetiosaurus are shown to be synonyms of Opisthocoelica.
||See "The Dinosaur Beds of the Grand River Valley of Colorado," this publication,
Geol. Series, No. 9.
*FIELD COL. MUS., GEOLOG. SER., Vol. II, No. 4.
away. Ten feet farther along the bank the distal end of the femur appeared. So hard was the concretionary matrix, in which the skeleton was encased, that drills and dynamite were at once called into service in order to make the excavation necessary for its removal.

When the pelvis was reached the face of the stripping was eighteen feet in height. From this point the series of caudal vertebrae curved backward, and dipping rapidly with the strata, led almost directly into the hillside. These conditions made it necessary to resort to tunneling. Accordingly a chamber twenty feet in length by eight feet in breadth was excavated before the search for displaced caudal vertebrae was abandoned.

The specimen as a whole was lying upon its right side, and apparently the entire skeleton had been present when embedded. The cervical vertebrae and the fore legs had been carried away by a process of erosion so slow that comparatively few fragments were found upon the surface. The vertebrae from the last cervical to the thirteenth caudal were but slightly displaced from their normal positions. (See frontispiece.) The remaining ten caudal vertebrae recovered were found more and more dissociated, until tunneling for them became unprofitable. Some of the chevrons were associated with the vertebrae, but most of them were displaced. The ribs were found in close approximation with their respective vertebrae. The right ilium was in position and classified with the sacrum; the femur was scarcely removed from the acetabulum. The pubes and ischia were slightly displaced from the left ilium was fragmentary.

This specimen has been prepared for exhibition with great care and patience, employing the energies of three skilled men for more than eighteen months. The spines and transverse processes of the caudal vertebrae were more or less distorted by the compression to which they had been subjected in the matrix. So far as was practicable, these distortions have been readjusted. The inevitable missing fragments have been replaced by plaster and carefully colored to match the adjacent parts. All portions thus restored are marked out by a line, but not so conspicuous as to mar the general appearance of the specimen, but distinct enough to be readily recognized when examined closely.

For information concerning the type specimen of Brontosaurus, and for advice in the preparation of this paper, the writer is indebted to Dr. S. W. Williston of the Museum staff.

SYNONYMY.

The number of terms applied to the group of reptiles variously designated as Sauropoda, Cetiosauria, and Opisthocoelia has led to confusion, at once annoying to the investigator and puzzling to the student. The oldest member of the group and the best known of the European genera is Cardiodon.* This was described by Owen in 1841, and for a long time included under the Crocodilia.

The first recognition of the ordinal rank of the Cardiodont reptiles was offered by Owen in 1859, when he proposed for them the name Opisthocoelia, as one of three suborders of crocodiles. The group was characterized as follows:** "The small group of Crocodylia, so-called, is an artificial one, based upon more or less of the anterior trunk vertebrae being united by ball-and-socket joints, but having the tail in front instead of, as in modern crocodiles, behind. Cuvier first pointed out this peculiarity in a crocodilian from the Oxfordian beds at Honfleur and the Kimmeridgian at Havre. The Reporter has described similar opisthocoelian vertebrae from the Great Oölite at Chipping Norton, from the Upper Liassic of Whitby, and of much larger size, from the Wealden formations of Sussex and the Isle of Wight. These specimens probably belonged, as suggested by him in 1842 and 1843, to the fore part of the same vertebral column as the vertebrae that in the fore part and slightly hollow behind, on which he founded the genus Cetiosaurus."

In this classification Owen was followed by Haeckel, but Huxley, in the following year, included Cardiodon in the Iguanodontidae. In 1879, Seelio* described the genus Cretosaurus, proposed for the same forms the order Cetiosauria, which he included under the subclass Dinosauria; † "My fossil presents some remarkable differences from other figured Dinosaurian specimens, and I have thought it proper to the attention of the Society, as indicating that distinct ordinal groups are probably confounded under the name Dinosauria. If the skull be Dinosaurian which was figured by Mr. Hulke as 90.5% of Iguanodon (and of its Dinosaurian character I entertain no doubt), and the specimen now described be Dinosaurian, in the ordinary sense of the term, as I believe, then no one will doubt the propriety of placing the latter animal, with its indisputable lacertian characteristics, in a distinct ordinal group from the Wealden animal, which has the skull closed anteriorly in a way to which no Lacertilian makes an approximation."

"This difference is, indeed, in harmony with lacertian differences in portions of the skull in Cetiosaurus; so that there been any

* In a recent publication by Lucy P. Bush Cardiodon is shown to have priority over Cetiosaurus.
† Report British Association for the Advancement of Science, 1879, p. 24.
reason for suspecting that the Potton fossil belonged to the Cetiosauria. I should have felt no difficulty in regarding it as the base of a Cetiosaurian cranium. . . . . On the whole, I regard the bone as indicating that in at least one Order of the Sub-class Dinosauria the bones of the base of the cranium were Rhynchcephalian rather than Avian."

In 1878 Marsh proposed to raise his previously established groups, Atlantosaurus to the rank of suborder, and to include in it the genera Atlantosaurus, Apatosaurus, Morosaurus, and Diplodocus. The suborder was clearly defined with regard to American groups, but the European forms and their previous classification were ignored, although a number of them clearly fall within the same family groups.

In this way these three synonymous terms have been adopted and used by various writers. "Opisthocoelia" has the undisputed claim to priority. As applied, it included as its characteristic representative Carciodon, the best known of the European forms. In its primary significance it is descriptive of all the well-known forms, both European and American, which have since been included in the group. It was followed by Haeckel and in part by Cope and Baur. The objection which has been urged against the term is, that it was proposed to be applied to a subdivision of the Crocodilia. This objection is not valid, since there are no opisthocoelous crocodiles with which the group can be confused. The homogeneity of the group according to the first definition was recognized when it was bodily transferred by Seeley into the Dinosauria, when it was defined as Sauropoda by Marsh, and when it was made an independent order by Baur. Its inclusion under the Crocodilia was designated at the outset as artificial; its present inclusion under the Dinosauria was regarded by Baur as equally artificial. If this be true, the same objection will hold against the terms later applied.

The term "Cetiosauria" has gained favor owing chiefly to the fact that it was offered as a subdivision of the Dinosauria and hence has coincided more nearly with later classification. It was based upon a distinction between the Cetiosaurian and Iguanodon skull, but that distinction had been taken for granted by earlier writers, and was only made necessary by Huxley's erroneous reference of Carciodon to the Iguanodontidae.

As regards the term "Sauropoda," it must be recognized that it was based upon a much more complete knowledge of the group, and as a result was much more clearly defined. But if we were to demand complete knowledge of structure and affinities, in support of a group name, very few genera and families now accepted would stand.


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The three terms, then, are essentially co-ordinate, and co-extensive. "Opisthocoelia" has priority, and is entitled to preference. The term will therefore be used in this paper to designate the order; "Cetiosauria" and "Sauropoda" being regarded as synonyms.

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**Fig. 1. Scapula and coracoid of Apatosaurus, after Marsh.**

**Fig. 2. Scapula and coracoid of Brontosaurus, after Marsh.**

The genus Apatosaurus Marsh was proposed in 1877 upon a considerable portion of a skeleton, but with brief description only. Early in 1879 the genus was characterized by the structure of the scapula,

coracoid, and sacrum, and these parts were figured. * In December of the same year the genus Brontosaurus was proposed upon an unusually complete specimen briefly described. † Later a more complete description was given and a number of parts figured. ‡ Two different restorations were later published. §

The genus Brontosaurus was based chiefly upon the structure of the scapula and the presence of five vertebrae in the sacrum. After examining the type specimens of these genera, and making a careful study of the unusually well-preserved specimen described in this paper, the writer is convinced that the Apatosaurus specimen is merely a young animal of the form represented in the adult by the Brontosaurus specimen. As before pointed out, || the imperfectly ossified condition of the scapula, coracoid, and sacrum indicates a young animal. (Figs. 1 and 2.) The presence of but three coalesced vertebrae in the sacrum points to the same conclusion as will appear from a comparative study of a series offered in this paper. The proportionate size of the two specimens, the shorter shaft and narrow distal end of the scapula, the outline of the coracoid, the open chevrons, the form of the anterior thoracic and the cervical vertebrae, and the structure of the pelvis (Figs. 3 and 4) display such similarity as one would expect in a young animal of the Brontosaurus type. In fact, upon the one occasion in which Professor Marsh compared these two genera he mentioned the similarity between the scapula of their respective types. In view of these facts the two genera may be regarded as synonymous. As the term "Apatosaurus" has priority, "Brontosaurus" will be regarded as a synonym.

The following species have been referred to this genus:


Refered to Morosaurus, ibid., (3), xvi, 484, Nov., 1878.


(Brontosaurus excelsus) this paper.


Of this number probably not more than two species are valid. A. ajax is based upon a specimen too young to admit of specific determination. A. grandi is a synonym. A. laticollis was described.

* Ibid., Vol. xvi, p. 36.
† Ibid., 3d Ser., Vol. xvi, p. 351.
‡ Ibid., 3d Ser., Vol. xx, p. 472-77.
§ Ibid., 3d Ser., Vol. xvi, Pl. 1; The Dinosaurs of North America, Pl. xli.
from a single cervical vertebra which may or may not be identical with the type species. *A. excelsus* is familiar as the type of "Brontosaurus," and is based upon a large part of a skeleton. The sixth and the last cervical vertebra of this specimen as figured by Marsh* show such a similarity to the type of *A. laticeps* as to indicate that the intervening ninth or tenth vertebra would prove identical. However, the present knowledge of the cervical series does not admit of positive identification. *A. amplius* has not been figured and cannot now be determined. The Museum specimen will be regarded as conspecific with the well known Yale specimen and designated as *Apatosaurus excelsus*.

The genus *Apatosaurus* may be distinguished from other members of the Opisthocoelia by the following characteristics: Scapula with shaft and spine almost at right angles; shaft long and slender with slightly expanded distal end; ischium with acetabular surface at right angle to shaft and distal end expanded; sacrum in adult specimens with five illum-supporting vertebrae; anterior dorsal spines paired, long, and slender; anterior caudal centra with lateral cavities.

**DESCRIPTION OF SKELETON.**

**Dorsal Vertebrae.** (Plates xlvi and li.) The vertebrae lying between the cervical and the sacral regions are all rib-bearing, and hence may be designated by the term "dorsal"; but in the following description they will be referred to as "presacral" and numbered from the sacrum forward in order to afford a definite basis of reckoning, since the fragmentary condition of presacral xi does not admit of its position in the series being determined with absolute certainty. However, there is every reason to believe that this vertebra is the last cervical.

The *dorsal vertebrae* are of the opisthocoelous type, and are all rib-bearing. So much may be said of them as a group—as to other characters they represent a continuous transition, passing from the elevated and slender type posteriorly to the depressed and wide-armed type of the anterior dorsal region. In view of this wide difference between the anterior and posterior extremities of the series, it is not surprising that isolated vertebrae have been made the types of three or more different genera. Variation between the extreme types of the dorsal series is especially noticeable in the following four vertebral elements. (1) The centra, (2) the neural spines, (3) the transverse processes, and (4) the capitular facets. In order to bring out their

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*Plates xx and xxi, the Dinosaurs of North America.*
slight; in vii it is shifted downward forming a median brace between the anterior and the inferior roots; in viii it appears as an anterior brace to the side of the inferior root; in ix and x it descends quite to the anterior margin of the centrum and forms a second inferior support equal in importance to the first.

The tubercular facets are borne low on the extremities of the transverse processes. They are irregularly concave and vary in size according to the strength of the ribs which they bear. In presacral i to vii they face outward and slightly downward; in ix and x their direction is altered so as to face more downward than outward.

The neural spines undergo a radical transformation in the dorsal region. (Plate xlv.) The posterior members of the series represent the extreme development of the straight, median spine. From this point to the eleventh presacral, or first cervical, they pass by a regular gradation from the simple to the bifurcate. This change is so regular that no point in the series can properly be designated as "nodal" but at the same time all are transitional. In presacral i, ii, and iii the spines are similar in length to the anterior sacral. In iv there is a noticeable shortening supplemented by a slight concavity on the anterior margin of the crest, which marks the first tendency toward bifurcation. In v and vi this concavity is deepened and the spine reduced in the latter to little more than half the length of that in iii. At the same time it has increased in breadth and the lateral angles of the crest have become acute and somewhat produced. Each of the lateral plates give rise to two diagonal branches; the median plate is noticeably reduced. In vii the anterior aspect of the spine presents a broad, flattened surface. The median plate is reduced to a mere rugose ridge on the anterior surface; posteriorly it is somewhat more marked. The lateral angles of the crest are extended, forming a pair of lateral processes surmounted by laterally flattened crests. However, the vestigial median plate still furnishes the chief anchorage for the dorsal muscles. In viii the median concavity descends to a level with the superior margin of the post-zygapophyses. The median plate is reduced to a mere roughening for muscular attachment which persists to the end of the series. Bifurcation may thus be regarded as complete. The spines in ix and x are slight and deeply excavated at their bases by lateral vacuities.

The post-zygapophyses are supported inferiorly by a pair of buttresses arising from the posterior surface of the neural arch, laterally by the posterior roots of the transverse processes, and superiorly by a second pair of buttresses descending from the lateral plates of the neural spine. In the posterior dorsal vertebrae the superior buttresses
### Field Columbian Museum.

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**Thoracic Ribs.**

Eighteen ribs, more or less complete, are preserved with this specimen. Ten of these belonging to the right side form a continuous series in which the first and last are so reduced in size as to indicate that the series is complete. Those of the left side correspond very closely with the right, except that the third and fourth have been carried away entirely. This number of ribs, preserved so nearly in their normal positions, may be regarded as conclusive proof that there were but ten vertebrae in the dorsal series.

In the first pair of ribs more than half of the distal ends were eroded away. The head and the tubercle are slender and divergent; the shafts taper toward the distal end and are too slender to have performed any important function. (Plate XLVII.) The second pair of ribs is considerably stronger than the first. Only the proximal half of the right and the head of the left are preserved. At this point the divergence of head and tubercle is most pronounced, the head forming an angle of sixty-five degrees with the shaft. The third and fourth pairs of ribs are the strongest of the series. The articular facets are broad and ragose, and stand at almost a right angle to the shaft. The proximal ends are expanded and massive, bearing trough-like fossae on their mesial surfaces. The distal ends are missing from both.

The fifth pair of ribs is complete and well preserved. The head is more elongate, indicating greater expansion of the thorax at this point. The distal end bears a broad and rounded surface for the attachment of the costal cartilage. The right member of this pair is of interest in having an enlargement in the shaft, due to an imperfectly healed fracture. The adjoining sixth rib has a similar fracture which failed to heal. The sixth pair is marked by a decided reduction in size, a noticeable shortening, and a slender and tapering distal end. The head continues to elongate, the tubercle to shorten. In the seventh and eighth pairs the shafts become shorter and slimmer, and the head more elongate. In the ninth the head and tubercle are quite reduced and the shaft is more curved at the proximal end. The tenth pair is reduced to mere rudiments, whose shafts are almost lost. The right one has coalesced with the vertebra by the head and tubercle while the distal end has a flattened surface which abutted the crest of the ilium.

<table>
<thead>
<tr>
<th>Measurement of Presacral Vertebra in Centimeters.</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
<th>VII</th>
<th>VIII</th>
<th>IX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height over all at median line.</td>
<td>184</td>
<td>131</td>
<td>129</td>
<td>120</td>
<td>120</td>
<td>120</td>
<td>120</td>
<td>120</td>
<td>120</td>
</tr>
<tr>
<td>Breadth across transverse processes.</td>
<td>231</td>
<td>214</td>
<td>208</td>
<td>204</td>
<td>204</td>
<td>204</td>
<td>204</td>
<td>204</td>
<td>204</td>
</tr>
<tr>
<td>Centrum, length of.</td>
<td>41</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
</tr>
<tr>
<td>Centrum, breadth at posterior end.</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
</tr>
<tr>
<td>Spine, length of lateral spine from concavity at median line.</td>
<td>17</td>
<td>17</td>
<td>17</td>
<td>17</td>
<td>17</td>
<td>17</td>
<td>17</td>
<td>17</td>
<td>17</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Measurements of Ribs.</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
<th>VII</th>
<th>VIII</th>
<th>IX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rib Number.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>Length</td>
<td>21.3</td>
<td>20.7</td>
<td>18.5</td>
<td>17.9</td>
<td>17.2</td>
<td>16.5</td>
<td>16.0</td>
<td>15.5</td>
<td>15.0</td>
</tr>
<tr>
<td>Breadth across head and tubercle.</td>
<td>4.30</td>
<td>5.10</td>
<td>5.00</td>
<td>4.40</td>
<td>4.05</td>
<td>4.00</td>
<td>3.30</td>
<td>3.20</td>
<td>3.10</td>
</tr>
<tr>
<td>Breadth of shaft at middle.</td>
<td>0.80</td>
<td>0.95</td>
<td>1.30</td>
<td>1.30</td>
<td>1.25</td>
<td>0.85</td>
<td>0.85</td>
<td>1.00</td>
<td>0.85</td>
</tr>
</tbody>
</table>
The sacrum in this specimen is composed of five vertebrae, coalesced by the centra, zygapophyses, and more or less by the sacral ribs. The second, third, and fourth vertebrae are in addition firmly conjoined by their neural spines, the crests of their neural arches, and the bases of their diapophyes. Their sacral ribs unite distally to form a yoke-like synostosis, which, in the Opisthocoelica, may fittingly be termed the sacrosternal yoke. This is approximately symmetrical to the transverse axis of the sacrum and is borne upon the rim of the acetabulum, which constitutes its chief support. These three vertebrae have been described by Osborn in "Camarasaurus" and by Williston in Morosaurus as constituting the primitive sacrum. They will therefore be designated in this paper as the primary sacrum, but in the series of vertebrae functional as sacral, or ilium-supporting vertebrae, they will be numbered two, three, and four. The first vertebra which functions as a sacral, but varies in the structure of its sacral rib, will be termed the dorso-sacral. In like manner the fifth of the series will be termed the caudo-sacral. (Plate XLVIII.)

The dorso-sacral bears evidence of having united with sacral III by its centrum and zygapophyses before adult age. The sacral ribs show a degree of coössification similar to that between the sacral ribs and the right ilium. The spine remains free, but stands close to the second spine—a condition which would tend to coalition. The caudo-sacral shows even more recent coössification with the primary sacrum. The centra are firmly coössified, the sacral ribs incompletely so; the zygapophyses are coössified, but little atrophied, the neural spine remains free and isolated. A comparison in structure between this vertebra and the first caudal shows no greater difference than that between caudals I and II.

The centrum in sacral I is not reduced in size and differs from the dorsal centra only in its thicker walls. The anterior end is slightly convex; the lateral cavities open just behind the base of the sacral rib. (Plate XLVIII.) The centra of sacrales II, III, IV are considerably reduced in size and are more firmly united. The pleuro-central cavities open upward, just back of the pedicles. The centrum of sacral V is firmly united with the preceding one, but is not reduced in size and is little excavated by lateral cavities. The posterior surface is quite concave in its lower half, the margin slightly reeding above.

The neural arches begin with the dorsal type in sacral I; in II, III, and IV they are drawn together antero-posteriorly and conjoined from

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before mentioned, the diaphyses and ribs are united throughout. In II, III, and IV the merging of the three neural arches, and consequent reduction of space, occupied by them in the antero-posterior direction, gives to the diaphyses the appearance of radiating from a common center. This feature is accentuated by the general tendency of sacra to be compressed in this direction while in the matrix, owing to the frailty of the arches as compared with the centra. This also accounts for the usual convexity of the inferior outline of the sacral series which should doubtless be concave.

**MEASUREMENTS OF SACRUM.**

<table>
<thead>
<tr>
<th>Description</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of five coalesced centra</td>
<td>1.260</td>
</tr>
<tr>
<td>Height of sacral I over all</td>
<td>1.330</td>
</tr>
<tr>
<td>Height of sacral II over all</td>
<td>1.310</td>
</tr>
<tr>
<td>Height of sacral III over all</td>
<td>1.230</td>
</tr>
<tr>
<td>Height of sacral IV over all</td>
<td>1.190</td>
</tr>
<tr>
<td>Vertical diameter of centrum I at anterior end</td>
<td>0.365</td>
</tr>
<tr>
<td>Lateral diameter of centrum I at anterior end</td>
<td>0.360</td>
</tr>
<tr>
<td>Vertical diameter of centrum II at posterior end</td>
<td>0.370</td>
</tr>
<tr>
<td>Lateral diameter of centrum II at posterior end</td>
<td>0.370</td>
</tr>
<tr>
<td>Breadth of coalesced spines II, III, and IV at crest</td>
<td>0.390</td>
</tr>
<tr>
<td>Breadth of coalesced spines II, III, and IV at base</td>
<td>0.285</td>
</tr>
<tr>
<td>Length of spine above prezygapophysis in I</td>
<td>0.260</td>
</tr>
<tr>
<td>Length of spine above prezygapophysis in II</td>
<td>0.260</td>
</tr>
<tr>
<td>Length of sacrocostal yoke</td>
<td>0.159</td>
</tr>
</tbody>
</table>

**MORPHOLOGY OF THE OPISTHOCELLIAN SACRUM.**

The composition of the sacrum in various genera of the Opisthocoelia has been regarded from almost as many points of view as there have been writers on the subject. Marsh looked upon the number of sacral vertebrae as a fixed quantity for each generic group and based many of his genera upon this character. In defining the order “Sauro- poda” he characterized the sacrum as composed of not more than four vertebrae. In later classifications the number of sacrals was not given as an ordinal character. Cope placed less stress upon the number of sacral vertebrae, but used it in generic distinctions.

Osborn, in 1898, described the sacrum of “Camarasaurus” as follows: “Camarasaurus had five sacral vertebrae; three of these constantly coalesced both by centra and neural spines, two others coalesced less constantly and possessed free spines.” Soon after, Williston offered the following more general characterization: “It is very clear that there are three typical vertebrae in all the genera of this family (Camarasauridae) as well as in the Morosauridae, if it be a distinct

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family, all of which present very distinct points of similarity. It is probable, as evidenced by the separated sacral vertebrae in Morosaurus lenit that the condition of ossification varies with age, the middle three uniting earliest, the first next, and the fifth last. The slight union of the fifth might, indeed, be absent in the adult without affording generic or even specific characteristics.”

A year later Dr. Osborn wrote of the sacrum of Diplodocus: “There are four rib-bearing true sacral vertebrae in Diplodocus instead of three, as hitherto described by Marsh. The three anterior sacrals, constituting the primitive Dinosaurian sacrum, are firmly united by their neural spines. These three spines coalesce into a single very robust spine showing the diaphyseal laminae separate.”

In his recent monograph on Diplodocus Mr. Hatcher described two sacra as follows: “The two splendid sacra belonging with skeletons 84 and 94 in our collections are unusually complete. . . . In each instance the vertebrae are firmly coossified with and give support to the ilia. In 84 the right ilium alone is preserved and this is united with all of five of the vertebrae which function as sacral either by means of true sacral ribs or the expanded diaphyseal laminae or by both these elements. All are coossified by their centra and the three median have their spines coalesced. . . . In skeleton 94, however, there are noticeable certain other more marked differences which are worthy of special notice as bearing directly upon the nature of the primitive Dinosaurian sacrum. In this skeleton the sacrum is present, with both ilia in position. The centra of the true sacrals are all coossified as in other sacrum. The neural spines of sacrals one and two coalesce and are coossified throughout their entire length as in 84, but the spine of sacral three is quite free from, though closely applied inferiorly to, that of the second sacral. This would seem to indicate that the primitive Dinosaurian sacrum consisted of two rather than three vertebrae, a condition found in the Crocodilia and most other living Reptilia. The fourth sacral in No. 94 bears a free spine and is coossified by its centrum with the third and does not differ in any essential respect from that described by Osborn or from that found to obtain in No. 84 of our collections.”

From the above it will be seen that Osborn and Williston agree upon the structure of the primitive sacrum as indicated by “Camarasaurus” (Apatosaurus), Morosaurus, and Diplodocus. This is based upon the tendency of the median three vertebrae to unite by spines and ribs. Hatcher has dissented from this opinion, postulating that the primitive Dinosaurian sacrum consisted of more than two vertebrae.

This conclusion is based upon a single sacrum of Diplodocus; a second sacrum referred to the same species and described in the same paper agrees with the usual type in having the spines of sacrals II, III, and IV coalesced. The sacrum just described in this paper also agrees in the same particular.

It will be observed that there is a considerable variation in the coossification of various elements in the Opisthocoelian sacrum, which cannot be attributed to age. By comparing the composition of known sacra of Apatosaurus, Diplodocus, and Morosaurus, it will be seen that there is a noticeable similarity in the development of that of the former two, while the latter stands quite afloat. This is well represented by the accompanying diagrammatic figures.

The Apatosaurus sacrum is represented by four, possibly five, known specimens. The most primitive composition is found in the young specimen in the Yale University collection, well known as the type of Apatosaurus. In this sacrum only the three primary centra with their coalesced ribs are preserved (Fig. 5). A second specimen, described by Dr. Osborn as Camasaurus,\(^*\) has, according to his description, the three primary centra coalesced by spines and sacral ribs as well as by the centra (Fig. 6). The dorso- and caudo-sacrals are both free; the latter, though structurally a caudal, was functional as an ilium-supporting vertebra. These characteristics as well as the size of the animal indicate that it was not quite adult. A third specimen in the Carnegie Museum figured \(^†\) by Mr. Hatcher as "Brontosaurus," may or may not belong to this genus (Fig. 8). The figure shows that the primary sacrals have their spines coalesced as in the typical adult. The caudo-sacral is firmly conjoined by centrum, ribs, and diapophyses as is the centrum of the dorso-sacral. The first caudal is also conjoined, at least in part.

The unusually well preserved sacrum in the Museum specimen may be taken as a typical representative of the adult of this genus. In this, sacrals II, III, and IV are firmly conjoined by centra, neural arches, sacral ribs, and bases of the diapophyses (Fig. 7). The centra, sacral ribs, diapophyses, and lateral spinous plates are more or less reduced from loss of function. The zygapophyses and zygosphenes are no longer traceable. The dorso-sacral is firmly coalesced by centrum and zygapophyses; the ribs are partially conjoined, the spine is free, but stands close to that of sacral II. The caudo-sacral is a typical anterior caudal coossified by centrum and zygapophyses, and partially by the ribs. The spine is free and isolated. The right ilium

\(^*\) Loc. cit.

\(^†\) Memoirs of the Carnegie Museum, Pl. X. Fig. 3.

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**Figures:***

- **Apatosaurus Series.**
  - Fig. 1.
  - Fig. 2.
  - Fig. 3.
  - Fig. 4.

- **Diplodocus Series.**
  - Fig. 5.
  - Fig. 6.

- **Morosaurus Series.**
  - Fig. 7.
  - Fig. 8.

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Diagrams illustrating the structure of the Opisthocoelian Sacrum.
is coossified by all of the ribs and diapophyses, the left evidently remained free. The type specimen of "Brontosaurus" is similar, so far as can be determined, except that the first presacral is also con-
joined (Fig. 9).

This series shows just such a development as one might expect in passing from a two-thirds grown animal to one of advanced age. The additional dorsal vertebrae united with the sacrum in the type specimen of "Brontosaurus" and the additional caudal united in the Carnegie Museum specimen, are but further evidence of the persistent tendency of adjacent vertebrae to coossify with the sacrum in animals of advanced age.

The four known sacra of Diplodocus show a very similar developmental series. The sacrum of D. longus, figured by Marsh, has only three vertebrae coossified by centra and by sacral ribs (Fig. 10). The posterior end of the sacrocastral yoke shows a facet for the caudo-sacral rib. The Carnegie Museum specimen No. 94 has vertebrae t, III, IV, and V coossified by the centra, III, IV, and V by the ribs, and II and III by the spines. The dorso-sacral remains free (Fig. 11). The American Museum specimen has an arrangement similar to that of the adult Apatosaurus, except that the sacral rib in the dorso-sacral is less strongly developed (Fig. 12). The Carnegie Museum specimen No. 84 is described as having this rib more nearly functional (Fig. 13).

The Morosaurus sacrum is known to the writer from four specimens. The type of M. lentus has four disarticulated sacral centra, each of which bear functional ribs not united with the centrum (Fig. 14). The neural arches are likewise free from the pedicles. The neural arch and spines figured with the posterior centrum in this specimen, and which has long been called in question, belongs with a caudal vertebra. It is proved beyond question by an almost identical specimen in this Museum.

The Morosaurus sacrum No. 5384 of the Museum has centra II and III, and IV and V, united in pairs (Fig. 14). The ribs are free from the centra as are the neural arches. The spines of II, III, and IV are imperfectly coossified by their zygaphyses. The specimen indicates an animal little more than half grown. A third Morosaurus sacrum in the University of Kansas (figured by Williston loc. cit.) has vertebrae I, II, III, and IV united by centra, spines II, III, and IV coossified and the sacral ribs of the same united to form the sacrocastral yoke (Fig. 15). The broad rib of the dorso-sacral is firmly united with this yoke and there is a blunt posterior projection from the fourth rib indicating that it abutted against the rib of the caudo-sacral which in this form has not been found conjoined. This specimen agrees very closely with the type of M. grandis so far as it will admit of determina-
tion. The Morosaurus sacra thus appear to fall into two groups. The first, as indicated by the type of M. lentus and No. 5384 of this Museum, has the dorso-sacral free. The second, as represented by the type of M. grandis and the Kansas University specimen, has the caudo-sacral free. A more important difference is that in the sacra of the former type the transverse axis passes between sacra I and IV, while in the latter it passes through sacral III as in Apatosaurus and

Diplodocus. If this feature proves constant it would indicate generic differences.

From the above it will be observed that the sacra of Apatosaurus and Diplodocus, so far as can be traced from the young animal to the adult, develop along similar lines. In Apatosaurus sacrales II, III, and IV coossify first as is shown by the two young specimens (Figs. 5 and 10), by the closer union of all the elements of these same vertebrae in the adult specimens (Figs. 7, 8, and 9), and by the noticeable tendency of articulating parts to atrophy from disuse. Sacral I usually unites next, and V last, as shown by Figs. 6, 7, and 8, although this order may sometimes be reversed, as is shown by Fig. 9. Coalition may be carried even farther, as appears by the union of Caudal I in Fig. 2 and presacral I in Fig. 9. In Diplodocus the same order is noticeable with the exception pointed out by Mr. Hatcher (Fig. 6), in which sacral I and the spine of IV remain free in a specimen apparently adult, while sacral V is coossified by its centrum. However, this is a variation similar in kind to that noted in Apatosaurus.

The above deductions carry out, for these two genera, the theory advanced by Osborn and supported by Williston, namely: That sacrales II, III, and IV represent the primitive sacrum. But how far back in the history of the group these conditions may have held remains a question. If we assume that the Opisthocoelium are derived from a bipedal ancestry, which were in turn derived from a crawling ancestor, we may explain the condition as follows:

It has been observed that the transverse axis of the pelvis passes through the ribs of sacral III. This would be the natural point for the pelvis to attach to the vertebral column in a terrestrial animal where the thrust of the femur is upward. The fact that sacral III has its centrum, ribs, diapophyses, zygaphyses, and neural spine most reduced indicates that it formed the primitive sacral center. Such an attachment doubtless served the primitive crawling reptilia, but as specialization in terrestrial habits progressed, and there was need of a more rigid pelvic structure, sacrales II and IV probably became con-
joined, one after the other. In this way the sacrum developed by alter-
nating additions on each side of the axis just as the perissodactyl foot in mammals has been reduced. With these three vertebrae united to form the sacrocostal yoke the ilium attained a firmness adapted to terrestrial habits, and yet sufficiently mobile for bipedal locomotion. If we may assume that the Opisthocoelia have passed through such a stage, this would account for the sacrum having become stable at this point in its development. If the form of the ilium had by that time become fixed, the sacrum would have been structurally complete. But with adaptation to quadrupedal habits, and the attendant increase in size, the need of a mobile sacrum was replaced by the demand for greater rigidity. In this way a fourth and fifth sacral, with occasional supernumeraries have been added.

MODIFICATION IN THE LAST PRESACRAL VERTEBRAE.

The probability that the Opisthocoelian sacrum has expanded by the addition of presacral vertebrae in front, as well as the addition of caudals in the rear, has been doubted by some later writers. The following features in the specimen under consideration are of interest as bearing directly upon this question:

1. The last pair of presacral ribs tend to coalesce with the vertebra by both head and tubercle.
2. The distal end of the right rib abutted the inner angle of the iliac crest and was evidently attached to it.
3. The position of the capitular attachment of the ribs passes by regular gradation from the lateral surface of the centrum in sacral II, to its extreme elevation on presacral III.
4. The capitular and tubercular elements, as well as the line of union with the diaphysis, can be traced in the rib of the dorso-sacral.

The last presacral rib on the right side of the Museum specimen is firmly coalesced by both head and tubercle. The left one is less completely so, although the process has gone far enough to have quite obliterated the articulating facets. The shaft of the right rib, unlike that figured by Hatcher in Diplodocus, is barely long enough to reach the anterior margin of the ilium. The distal end bears an oblique facet, which evidently abutted the inner angle of the iliac crest. There is no evidence of coossification and no corresponding facet on the ilium. As imbedded in the matrix, the end of the rib had slipped a few inches past the ilium, and the side of the shaft still bears an indentation caused by contact with the angle of its crest. An even more pronounced instance of modification in a presacral rib was noted by Dr. Williston in a specimen of Morosaurus in the Kansas University Museum. In this case the distal end of the rib had become expanded and was received by a distinct facet on the mesial angle of the ilium.

In this coossification may be recognized the initial stage of the conversion of a presacral rib into an ilium-supporting element. As the head and tubercle united with the vertebra and became immovable, and the distal end came in contact with the ilium, ligamentary attachment would naturally result. Consequent stress upon the attached rib would lead to specialization in order to meet the new function laid upon it.

The dorso-sacral rib bears evidence of just such a modification, which has been carried much farther (Fig. 1, Plate XLVIII). The diaphysis of the vertebra has been considerably reduced and overlaps the tubercular portion of the rib with which it has fused. The latter articulates distally with the crest of the ilium. The head of the rib has fused completely with the parapophysis at the latero-superior angle of the centrum. The distal portion of this element of the rib probably forms the stout process which abuts the great peduncle of the ilium, although this cannot be positively determined from the specimen under consideration. But there can be no doubt that the dorso-sacral of this genus is a modified presacral vertebra.

The position of the capitular attachment of the ribs on the lateral surface of the vertebral centra, as observed in the anterior dorsals, sacrals, and caudals, is evidently the primitive one. From that point the facets have been thrust upward by the dilation of the posterior theca and floating ribs. The position of the capitular attachment at the superior angle of the centrum in the dorso-sacral vertebra implies that the rib has either become fixed in its acquired function at a period in ancestral development, when the attachment of the last rib had reached this point in its upward progress, or that, having been elevated, it was again depressed in order to meet the stress of this new function. The amount of modification in the spine, zygapophyses, and centrum of this vertebra indicates that its union with the sacrum has taken place at a comparatively recent period.

CAUDAL VERTEBRAE.

The series of caudal vertebrae as represented by the Museum specimen is not essentially different from that figured in Marsh’s restoration of “Brentosaurus.” (See Plate iii.) Dr. Osborn has insisted that eight or ten of the anterior vertebrae were omitted in Marsh’s restoration, and has also estimated that seven anterior vertebrae were mis-

ing from the American Museum specimen No. 222, described by him as *Camarasaurus*. In this he has evidently fallen into error from mistaking sacral v for caudal t and from comparing the caudal series of this form with that of *Diplodus*. (See Figs. 11 and 12, Plate XLVII.)

As neither of the three caudal series above mentioned is complete distally they offer no positive basis of comparison as to number of vertebrae. In the Museum specimen the number of anterior caudals bearing ribs is twelve, that figured in the Yale specimen is the same, while the number observed by the writer in the American Museum specimen (exclusive of sacral v) is eleven. The diapophyses disappear in the Museum specimen and in the Yale specimen in caudal v; in the American Museum specimen they disappear in caudal iv. The number of anterior vertebrae having lateral cavities in the centra is five in the Museum specimen as compared with three described by Marsh in the Yale specimen. While the point of disappearance of such a vestigial element as the caudal rib cannot be regarded as constant, and the presence of lateral cavities in the centra is even more variable, the fact that these points in Marsh's restoration agree so closely with the Museum specimen indicates that the restoration is approximately correct in this particular. On the other hand, there is probably not more than one anterior caudal vertebra missing from the series in the American Museum specimen.

The first caudal vertebra has a number of characteristics which at once distinguish it from other members of the series. Most noticeable among these is the anterior articulating surface of the centrum, which is concave in its upper half, but convex below. The interior of the centrum contains numerous small cavities, the pedicles are hollow, the base of the spine is complicated by numerous infoldings of the peripheral lamina, the sacral ribs are expanded into broad, lateral wings coalesced with the diapophyses by a thin vertical plate thickened and rugose at its lateral border; the prezygapophyses face upward as well as inward, and are elevated at their bases by deep lateral fossae.

Each of the anterior caudal vertebrae bears a pair of lateral plates which project from the surface of the centrum, the neural arch, and the base of the spine. These are made up of two elements: (1) the caudal rib, which arises from the lateral surface of the centrum, and (2) the diapophysis, which springs from the neural arch as in the sacral and presacral vertebrae. These elements are very similar in form to those of the primary sacrals, except that they are connected by a continuous vertical plate which is thickened at its lateral border, forming a stout bar. (Plate t.t.)

The caudal rib springs from the lateral surface of the centrum,

above the middle, in the form of a stout process terminating in an expanded and rugose extremity analogous to the parapophyses. The diapophyseal element arises from the lateral surface of the neural arch by anterior, posterior, and inferior roots, analogous to those of the diapophyses in the thoracic vertebrae. The two elements are connected by a vertical plate, which bears on its lateral margin a thickened and rugose surface facing laterally. Passing backward in the series the diapophyseal element is reduced to a roughened, vertical ridge on the centrum in caudal iv. The parapophyseal element persists as a stout, vertically compressed process as far back as ix, disappearing entirely with xii.

The centrum in the first caudal vertebra, as before described, is concave in its upper half, but convex below. The posterior face is irregularly convex. The interior of the centrum has numerous small cavities, especially at the rim of the articular ends. There are no well developed lateral fossae. With the second vertebra the typical prococalous form of centrum begins. The anterior concavity continues quite marked as far back in the series as the ninth; from this point it diminishes in prominence, disappearing entirely with the sixteenth. The posterior surface of the centrum is but slightly convex in any of the caudal vertebrae. In the second caudal the surface is in general convex with a slight concavity a short distance above the center. Passing backward in the series this concavity increases in area to the obliteration of the general convexity, so that in the seventh the former predominates. From this point backward the posterior concavity persists, being most prominent from the tenth to the sixteenth. From this it will be seen that the prococalous type prevails from the first to the ninth and grades into an uncertain amphibocalous type which prevails as far back as the sixteenth, where it in turn gives place to an irregular amphiplatyan form.

Two sets of cavities occur in the centra of the anterior caudal vertebrae, the first above and the second below the root of the sacral ribs. These will be designated respectively as supra- and infra-costal fossae, according as they occur above or below the root of the caudal rib. These cavities cannot be regarded as constant characteristics, as they are sometimes present on one side and absent on the other. The lateral cavities in the centra persist as far back as caudal v in this specimen. In caudal t the supra-costal cavity is represented by a slight infolding of the periphery of the centrum on the anterior side of the lateral plate. In caudal u cavities are present on both the anterior and the posterior side of the lateral plate. In u there is a single supra-costal cavity on the posterior side; in iv the same persists,
but is reduced in size, disappearing entirely with \( v \). The infra-costal fossae begin with \( \text{II} \), become most pronounced in \( \text{IV} \), and disappear with \( v \).

The neural arch is low and massive throughout the caudal series, the neural canal forming a median groove in the upper side of the centra. The pedicles in the first caudal vertebrae, in addition to being hollow, are excavated laterally by deep cavities, which enter them on the anterior side of the lateral plate. They give rise also to the thin, vertical plate which connects the diapophyses and the caudal ribs. In the second caudal one pedicle is hollow, the other solid. Caudals \( \text{II} \) to \( v \), inclusive, have the pedicles excavated at the base posterior to the lateral plate. From this point backward the neural arch becomes a simple, low, massive structure, giving rise to the zygapophyses and the neural spines.

The neural spines are similar in their elementary structure to those of the posterior dorsal vertebrae. They are composed primarily of a stout median plate and a pair of slighter flanking plates. The median plate is rugose on the anterior and posterior margins for the attachment of inter-spinous ligaments. Near the crest the lateral plates are also thickened and rugose for muscular attachment. In the anterior members of the series the crest is cruciate in cross-section. Two pairs of lateral buttresses which arise from the pre- and postzygapophyses and join the lateral plate, act as a set of brace-roots in resisting antero-posterior strains. These lateral buttresses become rapidly reduced as we pass backward in the series, and disappear entirely in \( \text{XII} \). In the first caudal vertebra the spine is similar in height to that of the last sacral, and stands almost vertical, but the spines of the succeeding vertebrae are rapidly reduced in length and inclined backward (Plate LII). In \( \text{XIV} \) the spine is reduced to a short, blunt median plate and is but little expanded distally. With \( \text{XVII} \) the spines begin to elongate antero-posteriorly.

The zygapophyses are small in comparison with the size of the vertebrae. They articulate in this specimen as far back as the twenty-third vertebrae. The prezygapophyses are borne upon a pair of buttresses, which spring from the anterior surface of the neural arch. In the anterior members of the series they are supported, in addition, by two pairs of posterior roots, which arise respectively from the base of the lateral spinozal plate and from the diapophysis, as in the thoracic vertebrae. With the reduction of the diapophysial element in the lateral plate, the third root of the prezygapophyses merges into the first; the second root also disappears in caudal \( x \), leaving only the inferior buttress. The articulating surfaces are convex, and through-

![Fig. 18. Anterior view of chevrons, showing gradation in structure.](image)

The caudal chevrons are of three types, the closed arch, the open arch, or transitional type, and the double arch. (Fig. 18.) Of these the latter two appear far back in the series where the vertebrae are much reduced in size. The closed arch may therefore be considered as the most characteristic type. Many of the chevrons found with this specimen were so displaced that their position cannot be accurately determined. The presence of a short, stout chevron imbedded in the matrix beneath the first caudal vertebra suggests that all of the anterior caudal vertebrae may have been chevron-bearing.
THE PELVIS.

The pelvic bones are well preserved, except the left ilium, which is waterworn. On account of its absence the pelvis is figured from the right side in Plate 1, and the same parts reversed are used in Plate 31. The coossification of the pubis and ischium on the right side establishes beyond question the correct relation between these bones. Their distal ends are more divergent than Marsh's figure indicates. This, with the more forward inclination of the whole pelvis, as evidenced by the downward curvature of the presacral vertebrae, directs the ischium more backward and the pubis somewhat more downward than formerly figured in this genus. In fact, these relations approach very closely to those indicated by Marsh's figure of Atlantosaurus.*

The ilium is one-fourth larger than that figured in Marsh's restoration, and shows the character of the crest which was wanting in that specimen. It articulates mesially with the five coalesced sacral ribs and the corresponding diaphyses. The articulating surface for the ribs is a crescentic projection of the mesial surface just above the acetabulum. The greater and lesser peduncles articulate below with the proximal ends of the pubis and ischium, respectively.

The pubes are a pair of massive bones, broad in the proximal half and expanded into irregular, rugose knobs distally. They articulate proximally with the great peduncles of the ilium by broad cartilaginous connections, laterally with the ischia by their thin posterior margins, which extend downward from the acetabulum, and distally with one another by a cartilaginous union at the median line. The articulation with the ischia may in advanced age give place to coossification, as has occurred in the right side of the pelvis under consideration. Anterior to the ischio-pubic articulation there is a rugose thickening of the pubic border evidently for union with its fellow at the median line. It is probable that the pubes were connected by cartilage from the ischio-pubic articulation to the distal end. The pubic foramen opens downward just below the anterior border of the acetabulum. (Plate 1.)

The ischia are much slenderer than the pubes. Their proximal ends are expanded into broad, articular surfaces, which connect superi- orly with the lesser peduncles of the ilias, and inferiorly with the pubes by the anterior margin of the blades. They form the posterio-inferior boundary of the acetabulum. The shaft curves outward and backward

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* Dinosaurs of North America, P1. xvi.
terminating in a rugose knob. From the middle of the shaft to the distal end the pubes are joined in a more or less mobile ligamentary union.

The acetabulum is formed, in its upper half, by the inferior border, and the greater and lesser peduncles of the ilium; in the lower half by the proximal ends of the pubis and ischium. In the normal quadrupedal posture the thrust of the femur is received by the inferior border of the ilium just below the sacroiliac yoke. In the bipedal posture the weight would be borne by the great peduncle which is supported by the rib of the dorso-sacral vertebra.

The ribs of the dorso-sacral vertebra articulate with the anterior surface of the greater peduncle. Similarly the ribs of the caudo-sacral vertebra articulate with the posterio-internal surface of the lesser peduncle and with the mesial wall of the iliac plate. From the point of articulation of each of the five sacral ribs a transverse plate bends upward along the mesial wall of the iliac plate. These plates in the left side of the Museum specimen, have become firmly conjoined with the sacral ribs and the diapophyses, leaving only a small foramen above the sacroiliac bar.

The femur in the Museum specimen is compressed in the shaft antero-posteriorly, but is otherwise splendidly preserved. (Plate IL.) It is a stouter bone than that of any other known bythiococelan excepting the unusually stout-limied form designated by the species, A. amplus. The head is rugose and rises five centimeters above the great trochanter. The fourth trochanter is marked by a sharp and rugose ridge at the postero-internal angle of the shaft, slightly above the middle. The distal end is expanded into heavy condyles, deep, antero-posteriorly. The outer one is cleft by a deep, tubular groove.

<table>
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<td>Length</td>
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<td>Breadth, head and great trochanter</td>
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<tr>
<td>Breadth at middle of shaft</td>
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<tr>
<td>Breadth, distal end</td>
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<td>Length of fourth trochanter</td>
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</tr>
<tr>
<td>Antero-posterior diameter of head</td>
<td>0.300</td>
</tr>
</tbody>
</table>

The accompanying figure of the skeleton of Apatosaurus (Plate III.) is based upon the Museum specimen as figured in Plate I. The cervical series and the limbs are supplied according to Marsh's figure, with certain modifications where it is known to be in error. As the complete cervical series is not known, the number of vertebrae and the character of the neural processes are more or less conjectural. The skull is regarded as essentially unknown. The figure of the Museum specimen is made with the greatest care from projection drawings of each bone made separately and assembled in the figure as a whole. The distortions not corrected in working out the specimen are copied exactly in the drawing. Supplied parts are indicated by dotted lines in the separate figures.

The most noticeable feature brought out is the shortness of the body as compared with other proportions. The crest of the dorsal arch stands just in front of the sacrum. The long spines in this region evidently served as the center-pole to which the muscles for lifting both the anterior part of the body and the tail were attached. In general outline a striking similarity will be noticed between this figure and Marsh's first restoration of this genus. In fact, as pointed out in an earlier note, the original restoration represented almost the entire skeleton and was, in the main, correct. Later, Professor Marsh evidently became dissatisfied with its proportions and inserted three additional dorsal vertebrae, a lumbar, and two caudals. The number of ribs was raised from ten to thirteen, the crest of the dorsal arch was carried forward to the middle, and a sufficient length of costal cartilage was inserted to extend the thorax in proportion. These additions make almost exactly the extent of his error.
SUMMARY.

The following conclusions are derived from this paper.
1. "Opisthocoelia" has precedence over "Sauropoda" and "Cetiosauria."
2. *Brontosaurus* is a synonym of *Apatosaurus*.
3. The species *A. ajax* cannot be recognized in the adult; *A. excelsus* is probably a synonym of *A. latidens*; *A. amplis* is valid.
4. The number of dorsal vertebrae is ten.
5. There are no lumbar vertebrae.
6. There are five pairs of true, and five pairs of floating ribs.
7. The sacrum is made up of three primary and two secondary sacral vertebrae, all of which, in the adult, connect with the ilia by sacral ribs and diapophyses. The primary sacras are costae and spines; the secondary sacras are free until adult age and then coossify with the true sacras by centra and zygapophyses.
8. Sacral 1 is a modified dorsal, sacral 2 a modified caudal.
9. The last pair of floating ribs tends to coossify with the vertebra by head and tubercle, and with the ilia by the distal ends.
10. There are one or two more anterior caudal vertebrae than was figured in Marsh's restoration.
11. The caudal chevrons pass from the closed Y anteriorly to the double-arch type posteriorly very much as in *Diplodocus*.
12. The ilium inclines more forward, and the pubis and ischium are more divergent distally than previously figured.
13. The crest of the dorsal arch is at the anterior end of the sacrum.
PLATE XLVII.
APATOSAURUS.

Heads of right thoracic ribs, anterior view, about one-thirteenth natural size.
PLATE XLVIII.

APATOSAURUS.

Left side view of sacrum, from a photograph, $\times \frac{1}{3}$. 
Plate XLIX.

Fig. 1. Anterior end, sacrum of *Apatosaurus*, X ½.
Fig. 2. Anterior end, sacrum of young *Mamenchisaurus*, X ½.
PLATE L.

APATOSAURUS.

Sacrum and pelvis from right side, X 1/4.
PLATE LI.
APATOSAURUS.

Fig. 1. Lateral view of right femur, X ½.
Fig. 2. Anterior view of same.
Preliminary figure, skeleton of *Apatosaurus*, one forty-sixth natural size.
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