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UNITED STATES GEOLOGICAL EXPLORATION OF THE FORTIETH PARALLEL.
CLARENCE KING, GEOLOGIST-IN-CHARGE.

ODONTORNITHES:

A

MONOGRAPH

ON THE

EXTINCT TOOTHED BIRDS OF NORTH AMERICA;

WITH THIRTY-FOUR PLATES AND FORTY WOODCUTS.

BY

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TABLE OF CONTENTS.

ILLUSTRATIONS.

List of Plates.

PART I.

PART II.

List of Woodcuts. (Original.)

PREFACE.

The present volume is the first of a series of Monographs designed to make known to science the Extinct Vertebrate Life of North America. In the investigation of this subject, the writer has spent the past ten years, much of it in the field, collecting, with no little hardship and danger, the material for study, and the rest in working out the characters and affinities of the ancient forms of life thus discovered.

During this decade, the field work, extending from the Missouri River to the Pacific Coast, has so predominated, as the subject unfolded, that a plan of gradual publication became a necessity. The more important discoveries were briefly announced soon after they were made, but only where the specimens on which they were based admitted of accurate determination. The principal characters of the new groups were next worked out systematically, and published, with figures of the more important parts. When the investigation of a group is completed, the results, with full descriptions and illustrations, will be brought together in a monograph. This system has been carried out with the *Odontornithes*, and will be continued with the other groups. The investigation of several of these is now nearly completed, and the results will soon be ready for publication.

The material is abundant for a series of monographs on the marvellous extinct vertebrates of this country, and the results already attained are full of promise for the future. A somewhat careful estimate makes the number of new species of extinct vertebrates, collected since 1868, and now in the Yale College Museum, about 1,000. Nearly 300 of these have already been described by the writer, and some have been noticed or described by other authors, but at least one-half remain to be investigated.

Among the new groups brought to light by these researches, and already made known by descriptions of their principal characters, are the following, which will be fully described in subsequent volumes of the present series.

The first Pterodactyles, or flying reptiles, discovered in this country, were found by the writer in the same geological horizon with the *Odontornithes*, described in the present memoir. These were of enormous size, some having a spread of wings of nearly twenty-five feet; but they were especially remarkable on account of having no teeth, and hence resembling recent birds. They form a new order, *Pteranodontia*, from the type genus *Pteranodon.* Of this group, remains of more than six hundred individuals are now in the Yale College Museum—ample material to illustrate every important point in their osteology.

With these fossils, were found also great numbers of Mosasauroid reptiles, a group which, although rare in Europe, attained an enormous development in this country, both in numbers and variety of forms. Remains of more than fourteen hundred individuals, belonging to this order, were secured during the explorations of the last ten years, and are now in the Museum of Yale College.

The most interesting discoveries made in the Jurassic formation were the gigantic reptiles belonging to the new sub-order *Sauropoda*, including by far the largest land animals yet discovered. Another remarkable group of large reptiles found in the same formation were the *Stegosauria.* Other Dinosaurs from the same horizon, the "Atlantosaurus beds," show that this was the dominant form of vertebrate life in that age, and many hundred specimens of these reptiles are now in the Yale Museum.

In a lower horizon of the same formation, the "Sauranodon beds," were found the remains of a peculiar new group of reptiles, the *Sauranodontia*, allied to *Ichthyosaurus*, but without teeth.

In the Eocene deposits of the Rocky Mountains, the writer discovered a new order of huge mammals, the *Dinocerata*. Remains of several hundred individuals were secured, and a monograph on the group will follow the present memoir. In the same formation were found the remains of another new order of mammals, the *Tillodontia*, in many respects the most remarkable of any yet discovered. In the same Eocene deposits were secured the first remains of fossil *Primates* known from North America, as well as the first *Cheiroptera*, and *Marsupialia*. Abundant material also was found in the same region to illustrate the genealogy of the Horse, and a memoir on this subject is in course of preparation.

To General Sherman and General Sheridan, of the United States Army, my grateful acknowledgments are especially due, since without their continued assistance the investigations—of which the present volume is the first fruits—could not have been made. To the many other officers of the Army who aided me in the field during my various explorations, often in regions dangerous from hostile Indians, my sincere thanks are likewise due.

For important aid in the preparation of the present volume, I desire to express my full acknowledgments to Mr. Oscar Harger, Assistant in Palæontology, in the Museum of Yale College. My thanks are also due to Mr. George Bird Grinnell, Assistant in Osteology, for much valuable assistance, especially while the volume was in the press.

O. C. M.

YALE COLLEGE, New Haven, Conn., June 16th, 1880.

INTRODUCTION.

The remains of Birds are among the rarest of fossils, and very few have been discovered except in the more recent formations. According to present evidence, the oldest known Birds were imbedded in the Jurassic deposits of Europe, which have yielded three individuals belonging to the genus *Archæopteryx*, so well preserved that the more important characters can be determined. The only other remains of birds found in the Mesozoic of the Old World are a few specimens from the Cretaceous of England, which are too fragmentary to throw much light on the extinct forms they represent.

The earliest traces of Birds hitherto found in the strata of this country are from the Cretaceous, although we may confidently predict their discovery in the Jurassic beds, if not at a still lower horizon. There is at present no evidence whatever that any of the three-toed impressions in the Triassic, described as the footprints of Birds, were made by Birds; and the proof now seems conclusive that nearly all of them are the tracks of Dinosaurian reptiles, bones of which occur in the same deposits.

In the Cretaceous beds of the Atlantic Coast, and especially in the green-sand region of New Jersey, various remains of Birds have been found, and described by the writer.[1] These fossils, although often in excellent preservation, occur mainly as isolated bones, and hence their near affinities have not as yet been determined with certainty.

[1] See Synopsis at the end of this volume.

Along the eastern slope of the Rocky Mountains, and especially on the adjoining plains in Kansas and Colorado, there is a series of Cretaceous strata remarkably rich in vertebrate fossils. The deposits are all marine, and, away from the mountains, they lie nearly horizontal. They have suffered much from erosion, and are still wasting away, especially along the river valleys. These beds consist mainly of a fine yellow chalk and calcareous shale, both admirably adapted to preserve delicate specimens, and here have been found the extinct Birds which form the subject of the present memoir.

The geological horizon of the known *Odontornithes* is in the Middle Cretaceous, and corresponds to the strata named by the writer the "Pteranodon beds." The latter are included in sub-division number three, in Meek and Hayden's section. The accompanying fossils are Mosasauroid reptiles, which are very abundant; Plesiosaurs, allied to Pliosaurus; Pterodactyles, of the genus *Pteranodon;* and many Fishes. With these occur Rudistes, and occasionally Ammonites, Belemnites, and various other Cretaceous invertebrates.

The first Bird fossil discovered in this region was the lower end of the tibia of *Hesperornis*, found by the writer in December, 1870, near the Smoky Hill River in Western Kansas. Specimens belonging to another genus of the *Odontornithes* were discovered on the same expedition. The extreme cold, and danger from hostile Indians, rendered a careful exploration at that time impossible.

In June of the following year, the writer again visited the same region, with a larger party, and a stronger escort of United States troops, and was rewarded by the discovery of the skeleton which forms the type of *Hesperornis regalis*, Marsh. Various other remains of *Odontornithes* were secured, and have since been described by the writer. Although the fossils obtained during two months of exploration were important, the results of this trip did not equal our expectations, owing in part to the extreme heat (110° to 120° Fahrenheit, in the shade) which, causing sunstroke and fever, weakened and discouraged guides and explorers alike.

A considerable part of these Cretaceous deposits still remained unexplored, and in the autumn of 1872, a third expedition through this territory was undertaken by the writer, with a small party. Additional specimens of much interest were secured, including the type of the genus *Apatornis*, and one nearly complete skeleton of *Hesperornis*,—an ample reward for the hardship and danger we incurred.

The specimens thus secured by these various expeditions have since been supplemented by important additions, collected in the same general region by different parties equipped and sent out by the writer, who no longer could give his personal supervision to work in that field. The fossil Birds procured in this region since 1870, by these different expeditions, include remains of more than one hundred different individuals of the *Odontornithes.* These are all in the Museum of Yale College, and form the material on which the present volume is based.

A study of this extensive series of Bird remains brings to light the existence in this class of two widely separated types, which lived together during the Cretaceous period, in the same region, and yet differed more from each other than do any two recent birds. Both of these types possessed teeth, a character hitherto unknown in the class of Birds, and hence they have been placed by the writer in a separate sub-class, the *Odontornithes.* One of these groups includes very large swimming birds, without wings, and with the teeth in grooves *(Odontolcæ)*, and is represented by the genus *Hesperornis.* The other contains small birds, endowed with great powers of flight, and having teeth in sockets *(Odontotormæ)*, and biconcave vertebræ; a type best illustrated by the genus *Ichthyornis.* Other characters, scarcely less important, appear in each group, and we have thus a vivid picture of two primitive forms of bird structure, as unexpected as they are suggestive. A comparison of these two forms with each other, and with some recent birds, promises to clear away many difficulties in the genealogy of this class, now a closed type; and hence they are well worthy of the detailed description and full illustration here devoted to them.

The fossil birds now known from the Cretaceous deposits of this country are included in nine genera, and twenty species. These have all been described by the writer, and are represented, at present, by the remains of about one hundred and fifty different individuals. This is evidence of a rich and varied avian fauna in America during Mesozoic time, and likewise indicates what we may expect from future discoveries.

ODONTORNITHES.

PART I.

ODONTOLCÆ.

(Plates I–XX.)

CHAPTER I.

THE SKULL OF HESPERORNIS.

(Plates I–II and XX.)

It is most fortunate for science that *Hesperornis regalis*—with a single exception, the oldest bird known—should now be represented by remains as complete as any fossil skeleton yet discovered, even in the later formations. Nearly all the bones of the specimens obtained were almost as perfect as in life, when first found in the matrix; although the more delicate parts were sometimes unavoidably broken in removal, and occasionally small fragments were lost. Many of the bones were near their natural position when discovered, and in such cases a special effort was made to preserve this position, or retain a record of it, by drawings. However difficult such a method of collecting really is, in the region explored, its importance will be fully appreciated by anatomists.

Various remains belonging to about fifty different individuals of *Hesperornis* are now in the Museum of Yale College, and the most important of them are described in the present memoir.

THE SKULL. (Plates I–II.)

The skull of *Hesperornis regalis*, Marsh, is long and narrow, the rostral portion forming about two-thirds of its entire length (Plate I, figure 1). Viewed from above, the outline of the whole skull is wedge-shaped; and from the side, it presents a similar form, but somewhat more acute. It has a general resemblance to the skull of *Colymbus torquatus*, Brünnich (figure 2, page 9); but the brain-case is smaller, and the facial portion more produced. The position and size of the orbits, and of the anterior nasal apertures, are similar; but the likeness soon ceases, for the type of cranial structure is essentially different in the two genera.

In its more important characters, the skull of *Hesperornis* resembles that of the *Ratitæ*, or Struthious birds, and we shall find other striking evidences of affinity with this group in various portions of the skeleton. The base of the skull shows nearly all the cranial characters which Huxley, in his invaluable memoir on the Classification of Birds, lays down to distinguish the *Ratitæ*,[1] namely:

(1.) The posterior ends of the palatines, and the anterior ends of the pterygoids are very imperfectly, or not at all, articulated with the basisphenoid rostrum.

(2.) Strong "basipterygoid" processes, arising from the body of the basisphenoid, and not from the rostrum articulate with facets which are situated nearer the posterior than the anterior ends of the inner edges of the pterygoid bones.

(3.) The upper, or proximal, articular head of the quadrate bone is not divided into two distinct facets.

The occipital condyle in *Hesperornis* is cordate in outline, and its articular face is only moderately convex (Plate II, figure 4.) It is much less rounded than the condyle in the *Ratitæ*, and has a longer base. The articulation looks backward, and there is a shallow median groove on the upper half. The foramina in the base of the skull have the same general position as in recent Struthious birds.

[1] Proceedings Zoological Society of London, 1867, p. 418.

The palatines resemble those of the Ostrich. They are long, slender bones, extending from their union with the pterygoids, parallel with the axis of the skull, and joining the premaxillaries. In one specimen, they lie nearly in position, the left palatine being immediately beneath the left maxillary. In front of their junction with the pterygoid, and just anterior to their widest expansion, there is a deep pocket, very similar to that in the palatine of the Ostrich. The anterior half of the bone is slender, and tapers gradually to the extremity.

The vomers in *Hesperornis* are separate, as in lizards and a few existing birds. They are smaller than the palatines, and resemble the vomers of *Rhea*, more than those of the other *Ratitæ*. They are broadest at the base, which is obliquely truncated, and they taper gradually to the pointed extremity in front (Plate II, figure 8.) The thick posterior end may possibly have united with the pterygoid, as well as with the palatine. Both vomers are preserved in the skull figured in Plate I, but are displaced.

The bones of the brain-case are ankylosed, but in other parts of the skull the sutures are distinct, and many of them are open, as in the Ostrich and other *Ratitæ*. The orbits are large, and placed near together. There is a well-ossified interorbital septum, which is perforated by a large fenestra. (Plate I, figure 1, *of*.) The superior temporal arch is wanting, and the orbit was closed below by the strong quadrato-jugal bar. There was a large temporal fossa, bounded in front by a distinct postorbital process. There are well marked glandular depressions extending along the roof of the orbits, as in *Colymbus* and some other recent aquatic birds.

The quadrato-jugal bone is slender, and its articular head fits into a deep pit in the lower end of the quadrate. There is a large triangular lachrymo-nasal fossa, between the orbit and the anterior nasal opening. The latter is long and narrow, and closed behind by the nasal bone. The suture between the frontals and the beak was quite open. The lachrymal bone is distinct, and articulates with the frontal, nasal, and maxillary. The nasal is deeply excavated in front for the anterior narial aperture, and below joins both the maxillary and premaxillary.

The premaxillaries are elongate, and separate throughout their posterior two-thirds (Plate I, figure 5.) Their extremities touched the frontals. Their sides are deeply excavated for the anterior nares, and in front they are ankylosed, and form a long pointed beak, the end of which is somewhat decurved. This extremity, back to the nasal openings, has its surface pitted with irregular vascular foramina, indicating, apparently, that it was once covered with a horny bill, as in modern birds.

The various cranial characters above described may nearly all be found in recent birds, if we search through different groups; but in *Hesperornis* the stout maxillary bones were armed with well developed teeth, a feature unknown in this class, before the discovery of the remains described in the present volume. These teeth were set in a deep continuous alveolar groove, with only faint indications of separate sockets (Plate II, figure 1.) They resemble most nearly, in form and structure, the teeth of reptiles, and are fully described in the following chapter. There were no palatal teeth, and none in the premaxillaries.

The Brain.

The brain of *Hesperornis* was quite small, and more reptilian in type than in any adult bird hitherto examined. On page 9, figure 1, the skull in this genus is represented, with the outline of the brain-cavity in position. The skull of the Loon is added in figure 2, also with a cast of the brain in its natural position, and life size. A comparison of the two, places the relative magnitude and proportions of the brain in each in strong contrast. The reptilian type is shown on the same page in figure 3, which represents in natural size a cast of the brain-cavity of a young Alligator.

In *Hesperornis regalis* the olfactory lobes (figure 1, *ol*) were large and elongate, and their nerves passed out of the cranium by separate orifices, one on each side of the interorbital septum. The cerebral hemispheres (figure 1, *c*) were of very moderate size, much smaller, proportionally, than in any existing birds, and strongly resembling the corresponding part in some reptiles. The two lobes were narrow, and sub-ovate in outline,

Fig. 1.

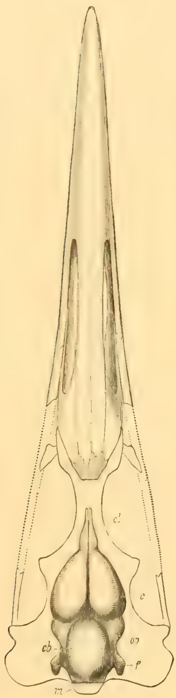

Fig. 3.

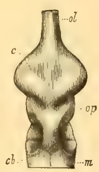

Fig. 2.

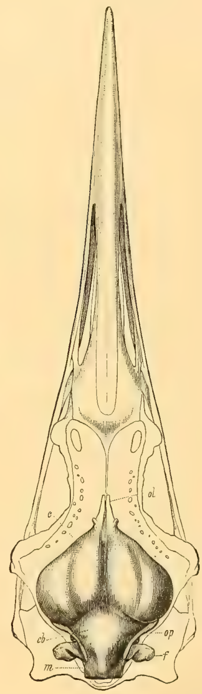

Figure 1. — Outline of skull and brain-cavity of *Hesperornis regalis*, Marsh; seen from above; three-fifths natural size.

Figure 2. — Outline of skull and brain-cavity of Loon, (*Colymbus torquatus*, Brünnich); same view; natural size.

Figure 3. — Cast of brain-cavity of young Alligator; seen from above; natural size.

ol. olfactory lobes; *c.* cerebral hemispheres; *op.* optic lobes; *cb.* cerebellum; *f.* flocculi; *m.* medulla.

and were separated above by an osseous median crest, depending from the roof of the brain case. The optic lobes (figure 1, *op*) were large, and very prominent, and only slightly covered above by the cerebral hemispheres. Their similarity in size and position to the optic lobes of reptiles is especially noteworthy. The optic nerves were large. The cerebellum (figure 1, *cb*) was quite large, and reptilian in its general features. The flocculi were well developed, and lodged in distinct cavities.

In contrasting the brain-cavity of *Hesperornis* with that of *Colymbus*, as shown together in figures 1 and 2, a striking difference is seen in the size, the latter being about three times the bulk of the former. The two skulls are represented of the same absolute length, for the purpose of direct comparison. If, moreover, the relative size of the entire skeleton in each case be likewise considered, the brain of *Hesperornis* would have even less than one-third the relative capacity of that of the Loon. As the two birds were evidently similar in shape, and habits, the comparison seems to be a fair one. Another marked difference in the brain of the two genera is seen in the relative size of the cerebral hemispheres, as represented in figures 1 and 2. The cerebral lobes of *Colymbus* are very large, and much expanded transversely; and it is in this portion of the brain that the real difference of size is most apparent.

These facts are especially important, since they tend directly to show that the essential principles of the law of brain-growth, established by the writer in extinct mammals, applies also to birds. This law, briefly stated, is as follows:

1. All Tertiary mammals had small brains.

2. There was a gradual increase in the size of the brain during this period.

3. This increase was confined mainly to the cerebral hemispheres, or higher portion of the brain.

4. In some groups, the convolutions of the brain have gradually become more complicated.

5. In some, the cerebellum and the olfactory lobes have even diminished in size.

6. There is some evidence that the same general law of brain-growth holds good for Birds and Reptiles, from the Cretaceous to the present time.[1]

The concluding suggestion was in part based on facts now published for the first time in the present memoir.

The Lower Jaws. (Plate I, figures 2--4.)

The lower jaws are long and slender, and were thickly set with teeth. The rami were united at the symphysis in front only by ligament, a feature unknown in modern adult birds. There is an imperfect articulation between the splenial and angular elements, which probably admitted of some motion; and all the other sutures are open, or distinguishable. There was apparently a mandibular foramen. There is a well marked shallow groove on the outer superior margin of each dentary bone, for the reception of the maxillary teeth, when the jaws were closed. (Plate I, figure 3, *b*.) The angle of the mandible extends backward but a short distance beyond the articular face for the quadrate, and the extremity is obliquely truncated.

The following measurements of the skull of *Hesperornis regalis* are taken mainly from the very perfect specimen figured in Plate I, and recorded as number 1206, in the Geological Catalogue of Yale College Museum. The other dimensions are derived from number 1207, of the same Catalogue, to which reference is made in all the numbers of specimens given in the descriptions that follow:

Measurements of Skull. (*Hesperornis regalis*, No. 1206.)

Length of skull, from occipital condyle to end of premaxillary,	257.0^{mm}
Greatest transverse diameter, behind temporal fossæ,	61.0
Least transverse diameter, between temporal fossæ,	30.0
Greatest transverse diameter, between temporal fossæ and orbits,	42.0
Least transverse diameter, between orbits,	9.0
Transverse diameter of premaxillaries, at anterior nares,	9.0
Antero-posterior diameter of anterior nares,	55.0

[1] American Journal of Science and Arts, vol. viii, p. 66, July, 1874; and vol. xii, p. 61, July, 1876.

Transverse diameter of anterior nares,	9.0mm
Extent of premaxillary in front of anterior nares,	88.0
Transverse diameter of occipital condyle,	10.0
Vertical diameter of occipital condyle,	6.0
Transverse diameter of foramen magnum,	9.0

Measurements of Skull. (*Hesperornis regalis*, No. 1207.)

Transverse diameter of occipital condyle,	9.0mm
Vertical diameter of occipital condyle,	8.0
Transverse diameter of foramen magnum,	12.5
Distance between external margins of quadrate articulation,	49.0
Greatest width of skull, behind quadrate articulations,	55.0
Transverse diameter of quadrate articulations,	8.0
Antero-posterior diameter of quadrate articulations,	6.5
Length of quadrate,	32.0
Transverse diameter of proximal end,	9.0
Antero-posterior diameter of proximal end,	7.0
Transverse diameter of shaft, at middle,	4.0
Vertical diameter of pit for quadrato-jugal,	6.0
Antero-posterior diameter of pit for quadrato-jugal,	4.0
Longest diameter of inferior condyle of quadrate,	12.0

Measurements of Lower Jaw. (*Hesperornis regalis*, No. 1206.)

Length of lower jaw,	257.0mm
Greatest vertical diameter of lower jaw,	25.0
Extent of alveolar groove,	138.0
Depth of alveolar groove,	5.0
Greatest diameter of posterior facet for articulation with quadrate,	14.0
Least diameter of posterior facet for articulation with quadrate,	5.0

CHAPTER II.

THE TEETH OF HESPERORNIS.

(Plates I, II, and XX.)

The absence of teeth has long been regarded as one of the best distinctive characters of Birds; since teeth are present in some members of all the other classes of vertebrates. All existing Birds have the jaws covered with a horny sheath, which is usually smooth. In some groups, this beak-covering is more or less serrated, and in a very few forms the elevations correspond to slight projections of the bone beneath, but no indications of true teeth have yet been found. This may all be said likewise of existing Turtles.

Geoffroy Saint-Hilaire and others have, indeed, detected in the young of some recent birds vascular papillæ which resembled those of embryonic teeth; but they were apparently portions of the undeveloped horny beak.

The teeth of *Hesperornis* are true teeth, with their distinctive characters as well marked as those of any reptile. In the upper jaw, they are confined to the maxillary bone alone, the premaxillary being entirely edentulous. In the lower jaw, the teeth extend from very near the anterior extremity of the ramus along the entire upper border of the dentary bone.

The teeth above and below were implanted in a continuous groove, somewhat like those of *Ichthyosaurus*. From the sides of the groove, slight projections extend between the teeth, thus forming faint indications of sockets; but these projections are not sufficient to materially lessen the width or depth of the groove. (Plate II, figure 11).

The teeth were evidently held in position by cartilage, which permitted some fore and aft movement; but lateral motion was much restricted by the depth and narrowness of the groove, and the large size of the fangs. With the decay of this cartilage after death, the teeth readily lost their erect position, and became more or less displaced.

In the best preserved specimen of *Hesperornis regalis* (number 1206), most of the teeth had fallen out of the grooves, when found, and were lying scattered along beside the jaws, as often seen in specimens of *Ichthyosaurus*. The embryonic sockets, in this specimen, indicate that there were fourteen functional teeth in the maxillary bone, and thirty-three teeth in the corresponding ramus of the lower jaw, as shown in Plate I, figures 1–4. In *Hesperornis crassipes* (number 1474), a number of teeth were likewise found in position in the jaws, but the exact number originally in each could not be determined.

The teeth of *Hesperornis* were gradually replaced by successional teeth, and this took place in a manner very similar to that in some reptiles. The germ of the young tooth was formed on the inner side of the fang of the tooth in use, and, as it increased in size, a pit for its reception was here gradually made by absorption. The old tooth at last became undermined, and was expelled by the new one, which occupied the same position, the number of teeth thus remaining the same.

The teeth of *Hesperornis* have conical pointed crowns, covered with smooth enamel, and supported on stout fangs. In form of crown and base, they closely resemble the teeth of Mosasauroid reptiles, one of which is represented on page 15, figure 7, for comparison. The outer and inner surfaces of the crown are separated by sharp ridges, which are without serrations. The outer side is nearly plane, and the inner surface strongly convex.

The crowns of the teeth are mainly composed of firm dentine, invested with a layer of enamel. The relative proportions of these are shown in figure 4. The pulp cavity was large, and in the specimen above represented was filled with calcite. The coronal walls of this cavity are smooth, and well defined. The fang consists of osteo-dentine.

Fig. 4.

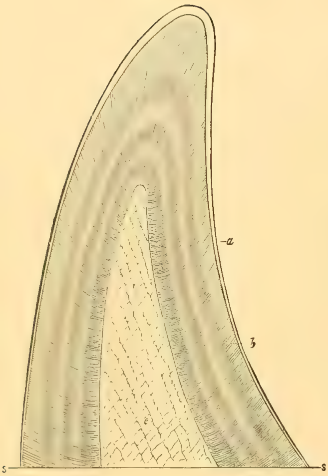

Fig. 6.

Fig. 5.

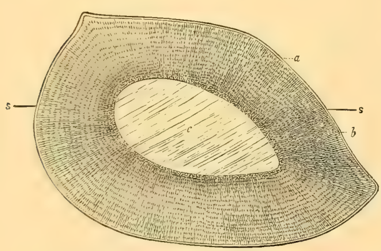

Fig. 7.

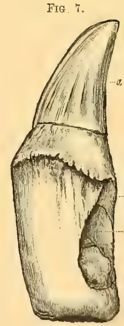

Figure 4. — Vertical section of tooth of *Hesperornis regalis*, Marsh; (No. 1206).
Figure 5. — Horizontal section of same tooth; both enlarged thirty-two diameters.
Figure 6. — Tooth of *Hesperornis regalis* (No. 1206); enlarged eight diameters.
Figure 7. — Tooth of *Mosasaurus princeps*, Marsh; half natural size.

a. enamel of crown; *b.* dentine; *c.* pulp cavity in crown; *b′* root of tooth; *c′.* absorbed cavity in root, *d.* young tooth; *ss.* intersection of horizontal and vertical sections.

The layer of enamel gradually increases in thickness from the base of the tooth to the apex, as shown in figure 4, *a*. It is also somewhat thicker over the anterior cutting edge than in other portions of the base of the crown, as indicated in figure 5. The line of junction between the enamel and the dentine is everywhere sharply defined. The enamel is dense and hard, the calcification having proceeded so far, in the specimens examined, that the constituent fibres could not be distinguished. The external surface of the enamel is nearly smooth, but marked by delicate striæ. There is no indication of cement on the coronal surfaces.

The dentine, which forms the mass of the crown, shows a well marked structure in both the vertical and horizontal sections, figures 4 and 5, *b*. It is firm and compact, and the calcigerous tubes are well defined. Near the base of the crown, they radiate horizontally, and in transverse section appear nearly straight, as shown in figure 5. Higher up in the crown, these tubes curve upward, diverging from the axis of the tooth less and less, until beneath the apex they become nearly parallel. In the dentine, there are distinct concentric lines of growth. These are seen near together and numerous in transverse section, figure 5, while those which appear in the vertical section, figure 4, are fewer in number, and more strongly marked.

The teeth of *Hesperornis*, taken by themselves, appear to resemble more nearly the detached teeth of Mosasauroid reptiles, than any others known, not excepting the teeth of *Ichthyornis*, which will be fully described in a subsequent chapter. The teeth in the latter have compressed crowns, and are implanted in distinct sockets. In all their main features, the teeth of *Hesperornis* are essentially reptilian, and no anatomist would hesitate to refer them to that class, had they been found alone. Combined with the other reptilian characters of *Hesperornis*, noted elsewhere in the present volume, they clearly indicate a genetic connection with that group.

CHAPTER III.

THE PRESACRAL VERTEBRÆ OF HESPERORNIS.

(Plates III–V and XX.)

In the type specimen of *Hesperornis regalis*, a number of vertebræ were preserved from various parts of the series, including nearly all of the caudals. Other individuals of this species, since discovered, have furnished all the missing vertebræ, except the atlas. An examination of the occipital condyle and of the anterior parts of the axis leaves little doubt as to the form and proportions of the atlas, so that the entire axial skeleton can now be determined with almost absolute certainty.

The presacral vertebræ of *Hesperornis* resemble in their more important characters the corresponding vertebræ of existing birds. The articular faces of the centra conform strictly to the modern ornithic type, an interesting fact, as we shall see, when we compare them with the vertebræ of another group of *Odontornithes*, from the same geological horizon.

The neck of *Hesperornis regalis* was long and slender. Including the atlas and axis, there were seventeen cervical vertebræ; and twenty-three in all between the skull and sacrum. The last three cervicals have free ribs, and would be called cervico-dorsals by some anatomists, and dorsals by some others. As the eighteenth vertebra is the first united to the sternum by the intervention of a sternal rib, it seems best to regard it as the first dorsal, and this view will be adopted in the present volume.

There are fourteen vertebræ in the coössified sacral series represented in Plates X and XI, and there were twelve more in the tail, as shown in Plate XII, making the entire column consist of forty-nine vertebræ. This is a very large number for this class, and is equaled in but very few recent birds.

None of the vertebræ of *Hesperornis* were ankylosed together, except in the sacral series, and at the extremity of the tail. None of the vertebræ contained pneumatic openings, although some were lightened by medullary cavities.

The Atlas and Axis. (Plates III and XX.)

The atlas was evidently a short ring of bone, very similar to the first vertebra in modern aquatic birds. Its articular cup for the reception of the occipital condyle was not deep, and was cordate in outline. The atlas articulated with the axis by well developed zygapophyses above, and by a crescent-shaped tubercle below. The centrum of the atlas is coössified with the axis, as the odontoid process.

The axis (Plate III, figure 1) is well preserved, and resembles the corresponding vertebra of the Loon (*Colymbus torquatus*, Brün.); but it is one-third larger, and a much stouter bone. The posterior articular face is much less oblique, being nearly vertical. The odontoid process is relatively shorter and broader, and its articular face is more extended backward, along the median line below. This process is slightly concave above, in prolongation of the floor of the neural canal. The centrum of the axis is expanded at each end, for its articular surfaces. The anterior expansion is considerably greater, and somewhat more gradual, than the posterior; and, at the least expanded portion, its thickness is less than two millimeters. The anterior articular surface is reniform, the upper outline being emarginate, to make room for the base of the odontoid process. The articulation is concave in both directions, but much more deeply concave vertically than transversely.

The anterior portion of the centrum of the axis is deeply excavated at the sides, nearly on a level with the floor of the neural canal, for the transmission of the vertebral artery. A very delicate bridge of bone may have existed here, completing the foramen. In the succeeding cervical vertebræ, this foramen is well developed, and may conveniently be termed the lateral foramen. It is formed by the diapophysis above and the parapophysis below, and closed externally by their union with the intervening pleurapophysis. In life, this aperture probably protected both the vertebral artery and vein, and the main trunk of the sympathetic nerve, as in most recent birds. A hypapophysis extending over about the posterior half of the centrum is indicated, but is not preserved. The posterior articular surface is nearly square in outline, with rounded corners. It is only slightly oblique, the lower portion projecting but little beyond the upper margin. As in ordinary birds, it is distinctly concave vertically, and convex transversely.

The neural arch was surmounted by a well developed neural spine, which is broken off in the present specimen. The pre-zygapophyses are small, oval, convex facets, slightly raised above the surrounding bone, and looking outward and upward at an angle of about 45°. The post-zygapophyses are much larger. They are concave, and look nearly directly downward. The neural canal is somewhat depressed, perhaps in part by crushing. The post-zygapophyses extend within about two millimeters of the posterior articular surface of the centrum. They are strongly supported above by a ridge arising upon the side of the neural arch, and running outward and backward over the post-zygapophyses. No vascular or pneumatic foramina are visible upon this vertebra.

This description of the axis of *Hesperornis regalis* is derived mainly from the specimen, number 1207, in which the series of presacral vertebræ is nearly complete. The following measurements are taken from the same vertebra:

Measurements of Axis. (No. 1207.)

Length of centrum, including odontoid process,	29.0^{mm}
Length of centrum,	21.0
Least transverse diameter of centrum (approximate),	2.0
Length of odontoid process,	8.0
Transverse diameter of odontoid process, at base,	7.2
Vertical diameter of odontoid process, at base,	4.0
Transverse diameter of anterior articulation of centrum,	13.0

Vertical diameter of anterior articulation of centrum,		6.0mm
Transverse diameters of posterior articulation of centrum,	superior,	9.0
	median,	7.0
	inferior,	8.0
Vertical diameter of posterior articulation of centrum,		8.0
Transverse diameter of vertebra, across pre-zygapophyses,		13.0
Transverse diameter of vertebra, across post-zygapophyses (approximate),		24.0
Greatest diameter of pre-zygapophyses,		5.5
Least diameter of pre-zygapophyses,		4.0
Diameters of post-zygapophyses,	vertical (approximate),	7.0
	horizontal,	7.5
Length of floor of neural canal,		30.0
Length of roof of neural canal (approximate),		26.0
Transverse diameter of anterior opening of the neural canal,		7.5
Vertical diameter of anterior opening of the neural canal,		6.0
Transverse diameter of posterior opening of the neural canal,		8.8
Vertical diameter of posterior opening of the neural canal,		5.0

The Third Vertebra. (Plate III, figure 2.)

The third vertebra of *Hesperornis regalis* resembles that of the Loon, but has the articular faces of the centrum less oblique. The centrum is compressed laterally, as in the axis, becoming quite narrow at and behind the middle; then expanding suddenly, for the posterior articulation. The anterior articular face is supported by a more gradual expansion. The face itself is somewhat oblique, looking downward at an angle of less than 30°. It is concave transversely, and convex vertically, as in ordinary birds. Immediately behind this articulation, the under surface of the centrum is excavated. Beyond the excavation, the hypapophysis gradually becomes prominent, quite thin in front, but expanded and flattened into a button-shaped process, below the posterior articulation. The latter face is very similar in shape to that of the axis, but is somewhat larger, as shown by the measurements, and slightly more oblique.

The neural arch bore a less powerful spine than that of the axis. The pre-zygapophyses are much longer, and larger than in the axis, and they look inward and upward, instead of outward, as in that vertebra. They are, however, turned only slightly inward. The post-zygapophyses are less elongated than the pre-zygapophyses; and, as in the axis, are strengthened by a ridge beginning about the middle of the upper part of the neural arch, and continued outward and backward. Between this ridge and the neural spine, the surface of the vertebra is excavated posteriorly, but the posterior edge of the neural arch is considerably thickened, and rises in a ridge connecting the post-zygapophyses with the base of the neural spine. Over the post-zygapophyses, this ridge is developed into a projecting tubercle. The lateral foramen for the vertebral artery is small, and over-arched by a strong bridge of bone, from which a short, stout, obtuse pleurapophysis projects backward, and somewhat downward. The floor of the foramen is continued as a groove for a short distance backward upon the side of the vertebra, bounded below by a well developed nearly horizontal ridge. A similar, but much smaller, ridge is seen above; and, over this, a slight ridge appears on some specimens, extending a little farther back on the vertebra.

The measurements given below show the principal dimensions of the third cervical vertebra of *Hesperornis regalis*, in the type specimen, number 1200, and in two other skeletons:

Measurements of Third Vertebra. (No. 1200.)

Length of centrum,	22.5^{mm}
Transverse diameter of anterior articulation of centrum,	9.0
Vertical diameters of anterior articulation of centrum,[1]	6.0– 8.0
Transverse diameters of posterior articulation of centrum,	9.8– 8.2
Vertical diameters of posterior articulation of centrum,	7.0– 9.6
Transverse diameter of vertebra, across pre-zygapophyses,	19.0
Transverse diameter of vertebra, across lateral foramina,	20.0
Transverse diameter of vertebra, across post-zygapophyses,	22.5–21.0
Diameters of pre-zygapophyses,	5.0– 9.0
Diameters of post-zygapophyses,	7.0– 8.0
Length of floor of neural canal,	22.0
Length of roof of neural canal,	21.0
Length of hypapophysis,	6.5

Measurements. (No. 1206.)

Length of centrum,	24.0^{mm}
Transverse diameter of anterior articulation of centrum,	10.0
Transverse diameters of posterior articulation of centrum,	9.0– 9.5
Vertical diameters of posterior articulation of centrum,	6.0– 8.0

[1] Where two measurements of the same part are given together, as in this case, they refer to the greatest and least dimensions of the portion named.

Transverse diameter of vertebra, across pre-zygapophyses,	23.0mm
Transverse diameter of vertebra, across post-zygapophyses,	29.0
Diameters of pre-zygapophyses,	7.0–11.0
Diameters of post-zygapophyses,	8.0–10.0
Length of floor of neural canal,	24.0
Vertical diameter of lateral foramen,	4.0
Length of pleurapophysis,	14.0
Length of free portion of pleurapophysis,	10.0
Extent of hypapophysis below vertebral articulation,	6.0
Diameter of terminal tubercle of hypapophysis,	7.5

Measurements. (No. 1207.)

Length of centrum,	22.0mm
Least transverse diameter of centrum,	1.5
Transverse diameter of anterior articulation of centrum,	10.0
Vertical diameter of anterior articulation of centrum,	5.2
Transverse diameters of posterior articulation of centrum,	8.6– 9.5
Vertical diameters of posterior articulation of centrum,	7.2– 9.0
Transverse diameter of vertebra, across pre-zygapophyses,	18.0
Transverse diameter of vertebra, across post-zygapophyses,	28.0
Diameters of pre-zygapophyses,	8.0– 4.0
Diameters of post-zygapophyses,	7.5– 8.6
Length of floor of neural canal,	22.0
Length of roof of neural canal,	22.0
Transverse diameter of anterior opening of neural canal,	7.5
Vertical diameter of anterior opening of neural canal,	6.0

THE FOURTH VERTEBRA. (Plate III, figure 3.)

The fourth vertebra resembles the third, but is larger and longer. The centrum is much excavated in the postero-lateral region, so as even to become somewhat translucent over a small area, about seven millimeters in advance of the posterior articulation. The latter is supported upon a very abrupt expansion of the centrum. In front, the centrum thickens quite evenly toward the anterior face. The under surface of the centrum presents, immediately behind the anterior articulation, a rather deep triangular fossa, the apex of the triangle pointing backward. Behind this fossa, the lower surface is nearly flat, with an acute median ridge, which divides below the posterior articular face, and sends, downward and outward, two somewhat triangular ear-like processes. The articular ends of the centrum are much as in the third vertebra, being slightly larger, and presenting about the same obliquity.

The neural arch is strong, flattened above, and strengthened behind by a ridge, as in the third vertebra. The neural spine extended more than half the length of the neural arch, and terminated behind just in advance of a median notch. The anterior zygapophyses are elongated, and are directed forward, upward, and a little more inward than in the third vertebra. The post-zygapophyses are strengthened by a lateral ridge, as in the preceding vertebra. The upper surface of the neural arch on each side of the spine is less depressed posteriorly. The lateral foramen was larger than in the third vertebra, and the pleurapophyses were longer, and directed nearly horizontally backward. In one specimen (number 1206), the median hypapophysial ridge is produced near the middle of the centrum into a conspicuous pointed hypapophysis.

The following measurements are taken from the fourth cervical vertebra of two individuals of *Hesperornis regalis*, and one, number 1474, of *Hesperornis crassipes*:

Measurements of Fourth Vertebra. (No. 1206.)

Length of centrum,	26.0mm
Transverse diameter of anterior articulation of centrum,	12.0
Vertical diameter of anterior articulation of centrum,	5.0
Transverse diameters of posterior articulation of centrum,	9.0–12.0
Vertical diameters of posterior articulation of centrum,	7.0– 9.0
Transverse diameter of vertebra, across pre-zygapophyses,	19.0
Transverse diameter of vertebra, across post-zygapophyses,	26.0
Diameters of pre-zygapophyses,	7.0–12.0
Diameters of post-zygapophyses,	9.0–11.0
Length of floor of neural canal,	26.0
Length of pleurapophysis,	21.0
Length of free portion of pleurapophysis,	17.0

Measurements. (No. 1207.)

Length of centrum,	24.0mm
Least transverse diameter of centrum,	0.5
Transverse diameter of anterior articulation of centrum,	11.8
Vertical diameter of anterior articulation of centrum,	4.5
Transverse diameters of posterior articulation of centrum,	9.0–11.0
Vertical diameters of posterior articulation of centrum,	8.0–10.0
Transverse diameter of vertebra, across pre-zygapophyses,	21.0

Transverse diameter of vertebra, across post-zygapophyses,	29.0mm
Greatest diameter of pre-zygapophyses,	9.0
Least diameter of pre-zygapophyses,	4.5
Greatest diameter of post-zygapophyses,	9.6
Least diameter of post-zygapophyses,	8.2
Length of floor of neural canal,	24.5
Length of roof of neural canal,	24.0
Transverse diameter of neural canal, at anterior opening,	8.5
Vertical diameter of neural canal, at anterior opening,	5.2
Transverse diameter of neural canal, at posterior opening,	9.0
Vertical diameter of neural canal, at posterior opening,	6.0

Measurements. (No. 1474.)

Length of centrum,	24.0mm
Vertical diameter of anterior articulation of centrum,	5.0
Transverse diameter of posterior articulation of centrum,	11.0
Vertical diameters of posterior articulation of centrum,	7.5–11.0
Length of floor of neural canal,	26.0

The Fifth Vertebra. (Plate III, figure 4.)

The fifth vertebra is a little longer and larger than the fourth, to which in most respects it is similar. The centrum, however, is not so much excavated in the postero-lateral region. The ridge above the groove entering the lateral foramen is more pronounced. The ventral side of the centrum is less deeply hollowed out behind the anterior articulation, and the depression blends more gradually with the general under surface, which bears no hypapophysis, but is excavated throughout its length. The articular surfaces are much as in the fourth vertebra, with the inferior portion of each a little more expanded. The pre-zygapophyses slope somewhat inward, and the post-zygapophyses are surmounted by a tubercle pointing outward and backward. The lateral foramen is larger than in the fourth vertebra, and the pleurapophysis longer. The base of the neural spine stops a little short of the anterior margin of the roof of the neural canal, and terminates at a notch posteriorly.

The measurements given below of the fifth cervical vertebra of *Hesperornis regalis* are derived from two different specimens, numbers 1206 and 1207.

Measurements of Fifth Vertebra. (No. 1206.)

Length of centrum,	28.0^{mm}
Transverse diameters of anterior articulation of centrum,	11.0–13.0
Vertical diameters of anterior articulation of centrum,	6.0– 9.0
Transverse diameters of posterior articulation of centrum,	10.0–15.0
Transverse diameter of vertebra, across pre-zygapophyses,	27.0
Transverse diameter of vertebra, across post-zygapophyses,	27.5
Diameters of post-zygapophyses,	8.0–10.0
Transverse diameter of lateral foramen,	3.5
Vertical diameter of lateral foramen,	6.5
Length of pleurapophysis,	25.0
Length of free portion of pleurapophysis,	17.0

Measurements. (No. 1207.)

Length of centrum,	28.0^{mm}
Least transverse diameter of centrum,	1.8
Transverse diameters of anterior articulation of centrum,	11.0–13.0
Vertical diameters of anterior articulation of centrum,	5.5– 8.0
Vertical diameter of posterior articulation of centrum,	8.0
Transverse diameter of vertebra, across pre-zygapophyses,	27.0
Transverse diameter of vertebra, across post-zygapophyses,	28.0
Greatest diameter of pre-zygapophyses,	10.0
Least diameter of pre-zygapophyses,	5.5
Greatest diameter of post-zygapophyses,	10.0
Least diameter of post-zygapophyses,	8.0
Length of floor of neural canal,	28.0
Length of roof of neural canal,	27.5
Transverse diameter of anterior opening of neural canal,	9.0
Vertical diameter of anterior opening of neural canal,	6.5
Transverse diameter of lateral foramen,	3.5
Vertical diameter of lateral foramen,	5.0

The Sixth Vertebra. (Plate III, figure 5.)

The sixth vertebra is larger than any of the preceding, and in general form resembles the fifth. The ridge on the side of the centrum, above the excavation for the lateral foramen, is continued downward and backward, until it falls into the much more prominent ridge, or crest, separating the lateral and ventral surfaces of the centrum. This latter ridge is strongly developed. Arising near the lower external angle of the front articulation, it first forms a considerable floor for the groove of the vertebral artery; and then is continued backward, and terminates on each side in a tubercle, directed outward, backward and downward, and situated below the upper portion of the posterior articulation.

The ventral surface of this vertebra is excavated behind the anterior articular face, and between the ridges on the opposite sides of the centrum. This excavation, however, is less pronounced than in the fifth vertebra, and has no definite posterior limit; but the depression continues through the whole length of the vertebra, nearly disappearing a little behind the middle of the centrum, and becoming again deeper posteriorly. The tubercle upon the upper part of the lamina enclosing the lateral foramen is larger and more prominent than in the fifth vertebra, and is situated farther from the pre-zygapophysis. It represents the diapophysis, and attains its full development in the dorsal vertebræ. The lateral foramen is larger than in the fifth vertebra. In the specimen from which the figures are mostly drawn, this vertebra is united to the following one by the matrix, and hence its posterior articular face is not exposed. The neural arch, also, is crushed, and the dotted outline of the neural spine is drawn from another specimen

The dimensions of the sixth vertebra of *Hesperornis regalis* here recorded include those of the type specimen, number 1200, and two others, both well preserved.

Measurements of Sixth Vertebra. (No. 1200.)

Length of centrum,	29.0mm
Transverse diameters of anterior articulation of centrum,	12.0–15.0
Vertical diameters of anterior articulation of centrum,	6.0–10.0
Transverse diameters of posterior articulation of centrum,	10.0–14.0
Vertical diameters of posterior articulation of centrum,	8.5–11.0
Transverse diameter of vertebra, across pre-zygapophyses,	19.0
Transverse diameter of vertebra, across diapophyses,	25.0
Transverse diameter of vertebra, across pleurapophyses, at base,	21.0
Diameters of pre-zygapophyses,	6.5– 9.8
Length of floor of neural canal,	30.0
Vertical diameter of lateral foramen,	5.5
Transverse diameter of lateral foramen,	3.0

Measurements. (No. 1206.)

Length of centrum,	31.0mm
Transverse diameters of anterior articulation of centrum,	10.0–12.0
Vertical diameters of anterior articulation of centrum,	6.0– 9.0
Transverse diameters of posterior articulation of centrum,	10.0–16.0

Vertical diameters of posterior articulation of centrum,	8.0–11.0mm
Transverse diameter of vertebra, across pre-zygapophyses,	20.0
Transverse diameter of vertebra, across post-zygapophyses,	21.0
Diameters of pre-zygapophyses,	6.5–12.0
Diameters of post-zygapophyses,	7.0–11.0
Length of floor of neural canal,	31.0
Total length of pleurapophysis,	29.0
Length of free portion of pleurapophysis,	21.0

Measurements. (No. 1207.)

Length of centrum,	30.0mm
Transverse diameters of anterior articulation of centrum,	11.5–14.0
Vertical diameters of anterior articulation of centrum,	5.5– 9.0
Transverse diameter of posterior articulation of centrum,	16.0
Transverse diameter of vertebra, across pre-zygapophyses,	28.0
Transverse diameter of vertebra, across post-zygapophyses,	27.0
Greatest diameter of pre-zygapophyses,	9.0
Least diameter of pre-zygapophyses,	5.2
Greatest diameter of post-zygapophyses,	10.0
Transverse diameter of anterior opening of neural canal,	10.0
Vertical diameter of anterior opening of neural canal,	7.0
Length of pleurapophysis,	23.0
Length of free portion of pleurapophysis,	18.0
Diameter of free portion of pleurapophysis, at base,	5.5
Vertical diameter of lateral foramen,	5.8
Transverse diameter of lateral foramen,	4.0

The Seventh Vertebra. (Plate III, figure 6.)

The seventh vertebra is slightly longer and larger than the sixth. The centrum has the lateral ridge above the groove for the vertebral artery less developed than in the sixth, and not coalescing with the ridge below; which, on the other hand, is well developed, and clearly bounds the lower surface of the centrum. This surface is broader than in the sixth vertebra, and widely excavated longitudinally, throughout, the excavation being much deeper and wider anteriorly than in the sixth vertebra, and nowhere disappearing on the surface of the centrum. Just behind the outer inferior margin of the anterior articular face on each side, is a tubercle, somewhat elongated longitudinally with the vertebra, and projecting downward, and slightly inward. These tubercles become a prominent feature on some of the succeeding vertebræ of the series, but only the faintest trace of them is visible on the sixth vertebra, and they may be considered as commencing upon the seventh. A similar structure is seen in the corresponding vertebra of the Loon. In *Rhea*, these tubercles suddenly appear upon the sixth vertebra. The elongated tubercles in which the lateral ridges terminate posteriorly are smaller and less conspicuous in the seventh than in the sixth vertebra. The articular surfaces are larger, and somewhat more expanded below.

The pre-zygapophyses are nearly flat, being only slightly convex. The post-zygapophyses are slightly concave, especially near the internal angle. The base of the neural spine extends over nearly the whole length of the neural arch, but was probably shorter antero-posteriorly above, than in the sixth vertebra. The lateral foramen is slightly larger, and the diapophysis upon its outer wall is greater, more produced downward and forward, and farther from the pre-zygapophysis than in the sixth vertebra. A short ridge rising into a crest over the post-zygapophysis is developed in one specimen (number 1208). The posterior outline of the neural arch is notched behind at the termination of the neural spine, as in the preceding vertebræ, but less deeply. The pleurapophyses are longer than in the sixth vertebra.

The measurements of two specimens of the seventh cervical vertebra of *Hesperornis regalis* are given below:

Measurements of Seventh Vertebra. (No. 1206.)

Length of centrum,	32.0mm
Transverse diameters of anterior articulation of centrum,	10.0–16.0
Vertical diameters of anterior articulation of centrum,	7.0–10.0
Transverse diameter of vertebra, across pre-zygapophyses,	25.0
Transverse diameter of vertebra, across post-zygapophyses,	27.0
Diameters of post-zygapophyses,	8.0–11.0
Total length of pleurapophysis,	31.0
Length of free portion of pleurapophysis,	23.0

Measurements. (No. 1207.)

Length of centrum,	32.0mm
Least transverse diameter of base of centrum,	8.5
Transverse diameters of anterior articulation of centrum,	11.0–16.0
Vertical diameters of anterior articulation of centrum,	6.5–10.0
Transverse diameters of posterior articulation of centrum,	11.0–15.5
Vertical diameters of posterior articulation of centrum,	6.5–10.0
Transverse diameter of vertebra, across pre-zygapophyses,	26.5

Transverse diameter of vertebra, across post-zygapophyses,	27.0^{mm}
Greatest diameter of pre-zygapophysis,	10.5
Least diameter of pre-zygapophysis,	6.4
Greatest diameter of post-zygapophysis,	12.0
Least diameter of post-zygapophysis,	8.0
Transverse diameter of neural canal, at anterior opening,	9.0
Vertical diameter of neural canal, at anterior opening,	6.5
Length of pleurapophysis,	31.0
Diameter of pleurapophysis, at base,	6.5
Vertical diameter of lateral foramen,	6.5
Transverse diameter of lateral foramen,	3.4

THE EIGHTH VERTEBRA. (Plate III, figure 7.)

The eighth vertebra is the largest cervical of the series, slightly exceeding both the seventh and the ninth in length. It closely resembles the seventh, being slightly larger in nearly all its dimensions. The ventral surface of the centrum is more broadly and deeply excavated anteriorly than in the seventh, and the tubercles, or processes, on each side of this excavation are more developed, and considerably incurved. They stand somewhat wider apart at their bases than in the seventh vertebra, and the whole under surface is more widely excavated. The two tubercles near the posterior end of the lower surface are small. The lateral ridge, starting at the upper end of the foramen for the vertebral artery, fades out upon the side of the centrum earlier than in the preceding vertebra. The diapophysis is somewhat stronger and larger than in the seventh vertebra, and the foramen itself is larger.

The neural spine is shorter than in the seventh cervical. It tapers rapidly almost to a point above, and terminates posteriorly at the margin of the neural arch. The latter shows no median notch at this point, as in the preceding vertebræ, the margin being gently and evenly excavated between the zygapophyses. The pre-zygapophyses are slightly convex, and the post-zygapophyses concave. The latter are strengthened by a ridge running along the side of the neural arch, and rising and becoming more prominent over the zygapophyses. The articular surfaces of the centrum are larger, and especially broader, below, than in the seventh vertebra. The pleurapophyses are of nearly the same length as in that vertebra.

The principal dimensions of the eighth vertebra, as determined from two specimens of *Hesperornis regalis*, are as follows:

Measurements of Eighth Vertebra. (No. 1206.)

Length of centrum,	33.0mm
Transverse diameters of posterior articulation of centrum,	11.0–15.0
Vertical diameters of posterior articulation of centrum,	8.0–12.5
Transverse diameter of vertebra, across post-zygapophyses (approximate),	22.5
Diameters of pre-zygapophyses,	7.0–11.0
Diameters of post-zygapophyses,	7.5–13.0
Length of roof of neural canal,	30.0
Total length of pleurapophysis,	33.0
Length of free portion of pleurapophysis,	25.0

Measurements. (No. 1207.)

Length of centrum,	33.0mm
Least diameter of centrum, at base,	9.8
Transverse diameters of anterior articulation of centrum,	12.0–17.0
Vertical diameters of anterior articulation of centrum,	7.0–11.0
Transverse diameter of posterior articulation of centrum,	16.0
Vertical diameter of posterior articulation of centrum,	9.0
Transverse diameter of vertebra, across pre-zygapophyses,	30.0
Transverse diameter of vertebra, across post-zygapophyses,	29.0
Greatest diameter of pre-zygapophysis,	10.5
Least diameter of pre-zygapophysis,	7.8
Greatest diameter of post-zygapophysis,	12.0
Length of roof of neural canal,	28.2
Transverse diameter of neural canal, at anterior opening,	9.0
Vertical diameter of neural canal, at anterior opening,	6.5
Total length of pleurapophysis,	32.0
Length of free portion of pleurapophysis,	21.0
Diameter of pleurapophysis, at base,	9.0
Vertical diameter of lateral foramen,	8.0
Transverse diameter of lateral foramen,	4.5

The Ninth Vertebra. (Plate III, figure 8.)

The ninth vertebra has a centrum slightly shorter than the eighth, but somewhat broader and stouter. The under surface of the centrum is slightly broader, and is more deeply and widely excavated anteriorly. This excavation, as in the preceding vertebra, is somewhat over-arched by two descending incurved processes, which are longer and larger than in the eighth vertebra, and are also set somewhat farther forward, so as to be on a line with the posterior margin of the articular surface. The tubercles at the posterior end of the lower surface are small, and scarcely noticeable. The ridge above the arterial groove upon the side of the centrum is much as in the eighth vertebra. The articular surfaces of the centrum are slightly broader below than in the preceding vertebra.

The ridge strengthening the posterior zygapophysis is well developed, and rises into a tubercle above the zygapophysis. This tubercle is especially developed in number 1206. The neural spine extends over slightly less of the neural arch than in the eighth vertebra, and probably was not as high. The outline of the arch is evenly concave between the post-zygapophyses, and not notched on the median line. The diapophysis is developed about as in the eighth cervical. The pleurapophyses are longer than in the preceding vertebra.

The dimensions of the ninth vertebra of *Hesperornis regalis* are shown in the tables given below:

Measurements of Ninth Vertebra. (No. 1206.)

Length of centrum,	32.5mm
Transverse diameter of anterior articulation of centrum,	16.8
Transverse diameter of posterior articulation of centrum,	12.2
Vertical diameter of posterior articulation of centrum,	7.0
Transverse diameter of vertebra, across pre-zygapophyses,	30.0
Transverse diameter of vertebra, across post-zygapophyses,	33.0
Diameters of post-zygapophyses,	10.5– 8.0
Length of floor of neural canal,	33.0
Length of pleurapophysis,	31.0
Length of free portion of pleurapophysis,	22.0

Measurements. (No. 1207.)

Length of centrum,	31.0mm
Least diameter of centrum, at base,	10.0
Transverse diameters of anterior articulation of centrum,	13.0–16.0
Vertical diameters of anterior articulation of centrum,	8.0–13.0
Transverse diameter of posterior articulation of centrum,	12.2
Vertical diameter of posterior articulation of centrum,	7.0
Transverse diameters of vertebra, across pre-zygapophyses,	27.0–34.0
Transverse diameter of vertebra, across post-zygapophyses,	31.0
Greatest diameter of pre-zygapophysis,	10.5
Least diameter of pre-zygapophysis,	8.0

Greatest diameter of post-zygapophysis,	12.0mm
Length of floor of neural canal,	31.5
Length of roof of neural canal,	28.0
Transverse diameter of neural canal, at anterior opening,	8.5
Vertical diameter of neural canal, at anterior opening,	6.5
Length of pleurapophysis,	31.0
Length of free portion of pleurapophysis,	20.0
Diameter of pleurapophysis, at base,	9.0
Vertical diameter of lateral foramen,	7.0
Transverse diameter of lateral foramen,	5.5

The Tenth Vertebra. (Plate IV, figure 1.)

The tenth vertebra is shorter and stouter than the ninth. The under surface is perceptibly broader, and somewhat more deeply excavated in front. The descending incurved processes, also, are longer than in the ninth vertebra, but the tubercles at the posterior ends of the lateral ridges are scarcely apparent. The ridge on the side of the centrum, above the vertebrarterial groove, is very similar to the one on the last vertebra. The neural spine is short, small, and low. The post-zygapophyses occupy a slightly more anterior position in this vertebra than in the preceding ones, a change that becomes more marked in the following vertebræ, where the zygapophyses are brought nearer together, in order to facilitate the dorsal flexure of the neck, near its base. The diapophysis is larger and more prominent than in the ninth vertebra, and the pleurapophyses are somewhat longer.

The proportions of the tenth vertebra of *Hesperornis regalis* are fully given in the accompanying measurements from two different specimens:

Measurements of Tenth Vertebra. (No. 1206.)

Length of centrum,	32.0mm
Transverse diameters of anterior articulation of centrum,	12.0–17.5
Vertical diameters of anterior articulation of centrum,	7.0–11.5
Transverse diameters of posterior articulation of centrum,	12.0–16.0
Vertical diameters of posterior articulation of centrum,	7.5–11.0
Transverse diameter of vertebra, across pre-zygapophyses,	34.0
Transverse diameter of vertebra, across post-zygapophyses,	32.0
Greatest diameter of pre-zygapophysis,	14.5
Least diameter of pre-zygapophysis,	8.0
Length of floor of neural canal,	30.0
Length of roof of neural canal,	26.0

Measurements. (No. 1207.)

Length of centrum,	30.0^{mm}
Least diameter of centrum, at base,	10.0
Transverse diameters of anterior articulation of centrum,	13.0–15.5
Vertical diameters of anterior articulation of centrum,	6.5–11.0
Transverse diameters of posterior articulation of centrum,	11.0–15.0
Vertical diameter of posterior articulation of centrum,	8.0
Transverse diameter of vertebra, across pre-zygapophyses,	36.0
Transverse diameter of vertebra, across post-zygapophyses,	32.0
Greatest diameter of pre-zygapophyses,	12.0
Least diameter of pre-zygapophyses,	8.0
Greatest diameter of post-zygapophyses,	13.0
Least diameter of post-zygapophyses,	8.0
Length of floor of neural canal,	29.0
Length of roof of neural canal,	23.0
Transverse diameter of neural canal, at anterior opening,	9.0
Vertical diameter of neural canal, at anterior opening,	5.5
Length of pleurapophysis,	33.0
Length of free portion of pleurapophysis,	23.0
Diameter of pleurapophysis, at base,	7.5
Transverse diameter of lateral foramen,	5.5
Vertical diameter of lateral foramen,	8.0

The Eleventh Vertebra. (Plate IV, figure 2.)

The eleventh vertebra is shorter than the tenth, and appears much shorter when seen from above, owing to the approach of the zygapophyses toward each other, to aid in the flexure of the neck. Its inferior surface is slightly less excavated than in the preceding vertebra, and the anterior descending processes occupy a more anterior position. The diapophysis is here developed into a prominent, tubercular, oblique ridge, running backward, downward and outward, and forming the antero-lateral margin of the vertebral outline, as seen from above. The neural spine is short, and small. The ridge running from the side of the vertebra to the post-zygapophysis rises into a prominent tubercle on each side of the upper surface of the vertebra. The post-zygapophyses are more oblique, and the pleurapophyses rather shorter than in the preceding vertebra.

The size and proportions of the eleventh vertebra of *Hesperornis regalis* are given in the measurements below:

Measurements of Eleventh Vertebra. (No. 1207.)

Length of centrum,	29.0mm
Least diameter of centrum, at base,	9.0
Transverse diameters of anterior articulation of centrum,	14.0–17.0
Vertical diameter of anterior articulation of centrum,	8.0
Transverse diameters of posterior articulation of centrum,	11.0–14.0
Vertical diameters of posterior articulation of centrum,	7.5–12.0
Transverse diameter of vertebra, across pre-zygapophyses,	39.0
Transverse diameter of vertebra, across post-zygapophyses,	32.0
Greatest diameter of pre-zygapophyses,	13.0
Least diameter of pre-zygapophyses,	8.0
Greatest diameter of post-zygapophyses,	13.0
Least diameter of post-zygapophyses,	9.5
Length of floor of neural canal,	27.5
Length of roof of neural canal,	21.0
Transverse diameter of neural canal, at anterior opening,	9.0
Vertical diameter of neural canal, at anterior opening,	5.5
Transverse diameter of neural canal, at posterior opening,	10.0
Total length of pleurapophysis,	30.0
Length of free portion of pleurapophysis,	24.0
Diameter of pleurapophysis, at base,	7.2
Transverse diameter of lateral foramen,	7.0
Vertical diameter of lateral foramen,	8.0

The Twelfth Vertebra. (Plate IV, figure 3.)

The twelfth vertebra is shorter than the eleventh, and the zygapophyses are more approximated. The post-zygapophyses are tubercular above, and the neural spine is rudimentary. The diapophysis is more projecting, but a little less elongated, than in the eleventh vertebra. The lateral foramen for the vertebral artery is larger, and the descending processes stronger. The pleurapophyses are somewhat shorter than in the preceding vertebra.

The dimensions of a nearly perfect twelfth vertebra of *Hesperornis regalis* are given in the table which follows:

Measurements of Twelfth Vertebra. (No. 1207.)

Length of centrum,	24.0mm
Least diameter of centrum, at base,	7.0
Transverse diameters of anterior articulation of centrum,	12.0–14.2
Vertical diameters of anterior articulation of centrum,	7.5– 9.0
Transverse diameter of vertebra, across pre-zygapophyses,	46.5

Transverse diameter of vertebra, across post-zygapophyses,	32.8mm
Greatest diameter of pre-zygapophyses,	13.0
Least diameter of pre-zygapophyses,	10.2
Greatest diameter of post-zygapophyses,	12.2
Least diameter of post-zygapophyses,	10.0
Length of floor of neural canal,	22.0
Length of roof of neural canal,	16.0
Transverse diameter of neural canal, at anterior opening,	9.0
Vertical diameter of neural canal, at anterior opening,	6.6
Transverse diameter of neural canal, at posterior opening,	9.0
Vertical diameter of neural canal, at posterior opening,	6.0
Total length of pleurapophysis,	25.0
Length of free portion of pleurapophysis,	15.0
Diameter of pleurapophysis, at base,	7.0
Transverse diameter of lateral foramen,	10.0
Vertical diameter of lateral foramen,	7.5

The Thirteenth Vertebra. (Plate IV, figure 4.)

The thirteenth vertebra in many respects resembles the twelfth, and is of about the same length. It is rather more excavated at the sides, and has apparently a somewhat larger lateral foramen. The neural spine is but slightly indicated, and in this and the next vertebra reaches its minimum of development. The anterior and posterior zygapophyses approach still nearer to each other, to aid the flexure of the neck, which is greatest at this point. The descending processes are short and stout, and the pleurapophyses much as in the twelfth vertebra.

The figures given below represent the anterior and posterior aspects of the vertebra here described.

Fig. 8.

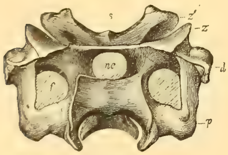

Fig. 9.

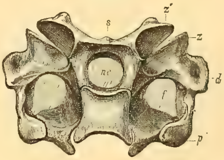

Figure 8. — Thirteenth vertebra of *Hesperornis regalis*, Marsh; (No. 1207), front view; natural size.
Figure 9. — The same vertebra; posterior view. *d.* diapophysis; *p.* parapophysis; *f.* lateral foramen; *nc.* neural canal; *s.* neural spine; *z.* pre-zygapophysis; *z'.* post-zygapophysis.

The dimensions of the thirteenth cervical vertebra in one series of *Hesperornis regalis* are given below:

Measurements of Thirteenth Vertebra. (No. 1207.)

Length of centrum,	25.0^{mm}
Least diameter of centrum, at base,	6.0
Transverse diameters of anterior articulation of centrum,	14.0–15.5
Vertical diameters of anterior articulation of centrum,	7.0–11.0
Transverse diameters of posterior articulation of centrum,	10.0–14.0
Vertical diameters of posterior articulation of centrum,	9.0–13.0
Transverse diameter of vertebra, across pre-zygapophyses,	49.0
Transverse diameter of vertebra, across post-zygapophyses,	31.5
Greatest diameter of pre-zygapophyses,	14.0
Least diameter of pre-zygapophyses,	9.0
Greatest diameter of post-zygapophyses,	12.0
Least diameter of post-zygapophyses,	10.0
Length of floor of neural canal,	25.0
Length of roof of neural canal,	17.0
Transverse diameter of neural canal, at anterior opening,	8.8
Vertical diameter of neural canal, at anterior opening,	7.0
Transverse diameter of neural canal, at posterior opening,	8.5
Vertical diameter of neural canal, at posterior opening,	9.0
Length of hypapophysis below centrum,	9.0

The Fourteenth Vertebra. (Plate IV, figure 5.)

The fourteenth vertebra measures a little less than the thirteenth along the centrum. The zygapophyses are approximated, and the neural spine is rudimentary, as in that vertebra. The lateral foramen appears to have been large, and enclosed by bone, which is in part broken away in the specimen represented in Plate IV. The most conspicuous feature of this vertebra is the great development of the inferior descending processes, or "catapophyses," as they are sometimes called. These are much flattened, with nearly parallel sides, and rounded ends. They arise near together on the antero-lateral lower part of the centrum, and descend obliquely forward, and a little outward. They are somewhat strengthened along their inner faces at the base by a low, broad, rounded ridge, which at its base forms, with its fellow of the opposite side, a pulley-shaped surface. They do not appear to have been quite symmetrical in their distal portions on the opposite sides.

The tubercle below the pre-zygapophysis begins in this vertebra to assume the form of a true diapophysis, or upper transverse process, but presents no articular surface for a rib. The centrum is somewhat excavated at the sides, and the excavation is bounded posteriorly by a rounded ridge. The latter begins near the posterior end of the inferior surface, and runs forward, upward and outward to the base of the diapophysis, on the lower part of which it is continued. Above this ridge, and behind the diapophysis, there is a shallow fossa.

This vertebra would be regarded by some anatomists as the last true cervical. Its dimensions taken from three well preserved specimens of *Hesperornis regalis* are given below:

Measurements of the Fourteenth Vertebra. (No. 1207.)

Length of centrum,	23.0^{mm}
Least diameter of centrum, at base,	7.0
Transverse diameters of anterior articulation of centrum,	12.5–18.0
Vertical diameters of anterior articulation of centrum,	7.0–11.5
Transverse diameters of posterior articulation of centrum,	11.0–15.0
Vertical diameters of posterior articulation of centrum,	8.0–11.0
Transverse diameter of vertebra, across pre-zygapophyses,	58.0
Transverse diameter of vertebra, across post-zygapophyses,	30.0
Diameters of pre-zygapophyses,	12.0–11.0
Diameters of post-zygapophyses,	11.0–11.0
Length of floor of neural canal,	20.5
Length of roof of neural canal,	16.0
Transverse diameter of neural canal, at anterior opening,	9.5
Vertical diameter of neural canal, at anterior opening,	7.0
Transverse diameter of neural canal, at posterior opening,	8.0
Vertical diameter of neural canal, at posterior opening,	7.0
Length of inferior descending processes,	17.0

Measurements. (No. 1476.)

Length of centrum,	24.0^{mm}
Least diameter of centrum,	8.0
Vertical diameter of anterior articulation of centrum,	8.8
Transverse diameters of posterior articulation of centrum,	10.5–15.0
Vertical diameters of posterior articulation of centrum,	9.5–13.0
Length of floor of neural canal,	21.0
Length of roof of neural canal,	16.0
Transverse diameter of neural canal, at anterior opening,	9.0
Vertical diameter of neural canal, at anterior opening,	8.0
Transverse diameter of neural canal, at posterior opening,	9.0
Vertical diameter of neural canal, at posterior opening,	8.0

Measurements of Fourteenth Vertebra. (No. 1477.)

Length of centrum	24.0mm
Transverse diameters of anterior articulation of centrum	13.0–19.0
Vertical diameters of anterior articulation of centrum	7.0–11.5
Transverse diameter of posterior articulation of centrum	11.0
Vertical diameter of posterior articulation of centrum	9.0
Transverse diameter of vertebra, across pre-zygapophyses	39.0
Transverse diameter of vertebra, across post-zygapophyses	33.0
Diameters of pre-zygapophyses	9.0–14.0
Diameters of post-zygapophyses	9.0–13.0
Length of floor of neural canal	22.0
Length of roof of neural canal	15.0
Transverse diameter of neural canal, at anterior opening	9.0
Vertical diameter of neural canal, at anterior opening	8.0
Transverse diameter of neural canal, at posterior opening	8.5
Vertical diameter of neural canal, at posterior opening	9.0
Distance between extremities of anterior and posterior zygapophyses	31.0

The Fifteenth Vertebra. (Plate IV, figure 6.)

The fifteenth vertebra is shorter than the fourteenth, and of peculiar shape. The centrum is deeply excavated at the sides, and its articular faces are transversely elongated. Below, it sends downward and forward a strong prismatic, or elongate pyramidal, hypapophysis, as long as the centrum. The shaft of this process is quadrate in horizontal section, with the anterior face excavated, and bearing a prominent pointed tubercle on its right margin, near the end. This peculiar hypapophysis is bifurcated at the extremity, and the prongs are divergent. They are somewhat unsymmetrical, the left one being slightly longer than the right, and directed a little more outward.

There is no lateral foramen, but a distinct subtriangular facet for the head of the first rib is borne on a short parapophysis, projecting to the anterior margin of the articular face of the centrum, and somewhat below it. The small rib supported by this articular face is represented in Plate VIII, figure 1. The diapophyses are broken off, just below the articular faces for the tubercle of the rib. The zygapophyses are rather less approximate than in the preceding vertebra, and the neural spine, though still rudimentary, is larger.

In addition to the figures of this vertebra given in Plate IV, the accompanying cut shows the posterior aspect of the same specimen.

FIG. 10.

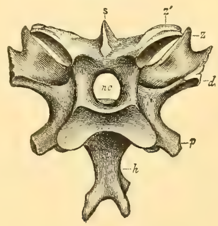

FIGURE 10.—Fifteenth vertebra of *Hesperornis regalis*, Marsh; (No. 1207), posterior view; natural size. *d.* diapophysis; *p.* parapophysis; *h.* hypapophysis; *nc.* neural canal; *s.* neural spine; *z.* pre-zygapophysis; *z'.* post-zygapophysis.

The measurements given below are from three vertebræ, in different individuals of *Hesperornis regalis*.

Measurements of Fifteenth Vertebra. (No. 1207.)

Length of centrum,	22.0mm
Transverse diameters of anterior articulation of centrum,	14.0–22.0
Vertical diameters of anterior articulation of centrum,	6.5– 7.5
Transverse diameters of posterior articulation of centrum,	14.0–19.0
Vertical diameter of posterior articulation of centrum,	13.0
Transverse diameter of vertebra, across pre-zygapophyses,	36.0
Transverse diameter of vertebra, across post-zygapophyses,	33.0
Diameters of pre-zygapophyses,	12.5–12.0
Diameters of post-zygapophyses,	13.0–11.0
Length of floor of neural canal,	22.0
Length of roof of neural canal,	19.0
Transverse diameter of neural canal, at anterior opening,	9.0
Vertical diameter of neural canal, at anterior opening,	7.5
Transverse diameter of neural canal, at posterior opening,	8.0
Vertical diameter of neural canal, at posterior opening,	9.0
Length of hypapophysis,	20.0
Length of bifid portion of hypapophysis,	5.0
Diameters of articulation for head of rib,	5.2– 3.5

Measurements of Fifteenth Vertebra. (No. 1476.)

Length of centrum,	22.0mm
Transverse diameter of anterior articulation of centrum,	22.0
Vertical diameters of anterior articulation of centrum,	6.0– 9.0
Transverse diameters of posterior articulation of centrum,	14.0–19.5
Vertical diameters of posterior articulation of centrum,	8.0–14.0
Transverse diameter of vertebra, across pre-zygapophyses,	36.0
Transverse diameter of vertebra, across parapophyses,	30.5
Diameters of pre-zygapophyses,	10.0–10.5
Length of floor of neural canal,	23.0
Length of roof of neural canal,	20.5
Transverse diameter of neural canal, at anterior opening,	9.0
Vertical diameter of neural canal, at anterior opening,	7.5
Transverse diameter of neural canal, at posterior opening,	8.0
Vertical diameter of neural canal, at posterior opening,	8.0
Diameters of articulation for head of rib,	6.0– 5.0

Measurements. (No. 1477.)

Length of centrum,	22.0mm
Transverse diameters of anterior articulation of centrum,	14.5–22.0
Vertical diameters of anterior articulation of centrum,	6.0– 7.5
Transverse diameters of posterior articulation of centrum,	15.0–22.5
Vertical diameters of posterior articulation of centrum,	8.0–14.5
Transverse diameter of vertebra, across pre-zygapophyses,	34.0
Transverse diameter of vertebra, across post-zygapophyses,	32.5
Diameters of pre-zygapophyses,	9.0–13.0
Diameters of post-zygapophyses,	10.5–14.0
Length of floor of neural canal,	21.0
Length of roof of neural canal,	20.0
Transverse diameter of neural canal, at anterior opening,	10.0
Vertical diameter of neural canal, at anterior opening,	8.0
Length of hypapophysis,	15.0
Diameters of articulation for head of rib,	7.0– 7.5
Distance between extremities of anterior and posterior zygapophyses,	37.5

THE SIXTEENTH VERTEBRA. (Plate IV, figure 7.)

The sixteenth vertebra differs considerably from the fifteenth, and begins to assume the distinctive features of the dorsal vertebræ. It is shorter than the fifteenth, and is the shortest vertebra between the atlas and the sacrum. The centrum is excavated at the sides, and its articular faces are laterally expanded, but of little vertical extent. A strong hypapophysis descends from the inferior surface, rather more vertically than in the preceding vertebra. The articular face for the head of the second rib is sub-oval in outline, with the long axis nearly vertical. The parapophysis supporting it is less prominent than in the fifteenth vertebra, and does not extend in front of, nor below, the anterior articulation of the centrum. The diapophyses are well developed, and somewhat ascending (Plate IV, figure 7, *b*). They are flattened above, and strengthened by a rounded ridge below. This ridge is united with the posterior portion of the diapophysis, but anteriorly they are separated by a rounded groove, which is shallow distally, but continues proximally into a deep excavation under the anterior zygapophysis.

The neural spine is well developed, and tubercular at the top, as in the succeeding vertebra, but of less antero-posterior extent. It is irregularly excavated at the base posteriorly by a fossa for the attachment of a ligament. The post-zygapophyses are less projecting, and somewhat nearer together than in the preceding vertebra.

The posterior aspect of the sixteenth vertebra is well represented in the following figure:

FIG. 11.

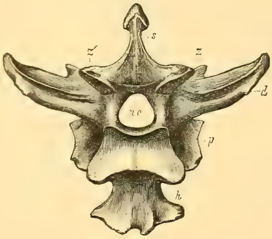

FIGURE 11.—Sixteenth vertebra of *Hesperornis regalis*, Marsh; (No. 1477), posterior view; natural size. *d.* diapophysis; *p.* parapophysis; *h.* hypapophysis; *nc.* neural canal; *s.* neural spine; *z.* pre-zygapophysis; *z'.* post-zygapophysis.

Full measurements of three specimens of the sixteenth vertebra of *Hesperornis regalis* will be found in the following tables:

Measurements of Sixteenth Vertebra. (No. 1207.)

Length of centrum,	18.0mm
Transverse diameters of anterior articulation of centrum,	17.0–24.0
Vertical diameters of anterior articulation of centrum,	5.0–10.5
Transverse diameters of posterior articulation of centrum,	13.0–19.0
Vertical diameters of posterior articulation of centrum,	7.5–14.0
Transverse diameter of vertebra, across pre-zygapophyses,	30.0
Transverse diameter of vertebra, across diapophyses,	61.0
Transverse diameter of vertebra, across post-zygapophyses,	27.0
Diameters of pre-zygapophyses,	13.8–11.0
Diameters of post-zygapophyses,	13.0–10.0
Length of floor of neural canal,	20.0
Length of roof of neural canal,	20.5
Transverse diameter of neural canal, at anterior opening,	10.0
Vertical diameter of neural canal, at anterior opening,	8.0
Transverse diameter of neural canal, at posterior opening,	8.0
Vertical diameter of neural canal, at posterior opening,	8.0
Diameters of articulation for head of rib,	8.8– 6.0
Diameters of articulation for tubercle of rib,	7.0– 4.0
Height of neural spine above floor of neural canal,	29.0
Antero-posterior diameter of neural spine,	12.0

Measurements. (No. 1476.)

Length of centrum,	18.0mm
Transverse diameter of anterior articulation of centrum,	24.0
Vertical diameters of anterior articulation of centrum,	5.0–10.0
Transverse diameters of posterior articulation of centrum,	16.0–20.5
Transverse diameter of vertebra, across pre-zygapophyses,	35.0
Transverse diameter of vertebra, across parapophyses,	33.5
Transverse diameter of vertebra, across diapophyses,	65.0
Transverse diameter of vertebra, across post-zygapophyses,	30.0
Diameters of pre-zygapophyses,	12.5–12.5
Diameters of post-zygapophyses,	10.0–11.5
Length of floor of neural canal,	23.0
Length of roof of neural canal,	21.0
Diameters of articulation for head of rib,	5.8– 8.6

Measurements. (No. 1477.)

Length of centrum,	19.0mm
Transverse diameters of anterior articulation of centrum,	13.0–22.5
Vertical diameters of anterior articulation of centrum,	6.0–10.5
Transverse diameters of posterior articulation of centrum,	15.0–23.0
Vertical diameters of posterior articulation of centrum,	9.0–13.5
Transverse diameter of vertebra, across diapophyses,	46.0
Transverse diameter of vertebra, across parapophyses,	30.0
Diameters of pre-zygapophyses,	10.5–14.0

Diameters of post-zygapophyses,	9.0–11.0
Length of floor of neural canal,	22.0
Length of hypapophysis,	18.0
Diameters of articulation for head of rib,	7.0– 9.0

THE SEVENTEENTH VERTEBRA. (Plate V, figure 1.)

The seventeenth vertebra, the last true cervical, is slightly longer than the sixteenth, and has assumed the more general characters of the dorsal vertebræ. The excavations at the sides of the centrum are rather less pronounced than in the preceding vertebra. The hypapophysis is strong, directed vertically downward, and is expanded at its distal end, as shown in the figure below.

FIG. 12.

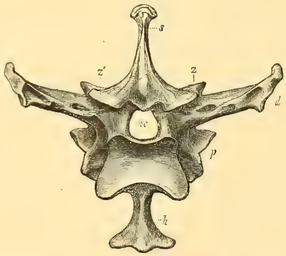

FIGURE 12.—Seventeenth vertebra of *Hesperornis regalis*, Marsh; (No. 1477), posterior view; natural size.

The posterior articulation of the centrum has a greater vertical extent than in the sixteenth vertebra. The articular surface for the head of the rib is larger, and a little more elevated, but not more prominent than in that vertebra. The diapophyses are directed somewhat upward, and supported beneath by a strong rounded ridge, above which as in the preceding vertebra, is a groove, ending in a deep pit below the pre-zygapophysis. The neural spine has a somewhat greater antero-posterior extent, and is higher than in the last vertebra. It is thickened and truncated at the top, as in the succeeding vertebræ. The posterior zygapophyses are less prominent, and nearer together, than in the sixteenth vertebra.

Full measurements of the seventeenth vertebra in *Hesperornis regalis* will be found below:

Measurements of Seventeenth Vertebra. (No. 1207.)

Length of centrum,	20.0mm
Transverse diameters of anterior articulation of centrum,	16.0–27.0
Vertical diameters of anterior articulation of centrum,	6.0–10.0
Transverse diameters of posterior articulation of centrum,	13.5–19.0
Vertical diameters of posterior articulation of centrum,	9.0–13.0
Transverse diameter of vertebra, across pre-zygapophyses,	28.0
Transverse diameter of vertebra, across diapophyses,	64.0
Transverse diameter of vertebra, across post-zygapophyses,	24.0
Diameters of pre-zygapophyses,	12.5– 9.0
Diameters of post-zygapophyses,	9.0– 8.5
Length of floor of neural canal,	22.0
Length of roof of neural canal,	21.0
Transverse diameter of neural canal, at anterior opening,	9.5
Vertical diameter of neural canal, at anterior opening,	7.5
Transverse diameter of neural canal, at posterior opening,	7.5
Vertical diameter of neural canal, at posterior opening,	7.5
Diameters of articulation for head of rib,	8.5– 6.0
Diameter of articulation for tubercle of rib,	7.0
Height of neural spine above floor of neural canal,	29.0
Antero-posterior diameters of neural spine,	13.5–18.5

Measurements. (No. 1476.)

Length of centrum,	22.0mm
Least diameter of centrum,	7.5
Transverse diameters of anterior articulation of centrum,	15.0–21.0
Vertical diameters of anterior articulation of centrum,	5.0–10.5
Transverse diameters of posterior articulation of centrum,	13.0–19.0
Vertical diameters of posterior articulation of centrum,	10.0–14.0
Transverse diameter of vertebra, across pre-zygapophyses,	25.0
Transverse diameter of vertebra, across parapophyses,	21.0
Transverse diameter of vertebra, across post-zygapophyses,	21.5
Diameter of pre-zygapophysis,	12.0
Diameters of post-zygapophyses,	8.5– 9.5
Length of floor of neural canal,	24.0
Length of roof of neural canal,	21.5
Diameter of articulation for head of rib,	6.5

Measurements. (No. 1477.)

Length of centrum,	20.0mm
Transverse diameters of anterior articulation of centrum,	13.5–25.0
Vertical diameters of anterior articulation of centrum,	5.0–10.0
Transverse diameters of posterior articulation of centrum,	15.0–21.0

Vertical diameters of posterior articulation of centrum,	9.0–14.5mm
Transverse diameter of vertebra, across pre-zygapophyses,	29.0
Transverse diameter of vertebra, across diapophyses,	63.0
Transverse diameter of vertebra, across parapophyses,	32.0
Transverse diameter of vertebra, across post-zygapophyses,	27.0
Diameters of pre-zygapophyses,	9.5–11.0
Diameters of post-zygapophyses,	7.5– 9.0
Length of floor of neural canal,	23.0
Length of roof of neural canal,	21.0
Transverse diameter of neural canal, at posterior opening,	8.0
Vertical diameter of neural canal, at posterior opening,	7.5
Length of hypapophysis,	19.0
Diameters of articulation for head of rib,	7.5– 9.0

The Eighteenth, or First Dorsal, Vertebra. (Plate V, figure 2.)

The eighteenth vertebra is a little longer than the seventeenth, and its centrum is stouter, and less excavated at the sides. The hypapophysis descends vertically, is longer than the centrum, and bears an oblique unsymmetrical expansion at the end. The articular face for the head of the rib is a little more elevated than in the preceding vertebra, but no larger. The rib supported by this vertebra is represented in Plate VIII, figure 4, and the adjoining sternal rib, in figure 16. The diapophyses are much as in that vertebra, and are preceded by a deep pit, extending beneath the posterior part of the pre-zygapophysis. A much smaller excavation is situated just behind the base of the diapophysis. The neural spine was somewhat larger than in the preceding vertebra, but is broken off in the specimen figured. (Plate V, figures 2, 2 *c*.) The post-zygapophyses are a little more approximate than in the seventeenth vertebra.

The size of the present vertebra and of its various parts in *Hesperornis regalis* is given in detail below:

Measurements of Eighteenth Vertebra. No. 1207.)

Length of centrum,	22.0mm
Transverse diameters of anterior articulation of centrum,	17.0–26.0
Vertical diameters of anterior articulation of centrum,	7.5–11.0
Transverse diameter of posterior articulation of centrum,	13.0
Vertical diameter of posterior articulation of centrum,	10.0
Transverse diameter of vertebra, across pre-zygapophyses,	25.0
Transverse diameter of vertebra, across diapophyses,	61.5

Transverse diameter of vertebra, across post-zygapophyses,	20.0mm
Diameters of pre-zygapophyses,	9.5– 7.0
Diameters of post-zygapophyses,	9.5– 8.0
Length of floor of neural canal,	23.0
Length of roof of neural canal,	23.0
Transverse diameter of neural canal, at anterior opening,	10.0
Vertical diameter of neural canal, at anterior opening,	7.0
Transverse diameter of neural canal, at posterior opening,	7.0
Vertical diameter of neural canal, at posterior opening,	7.0
Diameters of articulation for head of rib,	8.2– 6.5
Diameter of articulation for tubercle of rib,	6.5

Measurements of Eighteenth Vertebra. (No. 1476.)

Length of centrum,	25.0mm
Least diameter of centrum,	8.0
Transverse diameters of anterior articulation of centrum,	15.0–23.0
Vertical diameters of anterior articulation of centrum,	9.0–11.0
Transverse diameters of posterior articulation of centrum,	13.0–20.0
Vertical diameters of posterior articulation of centrum,	13.0–14.0
Transverse diameter of vertebra, across pre-zygapophyses,	24.0
Transverse diameter of vertebra, across parapophyses,	30.0
Transverse diameter of vertebra, across post-zygapophyses,	19.0
Diameter of pre-zygapophyses,	10.0
Diameters of post-zygapophyses,	8.0– 9.0
Length of floor of neural canal,	25.0
Length of roof of neural canal,	24.5
Transverse diameter of neural canal, at anterior opening,	8.0
Vertical diameter of neural canal, at anterior opening,	6.5
Transverse diameter of neural canal, at posterior opening,	7.0
Vertical diameter of neural canal, at posterior opening,	6.5
Diameters of articulation for head of rib,	7.0– 9.0

Measurements. (No. 1477.)

Length of centrum,	22.0mm
Transverse diameters of anterior articulation of centrum,	17.5–24.0
Vertical diameters of anterior articulation of centrum,	7.0–11.5
Transverse diameters of posterior articulation of centrum,	15.0–22.0
Vertical diameters of posterior articulation of centrum,	10.0–15.0
Transverse diameter of vertebra, across pre-zygapophyses,	23.0
Transverse diameter of vertebra, across parapophyses,	32.0
Diameters of pre-zygapophyses,	7.0– 8.5
Length of floor of neural canal,	23.0
Transverse diameter of neural canal, at anterior opening,	10.0
Vertical diameter of neural canal, at anterior opening,	7.0
Transverse diameter of neural canal, at posterior opening,	8.5
Vertical diameter of neural canal, at posterior opening,	7.0

The Nineteenth Vertebra. (Plate V, figure 3.)

The nineteenth vertebra is slightly longer than the eighteenth, and has a somewhat stouter centrum. The latter is as broadly, but rather less deeply, excavated at the sides, and was provided with a less powerful hypapophysis, which, however, is not preserved in the specimen figured. The articular surface for the head of the rib is a little higher on the side of the vertebra, and supported upon a rather less prominent parapophysis. The diapophyses, as in the preceding vertebra, point somewhat diagonally upward, and backward. They are grooved, especially near the base in front, and preceded by a much smaller and shallower pit than in the eighteenth vertebra. The depression behind the diapophysis is nearly as in that vertebra. The neural spine expands more antero-posteriorly at the top than in the eighteenth vertebra, and there is a somewhat larger fossa behind its base. The zygapophyses are similar to those in that vertebra.

Measurements of the nineteenth vertebra in *Hesperornis regalis*, taken from three specimens, will be found below:

Measurements of Nineteenth Vertebra. (No. 1207.)

Length of centrum,	24.0mm
Transverse diameters of anterior articulation of centrum,	16.5–23.0
Vertical diameters of anterior articulation of centrum,	9.0–12.0
Transverse diameters of posterior articulation of centrum,	13.5–22.0
Vertical diameters of posterior articulation of centrum,	10.0–14.5
Transverse diameter of vertebra, across pre-zygapophyses,	21.0
Transverse diameter of vertebra, across diapophyses,	61.0
Transverse diameter of vertebra, across post-zygapophyses,	19.0
Diameters of pre-zygapophyses,	10.0– 7.0
Diameters of post-zygapophyses,	10.0– 8.0
Length of floor of neural canal,	25.5
Length of roof of neural canal,	23.0
Transverse diameter of neural canal, at anterior opening,	8.0
Vertical diameter of neural canal, at anterior opening,	6.5
Transverse diameter of neural canal, at posterior opening,	7.5
Vertical diameter of neural canal, at posterior opening,	7.0
Diameters of articulation for head of rib,	8.0– 6.2
Diameter of articulation for tubercle of rib,	7.5
Height of neural spine above floor of neural canal,	33.0
Antero-posterior diameter of neural spine,	23.0

Measurements of Nineteenth Vertebra. (No. 1476.)

Length of centrum,	26.5mm
Least diameter of centrum,	8.6
Transverse diameters of anterior articulation of centrum,	15.0–23.0
Vertical diameters of anterior articulation of centrum,	13.0–12.0
Transverse diameters of posterior articulation of centrum,	13.0–14.0
Vertical diameters of posterior articulation of centrum,	13.0–20.0
Transverse diameter of vertebra, across pre-zygapophyses,	21.0
Transverse diameter of vertebra, across parapophyses,	30.5
Transverse diameter of vertebra, across diapophyses,	57.0
Transverse diameter of vertebra, across post-zygapophyses,	19.0
Diameters of pre-zygapophyses,	7.5– 8.0
Diameters of post-zygapophyses,	10.0–10.0
Length of floor of neural canal,	27.0
Length of roof of neural canal,	25.5
Transverse diameter of neural canal, at anterior opening,	9.0
Vertical diameter of neural canal, at anterior opening,	6.0
Transverse diameter of neural canal, at posterior opening,	7.0
Vertical diameter of neural canal, at posterior opening,	6.5
Diameters of articulation for head of rib,	6.0– 7.5
Antero-posterior diameter of neural spine at base,	18.0

Measurements. (No. 1477.)

Length of centrum,	24.0mm
Transverse diameters of anterior articulation of centrum,	17.0–24.0
Vertical diameters of anterior articulation of centrum,	8.5–12.0
Transverse diameters of posterior articulation of centrum,	15.0–24.0
Vertical diameters of posterior articulation of centrum,	12.0–15.0
Transverse diameter of vertebra, across pre-zygapophyses,	20.0
Transverse diameter of vertebra, across parapophyses,	30.0
Transverse diameter of vertebra, across post-zygapophyses,	19.0
Diameters of pre-zygapophyses,	7.0– 8.0
Diameters of post-zygapophyses,	7.0– 8.0
Length of floor of neural canal,	25.0
Length of roof of neural canal,	23.0
Transverse diameter of neural canal, at anterior opening,	9.0
Vertical diameter of neural canal, at anterior opening,	7.0
Transverse diameter of neural canal, at posterior opening,	8.0
Vertical diameter of neural canal, at posterior opening,	6.5
Diameters of articulation for head of rib,	6.2– 8.0
Antero-posterior diameter of neural spine at base,	15.0

The Twentieth Vertebra. (Plate V, figure 4.)

The twentieth vertebra is of about the same length as the nineteenth, or slightly longer, and is somewhat less deeply excavated at the sides.

Its articular faces are perceptibly larger. The hypapophysis is shorter and weaker, and the parapophyses are higher on the side of the vertebra, than in the last. The diapophyses point directly outward, and somewhat upward. They are thin, and scarcely grooved in front, and there is only a rudimentary pit at the base, but behind, there is a more pronounced depression. In number 1476, there is a pit on one side, and none on the other. The neural spine begins to increase slightly in height in this vertebra. Its base is broad, and it expands but little antero-posteriorly toward the top. The fossa at its base behind is large, and most of its anterior border is decidedly roughened for ligamentary attachment. The centrum of this vertebra is constricted, and has a medullary cavity, as shown in the figure below.

FIG. 13.

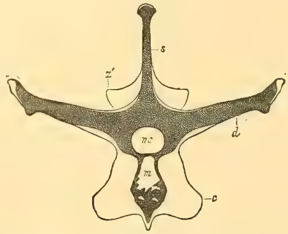

FIGURE 13.—Transverse vertical section of twentieth vertebra; (No. 1477). Front view; natural size. *d.* diapophysis; *c.* outline of posterior end of centrum; *m.* medullary cavity; *nc.* neural canal; *s.* neural spine; *z′.* outline of post-zygapophysis.

The dimensions of two well preserved examples of the twentieth vertebra in *Hesperornis regalis* are as follows:

Measurements of Twentieth Vertebra. (No. 1207.)

Length of centrum,	24.5mm
Transverse diameters of anterior articulation of centrum,	17.0–25.0
Vertical diameters of anterior articulation of centrum,	10.0–12.5
Transverse diameters of posterior articulation of centrum,	14.0–21.5
Vertical diameters of posterior articulation of centrum,	11.5–15.2
Transverse diameter of vertebra, across pre-zygapophyses,	20.0
Transverse diameter of vertebra, across diapophyses,	61.0

Transverse diameter of vertebra, across post-zygapophyses,	21.0mm
Diameters of pre-zygapophyses,	10.0– 8.0
Diameters of post-zygapophyses,	9.5– 9.0
Length of floor of neural canal,	26.0
Length of roof of neural canal,	23.5
Transverse diameter of neural canal, at anterior opening,	8.0
Vertical diameter of neural canal, at anterior opening,	6.0
Transverse diameter of neural canal, at posterior opening,	7.5
Vertical diameter of neural canal, at posterior opening,	6.2
Length of hypapophysis,	5.0
Diameters of articulation for head of rib,	8.0– 6.4
Diameter of articulation for tubercle of rib,	7.0
Height of neural spine above floor of neural canal,	34.0
Antero-posterior diameters of neural spine,	17.5–23.0

Measurements. (No. 1476.)

Length of centrum,	26.0mm
Least transverse diameter of centrum,	9.0
Transverse diameters of anterior articulation of centrum,	14.0–22.0
Vertical diameters of anterior articulation of centrum,	12.5–13.0
Transverse diameters of posterior articulation of centrum,	14.0–22.0
Vertical diameters of posterior articulation of centrum,	13.0–15.5
Transverse diameter of vertebra, across pre-zygapophyses,	20.0
Transverse diameter of vertebra, across parapophyses,	27.5
Transverse diameter of vertebra, across post-zygapophyses,	17.0
Diameters of pre-zygapophyses,	8.5–10.5
Diameters of post-zygapophyses,	8.5–10.0
Length of floor of neural canal,	27.0
Length of roof of neural canal,	23.0
Transverse diameter of neural canal, at anterior opening,	8.0
Vertical diameter of neural canal, at anterior opening,	5.5
Transverse diameter of neural canal, at posterior opening,	8.0
Vertical diameter of neural canal, at posterior opening,	5.5
Diameters of articulation for head of rib,	7.0– 8.0
Antero-posterior diameter of neural spine, at base,	19.0

The Twenty-first Vertebra. (Plate V, figure 5.)

The twenty-first vertebra is slightly longer than the twentieth, and the centrum is stouter, and less excavated at the sides. The hypapophysis is short and weak. The parapophyses are very short, so that the articulation for the head of the rib is scarcely raised above the general surface of the vertebra. It is situated nearly on a level with the neural canal, but extends somewhat below. The diapophyses in this vertebra begin to shorten, though but slightly, and are directed horizontally outward, and somewhat anteriorly. Neither in front of, nor behind their base, is there any proper pit in the vertebra. The neural spine is somewhat higher, but of less antero-posterior extent, than in the preceding vertebra, and the surfaces before and behind near the base are rather more roughened for the attachment of ligaments.

To indicate the range of variation in the vertebræ of *Hesperornis regalis*, measurements of the twenty-first vertebra in five individuals are given in the tables below. Number 1200 is the type of the species.

Measurements of Twenty-first Vertebra. (No. 1200.)

Length of centrum,	24.0mm
Least transverse diameter of centrum,	9.0
Transverse diameters of anterior articulation of centrum,	16.5–23.0
Vertical diameters of anterior articulation of centrum,	9.0–13.0
Transverse diameters of posterior articulation of centrum,	14.8–22.0
Vertical diameters of posterior articulation of centrum,	10.5–16.5
Transverse diameter of vertebra, across pre-zygapophyses,	20.0
Transverse diameter of vertebra, across parapophyses,	27.0
Diameters of pre-zygapophyses,	9.5–8.5
Length of floor of neural canal,	25.5
Length of roof of neural canal,	23.0
Transverse diameter of neural canal, at anterior opening,	7.0
Vertical diameter of neural canal, at anterior opening,	5.0
Transverse diameter of neural canal, at posterior opening,	8.0
Vertical diameter of neural canal, at posterior opening,	6.0
Diameters of articulation for head of rib,	7.0– 8.0

Measurements. (No. 1206.)

Transverse diameters of anterior articulation of centrum,	16.0–24.0mm
Vertical diameters of anterior articulation of centrum,	12.0–13.0
Transverse diameter of vertebra, across pre-zygapophyses,	20.0
Transverse diameter of vertebra, across parapophyses,	25.0
Diameters of anterior zygapophyses,	9.5–11.0
Transverse diameter of neural canal, at anterior opening,	7.5
Vertical diameter of neural canal, at anterior opening,	6.0
Diameters of articulation for head of rib,	6.0– 9.0
Length of hypapophysis,	14.0
Height of neural spine above floor of neural canal,	33.0
Antero-posterior diameters of neural spine,	17.0–21.0

Measurements of Twenty-first Vertebra. (No. 1207.)

Length of centrum	25.0mm
Transverse diameters of anterior articulation of centrum	17.0–27.0
Vertical diameters of anterior articulation of centrum	11.0–14.0
Transverse diameters of posterior articulation of centrum	15.0–23.0
Vertical diameters of posterior articulation of centrum	12.0–17.0
Transverse diameter of vertebra, across pre-zygapophyses	20.5
Transverse diameter of vertebra, across diapophyses	5.7
Transverse diameter of vertebra, across post-zygapophyses	19.0
Diameters of pre-zygapophyses	8.2– 9.8
Diameters of post-zygapophyses	8.8– 8.8
Length of floor of neural canal	26.0
Length of roof of neural canal	23.0
Transverse diameter of neural canal, at anterior opening	8.2
Vertical diameter of neural canal, at anterior opening	6.5
Transverse diameter of neural canal, at posterior opening	8.0
Vertical diameter of neural canal, at posterior opening	6.6
Diameters of articulation for head of rib	8.2– 8.2
Diameter of articulation for tubercle of rib	6.0
Height of neural spine above floor of neural canal	36.0
Antero-posterior diameters of neural spine	15.0–18.0

Measurements. (No. 1476.)

Length of centrum	26.0mm
Least transverse diameter of centrum	11.0
Transverse diameter of anterior articulation of centrum	21.0
Vertical diameter of anterior articulation of centrum	13.0
Transverse diameters of posterior articulation of centrum	15.5–21.0
Vertical diameters of posterior articulation of centrum	12.5–16.0
Transverse diameter of vertebra, across pre-zygapophyses	15.0
Transverse diameter of vertebra, across parapophyses	28.0
Transverse diameter of vertebra, across post-zygapophyses	18.0
Diameters of pre-zygapophyses	8.5–11.0
Diameters of post-zygapophyses	8.0–10.0
Length of floor of neural canal	26.0
Length of roof of neural canal	25.0
Diameters of articulation for head of rib	6.5– 8.0
Antero-posterior diameter of neural spine, at base	17.0

Measurements. (No. 1477.)

Length of centrum	25.0mm
Transverse diameters of anterior articulation of centrum	17.0–24.0
Vertical diameters of anterior articulation of centrum	10.0–15.0
Transverse diameters of posterior articulation of centrum	16.5–25.0
Vertical diameters of posterior articulation of centrum	13.0–17.5
Transverse diameter of vertebra, across pre-zygapophyses	18.0

Transverse diameter of vertebra, across parapophyses,	27.5mm
Length of floor of neural canal,	25.5
Transverse diameter of neural canal, at posterior opening,	8.5
Vertical diameter of neural canal, at posterior opening,	6.6
Diameters of articulation for head of rib,	7.0– 8.0
Height of neural spine above floor of neural canal,	38.0
Antero-posterior diameters of neural spine,	14.0–20.0

THE TWENTY-SECOND VERTEBRA. (Plate V, figure 6.)

The twenty-second vertebra is slightly shorter than the twenty-first. The centrum is stouter, and the articular faces are larger. The hypapophysis is short, and rudimentary. Parapophyses can hardly be said to exist, as the articular surface for the head of the rib is only elevated at its margin above the general surface of the vertebra. The diapophyses are short, and at the end tubercular, as in the next vertebra. They are directed somewhat downward and forward, with indications of a groove and pit in front, as on most of the preceding dorsals. The neural spine is higher than in the preceding vertebræ.

The following tables contain the dimensions of four examples of the twenty-second vertebra of *Hesperornis regalis:*

Measurements of Twenty-second Vertebra. (No. 1200.)

Length of centrum,	24.0mm
Least transverse diameter of centrum,	11.0
Transverse diameters of anterior articulation of centrum,	17.0–24.0
Vertical diameters of anterior articulation of centrum,	10.0–15.0
Transverse diameters of posterior articulation of centrum,	15.5–24.0
Vertical diameters of posterior articulation of centrum,	11.0–18.0
Diameter of vertebra, across pre-zygapophyses,	22.0
Diameter of vertebra, across parapophyses,	27.0
Diameter of vertebra, across post-zygapophyses,	22.0
Diameters of pre-zygapophyses,	9.0– 9.0
Diameters of post-zygapophyses,	9.0–10.0
Length of floor of neural canal,	25.5
Length of roof of neural canal,	21.0
Transverse diameter of neural canal, at anterior opening,	8.0
Vertical diameter of neural canal, at anterior opening,	6.0
Transverse diameter of neural canal, at posterior opening,	8.0
Vertical diameter of neural canal, at posterior opening,	6.5
Diameters of articulation for head of rib,	7.0– 7.5

Measurements of Twenty-second Vertebra. (No. 1207.)

Length of centrum,	24.5mm
Transverse diameters of anterior articulation of centrum,	18.0–27.5
Vertical diameters of anterior articulation of centrum,	10.0–14.5
Transverse diameters of posterior articulation of centrum,	15.0–28.0
Vertical diameters of posterior articulation of centrum,	12.0–18.0
Transverse diameter of vertebra, across pre-zygapophyses,	21.0
Transverse diameter of vertebra, across diapophyses,	50.0
Transverse diameter of vertebra, across post-zygapophyses,	21.0
Diameters of pre-zygapophyses,	10.0– 9.0
Diameters of post-zygapophyses,	10.0– 9.0
Length of floor of neural canal,	26.0
Length of roof of neural canal,	22.0
Transverse diameter of neural canal, at anterior opening,	9.0
Vertical diameter of neural canal, at anterior opening,	7.0
Transverse diameter of neural canal, at posterior opening,	8.0
Vertical diameter of neural canal, at posterior opening,	7.5
Diameters of articulation for head of rib,	8.0– 7.0
Length of hypapophysis,	4.0
Height of neural spine above floor of neural canal,	38.0
Antero-posterior diameters of neural spine,	14.0–18.0

Measurements. (No. 1476.)

Length of centrum,	26.0mm
Least transverse diameter of centrum,	11.4
Transverse diameters of anterior articulation of centrum,	17.0–24.0
Vertical diameters of anterior articulation of centrum,	11.5–14.0
Transverse diameters of posterior articulation of centrum,	16.0–22.0
Vertical diameters of posterior articulation of centrum,	13.0–17.5
Transverse diameter of vertebra, across pre-zygapophyses,	17.0
Transverse diameter of vertebra, across parapophyses,	26.0
Transverse diameter of vertebra, across post-zygapophyses,	18.0
Diameters of pre-zygapophyses,	8.0–11.0
Diameters of post-zygapophyses,	9.5–10.0
Length of floor of neural canal,	23.0
Length of roof of neural canal,	21.5
Diameters of articulation for head of rib,	6.8– 7.3
Antero-posterior diameter of neural spine, at base,	17.0

Measurements. (No. 1477.)

Length of centrum,	26.0mm
Vertical diameter of anterior articulation of centrum,	10.5
Transverse diameters of posterior articulation of centrum,	17.5–26.5
Vertical diameters of posterior articulation of centrum,	13.0–19.0
Diameters of pre-zygapophyses,	8.0– 9.2
Diameters of post-zygapophyses,	8.5– 9.0

Length of floor of neural canal,	26.0mm
Length of roof of neural canal,	22.0
Diameters of articulation for head of rib,	6.5– 7.5
Length of hypapophysis,	5.0

The Twenty-third Vertebra. (Plate V, figure 7.)

The twenty-third, or last free dorsal, vertebra differs little from the twenty-second, except in the diapophyses. The centrum is stouter, and somewhat flattened below, with no hypapophysis. The articular faces are larger than in the twenty-second vertebra. The diapophyses are short, tubercular, and directed strongly forward. The capitular surface is not quite as high on the side of the vertebra, hardly reaching above the middle of the neural canal. The neural spine is slightly higher, but of less antero-posterior extent than in the twenty-second vertebra. It is flattened and roughened, before and behind, for ligamentary attachment. The roughness extends much above the middle of the spine anteriorly, but not so far above posteriorly, where it is surmounted by a projecting angle in the outline. In its natural position, this vertebra is almost entirely included between the anterior projecting portions of the ilia.

The following measurements are taken from three vertebræ of *Hesperornis regalis*, all in excellent preservation, from different skeletons, found in the same geological horizon:

Measurements of Twenty-third Vertebra. (No. 1206.)

Length of centrum,	25.5mm
Transverse diameters of anterior articulation of centrum,	18.5–25.0
Vertical diameters of anterior articulation of centrum,	11.0–15.0
Transverse diameter of posterior articulation of centrum,	26.0
Vertical diameters of posterior articulation of centrum,	12.0–17.0
Transverse diameter of vertebra, across pre-zygapophyses,	18.0
Diameters of pre-zygapophyses,	9.0–10.5
Diameters of post-zygapophyses,	10.0–12.0
Length of floor of neural canal,	26.0
Transverse diameter of neural canal, at anterior opening,	6.5
Vertical diameter of neural canal, at anterior opening,	6.5
Diameters of articulation for head of rib,	6.0– 6.0
Height of neural spine above floor of neural canal,	35.0
Antero-posterior diameters of neural spine,	15.0–17.0
Least transverse diameter of centrum,	14.0

Measurements of Twenty-third Vertebra. (No. 1207.)

Length of centrum,	24.0mm
Transverse diameters of anterior articulation of centrum,	18.0–25.0
Vertical diameters of anterior articulation of centrum,	11.0–17.0
Transverse diameters of posterior articulation of centrum,	17.0–26.0
Vertical diameter of posterior articulation of centrum,	16.0
Transverse diameter of vertebra, across pre-zygapophyses,	21.0
Transverse diameter of vertebra, across diapophyses,	40.0
Transverse diameter of vertebra, across post-zygapophyses,	21.0
Diameters of pre-zygapophyses,	9.0–10.5
Diameters of post-zygapophyses,	11.0– 8.0
Length of floor of neural canal,	24.0
Length of roof of neural canal,	20.0
Transverse diameter of neural canal, at anterior opening,	9.5
Vertical diameter of neural canal, at anterior opening,	7.5
Transverse diameter of neural canal, at posterior opening,	10.0
Vertical diameter of neural canal, at posterior opening,	8.0
Diameters of articulation for head of rib,	7.0– 6.0
Height of neural spine above floor of neural canal,	40.0
Antero-posterior diameters of neural spine,	13.0–18.0

Measurements. (No. 1477.)

Length of centrum,	25.0mm
Transverse diameter of anterior articulation of centrum,	19.5
Vertical diameters of anterior articulation of centrum,	11.0–17.5
Transverse diameters of posterior articulation of centrum,	18.0–26.0
Vertical diameters of posterior articulation of centrum,	13.5–18.5
Transverse diameter of vertebra, across parapophyses,	32.0
Diameters of pre-zygapophyses,	8.0–10.0
Length of floor of neural canal,	25.0
Diameters of articulation for head of rib,	6.6– 7.2
Least transverse diameter of centrum,	15.8

CHAPTER IV.

THE SHOULDER GIRDLE AND RIBS OF HESPERORNIS.

(Plates VI–IX and XX.)

THE scapular arch of *Hesperornis* presents several very interesting features, and shows a wide divergence from the normal type in existing aquatic birds. Viewed as a whole, it has but little functional importance, and indicates a degradation of structure before unknown in this group of birds. It throws much light, however, on the past and present forms of flightless birds, both the denizens of land and of water. Its contrast with the powerful pelvic arch is especially noteworthy.

In its more important characters, the shoulder girdle of this genus shows an approach to that of the *Ratitæ*, or birds allied to the Ostrich. Some of these characters hint at reptilian affinities, while others are merely adaptive, and connected directly with the lack of wings. The most marked points of resemblance to Struthious birds, in this part of the skeleton, are the following:

1. The sternum is devoid of a keel.

2. The long axes of the adjacent parts of the scapula and coracoid are parallel, or identical.

These two most striking features are especially characteristic of the *Ratitæ*, according to Huxley, in the memoir already cited.[1]

[1] Proceedings Zoological Society, 1867, p. 418.

The cut given below will make plain these points in the scapular arch.

FIG. 14.

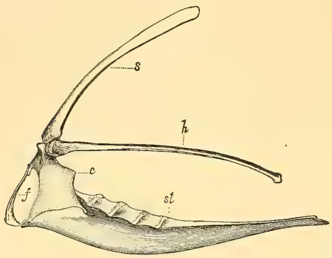

FIGURE 14.—Scapular arch of *Hesperornis regalis*, Marsh; side view; one-half natural size. *s.* scapula; *h.* humerus; *f.* clavicle, or furculum; *c.* coracoid; *st.* sternum.

THE SCAPULA.

(Plate VI, figure 7, and Plate VII, figures 5–7.)

The scapula in *Hesperornis* is a small, slender bone, somewhat curved, and of nearly equal width throughout its entire length. It is thickened at its proximal end, and transversely truncated, the outline of the extremity being subtrihedral. This extremity shows two articular facets, a small inner one for union with the coracoid, and a larger triangular one, forming the scapular portion of the glenoidal fossa. There is no acromial process. The shaft is nearly of uniform width, and its outer surface is convex, both fore and aft and transversely. The inner surface is concave longitudinally. The distal half gradually expands, and the end is thin, and spatulate. In its natural position in the skeleton, the scapula was nearly horizontal, with its posterior extremity somewhat depressed, and incurved.

The dimensions of the scapula in *Hesperornis regalis* are as follows:

Measurements of Scapula. (No. 1476.)

Length of scapula,	135.0^{mm}
Greatest diameter of proximal end,	12.0
Transverse diameter of proximal end,	9.0
Vertical diameter of glenoid articulation,	8.0
Least vertical diameter of shaft,	7.0
Width of distal end (approximate),	10.0

The Coracoid.

(Plate VI, figures 4–6, and Plate VII, figure 4.)

The coracoid of *Hesperornis* is quite small, and somewhat resembles the same bone in certain of the *Ratitæ.* It is short, thin, and widely expanded at the lower end, the whole bone being somewhat triangular in outline, when viewed from the front. The superior extremity has an articular head, with a facet on the inner side for the scapula, and a larger one, looking backward, downward, and outward, for the head of the humerus. A small compressed process extends above the articulation on the inner side. There is a long decurved process extending forward, inward, and downward, to support the upper end of the clavicle (Plate VIII, figure 8). Below the clavicular process, the bone is very thin, and emarginate. There is a sub-clavicular foramen through the shaft of the bone, a short distance below the articular head. The posterior margin sends out a wide, thin process, the extremity of which forms an obtuse angle somewhat above the middle of the bone.

The lower end of the coracoid has, along its whole border, an articular face for union with the sternum. This extremity is nearly straight, at right angles to the axis of the bone; but the anterior third is excavated, so that the outline here is concave. This portion of the lower border is much thinner than the posterior two-thirds.

The following measurements give the size of the coracoid in two individuals of *Hesperornis regalis :*

Measurements of Coracoid. (No. 1206.)

Length, from scapular to sternal articulation,	54.0mm
Greatest diameter of scapular and humeral articulation,	13.0
Least diameter of scapular and humeral articulation,	6.0
Greatest diameter of sternal end,	49.0
Transverse diameter of sternal end,	2.5

Measurements. (No. 1207.)

Length, from scapular to sternal articulation,	55.0mm
Greatest diameter of scapular and humeral articulation,	12.0
Least diameter of scapular and humeral articulation,	3.4
Transverse diameter of sternal end,	3.0

The Sternum. (Plates VI–VIII.)

The sternum in *Hesperornis* somewhat resembles in general form the corresponding bone in the genus *Uria*, but in other respects is more like that in the *Ratitæ*. It is thin and weak, and entirely without a keel. It is expanded in front, especially between the costal processes, and has two deep grooves for the reception of the coracoids. These grooves are placed obliquely, converging anteriorly, and are widely separated from each other. The sternum has a rounded mesial projection in front, which is somewhat thickened, but there is no true manubrium.

A comparison of the keelless sternum of *Hesperornis*, represented in Plate VIII, figure 6, with that of one of the *Ratitæ*, for example, the Emeu, as shown below, will make clear the resemblance in this part of the structure between these two types.

Fig. 15.

Figure 15.—Sternum of Emeu (*Dromæus Novæ Hollandiæ*, Latham); front view; one-half natural size. *a.* costal process; *b.* surface for articulation of sternal ribs; *c.* groove for left coracoid.

The sides of the sternum in *Hesperornis* are concave in outline, and in *Hesperornis regalis*, there are four articular projections on each side for the attachment of sternal ribs. These processes are all on the anterior half of the sternum. Behind these, the lateral margins are nearly parallel. The posterior end of the sternum is quite thin, and had two shallow emarginations. In *Hesperornis crassipes* (Plate VII), the sternum represented is nearly perfect, and in this species there are five articular faces on each side, for the sternal ribs. The posterior margin in the same species is less excavated than in *Hesperornis regalis*.

The measurements which follow are taken from the sternum of *Hesperornis regalis* (number 1206), and that of *Hesperornis crassipes* (number 1474).

Measurements of Sternum (*Hesperornis regalis.* No. 1206.)

Total length (approximate),	200.0^{mm}
Extent of articulations for ribs,	47.0
Diameter of first articulation for a rib,	13.0
Diameter of second articulation for a rib,	13.0
Diameter of third articulation for a rib,	13.0
Diameter of fourth articulation for a rib,	9.0

Measurements (*Hesperornis crassipes.* No. 1474.)

Length of sternum,	196.0^{mm}
Greatest transverse diameter of sternum,	160.0
Transverse diameter of sternum behind articulation for ribs,	86.0
Least transverse diameter of sternum behind articulation for ribs,	77.0
Extent of articulations for ribs,	52.0
Diameter of first articulation for a rib,	13.0
Diameter of second articulation for a rib,	12.0
Diameter of third articulation for a rib,	12.0
Diameter of fourth articulation for a rib,	12.0
Diameter of fifth articulation for a rib,	9.0
Extent of lateral margin beyond last articulation,	92.0

The Clavicles. (Plates VII–VIII.)

The clavicles of *Hesperornis* are separate, and are unlike those in any recent adult birds, although they strongly resemble the corresponding bones in some embryonic forms. The upper extremity is slender, and was united by ligament with the clavicular process of the coracoid. The shaft of the bone is much curved, and gradually expands below to the end, which is depressed, and transversely truncated. The extremity has an articular face for union with its fellow on the median line, and the two were evidently united by cartilage, and attached to the manubrial part of the sternum. The position of the clavicles in the skeleton is shown in the cut on page 58 (figure 14), and also in Plate VIII, figure 8, *cl.*

The measurements of two clavicles in *Hesperornis regalis*, (numbers 1206 and 1207), and one also of *Hesperornis crassipes*, (number 1474), are as follows:

Measurements of Clavicle. (No. 1206.)

Distance in direct line between the ends,	78.0mm
Transverse diameter of upper extremity,	2.0
Greatest diameter of lower extremity,	15.0
Least diameter of lower extremity,	5.0

Measurements. (No. 1207.)

Greatest diameter of lower extremity,	15.0mm
Least diameter of lower extremity,	5.5

Measurements. (*Hesperornis crassipes*, No. 1474.)

Distance in direct line between the ends (approximate),	80.0mm
Transverse diameter of upper extremity,	3.0
Greatest diameter of lower extremity,	12.0
Least diameter of lower extremity,	5.0

The Humerus. (Plate VIII, figures 1–4.)

The wings of *Hesperornis* were represented by the humerus alone, and this was rudimentary. The remaining bones of the anterior extremity had entirely disappeared, or, if minute remnants of them remained as ossicles, they were loosely attached to the extremity of the humerus by cartilage, and thus have left no trace of their union. In one specimen (number 1206,) the humerus is preserved entire, with most of the scapular arch, and is shown in its natural position, in figure 14, at the beginning of the present chapter, as well as in Plate XX.

The humerus of *Hesperornis* is long and very slender, and somewhat curved downward, especially in the distal half. The head is compressed, and has a convex ovate articulation for insertion into the shallow glenoidal cavity. The shaft is somewhat twisted, and of nearly equal width throughout its entire length. When the humerus is in position, the longer transverse axis of the middle of the shaft is horizontal, or at right angles to the same axis of the head. The shaft is nearly solid, having only a very small medullary cavity. There is no distinct radial or ulnar crest, and no trace of articular facets on the distal extremity.

The principal measurements of the above humerus of *Hesperornis regalis* are as follows:

Measurements of Humerus. (No. 1206.)

Length of humerus,	152.0mm
Greatest diameter of shaft,	7.0
Transverse diameter of shaft,	2.2
Greatest diameter of proximal end,	11.5
Greatest diameter of proximal articulation,	10.5
Transverse diameter of proximal articulation,	5.0
Greatest diameter of distal end,	6.0

The Vertebral Ribs. (Plates IX and XX.)

The ribs of *Hesperornis* present no marked features to distinguish them from those of modern birds. They are composed of dense bone, but some of them contain irregular cavities. The articulated vertebral ribs of *Hesperornis regalis* are nine in number, on each side. The first three of these were attached to the last three cervical vertebræ, and had their distal ends free. The remaining six are all well developed ribs, which were connected by means of the sternal ribs with the sternum.

The First Rib (Plate IX, figure 1) which is free in *Hesperornis regalis* was attached to the fifteenth vertebra, and is quite short. The head (*capitulum*) and tubercle (*tuberculum*) are both well developed, and the branches which support them stand nearly at right angles to each other, the neck of the rib being about twice the length of the tubercular support. The descending part of the rib below the tubercle tapers rapidly, and ends in a sharp point, scarcely below the body of the vertebra.

The Second Rib in this species (Plate IX, figure 2) was supported by the sixteenth vertebra, and is very much larger than the first. The branches sustaining the head and tubercle meet at an angle less than a right angle, and both articular facets are well developed. The shaft of this rib is stout, somewhat curved, and, when in its natural position, it descended nearly perpendicularly, ending in an obtuse free extremity.

The Third Rib (Plate IX, figure 3) is the last free rib, and was supported by the seventeenth, and last cervical, vertebra. It is longer than the preceding one, and, when in position, its shaft stood nearly vertical.

The head and tubercle are very similar to those in the preceding rib, but the tubercular process is shorter and stouter, and more inclined toward the body of the vertebra. The shaft is slender, and tapers gradually below to the extremity, which is obtuse, and somewhat incurved. This rib had a small uncinate process (Plate IX, figure 10), articulated to the posterior margin of its lower third. This process was placed nearly at right angles to the rib, and overlapped the outer surface of the rib which followed.

The Fourth Rib (Plate IX, figure 4), which was attached to the eighteenth, or first dorsal, vertebra, is much larger than the preceding, although its upper portion is very similar. The tubercular facet is less convex, and its supporting process shorter than in the rib last described. The shaft of this rib is more twisted, and flattened. The distal extremity is expanded, and terminates with an articular facet for union with the first sternal rib. The uncinate process (Plate IX, figure 11) is larger and longer than the preceding one. It was directed upward, and backward, and joined the rib from above at an acute angle.

The Fifth Rib (Plate IX, figure 5) is slightly longer than the fourth, and very similar to it. Unfortunately, the articular parts of the upper end of this rib are wanting in the most complete series (number 1206), but its general character is made evident from its position, and connection. The tubercle had a similar position to that of the preceding one, but was shorter, and nearly sessile. The uncinate process on this rib was large (Plate IX, figure 12), and, in position, extended upward and backward over the two following ribs. The distal extremity of this rib is very similar to that of the preceding one.

The Sixth Rib (Plate IX, figure 6) is considerably larger than the fifth, and its shaft is flatter, more twisted, and considerably more curved. The tubercular facet is sessile, and raised but very little above the neck. The uncinate process is large, and spatulate (Plate IX, figure 13), and was directed upward and backward. It is somewhat constricted a short distance above its articular face. The distal end of this rib is expanded, and widest at the extremity, which is abruptly truncated.

The Seventh Rib (Plate IX, figure 7) has a prominent head, placed on a slender neck, and the tubercular facet is merely a flat articular tract on the upper surface of the bone. This rib is considerably longer than the preceding, and its upper half is more curved. The lower half is nearly straight, and is flattened transversely. It supported a large uncinate process, which had a rather slender neck, and an expanded distal half, bent upward at a slight angle with the general axis of the bone (Plate IX, figure 14). The distal extremity of this rib is wider than the shaft, and horizontally truncated.

The Eighth Rib (Plate IX, figure 8) is very similar to the last, but is somewhat longer. The neck is very slender, and the tubercular facet has almost entirely disappeared. At the end of the upper fourth of this rib, there is an abrupt inward curve, and from this point to the lower extremity, the shaft is nearly straight, in the specimen preserved, and in its proportions is very much like that last described. This rib bears a very small uncinate process (Plate IX, figure 15), which is considerably curved upward, and is the last of the series.

The Ninth Rib (Plate IX, figure 9) is of about the same length as the preceding, but much more slender. It has no true tubercular face, and no uncinate process. Its shaft is nearly of equal width throughout its whole extent, and the distal end is not expanded. Its lower extremity is truncated at right angles to the shaft, and roughened for cartilaginous attachment with a slender sternal rib.

The Sternal Ribs. (Plates IX and XX.)

In *Hesperornis regalis*, there are four sternal ribs which articulated directly with each costal border of the sternum, and on this are four well developed processes for the union. Behind these true sternal ribs, were two others, which, as in many recent birds, united together at their lower attenuated extremities, and were thus attached to the preceding sternal rib by cartilage. In *Hesperornis crassipes*, there were five sternal ribs on each side articulating with the sternum.

The first sternal rib of *Hesperornis regalis*, uniting above by the intervention of the fourth vertebral rib with the eighteenth, or first true dorsal vertebra, is short and nearly straight (Plate IX, figure 16). It is obliquely truncated in front, and has an articular face for union with the sternum. The posterior end is expanded, somewhat rounded, and has on its upper posterior angle an articular facet for the vertebral rib which joins it.

The second sternal rib (Plate IX, figure 17) is longer and stouter than the first, and somewhat more curved downward. Its articular faces are similar, but the upper, or posterior, half of the shaft is much more compressed.

The third sternal rib is longer than the second, and somewhat less curved (Plate IX, figure 18). Its distal end is more slender, and the articular face oblique. The proximal, or posterior, portion is much flattened transversely, and the lower margin of this end extends beyond the articulation.

The fourth sternal rib, which united with the seventh vertebral rib, is long and slender, and considerably curved downward (Plate IX, figure 19). Its anterior articular face is oblique, and the adjoining portion of the shaft slender. The posterior extremity is expanded, and projects downward, and backward, below the articular face.

The next sternal rib, the fifth, did not unite directly with the sternum in *Hesperornis regalis*, but with the preceding rib near its base, and hence its anterior extremity has no true articular face. It is long and slender, curved downward throughout its middle portion, and its posterior end is thin and expanded (Plate IX, figure 20). This rib united with the eighth vertebral rib, and, in *Hesperornis crassipes*, it united also independently with the sternum, by a well developed articular tubercle.

The sixth sternal rib, in *Hesperornis regalis*, articulated with the ninth vertebral rib, and, in front, was attached lightly to the sternal rib last described.

In the small number of sternal ribs articulating with the sternum, *Hesperornis* resembles the Struthious birds, rather than the Natatores. The persistent articulation of the uncinate processes with the vertebral ribs is usual in birds incapable of flight, and has been observed in a few others.

The following measurements show the principal dimensions of the vertebral and sternal ribs, and uncinate processes in *Hesperornis regalis*. The length of the vertebral ribs is measured in a straight line, joining their extremities.

Measurements of Vertebral Ribs. (No. 1206.)

	1st.	2d.	3d.	4th.	5th.	6th.	7th.	8th.	9th.
Length, in a straight line,	37.	83.	--	145.	--	172.	190.	209.	--mm
Distance from center of head to center of tubercle,	23.	19.	19.	20.	--	20.	21.	21.	23.
Elevation of tubercle,	10.	10.	8.	7.	--	4.	1.	0.	--
Distance from tubercle to end of rib,	32.	83.	--	141.	--	159.	177.	194.	--
Distance of uncinate process from lower end of rib,			--	31.	35.	40.	52.	75.	

Measurements of Uncinate Processes. (No. 1206.)

	1st.	2d.	3d.	4th.	5th.	6th.
Length,	25.	54.	52.	55.	50.	30.mm
Diameter of articular end,	7.	12.	10.	11.	11.	8.
Least breadth,	5.	11.	9.	8.	6.	5.
Greatest breadth,	12.	15.	14.	15.	13.	8.

Measurements of Sternal Ribs. (No. 1206.)

	1st.	2d.	3d.	4th.	5th.
Length,	--	110.	--	--	--mm
Diameter of proximal articulation,	9.	11.	9.	8.	4.
Least antero-posterior diameter of shaft,	3.	5.	4.	3.	3.
Diameter of distal articulation,	6.	8.	8.	8.	7.
Diameter of distal end,	12.	--	15.	18.	17.

CHAPTER V.

THE PELVIC ARCH OF HESPERORNIS.

(Plates X–XI and XX.)

The pelvic arch of *Hesperornis* exhibits many features of interest, and characters more distinctly reptilian than that of any recent bird. In its general form, the pelvis of *Hesperornis regalis* resembles that of *Podiceps*. It is very long and narrow, as in that genus, and in other diving birds. The acetabulum differs from that in all known birds, in being closed internally by bone, except a foramen that perforates the inner wall, as in the Crocodiles. The ilium, ischium, and pubis, moreover, have their posterior extremities free and distinct. This reptilian character is seen, likewise, in the Emeu, as well as in *Tinamus*, which in other respects also shows affinities with the Ostriches.

The Ilium. (Plates X and XI.)

The ilium is extremely long and narrow. Its superior outline is gently arcuate, and this border joins the dorsal margin of the other ilium on the median line, thus forming a roof-shaped covering over nearly all the sacrum. The pre-acetabular portion of the ilium is only about one-fourth of its entire extent. From the acetabulum forward, the ilia diverge, showing at first, between their upper margins, the neural spines of the vertebræ below, and then, in front, the zygapophyses of the first of the sacral series. The anterior extremity of the ilium is thin, and rounded in outline, the ventral margin extending nearly to the bottom of the first sacral vertebra.

The post-acetabular part of the ilium is very elongate, and its lower border somewhat curved downward. The free extremity, behind the last coössified vertebra, is thin, and turned slightly upward, and outward. On the lower portion of the outer surface, there is a strong ridge, which arises behind the upper part of the anti-trochanter, and sweeps gently downward until it reaches the lower margin of the ilium; whence it rises gradually, and continues backward to nearly opposite the last sacral vertebra. This ridge is shown in Plate X, figure 1, and its prominence in this specimen (number 1206), may have been somewhat increased by pressure, before removal from the matrix.

The acetabulum has a well-defined border, which is nearly circular. Above this, there is a large anti-trochanter, or articular surface to which was applied the neck of the femur. The internal face of the acetabulum was not closed merely by fibrous tissue, as in modern birds, but by bone, which is penetrated by a foramen of moderate size, (Plate XI, figure 1, *af*). The acetabular region of the ilium is strongly coössified with the sacrum, while nearer its extremities the union is less perfect.

THE ISCHIUM. (Plates X and XI.)

The ischium forms part of the acetabulum, and anti-trochanter, and then, contracting rapidly, is continued backward as a long slender bone, which is entirely free at its distal end. Viewed from the side, the upper margin curves downward, nearly parallel with the convex ventral margin of the ilium, while the lower border is very gently arcuate, with the convexity below.

The distal extremity is obtusely pointed, and is somewhat turned upward and outward, terminating nearly opposite the posterior end of the ilium. The anterior half of the free portion is rod-like, and the distal half expands gradually, nearly to the extremity. The outer convex surface of the rod-like portion is continued over the distal half as an obtuse rounded ridge, which extends to the extremity. There are no processes on this bone extending upward toward the ilium, or downward to the pubis.

The following figures represent the pelvic bones of two recent birds, the Emeu and Grebe, which, in this part of the skeleton, also, repeat some of the characters seen in *Hesperornis*.

FIG. 16.

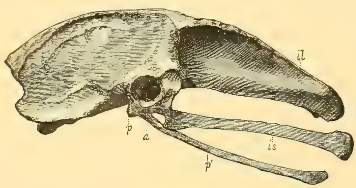

FIGURE 16.—Pelvis of Emeu (*Dromæus Novæ Hollandiæ*, Latham); side view; one-fifth natural size.

FIG. 17.

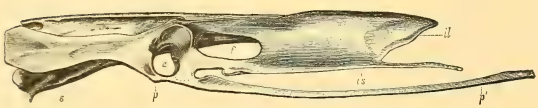

FIGURE 17.—Pelvis of Grebe (*Podiceps occidentalis*, Lawrence); side view; natural size.

FIG. 18.

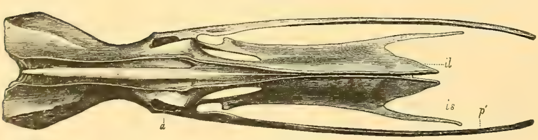

FIGURE 18.—The same pelvis (*Podiceps occidentalis*, Lawrence); seen from above.

The signification of the letters is the same in all the above figures, viz: *a.* acetabulum; *f.* ilio-sciatic foramen; *il.* ilium; *is.* ischium; *p.* pubis; *p'.* post-pubis; *s.* sacrum.

THE PUBIS. (Plates X and XI.)

The bone usually called "pubis" in modern birds, which the writer has shown to be probably the post-pubis, forms, in *Hesperornis*, the lower posterior portion of the acetabulum, and then extends backward as a long, slender, rod-like bone, nearly parallel with the ischium. It is somewhat longer than the ischium, and its distal extremity is truncated at right angles with the shaft. This bone is of nearly equal width throughout its entire length, and sends off no processes or projections toward the ischium, or from its own lower margin.

Viewed from the inner side, the bone above described is seen to pass beneath the acetabular foramen in a strong ridge, and terminate in front of the acetabulum, in an obtusely rounded tuberosity. This process may be seen in some recent birds, more particularly in those that especially use their posterior limbs. It has been called the ilio-pectineal process of the ilium, and is considered an outgrowth of that bone. The writer has shown, however, by a comparison of the pelvic elements in Dinosaurian reptiles and in birds, that this prominence should be regarded rather as probably representing the pubic bone of reptiles.[1]

The relation of the principal pelvic elements to each other in the pelvis of recent birds is illustrated in the figures given on page 71. In the pelves represented on page 73, the remnant of the reptilian pubis is still plainly to be seen, especially in *Geococcyx*. It is not improbable that the retention of this process may be due in part to the habits of certain species, as it seems to be best developed in running birds, and those that especially use the posterior limbs. A similar process is seen in some mammals, where it may serve a like purpose.

The outer surface of the pelvis in *Hesperornis*, especially of the ilium, is marked by delicate vascular impressions, but the bones themselves are dense, and nearly solid.

[1] American Journal of Science and Arts. Vol. xvi, p. 415, Nov., 1878; and vol. xvii, p. 92, Jan., 1879.

The three pelvic bones of *Hesperornis* are firmly coössified, as in existing birds, but the ilium is ankylosed to the sacrum in the acetabular region alone. The true pubic element, or "ilio-pectineal" process, is not larger than in many recent birds, and is much inferior in size to the corresponding protuberance in the pelvis of *Geococcyx*, and of *Tinamus*, shown below.

In these two genera, moreover, another point of resemblance to *Hesperornis* appears in the acetabulum, the inner margin of which is materially narrowed by ossification, although a large perforation remains. In *Hesperornis*, the acetabular foramen is much smaller than in any known bird, and during life was doubtless closed by the round ligament. This reduction of the acetabular opening by ossification strengthens the pelvis at this point, and thus is of service where powerful action of the posterior limbs is required.

Fig. 19.

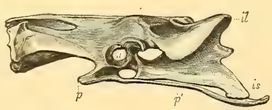

Figure 19.—Pelvis of *Geococcyx Californianus*, Baird; seen from the left; natural size.

Fig. 20.

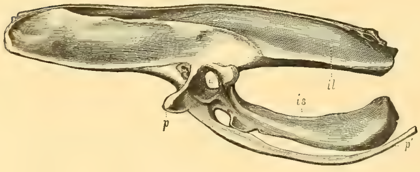

Figure 20.—Pelvis of *Tinamus robustus*, Sclater and Salvin; seen from the left; natural size. *a.* acetabulum; *il.* ilium; *is.* ischium; *p.* pubis; *p'.* postpubis.

The Sacrum. (Plates X and XI.)

The sacrum in *Hesperornis regalis* is very long and narrow, and the vertebræ which compose it are usually well coössified. The number of vertebræ in the true sacrum cannot be accurately determined, but in the ankylosed series, illustrated in plates X and XI, there are fourteen. This series may be conveniently described as the sacrum, although some of the anterior vertebræ are evidently sacro-dorsals, and some of the posterior should be regarded as urosacrals or caudals.

The first vertebra of the series is the twenty-fourth in number, counting from the skull. It is the largest of the sacral series, and is entirely enclosed between the ilia. Its transverse processes bear no articulated rib, but are expanded at the distal end, and abut directly against the ilium. The line of union of this vertebra with the succeeding one is strongly marked, and in one specimen of this species (number 1477), the vertebra is free, and hence it is represented in the figures below, and its measurements are given separately. The junction between the twenty-fifth and twenty-sixth vertebræ can be traced on the lower surface, but behind this the lines of union are obliterated, except two or three near the posterior end of the series.

The figures below represent the twenty-fourth vertebra taken from the series in which it is distinct.

Fig. 21.

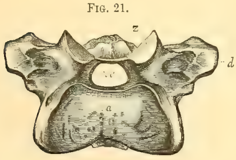

Fig. 22.

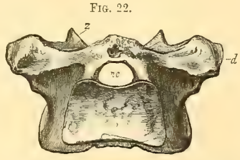

Figure 21.—Twenty-fourth vertebra of *Hesperornis regalis*, Marsh; (No. 1477) front view; natural size.
Figure 22.—The same vertebra; posterior view. The neural spine in this specimen is not preserved.
d. diapophysis; *nc.* neural canal; *z.* pre-zygapophysis.

The neural spines of the sacral vertebræ, and of the others coössified with them, are compressed transversely. With the exception of those of the two last, or urosacral, vertebræ, these spines do not extend above the upper margins of the ilia. These vertebræ are the longest of the series, surpassing in extent even the anterior ones.

Some of the principal dimensions of the pelvic arch of *Hesperornis regalis* are given in the measurements which follow:

Measurements of Pelvic Arch. (No. 1206.)

Length of ilium,	380.0mm
Depth of pelvis, across acetabulum,	74.0
Greatest depth of ilium, behind acetabulum,	52.0
Distance from anterior end of ilium to center of acetabulum,	104.0
Transverse diameter of acetabulum,	24.0
Total extent of coössified sacral vertebræ,	320.0
Length of the first sacral, or twenty-fourth, vertebra,	21.0
Transverse diameter of anterior articulation,	25.0
Vertical diameter of anterior articulation,	14.0
Length of ischium from posterior border of acetabulum,	260.0
Length of pubis and post-pubis,	330.0
Extent of pubis in front of anterior border of acetabulum,	15.0
Extent of post-pubis behind posterior border of acetabulum,	291.0
Vertical diameter of post-pubis, at base,	12.0
Greatest diameter of foramen in acetabulum,	12.0
Least diameter of foramen in acetabulum,	7.0
Height of anti-trochanter above acetabulum,	25.0
Antero-posterior extent of anti-trochanter,	22.0
Greatest distance between upper margins of anti-trochanters,	54.0

Measurements of Twenty-fourth Vertebra. (No. 1477.)

Length of centrum,	22.0mm
Least transverse diameter of centrum,	12.0
Transverse diameter of anterior articulation of centrum,	31.0
Vertical diameters of anterior articulation of centrum,	11.0–17.0
Transverse diameters of posterior articulation of centrum,	20.5–24.0
Vertical diameter of posterior articulation of centrum,	12.0
Transverse diameter of vertebra, across pre-zygapophyses,	20.0
Transverse diameter of vertebra, across diapophyses,	52.0
Diameters of pre-zygapophyses,	7.5–10.5
Length of floor of neural canal,	20.5

CHAPTER VI.

THE CAUDAL VERTEBRÆ OF HESPERORNIS.

(Plates XII and XX.)

THE tail of *Hesperornis regalis* presents some peculiarities of structure not before seen in birds. It was composed, apparently, of twelve vertebræ, and all of these are preserved, with the exception of that portion of the last which formed the extreme end of the tail. The number of caudal vertebræ in *Hesperornis regalis* exceeds those in any known recent bird, with the possible exception of the Great Auk (*Alca impennis*, Linn.), now nearly or quite extinct. The number falls far short, however, of that in the tail of *Archæopteryx*, which also differs essentially in its general structure from the caudal extremity of *Hesperornis*.

The anterior free caudals of *Hesperornis* are short, with high neural spines, and moderate transverse processes. They are opisthocœlian, as in the corresponding vertebræ of *Pavo* and *Geococcyx*. The middle and posterior caudals have very long, and horizontally expanded, transverse processes, which restricted lateral motion, and clearly indicate that the tail was mainly moved vertically, evidently as an aid in diving. The last three or four caudal vertebræ are firmly coössified, forming a flat, horizontal, terminal mass, analogous to, but quite unlike, the plough-share bone of modern birds.

The caudal vertebræ of *Hesperornis* are composed of compact osseous tissue, without pneumatic openings. None of them possess zygapophyses.

The First Caudal Vertebra. (Plate XII, figure 1.)

The first free caudal vertebra, which is the thirty-eighth in number, counting from the skull, is much shorter than the preceding one in the coössified sacral series, but considerably longer than those which follow. In its natural position, it was entirely included between the posterior extremities of the ilia.

The anterior articular face of the centrum is vertically elliptical in outline, and somewhat convex. Immediately behind this, the centrum is constricted, and then expands regularly to the posterior articular face, which is much larger than the one in front, and moderately concave. It is sub-circular in outline, but its transverse diameter exceeds its vertical, and the upper and lower margins are slightly notched on the median line.

The transverse processes extend downward, and slightly outward, and their external surfaces, which are nearly in the same plane as the sides of the neural arch, were attached to the divergent iliac bones by cartilage.

The neural spine was elevated, and much expanded in a fore and aft direction. The neural canal, at its anterior orifice, is much compressed transversely; its posterior outlet is triangular, and very large, indicating a marked expansion of the spinal cord in this region of the vertebral column. This feature was doubtless directly connected with the powerful movements of the tail.

The principal dimensions of the first free caudal, or thirty-eighth vertebra, in *Hesperornis regalis*, are given below:

Measurements of First Caudal Vertebra. (No. 1206.)

Length of centrum,	19.0^{mm}
Least transverse diameter of centrum,	6.0
Transverse diameter of anterior articulation,	6.5
Vertical diameter of anterior articulation,	8.0
Transverse diameter of posterior articulation,	11.0
Vertical diameter of posterior articulation,	8.0
Diameter of vertebra, across transverse processes,	20.0
Extent of transverse processes below centrum,	7.0
Length of floor of neural canal,	17.0
Vertical diameter of anterior opening of neural canal,	4.5
Vertical diameter of posterior opening of neural canal,	7.0

THE SECOND CAUDAL VERTEBRA. (Plate XII, figure 2.)

The second free caudal vertebra is much shorter than the preceding, and its centrum is much more massive. The anterior articular face is somewhat convex, and has a depressed sub-circular outline, with the lower half of the margin excavated. The posterior articular face is nearly flat, but somewhat concave near the centre.

The transverse processes are directed outward and slightly downward, terminating a little below the ventral surface of the centrum. They are longer than those of the preceding vertebra, but have less antero-posterior extent.

The neural spine is stout and elevated, and has its superior extremity expanded into a round knob. The neural canal is large, and vertically oval in outline, and its lower margin cuts into the upper border of the anterior articular face. The posterior margin of the neural arch, when seen from the side, is parallel with that of the posterior articular face of the centrum, and slightly in advance of it.

Measurements of Second Caudal Vertebra. (No. 1206.)

Length of centrum,	15.0mm
Transverse diameter of anterior articulation,	14.0
Vertical diameter of anterior articulation,	10.0
Transverse diameter of posterior articulation,	13.0
Vertical diameter of posterior articulation,	11.0
Diameter of vertebra, across transverse processes,	29.0
Length of transverse processes from centrum,	8.0
Length of floor of neural canal,	12.0
Vertical diameter of anterior opening of neural canal,	5.0
Vertical diameter of posterior opening of neural canal,	7.0
Height of neural spine above centrum,	21.0

THE THIRD CAUDAL VERTEBRA. (Plate XII, figure 3.)

The third caudal vertebra of *Hesperornis regalis*, or the fortieth in the column, is the shortest of the series, with the exception of those at the end of the tail. It is also the first caudal which is entirely behind the ends of the ilia, and its shortness is probably due to the fact that here the flexure of the tail essentially began.

The anterior articular face of the centrum is convex, broadly ovate in outline, and slightly notched above, below the neural canal. The posterior articular face is similar in form, and slightly concave.

The transverse processes are stouter than in the last vertebra, and their distal ends are thickened, and abruptly truncated. The axes of these processes, if continued to the axis of the neural spine, would meet in the neural canal, and form equal angles with it and with each other. The neural spine is elevated and massive, and its posterior margin is nearly vertical. Its apex is bent forward and expanded, and is cordiform in superior outline. The neural arch covers the whole of the centrum, and the canal is large, and vertically ovate in outline.

Measurements of Third Caudal Vertebra. (No. 1200.)

Length of centrum,	12.0mm
Least diameter, below transverse processes,	9.0
Transverse diameter of anterior articulation,	13.0
Vertical diameters of anterior articulation,	10.0–11.0
Transverse diameter of posterior articulation,	12.5
Vertical diameters of posterior articulation,	10.0–11.0
Diameter of vertebra, across transverse processes,	32.0
Length of floor of neural canal,	10.0
Length of roof of neural canal,	8.5
Vertical diameter of anterior opening of neural canal,	5.0
Vertical diameter of posterior opening of neural canal,	5.0
Transverse diameter of posterior opening of neural canal,	4.0
Height of neural spine, above floor of neural canal,	22.0
Transverse diameter of shaft of neural spine,	3.0
Transverse diameter of head of neural spine,	6.0
Antero-posterior diameter of diapophysis, at base,	6.5

The Fourth Caudal Vertebra. (Plate XII, figure 4.)

The fourth caudal vertebra is similar in many respects to the one last described, but the centrum is materially longer. The anterior articular face is considerably smaller than in the third vertebra. It is somewhat concave, and so deeply notched above for the neural canal as to be subcordate in outline. The posterior face is similar to that of the last vertebra, but the transverse processes are stouter, and extend more directly backward. The neural arch, when seen from the front, is very similar to that in the preceding vertebra, but its spine is shorter, and its cordiform apex is broader, and more turned forward.

Measurements of Fourth Caudal Vertebra. (No. 1200.)

Length of centrum,	12.0mm
Least diameter, below transverse processes,	7.5
Transverse diameter of anterior articulation,	11.5
Vertical diameters of anterior articulation,	9.2–11.0
Transverse diameter of posterior articulation,	10.2
Vertical diameters of posterior articulation,	9.5–10.0
Diameter of vertebra, across transverse processes,	32.0
Length of floor of neural canal,	10.5
Length of roof of neural canal,	8.2
Transverse diameter of anterior opening of neural canal,	4.0
Vertical diameter of anterior opening of neural canal,	5.0
Transverse diameter of posterior opening of neural canal,	4.0
Vertical diameter of posterior opening of neural canal,	4.5
Height of neural spine above floor of neural canal,	19.0
Least antero-posterior diameter of transverse processes,	6.5
Transverse diameter of shaft of neural spine,	3.0
Transverse diameter of head of neural spine,	7.0

THE FIFTH CAUDAL VERTEBRA. (Plate XII, figure 5.)

The fifth caudal vertebra of *Hesperornis regalis* is somewhat longer than the fourth, but its centrum is narrower, and its articular faces perceptibly smaller. The general form of the anterior articulation is sub-quadrate in outline, with the corners rounded. It is notched above for the neural canal, and has its lower border also indented on the median line. Both articular facets are somewhat concave.

The transverse processes are much longer than in the last vertebra, and their distal ends are expanded horizontally. The axes of the descending portion of these processes bear the same relation to the axis of the neural spine, as in the third vertebra, the three meeting in the neural canal, and including equal angles with each other. The lower surface of the transverse process extends somewhat below the ventral face of the centrum, and then turns abruptly upward and outward, nearly to the extremity, which is slightly deflected. Seen from above, the ends of these transverse processes appear rounded, and their posterior margins project behind the articulation of the centrum. The ventral surface of the body of this vertebra is concave in a fore and aft direction, and convex transversely.

A small free hypapophysis was articulated with the posterior lower margin of this vertebra, and also with the adjoining margin of the succeeding centrum. This bone resembles somewhat the corresponding part in the Loon, and is clearly homologous with the chevron bones in reptiles. The neural arch of the fifth caudal extends over nearly the whole centrum. The posterior margin of the spine curves backward above the neural canal, and the summit of the spine is directed forward. The neural canal is materially smaller than in the fourth vertebra, but is similar in outline.

Measurements of Fifth Caudal Vertebra. (No. 1200.)

Length of centrum,	13.0mm
Transverse diameter of anterior articulation,	11.0
Vertical diameters of anterior articulation,	9.0–10.2
Transverse diameter of posterior articulation,	11.0
Vertical diameters of posterior articulation,	9.0– 9.5
Length of floor of neural canal,	12.0
Length of roof of neural canal,	9.5
Transverse diameter of neural canal, at anterior opening,	3.2
Vertical diameter of neural canal, at anterior opening,	4.0
Transverse diameter of neural canal, at posterior opening,	4.0
Vertical diameter of neural canal, at posterior opening,	4.0
Diameter of vertebra, across transverse processes,	39.0
Antero-posterior diameter of transverse process, at base,	7.0

The Sixth Caudal Vertebra. (Plate XII, figure 6.)

This vertebra differs considerably from the fifth. Its centrum is longer, and much more slender. The transverse processes are much longer, and so expanded at their distal ends as to greatly restrict lateral motion; which was still further prevented by the same means in the succeeding vertebræ. The under surfaces of the transverse processes have a marked prominence at the point where the outward bend occurs. These prominences extend below the ventral surface of the centrum. A free hypapophysis, very similar to the one already described, articulated with the posterior margin of this vertebra also. The neural arch is mainly upon the anterior half of the centrum. The neural canal is small, and triangular in outline, and the neural spine is of moderate height.

Measurements of Sixth Caudal Vertebra. (No. 1200.)

Length of centrum,	13.5mm
Transverse diameter of anterior articulation,	11.0
Transverse diameter of posterior articulation,	10.0
Length of floor of neural canal,	13.5
Length of roof of neural canal,	10.0
Transverse diameter of neural canal, at anterior opening,	2.5
Vertical diameter of neural canal, at anterior opening,	2.5
Transverse diameter of neural canal, at posterior opening,	2.0
Vertical diameter of neural canal, at posterior opening,	3.8
Antero-posterior diameter of transverse process, at base,	8.0

The Seventh Caudal Vertebra. (Plate XII, figure 7.)

In the seventh caudal vertebra, the centrum becomes still more slender, and the transverse processes reach their greatest lateral expansion. The articular faces of the centrum are concave, and broadly oval in outline. The transverse processes pass off from the posterior half of the centrum, and extend directly outward, and somewhat backward. They are broadly expanded horizontally, and their extremities are abruptly truncated. The hypapophysis, which articulates with the posterior lower margin of this vertebra, has become coössified with the centrum of the succeeding vertebra. The neural arch is placed well forward. The neural canal is much reduced, and the neural spine was weak, and short.

Measurements of Seventh Caudal Vertebra. (No. 1200.)

Length of centrum,	13.0mm
Transverse diameter of anterior articulation,	10.2
Vertical diameter of anterior articulation,	8.0
Transverse diameter of posterior articulation,	8.0
Vertical diameter of posterior articulation,	7.0
Length of floor of neural canal,	14.0
Transverse diameter of neural canal, at anterior opening,	3.0
Vertical diameter of neural canal, at anterior opening,	3.0
Diameter of vertebra, across transverse processes,	59.0
Antero-posterior diameter of transverse process, at base,	8.0

The Eighth Caudal Vertebra. (Plate XII, figure 8.)

The eighth caudal vertebra of *Hesperornis regalis* has the centrum constricted medially, and shorter than that of the seventh. Its coössified hypapophysis was pointed in front, and projected beneath the posterior margin of the preceding vertebra. The transverse processes are elongate, and gradually expand after leaving the vertebra. Their posterior margins are at right angles to the axis of the centrum, and slightly in advance of its posterior articular face. The lower margin of this face was covered by the hypapophysis coössified with the centrum of the following vertebra, and, when in position, the anterior part of this process nearly reached the hypapophysis in front. The neural arch covers the greater part of the centrum, and the neural spine is short, and compressed.

Measurements of Eighth Caudal Vertebra. (No. 1200.)

Length of centrum,	15.2mm
Transverse diameter of anterior articulation,	8.0
Vertical diameter of anterior articulation,	7.0
Vertical diameter of anterior articulation, with hypapophysis,	11.0
Transverse diameter of posterior articulation,	8.5
Vertical diameter of posterior articulation,	6.0
Length of floor of neural canal,	14.5
Transverse diameter of neural canal, at anterior opening,	2.0
Vertical diameter of neural canal, at anterior opening,	3.0
Diameter of vertebra, across transverse processes,	57.0
Antero-posterior diameter of transverse process, at base,	8.0
Transverse diameter of hypapophysis,	8.5
Vertical diameter of hypapophysis,	4.0

The Ninth Caudal Vertebra. (Plate XII, figure 9.)

The ninth caudal vertebra has a low depressed centrum, and enormous transverse processes. The articular faces are nearly plane. The anterior is crescent-shaped, with the angles rounded, and the convexity, which is above, is notched for the neural canal. The ventral surface has a large hypapophysis, coössified with its anterior half, and projecting beneath the preceding vertebra. The transverse processes pass off from the centrum nearly at right angles with the axis (figure 23, page 86), and they are much expanded horizontally. Their distal ends are truncated somewhat obliquely, and the outer posterior angles are on a line with the posterior articular face of the centrum. The neural spine is low, and of considerable antero-posterior extent.

Measurements of Ninth Caudal Vertebra. (No. 1200.)

Length of centrum,	16.0mm
Transverse diameter of anterior articulation,	10.0
Vertical diameter of anterior articulation,	4.0
Transverse diameter of posterior articulation,	9.5
Length of floor of neural canal,	15.5
Transverse diameter of neural canal, at anterior opening,	2.6
Diameter of vertebra, across transverse processes,	56.0
Antero-posterior diameter of transverse process, at base,	10.5
Anterior extent of hypapophysis in front of centrum,	8.0
Transverse diameter of hypapophysis,	6.5
Vertical diameter of hypapophysis,	2.0

The Tenth, Eleventh, and Twelfth Caudal Vertebræ.

(Plate XII, figure 10.)

The remaining caudal vertebræ of *Hesperornis regalis* are coössified into a broad, horizontal, terminal bone, homologous with the *pygostyle*, or plough-share bone, in existing birds. In this terminal mass, the tenth vertebra retains the general form of the ninth, but its transverse processes are less elongate, and less expanded. Its centrum is depressed, and there is a small hypapophysis coössified with its anterior ventral surface. The neural arch remains distinct, and there is a short neural spine. The expanded transverse processes extend outward at right angles to the axis of the centrum, and project but slightly below its under surface. Their extremities are obliquely truncated by the removal of the outer posterior angle.

The eleventh vertebra is much smaller than the tenth, and firmly coössified with it. Its transverse processes are slender, and are directed forward as well as outward. Its hypapophysis is coössified with the centrum, and in part with the posterior surface of the preceding vertebra. The neural spine is very low, but distinct.

The twelfth vertebra, which apparently forms the termination of the tail, is firmly ankylosed with the eleventh, but the greater portion of its centrum has been broken off in the present specimen, and is lost. Its general form is indicated in the restoration of *Hesperornis* in Plate XX.

Measurements of Terminal Caudal Vertebræ. (No. 1200.)

Transverse diameter of anterior articulation of tenth caudal vertebra,	10.0mm
Vertical diameter of anterior articulation,	3.5
Height of neural spine above floor of neural canal,	4.2
Diameter of vertebra, across transverse processes,	48.0
Antero-posterior extent of neural spine,	13.0
Antero-posterior diameter of transverse process, at base,	8.0
Antero-posterior extent on median line of the parts preserved of tenth and following vertebra,	25.0
Diameter of the part preserved of eleventh vertebra, across transverse processes,	27.0

The last six or seven vertebræ in the tail of *Hesperornis regalis* were so interlocked by the expanded transverse processes, as shown in figure 23, below, that very little lateral motion was possible. The hypapophyses, also, of the last two free caudals, would restrict vertical flexure materially, so that the end of the tail would move mainly as a whole. This would give great power, similar to that in the Beaver's tail, or in the flexible blade of an oar.

Fig. 23.

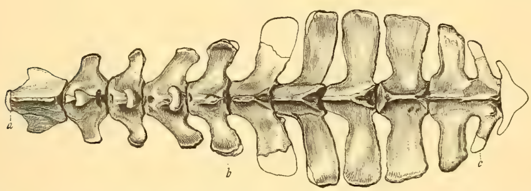

Figure 23.—Caudal vertebræ of *Hesperornis regalis*, Marsh; seen from above, in position; two-thirds natural size. *a.* anterior convex face of first caudal; *b.* transverse process of fifth caudal; *c.* transverse process of eleventh caudal, or middle vertebra of the pygostyle.

CHAPTER VII.

THE LEGS AND FEET OF HESPERORNIS.

(Plates XIII–XX.)

The posterior limbs of *Hesperornis regalis* present an admirable example of adaptive structure. The means of locomotion were confined entirely to these extremities, and the life of *Hesperornis* was probably more completely aquatic than that of any known bird. It may fairly be questioned whether it could even be said to walk on land, although some movement on shore was of course a necessity. Considering the posterior limb as a whole, it will be found a nearly perfect piece of machinery for propulsion through the water. Provision was made for a very powerful backward stroke, followed by a quick recovery, with little loss by resistance, a movement quite analogous to the strong stroke of an oar, feathered on its return.

Among recent birds, we have, in the genus *Podiceps*, the nearest approach to the legs and feet of *Hesperornis*, and the osseous structure of these parts is essentially the same throughout in the two genera. The muscular system, also, of this member must have been very similar in both. In many respects, however, the bones of the posterior limbs of *Hesperornis* present evidences of a more primitive structure than is seen in any recent diving birds.

The Femur. (Plate XIII.)

The femur of *Hesperornis regalis* is remarkably short and stout, more so than in any known bird, recent or fossil. In its general features, it resembles the femur of *Podiceps*, but the shaft is much stouter, and is flattened in an antero-posterior direction. The head is large, and well rounded, and is supported by a short and powerful neck. There is a deep pit on the inner superior surface of the head, for the insertion of the round ligament. The great trochanter is very large, and extends outward a considerable distance beyond the shaft. Its upper surface is below that of the head, and there is a concave depression seen between the two, when the femur is viewed from the front. The whole upper end of the femur, outside of the head, is covered by an articular surface, which plays against the anti-trochanter of the ilium.

The shaft of the femur is somewhat curved, with the convexity forward, and is marked on the posterior, inner, and outer surfaces by strong prominences for the attachment of muscles. The shaft contains no pneumatic foramina, but there is a large medullary cavity, in the bone, as shown in the two sections represented below:

Fig. 24.

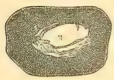

Fig. 25.

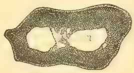

Figure 24.—Transverse section through shaft of femur of *Hesperornis regalis*; (No. 1472), top view; natural size.
Figure 25.—Transverse section of same bone (No. 1489), just above distal articulation. *m.* medullary cavity.

The distal end of the femur is much expanded transversely, and, of the two anterior condyles, the outer is much the larger. The groove between these condyles is shallow, and on a line with the axis of the shaft. On the posterior distal surface, there is a strong obtuse ridge which plays between the upper ends of the tibia and fibula. The ridge passes upward and outward, and ends nearly opposite the outer margin of the shaft.

The femur is one of the most characteristic bones in *Hesperornis regalis*, and to show its variation in the species, measurements are given below from five different individuals, the first, number 1200, being the type:

Measurements of Femur. (No. 1200.)

	Left.	Right.
Length of femur,	99.0mm	99.0mm
Antero-posterior diameter of head of femur,	18.5	18.5
Greatest proximal diameter of shaft,	53.0	52.0
Greatest distal diameter of shaft,	53.0	54.0
Least transverse diameter of shaft,	22.5	22.0
Least antero-posterior diameter of shaft,	18.0	19.2
Greatest diameter of distal articulation,	53.0	53.0
Greatest diameter of tibial articulation,	40.0	40.0
Transverse diameter of fibular articulation,	14.0	14.5
Greatest diameter of inner condyle,	21.0	21.0
Least diameter of inner condyle,	14.0	14.5
Length across the curve of ridge between tibia and fibula,	27.0	25.0

Measurements. (No. 1206.)

Length of left femur,	96.0mm
Diameter of head of femur,	18.0
Transverse diameter of proximal end,	51.0
Transverse diameter of shaft near middle,	22.0
Transverse diameter of distal end,	49.0
Greatest diameter of distal articulation,	49.0
Greatest diameter of tibial articulation,	37.0
Transverse diameter of fibular articulation,	14.0
Greatest diameter of inner condyle,	21.0
Least diameter of inner condyle,	13.0
Length of ridge between tibia and fibula,	25.0

Measurements. (No. 1207.)

	Left.	Right.
Length of femur,	98.5mm	101.0mm
Antero-posterior diameter of head of femur,	19.0	18.5
Transverse diameter of proximal end,	52.0	52.0
Least transverse diameter, near middle,	22.0	22.0
Transverse diameter of distal end,	52.0	53.0
Antero-posterior diameter, near middle,	18.0	18.0
Greatest diameter of distal articulation,	53.0	53.0
Greatest diameter of tibial articulation,	40.0	40.0
Transverse diameter of fibular articulation,	15.0	16.0
Greatest diameter of inner condyle,	21.0	21.0
Least diameter of inner condyle,	13.0	13.0

Measurements of Femur. (No. 1476.)

Length of right femur,	105.0mm
Diameter of head of femur,	19.2
Transverse diameter of proximal end,	54.0
Transverse diameter of shaft near middle,	21.0
Transverse diameter of distal end,	53.0
Vertical diameter, near the middle,	19.0
Greatest diameter of distal articulation,	53.0
Greatest diameter of tibial articulation,	38.0
Transverse diameter of fibular articulation,	15.5
Greatest diameter of inner condyle,	20.0
Least diameter of inner condyle,	13.0
Length of ridge between tibia and fibula,	25.0

Measurements. (No. 1477.)

Length of right femur,	97.0mm
Antero-posterior diameter of head of femur,	19.0
Greatest proximal diameter of shaft,	53.0
Greatest distal diameter of shaft,	51.0
Least transverse diameter of shaft,	23.0
Antero-posterior diameter of shaft, near middle,	20.0
Greatest diameter of distal articulation,	52.0
Greatest diameter of tibial articulation,	38.0
Transverse diameter of fibular articulation,	15.0
Greatest diameter of inner condyle,	20.0
Least diameter of inner condyle,	12.5

Measurements. (*Hesperornis crassipes*, No. 1474.)

Maximum diameter of distal end of right femur,	51.0mm
Transverse diameter of shaft,	21.0
Vertical diameter of shaft,	21.0
Greatest diameter of shaft, at middle,	25.2

The Tibia. (Plates XIV and XX.)

The tibia of *Hesperornis regalis* is very long and powerful, and much the largest bone in the skeleton. In its general features, it most resembles the tibia in the genus *Podiceps*. It is somewhat expanded at its proximal end, where it articulates with the femur, and the articular faces are placed obliquely, and inclined outwards. The inner articular face is much the larger, and is slightly concave. The outer face is somewhat convex, and is only partly separated from the other by a constriction of the articular surface. The outer articulation projects considerably beyond the external margin of the shaft, and is supported below by a strong rounded ridge, which, lower down, passes into the true fibular ridge. There is a strong epicnemial crest on the anterior surface of the proximal end, which, above the articulation, rises into a powerful tuberosity, or cnemial process. To the outer posterior surface of this spine, the patella was attached (Plate XX).

The shaft of the tibia is nearly straight, with its transverse, slightly greater than its fore and aft, diameter. Seen from in front, the outer margin appears slightly concave, and the inner margin convex. The fibular ridge is strongly developed, and can be traced along the proximal three-fourths of the bone. Just below the middle, it disappears for a short distance, being cut off by an oblique groove for the artery, which here passed between the tibia and fibula. In the type specimen, number 1200, the surface of the shaft is marked by delicate vascular impressions, which are imperfectly indicated in Plate XIV, figure 1. In the specimen itself, these impressions are as perfect as in life, and well illustrate the marvelous degree of preservation characteristic of the vertebrate fossils from this geological horizon.

The surface of the tibia shows no pneumatic foramina, but there is a rather large medullary cavity in the shaft. The size of this cavity is shown in the accompanying cuts, which represent transverse sections of the tibia near the middle, and near the distal end.

FIG. 26.

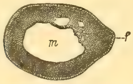

FIG. 27.

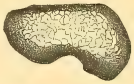

FIGURE 26.—Transverse section through middle part of tibia of *Hesperornis regalis*; (No. 1207), top view; natural size.

FIGURE 27.—Transverse section through same bone; (No. 1491), near distal end; same view; natural size. *m.* medullary cavity; *f.* fibular ridge.

The distal end of the tibia resembles that of the same bone in *Podiceps*, but the inner condyle is here much the larger, and the two are only moderately expanded. The inner condyle extends somewhat below the outer one, but its fore and aft diameter is much less. The transverse diameter of the two condyles, when seen from the front, is sub-equal, and the groove between them does not correspond with the axis of the bone, but is somewhat inclined inward. There is no osseous bridge in front, over the canal through which passes the tendon of the *tibialis anticus* muscle. The absence of this osseous bridge is noteworthy also in *Podiceps*, as it is apparently present in all other known aquatic birds. The groove between the posterior projections of the two condyles is broad, and flat, but narrows rapidly above.

In the tables below will be found detailed measurements of the tibia of *Hesperornis regalis*, in the type, and in one other specimen:

Measurements of Tibia. (No. 1200.)

	Left.	Right.
Length of tibia,	320.0^{mm}	320.0^{mm}
Elevation of cnemial process,	22.0	22.0
Greatest diameter of proximal articular surface,	35.0	38.0
Transverse diameter of inner proximal articular surface,	18.0	20.0
Antero-posterior diameter of inner proximal articular surface,	26.0	
Transverse diameter of outer proximal articular surface,	18.0	19.0
Antero-posterior diameter of outer proximal articular surface,	14.0	15.0
Transverse diameter of shaft below fibular ridge,	23.0	
Antero-posterior diameter of shaft below fibular ridge,	16.0	
Transverse diameter of distal articular surface,	26.0	32.0
Antero-posterior diameter of external condyle,	32.0	
Antero-posterior diameter of internal condyle,	19.0	19.0
Depth of groove between condyles,	9.0	8.0

Measurements. (No. 1476.)

	Left.	Right.
Length of tibia,	335.0^{mm}	325.0^{mm}
Elevation of cnemial process,	21.0	23.0
Greatest diameter of proximal articulation,	33.0	36.0
Transverse diameter of inner proximal articulation,	17.0	18.5
Antero-posterior diameter of inner proximal articulation,	23.0	22.0
Transverse diameter of outer proximal articulation,	15.5	15.5
Antero-posterior diameter of outer proximal articulation,	12.5	
Transverse diameter of shaft below fibular ridge,	21.5	22.0
Antero-posterior diameter of shaft below fibular ridge,	16.5	16.5
Transverse diameter of distal articulation,	26.0	32.5
Antero-posterior diameter of external condyle,	32.5	30.5
Antero-posterior diameter of internal condyle,	20.0	

THE PATELLA. (Plates XV and XX.)

The patella in *Hesperornis regalis* is a large bone, and entirely distinct from the tibia. In its general proportions, it resembles the patella in *Podiceps.* It differs materially, however, in being perforated by a large foramen for the tendon of the *ambiens* muscle, agreeing in this respect with the patella of the Gannet (*Sula bassana*, Briss.). The patella is much compressed transversely. Seen from the side, it is triangular in outline, and the outer surface is concave. When in position, its longer axis was nearly parallel with the axis of the tibia. Its lower extremity bears a large twisted articular face for union with the femur, and the lower posterior half of the inner side is roughened for attachment to the cnemial spine.

The position of the patella in the skeleton is shown in Plate XX. When at rest, it extended in front of the anterior margin of the ilium, and, by its muscular attachments, added greatly to the power of the posterior limbs in swimming. The superior extremity is obtusely pointed, and the outer margin is arcuate.

The following measurements are taken from the patella of three specimens of *Hesperornis regalis*, and one, number 1474, of *Hesperornis crassipes :*

Measurements of Patella. (No. 1207.)

Total length of patella,	98.0mm
Length of posterior side,	87.0
Greatest diameter of articulation,	37.0
Least diameter of articulation	25.0
Distance from foramen to upper end of patella,	71.0
Vertical diameter of foramen,	6.0

Measurements. (No. 1476.)

Total length of patella,	100.0mm
Length of posterior side,	84.0
Greatest diameter of articulation (approximate),	35.0
Least diameter of articulation (approximate),	25.0
Distance from foramen to upper end of patella,	75.0

Measurements of Patella. (No. 1477.)

Total length of patella,	103.0mm
Length of posterior side,	90.0
Greatest diameter of articulation,	41.0
Least diameter of articulation,	27.0
Distance from foramen to upper end of patella,	75.0

Measurements. (*Hesperornis crassipes*, No. 1474.)

Total length of patella,	109.0mm
Length of posterior side,	98.0
Greatest diameter of articulation,	38.0
Least diameter of articulation (approximate),	25.0
Distance from foramen to upper end of patella,	82.0

The Fibula. (Plates XV and XX.)

The fibula of *Hesperornis* agrees essentially with that of *Podiceps* in its general characters. It is about three-fourths of the length of the tibia, and was united to the fibular ridge of that bone only by cartilage. The proximal end is sub-quadrilateral in outline, and presents two articular facets; a large outer one, which is slightly concave, for union with the outer facet of the femur, and a smaller, oblique face on its inner margin, which meets the outer part of the femoral ridge, separating the fibula from the tibia. The distal half of the fibula is slender, and gradually tapers to the pointed lower extremity. This bone appears to be solid throughout, with no cavities, except minute vascular foramina.

The measurements which follow give the main dimensions of the fibula in *Hesperornis regalis*:

Measurements of Fibula. (No. 1200.)

Length of fibula,	240.0mm
Antero-posterior diameter of proximal end,	22.0
Transverse diameters of proximal end,	13–15.0
Greatest diameter of shaft,	17.0

Measurements. (No. 1476.)

Antero-posterior diameter of proximal end of fibula,	23.0mm
Transverse diameter of proximal end,	12.0
Greatest diameter of shaft,	16.0
Antero-posterior diameter of shaft, at same point,	8.5

Measurements. (No. 1477.)

Antero-posterior diameter of proximal end of fibula,	21.0^{mm}
Transverse diameter of proximal end,	13.0
Greatest diameter of shaft,	16.0
Transverse diameter of shaft, at same point,	7.0

THE TARSO-METATARSUS. (Plates XVI and XVII.)

In the tarso-metatarsal bone of *Hesperornis regalis*, we have the extreme modification of a form characteristic of modern diving birds. There were four digits in the foot, the fifth being entirely absent, as in all known birds, recent and fossil. In the adult *Hesperornis*, the second, third, and fourth metatarsals are thoroughly coössified into a stout, transversely compressed bone of moderate length, but in most specimens traces of the sutures remain. The fourth metatarsal element so greatly exceeds the other two in size, that it forms by far the greatest part of the entire tarso-metatarsal bone.

The plane of motion for the whole limb, which above was coincident with the axes of the femur and tibia, was continued below through this element of the tarso-metatarsal, and down through the fourth, or outer, digit, which it supported. In this structure of *Hesperornis*, so admirably adapted for swimming, we have an example of the same kind of specialized modification which has prepared the foot of the Ostrich, among recent birds, and the Horse among mammals, for extreme speed on the land.

The proximal end of the tarso-metatarsal is covered by two articular faces for union with the condyles of the tibia. The outer one is about half the size of the inner, and the two are separated by a prominent obtuse ridge. There is no hypotarsus, and there are no canals, or even grooves, for tendons on the posterior face of the proximal end, as seen in the Divers, and most other birds. This part of the bone is occupied by a rugose triangular tract, covered in life by cartilage, over which the tendons passed. Below this, there is a broad shallow depression, extending rather more than half the way to the distal extremity.

The outer surface of the tarso-metatarsus is slightly concave longitudinally, and convex transversely. On the anterior face, there is a deep groove between the third and fourth metatarsal elements. This groove begins above in the fossa, just beneath the superior articulation, and it becomes deeper throughout its lower half, and ends in the foramen between the third and fourth metatarsals, just above the distal condyles, as in the corresponding bone in *Podiceps,* and many other recent birds. There is a shallow groove, also, between the second and third metatarsals, which commences above, in the fossa already mentioned.

The fourth metatarsal terminates below in a prominent free articular end, somewhat resembling, in general form, the distal end of the tibia. This extremity is truncated, nearly at right angles with the axis of the bone, and it projects considerably below the adjoining articular end of the third metatarsal. The inner condyle is much more prominent than the outer, especially in front.

The third metatarsal element is scarcely one-third the size of the fourth, and is placed somewhat behind, and back of it. The distal extremity is hence oblique, and the inner condyle is smaller than the outer.

The second metatarsal element is still smaller and shorter, but its distal free extremity is but little inferior in size to the third. When the tarso-metatarsal bone is seen from the front, the third element is almost entirely concealed.

The first metatarsal is not coössified with the main shaft of the tarso-metatarsal bone, but is a mere remnant, united to the lower half of the second by cartilage. Its place of union is indicated by an elongated oval indentation, on the inner margin of the second metatarsal, above its articular extremity.

In *Hesperornis crassipes,* the tarso-metatarsal bone presents some interesting points of difference from that of *Hesperornis regalis.* It is stouter and more massive, and on the inner side of the upper half there is a large tuberosity, somewhat similar to the ossified support of a rudimentary spur (Plate XVII). This tuberosity is of equal size on each of the two metatarsals of the type specimen, number 1474. The sutures uniting the three metatarsals are well marked in this species. The large rugosity on the tarso-metatarsal bone is a striking character, and may possibly be an indication of sex.

The tarso-metatarsal of *Hesperornis gracilis* is similar in its general character to the corresponding bone in *Hesperornis regalis*, but is of more slender proportions.

The measurement of the tarso-metatarsal bones of the three known species of *Hesperornis* are given below from the type specimens.

Measurements of Tarso-metatarsus. (*Hesperornis regalis*, No. 1200.)

	Left.	Right.
Length to end of outer articulation,	136.0mm	136.0mm
Length to end of median articulation,	131.0	131.0
Length to end of inner articulation,	116.0	116.0
Antero-posterior diameter of proximal end,	21.0	21.0
Transverse diameter of proximal end,	34.0	34.0
Antero-posterior diameter of inner metatarsal, at the middle,	16.5	16.5
Antero-posterior diameter of outer metatarsal, at the middle,	22.0	22.0
Transverse diameter of shaft, at the middle,	14.0	14.0
Transverse diameter of outer distal articulation,	15.0	15.0
Vertical diameters of outer distal articulation,	12–20.0	12–20.0
Transverse diameter of median distal articulation,	8.0	8.0
Vertical diameter of median distal articulation,	15.0	14.5
Transverse diameter of inner distal articulation,	9.0	9.0
Vertical diameters of inner distal articulation,	12.5–14.0	12.5–14.0

Measurements. (No. 1206.)

	Left.
Length to end of outer articulation,	132.0mm
Length to end of median articulation,	128.0
Length to end of inner articulation,	117.0
Antero-posterior diameter of proximal end,	21.0
Transverse diameter of proximal end,	32.0
Antero-posterior diameter of inner metatarsal, at the middle,	18.0
Antero-posterior diameter of outer metatarsal, at the middle,	22.0
Transverse diameter of shaft, at the middle,	13.5
Transverse diameter of outer distal articulation,	15.0
Vertical diameters of outer distal articulation,	15–12–19.0
Transverse diameter of median distal articulation,	8.0
Vertical diameter of median distal articulation,	15.0
Transverse diameter of inner distal articulation,	9.0
Vertical diameters of inner distal articulation,	12.5–14.0

Measurements of Tarso-metatarsus. (No. 1207.)

	Left.	Right.
Length to end of outer articulation,	mm	136.0mm
Length to end of median articulation,		132.0
Length to end of inner articulation,		118.0
Transverse diameter of proximal end,		33.0
Antero-posterior diameter of inner metatarsal, at the middle,		17.0
Antero-posterior diameter of outer metatarsal, at the middle,		21.0
Transverse diameter of shaft, at middle,		13.0
Transverse diameter of outer distal articulation,		14.0
Vertical diameters of outer distal articulation,	14–10–18	14–10–18.0
Transverse diameter of median distal articulation,		8.0
Vertical diameter of median distal articulation,		15.0
Transverse diameter of inner distal articulation,	8.5	8.5
Vertical diameters of inner distal articulation,	13–15.0	13.5–15.0

Measurements. (No. 1476.)

	Left.	Right.
Length to end of outer articulation,	136.0mm	136.0mm
Length to end of median articulation,	134.0	134.0
Length to end of inner articulation,	120.0	121.0
Antero-posterior diameter of proximal end,	21.0	21.0
Transverse diameter of proximal end,	31.0	31.0
Antero-posterior diameter of inner metatarsal, at the middle,	15.5	15.5
Antero-posterior diameter of outer metatarsal, at the middle,	20.5	20.5
Transverse diameter of shaft, at middle,	12.5	12.5
Transverse diameter of outer distal articulation,	15.0	15.0
Vertical diameters of outer distal articulation,	18.0	13–10–18.0
Transverse diameter of median distal articulation,	8.5	8.5
Vertical diameter of median distal articulation,	16.0	16.0
Transverse diameter of inner distal articulation,		8.0
Vertical diameters of inner distal articulation,	12.5–15.0	13–15.0

Measurements of Tarso-metatarsus. (*Hesperornis crassipes*, No. 1474.)

	Left.	Right.
Length to end of outer articulation,	135.0mm	135.0mm
Length to end of median articulation,		129.0
Length to end of inner articulation,	116.0	116.0
Antero-posterior diameter, at proximal end,	21.0	21.0
Transverse diameter of proximal end,	31.0	32.0
Antero-posterior diameter of inner metatarsal, at the middle,	17.0	17.0
Antero-posterior diameter of outer metatarsal,	22.0	22.0
Transverse diameter of shaft, at the middle,	19.0	19.0
Greatest diameter of shaft, at tuberculation,	30.0	30.0
Transverse diameter of outer distal articulation,	15.0	15.0
Vertical diameter of outer distal articulation,	19.0	19.0
Transverse diameter of median distal articulation,		7.8

Vertical diameter of median distal articulation,	mm	14.4mm
Transverse diameter of inner distal articulation,	9.0	9.0
Vertical diameter of inner distal articulation,	11.5	11.5

Measurements of Tarso-metatarsus. (*Hesperornis gracilis*, No. 1478.)

	Left.	Right.
Length to end of outer articulation,	138.0mm	mm
Length to end of median articulation,	133.0	
Length to end of inner articulation,	117.0	
Antero-posterior diameter of proximal end,	19.0	
Transverse diameter of proximal end,	31.0	
Antero-posterior diameter of inner metatarsal, at the middle,	16.0	
Antero-posterior diameter of outer metatarsal, at the middle,	18.0	
Transverse diameter of shaft, at the middle,	12.0	12.0
Transverse diameter of outer distal articulation,	14.0	14.0
Vertical diameters of outer distal articulation,	12–10–17.0	12–10–16.5
Transverse diameter of median distal articulation,	7.5	7.5
Vertical diameter of median distal articulation,	14.0	14.0
Transverse diameter of inner distal articulation,	7.0	7.0
Vertical diameters of inner distal articulation,	10–12.0	10.5–13.0

Measurements of First, or Hallux, Metatarsal. (*Hesperornis regalis*, No. 1476.)

Length of first metatarsal element,	20.0mm
Greatest diameter of distal end,	8.0
Least diameter of distal end,	3.0
Greatest thickness of shaft,	3.0

The Feet of Hesperornis. (Plate XX.)

The feet of *Hesperornis* resembled more closely those of the genus *Podiceps* than of any other known birds. The number of digits is the same, the number of phalanges in each digit identical, but the proportions of the latter are different, and quite peculiar. In *Podiceps*, and the other Grebes, the outer toe is indeed the longest, but the middle one almost equals it in length and size, while the second is but slightly smaller. In *Hesperornis*, however, the fourth, or outer, toe is the dominant one, being three or four times as powerful as the adjoining middle one, or indeed, as the other three combined. Again, the phalanges in *Podiceps* are very elongate and slender, and the terminal ones spatulate, while, in *Hesperornis*, the phalanges are short and thick, with the terminal ones more or less pointed. The phalanges in *Hesperornis* are, in fact, shorter than in most swimming birds, and in their individual proportions remind one of the toe bones of the Penguins.

The Outer, or Fourth, Digit. (Plates XVIII and XX.)

In describing the phalanges of the feet, it will be convenient to begin with the outer, or main, digit. This was supported by the large distal articulation of the tarso-metatarsal bone, and its general direction was forward, and somewhat outward, nearly in the same plane with the axes of this bone and the tibia.

The first phalanx (Plate XVIII, figure 1) is short and stout, and somewhat compressed transversely, at its proximal extremity. This end has two deeply concave articular facets for union with the condyles of the fourth metatarsal. Of these facets, the inner is larger than the outer, and the articular surface, as a whole, shows an approach to the peculiar joint structure seen in the more distal articulations of the foot. The shaft of this bone is rounded on its dorsal surface, somewhat flattened on the external side, and deeply excavated on the outer inferior margin, a character seen also in the succeeding phalanges.

The distal end of this phalanx is sub-triangular in outline, and entirely covered by the articular surface. The latter consists of a semi-circular, slightly convex, articular facet, which occupies the inner two-thirds of the extremity, while the rest consists of a prominent rounded peg, or tubercle, projecting considerably beyond the remaining surface. This process fits into a corresponding cavity in the proximal end of the succeeding phalanx. The more flattened surface, which partially surrounds this peg, meets a similar surface on the inner side of the same phalanx. This peculiar articulation necessitates rotation (feathering) with flexion, and greatly increases the strength of the joints. This crescent-peg joint, more or less modified, is characteristic of all the principal phalanges of *Hesperornis*, and somewhat the same structure is seen in the genus *Podiceps*.

The second phalanx (Plate XVIII, figure 2) of the fourth digit resembles the first, but is smaller in all its proportions, and considerably more compressed transversely. The articulation of the proximal end is similar to that of the preceding phalanx, but the outer facet has encroached considerably on the inner, which is thus materially narrowed. The excavation on the outer inferior margin of the shaft is deep, and continues to the distal extremity. The tubercle on the distal end is prominent, and its apex is obliquely truncated. The remaining articular surface is less convex than in the phalanx last described.

The third phalanx (Plate XVIII, figure 3) of the fourth digit is almost precisely equal to the second in length, but is more slender in its remaining proportions. It is much more compressed transversely than the second, and the two articular faces of its proximal end are more nearly equal. The tubercle on the distal end is much like that in the preceding phalanx, but the remaining articular surface is smaller, and less convex. The outer inferior excavation of the shaft materially diminishes the weight of this bone.

The fourth phalanx (Plate XVIII, figure 4) of the outer digit is long and slender, and much compressed, especially at its distal end. The outer articular face of the proximal extremity is narrow, but much larger than the inner. The latter is vertically oval in outline, and confined to the superior half of the face. Seen from above, this bone gradually tapers from its proximal to its distal end, but the outer view shows that the sides of the shaft are nearly parallel. The outer inferior surface is slightly concave, and the distal extremity is truncated, nearly at right angles to the axis of the shaft.

The articular face on the lower extremity has almost entirely lost the crescent and peg structure, and resembles the distal articulation of the phalanges in ordinary birds and reptiles. The compression of this bone, and modification of its articulation, permit the partial rotation of the digit, so that when at rest, the flattened extremity was nearly horizontal. A similar structure is seen in the other digits. The same relative position of the toes was maintained in the backward stroke, but in the recovery, the foot was turned edgewise, and the digits followed each other in the same vertical plane, the outer being in advance.

The terminal bone of the fourth digit is wanting in all the specimens of *Hesperornis* yet discovered, but its general form may be conjectured from the corresponding joint of the second toe, which is in a state of good preservation. From this specimen, the outline of the terminal phalanx of the outer digit has been indicated in the restoration of *Hesperornis regalis*, Plate XX.

Measurements of the phalanges preserved of the fourth digit in *Hesperornis regalis*, and *Hesperornis crassipes* will be found below:

Measurements of First Phalanx of Fourth Digit. (*Hesperornis regalis*, No. 1200.)

Length of first phalanx,	44.0mm
Vertical diameter of proximal articulation,	19.0
Transverse diameter of proximal articulation,	16.0
Greatest diameter of shaft,	22.0
Least transverse diameter of shaft,	13.0
Least vertical diameter of shaft,	11.0
Transverse diameter of distal articulation,	15.5
Vertical diameter of distal articulation,	15.5
Diameter of "peg" in distal articulation,	7.5

Measurements. (No. 1206.)

Length of first phalanx,	42.5mm
Vertical diameter of proximal articulation,	18.0
Transverse diameter of proximal articulation,	16.0
Greatest diameter of shaft,	22.0
Greatest transverse diameter of shaft,	17.0
Least transverse diameter of shaft,	13.0
Least vertical diameter of shaft,	10.5
Transverse diameter of distal articulation,	15.0
Vertical diameter of distal articulation,	15.5
Diameter of "peg" in distal articulation,	7.0

Measurements of First Phalanx. (*Hesperornis crassipes*, No. 1474.)

Length of first phalanx,	42.0mm
Vertical diameter of proximal articulation,	18.0
Transverse diameter of proximal articulation,	16.0
Greatest diameter of shaft,	21.5
Least transverse diameter of shaft,	12.5
Least vertical diameter of shaft,	12.0
Transverse diameter of distal articulation,	15.0
Vertical diameter of distal articulation,	15.5
Diameter of "peg" in distal articulation,	7.5

Measurements. (*Hesperornis gracilis*, No. 1478.)

Length of first phalanx,	41.0mm
Vertical diameter of proximal articulation,	17.0
Transverse diameter of proximal articulation,	15.0
Greatest diameter of shaft,	20.0
Least transverse diameter of shaft,	12.5
Least vertical diameter of shaft,	10.0
Transverse diameter of distal articulation,	14.0
Vertical diameter of distal articulation,	15.0
Diameter of "peg" in distal articulation,	6.5

Measurements of Second Phalanx. (*Hesperornis regalis*, No. 1200.)

Length of second phalanx,	39.5mm
Greatest diameter at proximal end,	16.5
Least diameter at proximal end,	13.0
Transverse diameter of proximal articular face,	13.0
Vertical diameter of proximal articular face,	13.0
Least diameter of shaft,	12.0
Greatest diameter at distal end,	15.0
Maximum diameter of distal articular face,	14.0
Transverse diameter of "peg" in distal articular face,	4.6

Measurements. (No. 1206.)

Length of second phalanx,	40.0mm
Greatest diameter of proximal end,	16.5
Least diameter of proximal end,	13.5
Transverse diameter of proximal articular face,	14.0
Vertical diameter of proximal articular face,	15.0
Least diameter of shaft,	8.0
Least fore and aft diameter of shaft,	12.0
Greatest diameter of distal end,	15.0
Greatest diameter of distal articular face,	14.0
Diameter of "peg" in distal articular face,	4.5

Measurements of Second Phalanx. (*Hesperornis crassipes*, No. 1474.)

Length of second phalanx,	38.0mm
Greatest diameter at proximal end,	17.0
Least diameter at proximal end,	13.0
Transverse diameter of proximal articular face,	12.5
Vertical diameter of proximal articular face,	14.5
Least fore and aft diameter of shaft,	12.0
Least diameter of shaft, at distal end,	14.0

Measurements of Third Phalanx. (*Hesperornis regalis*, No. 1200.)

Length of third phalanx,	40.0^{mm}
Greatest diameter of proximal end,	18.0
Least diameter of proximal end,	9.0
Greatest diameter of proximal articular surface,	15.0
Least diameter of proximal articular surface,	8.0
Least fore and aft diameter of shaft,	11.0
Greatest diameter of distal end,	12.5
Least diameter of distal end,	5.5
Greatest diameter of distal articular surface,	10.0
Diameter of "peg" in distal articular surface,	4.8

Measurements. (No. 1206.)

Length of third phalanx,	41.0^{mm}
Greatest diameter of proximal end,	17.0
Least diameter of proximal end,	10.0
Greatest diameter of proximal articular surface,	15.0
Least diameter of proximal articular surface,	10.0
Least fore and aft diameter of shaft,	11.0
Least diameter of shaft,	6.0
Least diameter of distal end,	6.5
Diameter of "peg" in distal articular surface,	3.0

Measurements of Fourth Phalanx. (*Hesperornis regalis*, No. 1200.)

Greatest diameter of proximal end,	14.0^{mm}
Least diameter of proximal end,	7.5
Greatest diameter of proximal articulation,	12.0
Least diameter of proximal articulation,	6.5

The Third Digit. (Plates XVIII and XX.)

The third digit was very much smaller than the fourth, and was supported by the small middle metatarsal element. It consisted of but four phalanges, and, when at rest, was directed forward and slightly inward.

The first phalanx (Plate XVIII, figure 5) is shorter than the first in the outer toe, and much more slender, the whole bone being greatly compressed transversely. The proximal extremity is triangular in outline, and its articular face is divided by a sharp vertical ridge. The shaft is somewhat sigmoid longitudinally, and the articulation of the distal end is divided into two sub-equal portions by a nearly vertical groove.

This articulation shows an approach to the crescent and peg structure, but in its main features resembles the usual phalangeal joint in birds.

The second phalanx in this digit (Plate XVIII, figure 6), is much shorter than the first, somewhat less compressed, but in other respects, very similar. The shaft is nearly straight, and but very slightly excavated on its outer inferior surface.

The third phalanx (Plate XVIII, figure 7) is materially longer than the second, and much more slender. It shows the same tendency toward horizontal flattening, seen in the penultimate phalanx of the outer toe, the advantage of which has been explained above. The proximal articulation is subcircular in outline, and moderately concave. The distal extremity is much compressed.

The fourth, or terminal, phalanx of this digit has not been recovered, but the articulation which supported it, and the shape of the ultimate phalanx of the second toe, indicate its form and general proportions, which are represented in Plate XX.

The principal dimensions of the phalanges in the third digit of *Hesperornis regalis* and *Hesperornis crassipes* are as follows:

Measurements of First Phalanx of Third Digit. (*Hesperornis regalis*, No. 1200.)

Length of first phalanx,	41.0^{mm}
Greatest vertical diameters of proximal end,	18.–19.0
Least vertical diameter of proximal end,	14.0
Transverse diameter of proximal end,	10.0
Greatest vertical diameter of proximal articulation,	14.0
Least vertical diameter of proximal articulation,	12.0
Transverse diameter of proximal articulation,	8.5
Least vertical diameter of shaft,	8.0
Least transverse diameter of shaft,	6.2
Greatest diameter of shaft, at distal end,	10.0
Least diameter of shaft, at distal end,	8.0
Greatest vertical diameters of distal articulation,	8.–10.0
Least vertical diameter of distal articulation,	7.5
Transverse vertical diameter of distal articulation,	7.5

Measurements of First Phalanx of Third Digit. (*Hesperornis crassipes*, No. 1474.)

Length of first phalanx,	39.0mm
Transverse diameter of proximal end,	9.0
Transverse diameter of proximal articulation,	9.0
Least vertical diameters of distal articulation,	8.5–10.0
Least vertical diameter of shaft,	8.0
Least transverse diameter of shaft,	7.0
Greatest diameter of shaft, at distal end,	10.0
Least diameter of shaft, at distal end,	8.5
Least vertical diameter of distal articulation,	7.5
Transverse diameter of distal articulation,	7.5

Measurements of Second Phalanx. (*Hesperornis regalis*, No. 1200.)

Length of second phalanx,	30.0mm
Greatest vertical diameter of proximal end,	14.0
Transverse diameter of proximal end,	8.0
Vertical diameter of proximal articulation,	11.0
Transverse diameter of proximal articulation,	7.0
Least fore and aft diameter of shaft,	7.0
Least minimum diameter of shaft,	4.0
Greatest diameter of distal end,	8.0
Least diameter of distal end,	6.5
Greatest diameter of distal articulation,	7.8
Transverse diameter of distal articulation,	6.0

Measurements of Third Phalanx. (*Hesperornis regalis*, No. 1200.)

Greatest diameter of proximal end,	10.0mm
Least diameter of proximal end,	5.5
Greatest diameter of proximal articulation,	9.0
Least diameter of proximal articulation,	5.0

The Second Digit. (Plates XIX and XX.)

The second digit was much smaller than the third, and composed of three phalanges. It was supported by the short free extremity of the inner element of the tarso-metatarsal bone, and was directed inward and forward.

The proximal end of the first phalanx (Plate XIX, figure 1) was raised above the general plane of the foot. Its proximal end is trihedral in outline, and the distal end also, although the shaft is twisted so that the boundary lines of the two are not parallel. The two extremities are truncated obliquely, making the outer margin of the bone considerably shorter than the inner. The shaft of the bone is depressed, and the outer and inner margins converge distally.

The second phalanx of this digit (Plate XIX, figure 2) is somewhat similar to the first, but shorter, and much more slender. The extremities are less obliquely truncated, and the shaft and distal end are much more flattened. The articular faces of this phalanx, as well as of the others in this digit, admit of considerable rotation, but have the crescent and peg articulation only partially developed.

The terminal phalanx of the second digit (Plate XIX, figure 3) is short, much depressed, and pointed at its distal end. Seen from above, it is wedge-shaped in outline, with the proximal articulation at right angles to the axis of the bone. In its natural position, this phalanx had its superior surface turned more or less outward, and during recovery after the backward stroke it was turned edgewise, so that this face looked entirely outward.

The measurements of the phalanges of the second digit in *Hesperornis regalis*, and *Hesperornis crassipes*, are given in the tables below:

Measurements of First Phalanx of Second Digit. (*Hesperornis regalis*, No. 1206.)

Greatest diameter of proximal end,	14.5mm
Vertical diameter of proximal end,	12.0
Transverse diameter of proximal end,	13.0
Vertical diameter of proximal articulation,	11.0
Transverse diameter of proximal articulation,	11.0

Measurements. (No. 1476.)

Length of first phalanx,	42.0mm
Greatest diameter of proximal end,	15.0
Vertical diameter of proximal end,	13.0
Transverse diameter of proximal end,	13.8
Vertical diameter of proximal articulation,	11.0
Transverse diameter of proximal articulation,	10.2
Least vertical diameter of shaft,	6.5
Least transverse diameter of shaft,	8.5
Greatest vertical diameter of distal end,	9.0
Least vertical diameter of distal end,	8.0
Transverse diameter of distal end,	9.0

Measurements of First Phalanx of Second Digit. (*Hesperornis crassipes*, No. 1474.)

Length of first phalanx,	40.5^{mm}
Greatest diameter of proximal end,	14.5
Vertical diameter of proximal end,	12.5
Transverse diameter of proximal end,	13.0
Vertical diameter of proximal articulation,	12.0
Transverse diameter of proximal articulation,	10.0
Greatest vertical diameter of distal end,	8.5
Least vertical diameter of distal end,	7.5
Transverse diameter of distal end,	8.0

Measurements of Second Phalanx. (*Hesperornis regalis*, No. 1476.)

Length of second phalanx,	41.0^{mm}
Greatest (transverse) diameter of proximal end,	10.0
Vertical diameter of proximal end,	9.0
Transverse diameter of proximal articulation,	9.0
Vertical diameter of proximal articulation,	7.2
Least transverse diameter of shaft,	6.2
Vertical diameter of shaft,	3.6
Transverse diameter of distal end,	7.2
Vertical diameter of distal end,	3.0
Transverse diameter of distal articulation,	6.5
Vertical diameters of distal articulation,	2.5–3.0

Measurements of Third Phalanx. (No. 1476.)

Length of third phalanx,	15.0^{mm}
Transverse diameter of proximal end,	7.0
Vertical diameter of proximal end,	3.3

The First Digit. (Plates XVIII, XIX and XX.)

The metatarsal rudiment of the hallux, or first digit (Plate XIX, figure 4) has already been described. It supported below a first phalanx (Plate XIX, figure 5), much flattened, and of moderate length. The digit was completed by a short, pointed, terminal phalanx (Plate XIX, figure 6), very similar in its general form and proportions to the ungual phalanx of the second digit. The hallux was directed forward and inward, like the first digit of *Colymbus*, and not backward, as in most modern birds. The diminutive size of this digit in *Hesperornis*, and the rounded loose joints between the phalanges show that it was of little service in locomotion.

The following are the principal dimensions of the phalanges of the hallux in *Hesperornis regalis :*

Measurements of First Phalanx of First Digit. (*Hesperornis regalis,* No. 1476.)

Least transverse diameter of first phalanx,	6.0mm
Vertical diameter of shaft,	3.0
Transverse diameter of distal articulation,	6.0
Vertical diameter of distal articulation,	2.0

Measurements of Second Phalanx. (No. 1476.)

Length of second phalanx,	14.0mm
Transverse diameter of proximal end,	7.0
Vertical diameter of proximal end,	3.0
Greatest transverse diameter,	7.6

CHAPTER VIII.

THE RESTORATION OF HESPERORNIS. (Plate XX.)

THE foregoing description of the individual bones of *Hesperornis,* together with the full illustrations given in the accompanying plates, will make clear to anatomists all the important points in the osseous structure of this ancient bird, in many respects the most interesting member of the class yet discovered. With the exception of one or two terminal toe-bones, and the extreme point of the tail, every part of the skeleton is preserved in one or more specimens, and this ample material has been used in the restoration represented in Plate XX. Not a few of the bones were nearly in their natural position, when discovered, and the remainder have been assigned to their appropriate places in the skeleton, after much careful comparison of the fossils with the nearest allied living forms. It is therefore confidently believed that the field of conjecture has been reduced to a minimum in the skeleton as restored.

The restoration of *Hesperornis regalis* in Plate XX represents the skeleton one-half natural size, and in a position which the bird doubtless sometimes assumed when on land, although it is probably more erect than was habitual. On the water, the body was of course more nearly horizontal, the neck more bent, and the legs usually much farther behind.

In the preceding Plates, I–XIX, the bones of *Hesperornis regalis* have been represented in natural size, and the magnitude of the whole bird may be judged from the fact that the skeleton, if extended, would measure about six feet (1.8^{M}) from the point of the bill to the end of the toes. *Hesperornis crassipes* was somewhat larger, and *Hesperornis gracilis*, so far as known, was apparently smaller, and of more delicate proportions. When on land in the position represented in Plate XX, *Hesperornis regalis* would be rather more than three feet in height.

Hesperornis was a typical aquatic bird, and in habit was doubtless very similar to the Loon, although, flight being impossible, its life was probably passed entirely upon the water, except when visiting the shore for the purpose of breeding. The nearest land at that time was the succession of low islands which marked the position of the present Rocky Mountains. In the shallow tropical sea, extending from this land five hundred miles or more to the eastward, and to unknown limits north and south, there was the greatest abundance and variety of fishes, and these doubtless constituted the main food of the present species. *Hesperornis*, as we have seen, was an admirable diver, while the long neck with its capabilities of rapid flexure, and the long slender jaws armed with sharp recurved teeth formed together a perfect instrument for the capture and retention of the most agile fish. As the lower jaws were united in front only by cartilage, as in Serpents, and had on each side a joint which admitted of some motion, the power of swallowing was doubtless equal to almost any emergency.

Having thus shown what the skeleton of *Hesperornis* is, and what its mode of life must have been, it remains to consider the more important question of how the peculiar combination of general and specialized characters manifested in its structure originated. The two most striking features of *Hesperornis* are the teeth, and the limbs, and an inquiry in regard to them first suggests itself.

The teeth of *Hesperornis* may be regarded as a character inherited from a reptilian ancestry. Their strong resemblance to the teeth of reptiles, in form, structure, and succession, is evidence of this, and their method of implantation in a common alveolar groove (Holcodont), conforms strictly to what we have in one well known group of reptiles, exemplified by *Ichthyosaurus*. This method of insertion in the jaw is a primitive dental character, quite different from what we should naturally expect as an accompaniment of the modern style of vertebra, and is a much lower grade than the implantation of the teeth in distinct sockets (Thecodont), a feature characteristic, as we shall see, of another group of Odontornithes, of which *Ichthyornis* is the type. These teeth indicate unmistakably that *Hesperornis* was carnivorous in habit, and doubtless was descended from a long line of rapacious ancestors.

In considering the limbs of *Hesperornis*, two explanations of their peculiar modifications naturally suggest themselves. The rudimentary wings, viewed in the light of modern science, clearly indicate that *Hesperornis* was in this respect a degraded type. The Struthious characters which we have noticed in various parts of the skeleton might be regarded, not as evidence of close relationship, but rather as general reptilian characters, common to the two groups through inheritance from a remote reptilian ancestry. According to this view, the wings may have been gradually lost by disuse, after the aquatic life was assumed. In proportion as the wings diminished, the legs and feet increased in size, for their work increased. This change would be strictly in accordance with the law of compensation, and the well known economy of nature.

We may suppose, moreover, the ancestors of *Hesperornis* to have been at one time on an equality with the Loon, and later with the Penguin, in respect to means of flight and swimming. As the wings slowly diminished in size, first came the loss of flight, while the wings retained, doubtless for a long time, their power of propulsion through the water. As this too became gradually restricted, the legs and feet gained proportionally. The power derived from them, aided indirectly by the tail, in time so predominated, that the wings became entirely aborted, a remnant of the humerus alone remaining.

During the life-history as thus indicated, *Hesperornis* would exemplify in the waters of the Cretaceous period the evolution that has recently taken place in ocean navigation, in the gradual change of the side-wheel steamer into the modern propeller.

Another explanation seems on the whole more reasonable, and more in accordance with the known facts. The Struthious characters, seen in *Hesperornis*, should probably be regarded as evidence of real affinity, and in this case *Hesperornis* would be essentially a carnivorous, swimming Ostrich. The diminutive wings and very large posterior extremities would then have been acquired on land, by the same means that have given similar characters to the *Ratitæ*, and subsequently have been adapted to an aquatic life. Against this view, the carnivorous character of *Hesperornis* would be no valid objection. The long neck and peculiar jaws and teeth would be equally effective in seizing prey on the land, and many of the herbivorous cotemporaries would doubtless have been easy victims. This would be precisely analogous to what we have among the corresponding groups in the Dinosaurs.

There is to-day no evidence that any of the Struthious birds, or their ancestors, ever possessed the power of flight, although this is generally assumed. The case is even stronger with *Hesperornis*, as this genus stands much nearer the ancestral type, both in structure and in time. The absence from the sternum of any trace of a keel is alone strong proof against flight; the peculiar Dinosauroid union of the scapula and coracoid, unlike that of any volant bird or reptile, confirms this; and other testimony bearing in the same direction is not wanting.

All Carinate birds, moreover, so far as known, indicate by their embryology that they have passed through the Struthious, or lower stage; and some of them, *Tinamus*, for instance, still retain one or more of its distinctive characters. There are, indeed, various flightless birds, recently extinct, which do not belong to the Ostrich group, but are truly Carinate in all their essential features. The Dodo *(Didus)*, Solitaire *(Pezophaps)*, *Cnemiornis*, and *Notornis* are well known examples; but these all show in their shoulder-girdle unmistakable traces of the lost power of flight. The characters necessary to volant movements, once attained, would appear never to be completely lost, and this alone seems to furnish a crucial test. When such suggestive indications are wanting in the skeleton, we may fairly challenge any assumption of previous flight.

Although *Hesperornis* may thus, like its Reptilian ancestry, have always been incapable of flight, the anterior limbs may have long continued limited aids to locomotion. Whether used actively in the air, like the wings of the Ostrich, or of young swimming birds, or passively, like the sail-set pinions of a Swan, or later as imperfect paddles, the wings of *Hesperornis* were certainly not well fitted for diving, and hence they gradually became useless, and virtually disappeared. We may imagine among the reasons for the gradual loss of wings, the fact that they were too weak to be of much service under water, while from their position they added greatly to the resistance, especially during rapid diving. To diminish this resistance, they would naturally be applied closely to the side, and from such disuse, would gradually suffer atrophy.

In this great swimming bird, as thus modified, we have presented to us an interesting problem in animal mechanics. The wings may be regarded as wanting, since the remnant of the humerus was attached closely to the side, as in the Apteryx, if not entirely concealed beneath the skin, like a scapula. The locomotion was therefore entirely performed by means of the posterior limbs, a specialization here seen for the first time in aquatic birds, recent or fossil. Those who have observed a Penguin or a Loon swimming beneath the water know what a vigorous use such birds then make of their wings, however useless these members may appear to be on land. Not only do the wings, in such a case, assist in the forward movement through the water, but they are of much service in steering. A Penguin, when in swift sub-aqueous flight, can turn around, by the aid of its wings, while moving twice its length. *Hesperornis* had no such aid, but the legs and feet were far superior, for swimming and diving, to those of the Penguins, not merely in power, but in the more perfect adaptive mechanism. This was doubtless the main reason why the posterior limbs of *Hesperornis* became so predominant.

The tail of *Hesperornis* was clearly of great service in its aquatic life. In the number of vertebræ and length, it exceeds nearly all known birds, and it is unique in its widely expanded transverse processes, and in its depressed, horizontal, plough-share bone. This broad horizontal tail reminds one of that of the beaver, and was undoubtedly of great assistance in steering, and in diving. Whether it was, like the beaver's tail, destitute of feathers, or like the tail of *Plotus* was furnished with long stiff *rectrices*, so as to act as a rudder, cannot at present be determined with certainty, although the latter view seems more probable. That *Hesperornis* was provided with feathers of some kind, we can hardly doubt.

The surrounding circumstances were evidently very favorable to *Hesperornis* for a long period. There was apparently during this time an absence of enemies in the air above, and an abundance of food in the water. *Hesperornis* was more than a match for the gigantic toothless Pterodactyles, which hovered over the waters here in such great numbers, and the other inhabitants of the air all appear to have been small. The ocean in which *Hesperornis* swam teemed with fishes of many kinds, and thus a great variety of food was at hand, and obtained with little effort. In this aquatic paradise *Hesperornis* flourished, disturbed only by the serpentine Mosasaur, which, even without tradition, we may imagine, caused its banishment, if not its destruction.

In the preceding description, the writer has compared *Hesperornis* with the Ratitæ, or Ostrich group, and also with the diving birds as exemplified by *Colymbus* and *Podiceps*, and the more noteworthy points of resemblance or difference have been stated. It will hardly be profitable to extend the comparison to other groups of modern birds, as the similarity in points of structure is mainly of a general nature.

The genus *Archæopteryx* from the Jurassic of Europe, the only bird at present known more ancient than *Hesperornis*, presents some marked points of difference, for example, its elongated tail; as well as some peculiar resemblances, which will be discussed in the concluding part of this volume.

The genera *Ichthyornis* and *Apatornis*, which are from the same geological formation as *Hesperornis*, and are very fully described in the following chapters, differ widely from that genus in having biconcave vertebræ, as well as in other most important characters.

Hesperornis really stands alone among all known birds, and the special characters which thus separate it will be stated in the table of classification at the end of the present memoir.

ODONTORNITHES.

PART II.

ODONTOTORMÆ.

(Plates XXI–XXXIV.)

CHAPTER IX.

THE SKULL AND TEETH OF ICHTHYORNIS.

(Plates XXI, XXVI, and XXXIV.)

The birds included in the second order of *Odontornithes*, so far as now known, were all of small size, and possessed powerful wings, and very small legs and feet. They differed widely therefore in form and habit from those described in Part I, and, as we shall see, exhibited various significant characters, which distinguish them more strongly from the *Odontolcæ* than any existing birds are separated from each other. Some of these characters, as for instance their biconcave vertebræ, separate them widely from all birds recent and extinct, and point back unmistakably to a very lowly ancestry, even below the reptiles.

The remains of this group preserved are more or less pneumatic, and this fact, in connection with their small size, is perhaps the main reason why so few have been discovered. As might naturally be expected, the hollow bones of flying birds, being filled with air, enable the carcass to float upon the water much longer than it otherwise would, and it is thus liable to be destroyed by fishes or other animals. Hence, the chances of the entombment of a complete skeleton are greatly diminished. Such delicate bones, moreover, even after their entombment, require a favorable combination of circumstances for their preservation in good condition.

Fortunately, the bottom of the Cretaceous ocean, in which the remains of these birds were embedded, left nothing to be desired in this respect, since in its fine calcareous sediments the most delicate vascular impressions of the bones were often preserved.

A most careful search in these deposits, as they are now exposed on the Plains east of the Rocky Mountains, conducted by the writer in person, with the aid of other members of the various expeditions already mentioned, has resulted in bringing to light various remains representing no less than seventy-seven different individuals of this group of the *Odontornithes.* These remains are all in the Yale College Museum, and form the material on which the following descriptions are based. An investigation of these fossils shows that they are included in two well marked genera, *Ichthyornis* and *Apatornis*, the former represented by several species, and the latter by only one. These were all small birds, scarcely larger than a Pigeon. In their powerful wings and small legs and feet, they remind one of the Terns, and, according to present evidence, they were aquatic birds of similar life and habits.

The Skull. (Plate XXI.)

In *Ichthyornis dispar*, the type of the genus *Ichthyornis,* and of the order *Odontotormæ*, the skull was very large in proportion to the rest of the skeleton. This disproportion is shown in the restoration on Plate XXVI. The cranial portion of the skull is quite short, but the facial part is much produced. The occipital condyle is very small, and directed backward. Above the condyle, the occipital portion of the skull was nearly vertical. The lateral margin of this surface is bounded by a sharp ridge which separates it from the temporal fossa, and this ridge united with its fellow above was continued forward on the median line, as a sagittal crest, between the temporal fossæ. The latter were large and deep, and were separated from the orbit by a moderate post-orbital process. The orbits were very large, and near together. The quadrate is well preserved in one species, and its articular head has only a single facet, as in *Hesperornis*, and the *Ratitæ.*

The quadrate of *Ichthyornis victor* is represented in the cuts below, figure 28. It is of large size, and in its general form does not differ essentially from the quadrate in some modern birds. The undivided articular head (figure 28, *h*) is its most important feature.

Fig. 28.

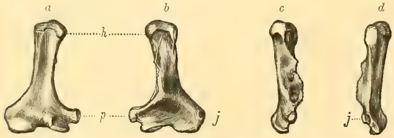

Figure 28.—Quadrate bone of *Ichthyornis victor*, Marsh; twice natural size. *a.* posterior view; *b.* front view; *c.* inner view; *d.* outer view; *h.* head; *p.* articulation for pterygoid; *j.* depression for jugal.

The skull of *Ichthyornis* has deep glandular depressions along the roof of the orbits, similar to those on the cranium of *Hesperornis*, and some recent water birds. The premaxillary bones are separate throughout their posterior half, but were doubtless firmly united in front. The anterior part of these bones has not been recovered, but the lower jaws would seem to indicate that in some respects it resembled the beak of *Hesperornis*.

In the type specimen (number 1450), the occipital condyle is subtrihedral in outline, when seen from behind. In another specimen (number 1459) this condyle is cordate in form, resembling the corresponding part in *Hesperornis*. In most of its features, the base of the skull is more like that of *Hesperornis* than of any modern birds.

The Brain.

The brain of *Ichthyornis* was remarkably small, and in its main features, strongly reptilian. In form and proportions, it resembled the brain of *Hesperornis* more nearly than that of any other known bird. The figure given below represents an outline of the skull of *Ichthyornis victor*, with a cast of the brain-cavity in position. A comparison of this figure with that of the skull and brain of *Hesperornis*, represented on page 9, will show the main points of resemblance. The most noticeable reptilian features in the two brain-casts are the elongated form, and prominent optic lobes.

The olfactory lobes of *Ichthyornis* (figure 29, *ol*) were large and prominent. They were separated in front by the inter-orbital septum, and their crura made their exit, apparently, through separate foramina.

The cerebral hemispheres were of moderate size, and proportionally less elongate than in *Hesperornis*. Their form and proportions, in *Ichthyornis victor*, are well shown in figure 29, *c*, which represents a cast taken directly from a cranium with this portion well preserved.

The optic lobes (figure 29, *op*) are very large, and the brain at this part was nearly as wide as across the hemispheres. The cerebellum (*cb*) was large, and elongate.

The general form and dimensions only of the posterior part of the brain of *Ichthyornis* are shown in figure 29, and hence are indicated by a uniform shading. The outline given was obtained from a comparison and measurements of two different specimens.

Fig. 29.

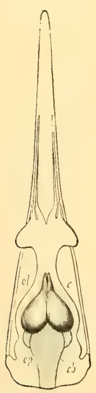

Fig. 30.

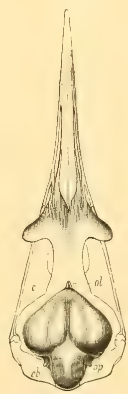

Figure 29.—Outline of the skull and brain-cavity of *Ichthyornis victor*, Marsh; seen from above; five-sixths natural size.

Figure 30.—Outline of the skull and brain-cavity of *Sterna cantiaca*, Gmelin; same view; natural size. *ol.* olfactory lobes; *c.* cerebral hemispheres; *op.* optic lobes; *cb.* cerebellum.

Figure 30 represents the skull and cast of the brain-cavity of a Tern, and the figure of *Ichthyornis*, beside it, is made of the same absolute length for comparison. The Tern was chosen for this purpose because in size and structure of its skeleton it bore considerable resemblance to *Ichthyornis*. The mode of life, also, of the two birds was probably similar.

In comparing the brain-cavity of *Ichthyornis* with that of *Sterna*, as shown in figures 29 and 30, the strong contrast in size is at once apparent, while the most marked difference is seen in the cerebral hemispheres. If the latter alone be compared, the hemispheres of *Ichthyornis* are less than one-fourth the size of those of *Sterna*. If, however, the bulk of the entire brain of each be compared, that of *Ichthyornis* would be less than one-third the size of that of the Tern. This would hold true after allowing a considerable reduction for any uncertainty in regard to the exact proportions of the posterior part of the brain-case of *Ichthyornis*.

The result of this comparison between *Ichthyornis* and the Tern agrees very closely with that obtained in contrasting the size of the brain-cavities of *Hesperornis* and *Colymbus*, as given on page 10; and hence is of special interest, as in no other instances have the brain-cavities of Mesozoic birds been investigated.

The Lower Jaws. (Plates XXI and XXVI.)

In the type specimen of *Ichthyornis dispar* (No. 1450), both lower jaws are preserved. The two rami are entirely separate, having been united in front only by cartilage. They are large and massive, nearly straight, and much compressed transversely, especially in the posterior portion. The upper margin of the dentary bone is nearly straight. The anterior extremity is rounded, and without any distinct symphysial surface. The right ramus is well shown in Plate XXI, figures 2, 3, and 4. The sutures in this jaw are nearly all obsolete, with the exception of that between the splenial and angular bones. This suture is especially open on the inner surface of the jaw (figure 2, *e*), and, in life, doubtless admitted of some motion. There is no mandibular foramen, and, just behind the articular face for the quadrate, the extremity is abruptly truncated.

The dentigerous portion of the lower jaw is so similar to that of some of the smaller Mosasauroid Reptiles, that, without other portions of the skeleton, the two could hardly be distinguished.

The Teeth. (Plate XXI.)

The teeth of *Ichthyornis* were implanted in distinct sockets, thus differing widely from those of *Hesperornis*. They are all sharp and pointed, more or less compressed, and strongly recurved. The crowns are coated with enamel, and the two fore and aft cutting edges are sharp and smooth, without serrations.

The maxillary teeth appear to have been larger than those opposing them. Their alveolar cavities are crowded together, and yet distinctly separated from each other by a thin septum of bone. They are oval in outline, and quite shallow, owing to the small vertical extent of the maxillary (Plate XXI, figure 1, and 1*a*). Whether the premaxillary bones contained teeth is uncertain, but they were probably edentulous, as in *Hesperornis*.

The dental cavities in the lower jaw are elliptical in outline, and vary in size according to position. They are in general deeper, and separated more widely from each other, than those in the maxillaries. In the right lower jaw of the type specimen of *Ichthyornis dispar*, there are twenty-one distinct sockets. The anterior one is very near the extremity, and contains a tooth of moderate size. The largest teeth in the lower jaw are just back of the middle of the dentary bone. From this region to the posterior end of the dentary, the teeth diminished gradually in size. The whole surface of each tooth exposed above the jaw is covered with smooth enamel. In the right lower jaw of the type specimen, there are eight teeth still in their sockets, and from these the others have been restored in outline, as shown in Plate XXI.

In *Ichthyornis anceps* (number 1749), the lower jaws are more slender than in the type species, and the number of teeth greater. The anterior half of the dentary contained large teeth only. The posterior eleven teeth were all small, and nearly uniform in size.

A specimen of *Ichthyornis victor* (number 1735) had much stouter and deeper lower jaws than *I. dispar*, but they appear to have contained the same number of teeth.

In the lower teeth of *Ichthyornis*, the pulp-cavity passes well up into the base of the crown. The fang is compressed, and directed downward and forward. It is firmly set in a deep socket, which it nearly or quite fills. The dental succession took place vertically, as in Crocodiles and Dinosaurs; not laterally, as in *Hesperornis*, and the Mosasaurs, a fact of no little significance. The young teeth are much inclined when they first appear above the jaw, after the old teeth have been expelled.

The following measurements of portions of the skull and jaws of *Ichthyornis* are from the specimens above described:

Measurements of Skull. (No. 1459.)

Transverse diameter of occipital condyle,	3. mm
Median vertical diameter of occipital condyle,	2.2
Distance between upper margins of orbits,	4.5

Measurements of Jaws. (No. 1450.)

Extent of three sockets for maxillary teeth,	5. mm
Length of entire lower jaw,	67.
Extent of alveolar margin,	41.
Transverse diameter of ramus,	2.
Greatest vertical diameter,	8.
Transverse diameter of jaw at articulation,	5.5
Height of crown of tenth tooth, above jaw,	2.1
Depth of ramus, below first tooth,	4.5
Depth of ramus, below last tooth,	3.

Measurements of Lower Jaw. (No. 1749.)

Extent of ramus containing twenty-two teeth,	36.5mm
Depth of ramus, below second tooth,	2.
Depth of ramus, below last tooth,	4.5

Measurements of Lower Jaw. (No. 1735.)

Extent of ramus containing the last eleven teeth,	20. mm
Depth of ramus, below first of above teeth,	4.
Depth of ramus, below last tooth,	4.5

CHAPTER X.

THE PRESACRAL VERTEBRÆ OF ICHTHYORNIS.

(Plates XXII, XXVI, XXVII, and XXXIV.)

The presacral vertebræ of *Ichthyornis* present characters more remarkable than those of any other known birds, and hence those preserved are here described in detail, and fully illustrated. The series is not complete in any one skeleton yet discovered, but the large number of vertebræ secured in various specimens make clear the more important features of this part of the structure.

None of the vertebræ of *Ichthyornis*, in front of the sacrum, are ankylosed together, and a number of them contain cavities in the sides, which are apparently pneumatic. Among existing birds, the Terns appear to bear the nearest general resemblance to *Ichthyornis*, and hence their vertebræ are here used for comparison with those of that genus.

The Atlas. (Plate XXVII, figure 1.)

The atlas of *Ichthyornis*, as in most living birds, is a ring of bone, very short antero-posteriorly, compared with the succeeding vertebræ. In *Ichthyornis victor* (number 1733), it is only about one-third as long as the axis, exclusive of the odontoid process, the proportion being nearly the same as in *Sterna regia*, Gambel.

The centrum of the atlas in *Ichthyornis* is coössified with that of the axis, forming a true odontoid process, which is robust, and somewhat convex upon its upper surface. The hypapophysis presents a crescent shaped articular surface in front, for articulation with the occipital condyle. The angles of this crescent are prominent on each side above the odontoid process, and during life doubtless gave attachment to a ligamentary bridge above that process, completing a nearly circular cup, adapted to the occipital condyle, as in existing birds. The hypapophysis is produced below into a somewhat wedge-shaped process, pointing slightly backward, and strengthened at the base behind by a low small tubercle on each side.

The posterior articular face of the hypapophysis is imperfectly exposed in the specimen figured, but was evidently adapted to the anterior articular surface of the axis, in such a manner as to allow only a rotary movement about the odontoid process. This motion was, however, much limited by the strong zygapophyses, which are much better developed than in the Tern. They are strengthened by a ridge rising on the side of the vertebra, and running upward, backward, and somewhat outward, and ending, above the zygapophysis, in an obtusely pointed tubercle. A similar form of zygapophyses is seen in the Egyptian Stork, *Ciconia alba*, but in the Tern, these processes are rudimentary. The upper surface of the atlas is not well preserved in the specimen here described, but appears to have been destitute of a neural spine.

THE AXIS. (Plate XXVII, figure 1–1 *d.*)

The axis of *Ichthyornis* (number 1733) is proportionally a little longer than in the Tern. The centrum is firmly coössified in front with the centrum of the atlas, no trace of the suture remaining. Below the odontoid process, is a large articular surface, not exposed in the present specimen, but evidently of a lunate form, somewhat concave, and permitting little motion except rotary. The lateral and inferior edges of this articular surface are distinct, and rather acute; and the articulation is borne upon an anterior expansion of the centrum, which attains its greatest diameter at the edges of the articular surface. These characters are well shown in number 1775.

The ventral surface of the centrum is evenly rounded for nearly one-third of its length, then excavated on each side of a median carina, which thickens backward, and nearly acquires the character of a hypapophysis below the posterior articular surface. On each side of the centrum near the middle, is a rather acute salient tubercle, just behind which the transverse diameter of the centrum is at the minimum. Above and a little behind these tubercles, are large pneumatic foramina.

The posterior articular face of the centrum is much smaller than the anterior, and is sub-quadrate in outline. It is distinctly concave vertically, and less so laterally; and begins to assume the peculiar character seen in the biconcave articulations of the following vertebræ.

The pre-zygapophyses are sessile facets on the anterior margin of the lateral walls of the neural canal. They project very slightly in front of the general contour lines, much less however than in *Ciconia*, while in the Tern these processes do not project at all. The post-zygapophyses are larger than the pre-zygapophyses, and in form are sub-triangular, with rounded angles. They are concave in a lateral direction, and strengthened above by a stout ridge running out, somewhat beyond the zygapophysis on each side, into a blunt point. This projection is much weaker than in the Tern, where the post-zygapophyses are surmounted by prominent, divergent processes. The neural spine was low, and stout, more elongate antero-posteriorly, but less robust, than in the Tern.

The following measurements show the principal dimensions of the atlas and axis in one specimen of *Ichthyornis victor:*

Measurements of Atlas and Axis. (No. 1733.)

Length of atlas,	2.7mm
Length of centrum of axis,	7.0
Length of centrum of axis, including odontoid process,	9.0
Transverse diameter of cup in atlas,	3.5
Transverse diameter of atlas, across zygapophyses,	7.0
Transverse diameter of anterior articulation of axis,	3.5
Vertical diameter of posterior articulation of axis,	2.7
Transverse diameter of posterior articulation of axis,	1.8
Transverse diameter of vertebra, across post-zygapophyses (approximate),	9.0

THE THIRD VERTEBRA. (Plate XXVII, figure 2.)

The third cervical vertebra of *Ichthyornis* (number 1733) differs much from the second, and in several respects resembles the corresponding vertebra in the Tern. The centrum is deeply excavated in front, and the anterior articulation is much inclined to the axis of the vertebra. Behind this excavation, the centrum abruptly becomes wedge-shaped, but the lower edge thickens posteriorly, and, below the posterior articulation, is about half as broad as the articular surface itself.

The plane of the anterior articulation is nearer horizontal than vertical, being inclined at an angle of nearly or quite 60°, with the axis of the centrum. In a vertical section, this articulation is moderately convex, while laterally it is strongly concave, thus presenting an approach to the characters of the ordinary avian vertebral articulation. The posterior articular surface of the axis, and of this vertebra also, fail to show this peculiarity. This specialized feature, occurring at the first bend of the neck, gives a direct hint as to the origin of the unique articulation in the vertebræ of modern birds. The full explanation of this articular structure will be given in a subsequent chapter.

The posterior articulation is, like that of the axis, sub-quadrate in outline, but is more elongate vertically than in that vertebra. This face is concave vertically, and less so horizontally, except perhaps near the margins, which are rounded. On the sides of the centrum near the lower part of the anterior articular surface, rather strong parapophyses are developed, which are connected with the diapophyses above by a strong bridge of bone, or pleurapophysis. These together enclose on each side a small, vertically oval, lateral foramen.

Immediately above, and a little external to the lateral foramina, are the strong and elongated pre-zygapophyses, which are directed somewhat obliquely downward, outward, and forward, and are about equally convex in both directions. They are proportionally longer than in the Tern, and look more directly upward and less inward than in that species. Below, they are strengthened by a ridge running up from the outer wall of the lateral foramen. The post-zygapophyses are shaped much as in the preceding vertebra, being only about half as long as the pre-zygapophyses, and looking almost directly downward. They are surmounted on each side by a blunt tubercle pointing outward and backward, but much less salient than in the Tern. The neural spine was moderately strong, but is much broken in the specimen here described, number 1733.

Full measurements of the third cervical vertebra of *Ichthyornis victor* are given below:

Measurements of Third Vertebra. (No. 1733.)

Length of centrum,	6.0mm
Transverse diameter of anterior articulation of centrum,	2.5
Vertical diameters of anterior articulation of centrum,	1.8–1.0
Transverse diameter of posterior articulation of centrum,	2.0
Vertical diameter of posterior articulation of centrum,	2.7
Transverse diameter of neural canal,	2.6
Vertical diameter of neural canal,	2.0
Transverse diameter of vertebra, across pre-zygapophyses,	7.5
Transverse diameter of vertebra, across post-zygapophyses,	9.2
Transverse diameter of lateral foramen,	0.8
Vertical diameter of lateral foramen,	1.1

The Tenth Vertebra. (Plate XXVII, figure 3).

A vertebra from the cervical series, in number 1733, appears to correspond best to the ninth cervical of *Sterna regia*, with which it may be compared. The inferior surface of the centrum is flattened laterally, but concave longitudinally. The anterior articulation is somewhat crushed below, but seems to have been concave in both directions, and of a subquadrate form. The posterior articulation is more rounded, but has a nearly straight upper margin. It is about equally concave in both directions, and rounded on the edges.

From the antero-lateral regions of the inferior surface of the centrum, are two projecting processes, or catapophyses, extending downward and somewhat forward to a distance nearly equal to the vertical diameter of the anterior articulation of the centrum.

Above and external to these, on each side, are the parapophyses, united to the diapophyses by the ankylosed pleurapophyses, which together enclose the lateral foramen of the centrum. The posterior prolongations of the pleurapophyses are broken off.

The pre-zygapophyses look upward and backward at an angle of nearly 45°, and a little inward. They are elongated, being fully twice as long as broad, and are semi-oval in form. At the sides of the vertebra, they are connected by a ridge with the bases of the post-zygapophyses. Above this ridge, on each side of the vertebra, is a deep foramen, apparently pneumatic. The post-zygapophyses are similar in shape to the pre-zygapophyses, but look nearly directly downward, and a little outward. They are each surmounted by a low tubercle, which does not project beyond the zygapophysis, but is placed nearly above the middle of it. The upper surface of this vertebra is flattened, and destitute of a neural spine. It presents a shallow oval depression at the middle of the anterior margin, and, behind, shows a similar, but somewhat larger and deeper median pit for ligamentary attachment.

The principal dimensions of the tenth vertebra of *Ichthyornis victor* are as follows:

Measurements of Tenth Vertebra. (No. 1733.)

Length of centrum,	6.0mm
Transverse diameter of anterior articulation of centrum,	3.0
Vertical diameter of anterior articulation of centrum,	2.1
Transverse diameter of posterior articulation of centrum,	2.8
Vertical diameter of posterior articulation of centrum,	2.8
Transverse diameter of neural canal,	2.7
Vertical diameter of neural canal,	2.2
Transverse diameters of vertebra, across pre-zygapophyses,	8.8–10.0
Transverse diameter of vertebra, across post-zygapophyses,	8.5
Transverse diameter of lateral foramen,	2.0
Vertical diameter of lateral foramen,	1.8

The Twelfth Vertebra. (Plate XXII, figure 1.)

A vertebra here regarded as the twelfth of the series (number 1450) resembles the eleventh cervical of *Sterna regia.* The centrum is much reduced in thickness near the middle, and is pierced on each side by a pneumatic foramen. A strong hypapophysis arises from the anterior part of the lower surface, and extends downward, and a little forward. Its base is about two-thirds the antero-posterior extent of the centrum, and, below, it is broadly rounded. The anterior face of the centrum is slightly inclined to the axis of the bone, so as to look somewhat downward. It is sub-quadrate in outline, with rounded angles, and is slightly broader below than above. The margin, except below, is prominent, and the face is concave in both directions. The posterior face is more nearly circular, in outline, but flattened above, and is more concave than the anterior.

Strong diapophyses arise on the lower part of the anterior end of the centrum, and are directed outward, backward, and downward. They are united with slender pleurapophyses, which complete the lateral foramina by union with the parapophyses above, just below and exterior to the pre-zygapophyses. The lateral foramina are larger in proportion to the size of the centrum than in the eleventh cervical of the Tern, as is also the neural canal.

The pre-zygapophyses look strongly inward, and somewhat upward and backward, and are separated from the post-zygapophyses by a distance only about equal to their length. Between the pre-zygapophyses, the neural canal is broadly open above. The post-zygapophyses look almost directly downward, and somewhat outward. They are well elevated above the floor of the neural canal by its nearly perpendicular walls. The roof of the neural canal is short on the median line, excavated by a longitudinally oval pit below, and bears a rudimentary neural spine, less prominent than in corresponding vertebra of the Tern. Below the neural spine, behind, is a pit for ligamentary attachment. The neural canal is large.

The following are the main measurements of this vertebra in the type specimen of *Ichthyornis dispar*:

Measurements of Twelfth Vertebra. (No. 1450.)

Length of centrum,	5.5mm
Vertical diameter of anterior articulation of centrum,	2.5
Transverse diameter of anterior articulation of centrum,	2.8
Length of hypapophysis,	2.8
Antero-posterior diameter of hypapophysis, at base,	3.0

Transverse diameter of vertebra, across diapophyses,	10.0mm
Transverse diameter, across pre-zygapophyses,	7.6
Transverse diameter of vertebra, across post-zygapophyses,	7.0
Vertical diameter of neural canal,	2.4
Transverse diameter of neural canal,	2.6
Greatest diameter of lateral foramen,	2.6
Least diameter of lateral foramen,	2.0
Height of neural spine, above floor of neural canal,	4.8

THE FOURTEENTH VERTEBRA. (Plate XXII, figure 2.)

Another vertebra (number 1450) is probably the fourteenth of the series. The centrum is narrow at the middle, but is rounded below, and sends down anteriorly a strong hypapophysis, which is broad, and slightly bifid. The anterior face is sub-circular in outline, slightly flattened above, and concave. The posterior face is similar in shape, and a little more concave. The lateral foramina are somewhat imperfect, but the diapophysis is strong, and the pleurapophysis projects well backward. The diapophysis projects below, and outside of the pre-zygapophysis. The neural canal is large.

The pre-zygapophyses look somewhat backward, and strongly inward and upward, and are separated from the post-zygapophysis by an interval about equal to their length. The post-zygapophyses look downward and outward, and are each surmounted by a low tubercle. The roof of the neural canal is short on the median line, with a shallow pit in front. It has a barely perceptible rudiment of a spine, and a transversely oval pit behind, looking directly backward. There appear to be pneumatic foramina at the sides, and also below, on the sides of the centrum.

This vertebra of the type specimen of *Ichthyornis dispar* measures as follows:

Measurements of Fourteenth Vertebra. (No. 1450.)

Length of centrum,	6.0mm
Vertical diameter of anterior articulation of centrum,	2.4
Transverse diameter of anterior articulation of centrum,	2.8
Length of hypapophysis,	2.0
Vertical diameter of posterior articulation of centrum,	2.5
Transverse diameter of posterior articulation of centrum,	2.7
Transverse diameter of vertebra, across diapophyses,	10.2

Transverse diameter of vertebra, across pre-zygapophyses,	7.5mm
Transverse diameter of vertebra, across post-zygapophyses,	7.0
Vertical diameter of neural canal,	2.2
Transverse diameter of neural canal,	2.0
Greatest diameter of lateral foramen,	2.5
Least transverse diameter of centrum,	1.5

The Fifteenth (?) Vertebra. (Plate XXVII, figure 4.)

A rather poorly preserved vertebra (number 1733) corresponds imperfectly with the fifteenth vertebra of *Sterna regia*, with which it may be compared. The centrum is constricted medially, but expands at each end to support the articular faces, both of which are sub-circular, and very slightly concave. The posterior face is rather deeper than the anterior, which is somewhat inclined, so as to look a little downward and forward. Beneath the anterior face, is a triangular area, with a small tubercle at each of the upper external angles. Below, the centrum is continued downward into a thin hypapophysis, the base of which does not extend backward on the centrum quite to the posterior end. Above, on each side is a large oval pneumatic foramen. The articular surface to receive the head of the rib is situated near the base of the lateral wall of the neural canal. The diapophysial articular surface for the tubercle of the rib is broken off.

The pre-zygapophyses are elongate, and look nearly directly upward, and somewhat inward. They are considerably farther apart than the post-zygapophyses, the difference being rather greater than in the corresponding vertebra of the Tern. The post-zygapophyses are imperfectly preserved in this specimen, but appear to be shorter than the pre-zygapophyses. The neural spine is absent, having been entirely broken away, so as to expose the neural canal.

This vertebra of *Ichthyornis victor* has the following dimensions:

Measurements of Fifteenth (?) Vertebra. (No. 1733.)

Length of centrum,	5.6mm
Transverse diameter of anterior articulation of centrum,	3.5
Vertical diameter of anterior articulation of centrum,	3.0
Transverse diameter of posterior articulation of centrum,	3.0
Vertical diameter of posterior articulation of centrum,	2.6
Transverse diameter of vertebra, across pre-zygapophyses,	8.0
Transverse diameter of vertebra, across post-zygapophyses,	6.2

THE SIXTEENTH VERTEBRA. (Plate XXII, figure 3.)

A vertebra of the type specimen (number 1450) resembles both the sixteenth and seventeenth of the Tern. It belongs in the dorsal series. The centrum has its least transverse diameter at the middle, and sends perpendicularly downward from the anterior half a sub-conical hypapophysis, two-lobed at the apex. This process is wanting in the Tern. The articular faces of the centrum are sub-circular in outline, somewhat flattened above. Both are concave, and the posterior is more deeply so than the anterior.

The centrum is very deeply excavated at the sides, above the middle, leaving only a thin wall on the median line. The articulation for the head of the rib is borne on the lateral wall of the neural canal, and is obliquely oval in outline. The diapophyses are broken away in this specimen, and the neural spine is very imperfect. The zygapophyses of the opposite sides are near together. The pre-zygapophyses project but little in front of the centrum, while the post-zygapophyses extend nearly their whole length behind it.

Another vertebra (number 1733), somewhat posterior to that regarded as the fifteenth, has the centrum preserved, but is not figured. This centrum is rounded below, slightly carinate on the median line, and sends down three divergent tubercles near its anterior end. Two of these are lateral, and somewhat divergent. The third is smaller, and more acute, and is median in position, thus representing a hypapophysis. The anterior face of the centrum is injured in this specimen, but appears to have been, like the posterior face, sub-circular, and somewhat concave. On each side above the middle, the body of the centrum is excavated, so as to leave only a thin longitudinal median wall to support the floor of the neural canal. The articular surface for the head of the rib is above this excavation, on the lateral wall of the neural canal.

The sixteenth vertebra of *Ichthyornis dispar* measures as follows:

Measurements of Sixteenth Vertebra. (No. 1450.)

Length of centrum,	5.8mm
Least diameter of centrum,	1.2
Vertical diameter of anterior articulation of centrum,	2.5
Transverse diameter of anterior articulation of centrum,	2.5
Vertical diameter of posterior articulation of centrum,	2.4
Transverse diameter of posterior articulation of centrum,	2.4
Length of hypapophysis,	1.8
Transverse diameter of neural canal,	1.8
Transverse diameter of vertebra, across pre-zygapophyses,	3.3
Transverse diameter of vertebra, across post-zygapophyses,	2.5

THE SEVENTEENTH VERTEBRA. (Plate XXVII, figure 5.)

A dorsal vertebra (number 1733) may be best compared with the seventeenth vertebra of the Tern, to which it bears some resemblance The centrum is but little contracted at the sides, and is almost evenly rounded below. It presents near its anterior end two unequal tubercles, the right one being the larger. The articular faces are slightly elongated vertically, and nearly equally concave.

The sides of the centrum in this vertebra are deeply excavated above the middle for almost the entire length, so that only a thin layer of bone is left to support the floor of the neural canal. This structure is much like that in the corresponding vertebra of the Tern, and a little more pronounced than in what may have been the preceding vertebra. The articular surface for the head of the rib is situated above the anterior part of this excavation, and is supported by a ridge running upward and backward on the outer wall of the neural canal.

The pre-zygapophyses are elongated, and approximate. The diapophyses are both broken off. The post-zygapophyses are a little nearer together than the pre-zygapophyses. The neural spine was strong, but is much fractured in the present specimen.

This vertebra of *Ichthyornis victor* has its principal dimensions as follows:

Measurements of the Seventeenth Vertebra. (No. 1733.)

Length of centrum,	6.7mm
Least transverse diameter of centrum,	1.8
Transverse diameter of anterior articulation of centrum,	2.5
Vertical diameter of anterior articulation of centrum,	3.0
Transverse diameter of posterior articulation of centrum,	2.5
Vertical diameter of posterior articulation,	3.2
Transverse diameter of vertebra, across pre-zygapophyses,	4.0
Transverse diameter of vertebra, across post-zygapophyses,	3.2

The Eighteenth Vertebra.

Another vertebra (number 1733) not figured, evidently posterior to the one above described, has the under surface of the centrum somewhat hour-glass shaped, and nearly alike at each end, being destitute of tubercles or hypapophysis, and very evenly rounded throughout below. The articular faces are sub-circular, and about equally concave. Laterally, this centrum, like the one before it, is deeply excavated nearly to the middle on each side, leaving a thin wall of bone along the median line to support the floor of the neural canal. The articular face for the head of the rib is above the anterior part of this excavation, and is obliquely oval. The diapophyses, zygapophyses, and most of the neural spine, are broken away in this specimen.

In one of the best preserved skeletons of *Ichthyornis victor* (number 1732), several vertebræ, apparently consecutive, lie near together in front of the sacrum. The first of these, or the eighteenth vertebra, has been thrown somewhat out of the line of the next two, and possibly may not have been consecutive with them. The centrum is badly crushed, but was evidently excavated at the sides above, as in the Tern, and had concave articular faces. The neural spine was about two-thirds as long antero-posteriorly as the centrum, and was proportionally higher than in the Tern. It does not appear to have been united to the adjoining spines by ossified tendons, as in that bird. The posterior zygapophyses are approximate laterally, as in the succeeding vertebræ, and look outward as well as downward. The diapophyses were broad, and directed somewhat backward.

The Nineteenth Vertebra.

The succeeding vertebra in the above series (number 1732) is somewhat crushed laterally, so that the centrum appears keeled, but it was probably rounded below. At the sides, it is excavated, leaving only a thin median wall. The diapophyses are strong, nearly horizontal, and directed somewhat backward. They are supported by a vertical ridge below, and bear at the end a small sub-circular articular face for the tubercle of the rib. Their upper surfaces are moderately broad. The neural spine is as extensive at its thickened upper end as the centrum.

A vertebra not figured, which may be regarded as the nineteenth, is represented in one specimen (number 1733) by less than half of a centrum, apparently the posterior end, which has a nearly circular and slightly concave articular face. This centrum is broken near the middle, showing a transverse section very similar in form to that of a T rail inverted. A similar section might be made across the centra of the three preceding vertebræ of this species (*Ichthyornis victor.*)

The Twentieth Vertebra.

Another more posterior vertebra not figured, belonging to this specimen (number 1733), has a shorter and stouter centrum than the preceding, and is less excavated at the sides. The articular surfaces are concave. The parapophysial surface for the head of the rib is small, and elevated. The neural canal is much crushed, and the zygapophyses, diapophyses, and neural spine, are broken away.

The twentieth vertebra of number 1732 is broader below than the nineteenth, and rounded, without trace of hypapophysis. The sides of the centrum are excavated above the middle, and the articular faces are sub-circular, and moderately concave.

The diapophyses are strong, and supported by a ridge below. They are directed somewhat backward, and terminated by a small face for the articulation of the tubercle of the rib.

The Twenty-first Vertebra. (Plate XXII, figure 4.)

A vertebra in the type specimen (number 1450) may be compared with the twenty-first of *Sterna regia.* The centrum is somewhat crushed, but appears to have been moderately broad below, and destitute of any hypapophysis. It is deeply excavated at the sides, as are the other dorsals, at least those from the posterior part of the series. The articulation for the head of the rib is obliquely oval. The diapophyses as well as the neural spine are broken off; and the zygapophyses are crushed out of position, but were approximate laterally, as in the preceding vertebræ.

A vertebra (number 1732) adherent to the anterior end of the sacrum, and almost wholly in front of the ilia, thus corresponding with the twenty-first vertebra of the Tern, is also exposed in the matrix with that above described. The neural spine appears to have been developed much as in the Tern, but is here crushed. The diapophyses are broad, and at the end were united to those adjoining by flattened ossified tendons. The pre-zygapophyses look obliquely inward, and upward.

The following measurements give the size of the twenty-first vertebra in the type specimen of *Ichthyornis dispar:*

Measurements of Twenty-first Vertebra. (No. 1450.)

Length of centrum,	6.0mm
Least diameter of centrum,	1.5
Vertical diameter of anterior articulation of centrum,	2.5
Transverse diameter of anterior articulation of centrum,	3.0
Vertical diameter of posterior articulation of centrum,	2.4
Transverse diameter of posterior articulation of centrum,	2.5
Transverse diameter of vertebra, across pre-zygapophyses,	3.0
Transverse diameter of vertebra, across post-zygapophyses,	2.5

CHAPTER XI.

SHOULDER-GIRDLE OF ICHTHYORNIS AND APATORNIS.

(Plates XXIII, XXIX, and XXXIV.)

The scapular arch of *Ichthyornis*, and its near ally *Apatornis*, conforms strictly to the type seen in living carinate birds. This part of the skeleton gives no hint of the peculiar reptilian features in other portions of the structure, and has none of the Struthious characters noticed in *Hesperornis*. There is apparently no part of the entire shoulder girdle of *Ichthyornis*, or the allied genus, that might not have been used by some existing birds with strong powers of flight.

The Scapula. (Plates XXIX, and XXXIV.)

In the *Odontotormæ*, the scapula presents two well marked types. In *Ichthyornis* (Plate XXIX, figures 9, 9*a*, 10–12), the bone is robust near its articular end, where it is moderately, but suddenly, expanded and thickened, much as in *Ardea*. Here, it presents two confluent articular surfaces. The larger of these forms a part of the glenoid fossa, and the smaller is for articulation with the coracoid. The scapular part of the glenoid fossa is flattened, slightly narrower below than above, and strongly inclined to the plane of the bone. In its largest dimension, it is slightly concave in section, while transversely it is nearly flat, but rounded at the edges. The articular surface for union with the coracoid is nearly hemispherical, and adapted to the subcircular pit in that bone. The acromial process of the scapula is conical, short and pointed, and does not project beyond the articular portion of the bone. The shaft is hollow at the lower end.

In the genus *Apatornis*, the scapula (Plate XXIX, figures 1, 1*a*, 2–4) is elongate, and distally flattened. In a side view, the lower half is curved, while the upper or distal half is nearly straight. In a front view, the bone appears regularly curved throughout. The proximal end is moderately and gradually expanded transversely, and bears the two customary articular surfaces. The upper and larger of these, forming the scapular portion of the glenoid fossa, is very oblique to the plane of the bone, and is distinctly convex in both directions. It increases in transverse diameter toward the base, instead of becoming narrower in that region, as in *Ichthyornis*. The articular surface for the coracoid is much as in that genus, being sub-hemispherical, and adapted to the pit on the face of the coracoid. This articular face is bounded internally by a distinct ridge, as shown in figure 3.

The principal difference, however, between this scapula and that of *Ichthyornis* is shown in the development of the acromial process, which in *Apatornis* is highly developed, and projects far beyond the articular surfaces of the bone, as in *Graculus*. Anteriorly, this process is obliquely truncated, so that at the end it is blunt, and somewhat wedge-shaped. Its general direction is inclined at an angle of forty-five degrees with the direction of the shaft of the bone at its origin.

The shaft of the scapula is perfectly preserved in specimen number 1734. It is here broadest just below the middle, where the upper edge becomes thin, and somewhat expanded. Beyond the middle, the bone tapers to near the distal end, and the extremity is rounded. The scapula decreases pretty regularly in thickness from near the proximal to the distal extremity, where it becomes thin and blade-like.

The following measurements indicate the size of the scapula in *Ichthyornis* and *Apatornis*.

Measurements of Scapula. (*Ichthyornis dispar*, *No.* 1718.)

Greatest diameter, across humeral articulation,	7.5mm
Least diameter, through humeral articulation,	2.8
Length of acromial process, from base,	0.6

Measurements of Scapula. (*Ichthyornis victor*, No. 1452.)

Greatest diameter, across humeral articulation,	8. mm
Least diameter, through humeral articulation,	3.
Length of acromial process, from base,	0.8

The various bones in the scapular arch of *Ichthyornis* are shown in position in the figure below.

FIG. 31.

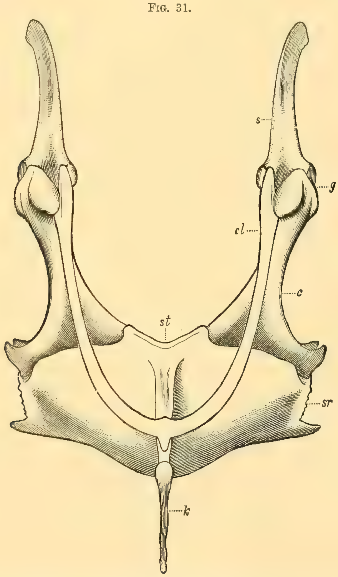

FIGURE 31.—Scapular arch of *Ichthyornis victor*, Marsh; twice natural size. *s.* scapula; *c.* coracoid; *cl.* clavicle, *st.* sternum; *k.* keel of sternum; *sr.* costal border; *g* glenoid fossa.

Measurements of Scapula. (*Apatornis celer*, No. 1734.)

	Left.	Right.
Length of scapula,		52.5mm
Greatest diameter, across humeral articulation,	5.1mm	
Least diameter, through humeral articulation,	2.	
Length of acromial process, from base,	3.5	
Diameter of shaft, above humeral articulation,	3.	3.

The Coracoid. (Plate XXIII and XXIX.)

In the genus *Ichthyornis*, the coracoid is a strong bone, much widened at the proximal end, where it articulates with the sternum in an elongated groove on each side. These grooves, and consequently the coracoids in their natural position, cross the median line in front in such a manner that the right coracoid is external to, or in front of, the left, as in the herons and their allies, and in some other birds. The proximal end is much expanded, as in *Colymbus*, but the bone is less robust than in that genus. The external part of the expanded portion is thin, and is short in the line of the axis of the bone. The inner angle of the expansion is produced and acute, as in *Ardea*.

The shaft of the coracoid is flattened, nearly or quite as far as the articular surface for the humerus. This surface is nearly flat, suboval, and somewhat less than twice as long as broad. The articular surface for the scapula is a nearly hemispherical pit, or cup, in diameter about equal to the transverse diameter of the humeral articulation. It is placed just within the lower end of that articulation, instead of almost wholly below it, as in *Apatornis*.

Just beneath the articular face for the scapula, is a foramen, perforating the base of a strong sub-scapular process, which is crushed and broken away from most of the specimens preserved. This process is triangular in shape (Plate XXIX, fig. 16), and much like that seen in *Ardea herodias*, Linn. Below and beyond the articular faces, the coracoid is flattened vertically, and, at the end, it is expanded; but, as in *Ardea*, it presents no facet for articulation with the clavicle, which is unknown in *Ichthyornis*. The shaft of the bone is hollow, with thin walls.

The coracoid of *Apatornis* resembles in general that of *Ichthyornis*, but is less expanded at the lower or sternal end; and these ends overlapped much less extensively than in that genus, if indeed they overlapped at all. The articular surface for the scapula is, as in *Ichthyornis*, a hemispherical cup, but it is placed almost wholly below the articular surface for the humerus, or the coracoid part of the glenoid cavity.

The articulation for the humerus is comparatively broader than in *Ichthyornis*, and is excavated in the middle, instead of being nearly flat, as in that genus. Under and beyond these articular faces, the coracoid is flattened vertically, almost to an edge, below. The shaft of the bone is bent strongly inward beyond the glenoid cavity, instead of continuing nearly straight, and there is a pronounced terminal knob, but no distinct face for articulation with the clavicle. The glenoidal, or subscapular, process is perforated by a foramen at its base, as in *Ichthyornis*. The shaft of the coracoid is hollow.

Measurements of the coracoids in the types and some other specimens of *Ichthyornis* and *Apatornis* are given below.

Measurements of Coracoid. (*Ichthyornis dispar*, No. 1450.)

Length of sternal articulation,	16. mm
Greatest antero-posterior diameter of proximal end,	1.7
Antero-posterior diameter of shaft, where broken,	2.2
Transverse diameter of shaft, where broken,	4.

Measurements of Coracoid. (*Ichthyornis dispar*, No. 1718.)

Length of humeral articulation,	6. mm
Greatest transverse diameter of humeral articulation,	3.4
Transverse diameter of shaft, below humeral articulation,	3.8
Vertical diameter of clavicular process,	5.
Transverse diameter of clavicular process,	2.2

Measurements of Coracoid. (*Ichthyornis victor*, No. 1452.)

Length of humeral articulation,	6.5mm
Greatest transverse diameter of humeral articulation,	4.
Least transverse diameter of shaft, below articulation,	3.5
Vertical diameter of clavicular process,	5.2
Transverse diameter of clavicular process,	2.8

Measurements of Coracoid. (*Ichthyornis victor*, No. 1727.)

Length of humeral articulation,	6.2mm
Transverse diameter of humeral articulation,	4.
Vertical diameter of clavicular process,	5.5
Transverse diameter of clavicular process,	3.

Measurements of Coracoid. (*Ichthyornis victor*, No. 1741.)

Length of humeral articulation,	6. mm
Greatest transverse diameter of humeral articulation,	3.6
Diameter of shaft below humeral articulation,	4.
Vertical diameter of clavicular process,	6.
Transverse diameter of clavicular process,	3.

Measurements of Coracoid. (*Ichthyornis victor*, No. 1743.)

Length of coracoid,	34. mm
Length of humeral articulation,	6.
Width of humeral articulation,	3.2
Diameter of pit for scapula,	3.
Depth of clavicular process,	5.
Transverse diameter of clavicular process,	3.
Length of glenoid process,	4.2+
Transverse diameter of shaft,	4.
Vertical diameter of shaft,	2.5

Measurements of Coracoid. (*Ichthyornis victor*, No. 1745.)

Length of coracoid,	32. mm
Length of humeral articulation,	6.
Width of humeral articulation,	3.4
Diameter of pit for scapula,	3.4
Vertical diameter of clavicular process,	5.
Transverse diameter of clavicular process,	2.8
Transverse diameter of shaft,	4.
Antero-posterior diameter of shaft,	2.6

Measurements of Coracoid. (*Ichthyornis victor*, No. 1458.)

Length of humeral articulation,	6. mm
Greatest transverse diameter of humeral articulation,	3.2
Least transverse diameter of shaft, below articulation,	3.8
Vertical diameter of clavicular process,	5.
Transverse diameter of clavicular process,	2.5
Diameter of scapular articulation,	3.8
Length of glenoid process,	4.

Measurements of Coracoid. (*Ichthyornis validus*, No. 1446.)

Longest diameter of humeral articulation,	8. mm
Transverse diameter of humeral articulation,	4.2
Least transverse diameter of shaft, below articulation,	4.5
Vertical diameter of clavicular process,	5.5
Transverse diameter of clavicular process,	3.

Measurements of Coracoid. (*Apatornis celer*, No. 1734.)

	Left.	Right.
Length of coracoid,		24. mm
Length of humeral articulation,	5.5	
Transverse diameter of humeral articulation,	3.8	
Diameter of shaft below humeral articulation,		3.
Vertical diameter of clavicular process,	5.	5.
Transverse diameter of clavicular process,	2.5	
Diameter of sternal end,		14.

The Clavicle. (Plate XXIX, figure 7.)

The only portion of the clavicle yet known among the *Odontotormæ* is a fragment from the upper end of that bone, in *Apatornis*. This fragment is considerably flattened, probably in part by pressure. It presents no face for articulation with the coracoid, but tapers to a flattened point at the top, where it is adapted for attachment to the acromial process of the scapula.

The Sternum. (Plates XXIII, XXIX, and XXXIV.)

The sternum in the type species of *Ichthyornis* is deeply keeled, affording ample room for muscular attachment. The manubrium is broad, and somewhat unsymmetrical. The coracoid grooves are elongated, and overlap widely across the median line, as in *Ardea*, and some birds of prey. As usually occurs in living birds with this peculiarity, the inner end of the left coracoid was above that of the right. These grooves become shallow near the middle, where the ridge of bone behind nearly disappears, but, toward the outer end, the ridge is again well developed, and acute. The lateral margins and all the posterior part of the sternum are absent from the type specimen of *Ichthyornis dispar*.

The specimen of *Ichthyornis victor* (number 1461) in which the sternum is preserved shows a strong and deep keel, robust and prominent in front.

The manubrium closely resembles that of *Ichthyornis dispar*. The coracoid grooves overlap widely on the median line, the left being above the right, as in *Ichthyornis dispar*. The costal processes and the posterior outline of the specimen are not preserved.

In the genus *Apatornis*, the sternum was keeled, as in *Ichthyornis*, although the precise depth of the keel cannot be determined. The manubrium was narrower than in *Ichthyornis*, and symmetrical, and ended in a blunt point. The coracoid grooves scarcely more than meet on the median line, and the left is but little depressed below the right, the asymmetry being only about as great as in *Graculus dilophus*, Gray. The costal process is triangular, and the costal border presents six articular faces for sternal ribs. The first of these is comparatively small and indistinct, and is well in advance of the five succeeding ones. The latter are separated by nearly equal intervals, each about two-thirds as long as the first. The posterior outline of the sternum is much broken, but appears to have been deeply emarginate.

The following measurements are taken from the specimens mentioned above:

Measurements of Sternum. (*Ichthyornis dispar*, No. 1450.)

Transverse diameter, near anterior end,	32.5 mm
Depth of keel, as preserved,	10.

Measurements of Sternum. (*Ichthyornis victor*, No. 1461.)

Length of keel, at base,	34. mm
Maximum length of keel,	45.
Depth in front,	13.5

Measurements of Sternum. (*Apatornis celer*, No. 1734.)

Greatest transverse diameter,	33. mm
Least transverse diameter,	28.

CHAPTER XII.

THE WINGS OF ICHTHYORNIS AND APATORNIS.

(Plates XXIV–XXVI and XXX–XXXI.)

THE wings in the two genera of *Odontotormæ* clearly indicate very strong power of flight, thus differing as widely as possible from the corresponding parts in *Hesperornis.* In *Ichthyornis*, nearly all the bones of the wings are well preserved, and these are all remarkably like those of some carinate birds living to-day. These remains give but slight indications of the reptilian features seen in the portions of the skeleton already described.

THE HUMERUS. (Plates XXIV and XXX.)

The humerus in *Ichthyornis* is strong and well developed, thus differing widely from that of *Hesperornis.* The most striking feature of the bone is the enormous radial crest, surpassing in comparative size that of any living bird. It is well shown on Plate XXIV, figure 3, *rc.* This crest is, moreover, remarkable for its position, which is in a plane nearly parallel with the long axis of the head of the humerus, instead of considerably inclined to this axis, as in most birds. This fact is clearly shown by a number of well preserved examples, including the type specimen of *Ichthyornis dispar* (number 1450). In these two points, the humerus of *Ichthyornis* strongly resembles the corresponding bone in the Pterodactyles.

The nearest approach in size among modern birds to the radial crest of *Ichthyornis* is perhaps to be found among raptorial species, where its elongation along the shaft of the bone is considerable, but its height is still proportionally much less than in the present genus. In *Sterna*, this crest is even less than half the comparative size in *Ichthyornis.* The ulnar tuberosity is also well developed, and, like the radial crest, is nearly in the same plane with the head of the humerus. No pneumatic foramina are to be seen in the specimens preserved.

The distal end of the humerus of *Ichthyornis* resembles that of the genus *Ardea,* rather than *Sterna,* the ectocondyloid process being represented only by a low tubercle. The shaft of the bone is hollow, with moderately thin walls, and its length is about one-fifteenth less than that of the ulna. In the genus *Sterna,* the humerus is about one-fifth less in length than the ulna

Dimensions of the humerus in the type specimen and in four other species of the *Odontotormæ* are given below:

Measurements of Humerus. (*Ichthyornis dispar,* No. 1450.)

Length of humerus,	58.0^{mm}
Greatest diameter of proximal end,	13.0
Diameters of proximal articulation,	3.0–10.0
Diameters of distal end,	9.6– 5.0
Least diameters of shaft,	3.0– 4.8
Length from proximal end to rise of radial crest,	23.5
Transverse diameter, across radial crest,	12.0

Measurements of Humerus. (*Ichthyornis dispar,* No. 1730.)

Length of humerus,	62.5^{mm}
Greatest diameter of proximal end,	15.
Transverse diameter of proximal end,	3.1
Diameter of shaft,	5.2
Greatest diameter of distal end,	9.
Antero-posterior diameter of ulnar condyle,	5.

Measurements of Humerus. (*Ichthyornis victor,* No. 1742.)

Length of left humerus,	72. ^{mm}
Greatest diameter of proximal end,	17.
Diameters of proximal articulation,	13–4.
Diameters of distal end,	12.5–5.5
Diameter of shaft (approximate),	6.5

Measurements of Humerus. (*Ichthyornis victor*, No. 1447.)

Length of right humerus,	71.5mm
Antero-posterior extent of proximal articulation,	17.6
Transverse diameter of proximal articulation,	4.
Transverse diameter of distal articulation,	11.2
Greatest diameter of radial condyle,	5.5

Measurements of Humerus. (*Ichthyornis victor*, No. 1452.)

Greatest diameter of proximal articulation,	16.3mm
Transverse diameter of proximal articulation,	3.9
Greatest diameter of distal end,	12.1
Greatest diameter of radial condyle,	6.

Measurements of Humerus. (*Ichthyornis victor*, No. 1457.)

Greatest diameter of distal end,	11. mm
Antero-posterior diameter of radial condyle,	5.2
Vertical diameter of radial condyle,	6.5
Diameter of shaft,	5.5

Measurements of Humerus. (*Ichthyornis tener*, No. 1738.)

Greatest diameter of distal end,	7.5mm
Antero-posterior diameter of radial condyle,	3.3
Vertical diameter of radial condyle,	4.5

THE RADIUS. (Plates XXIV and XXX.)

The radius like the other bones of the wing in *Ichthyornis* is strong and robust. The proximal end is of moderate size, and presents a sub-elliptic, slightly concave, articular face for the condyle of the humerus, and a slight lateral facet for the ulna. Nearly opposite this facet, the bone is distinctly tuberculated, and on the side toward the ulna at a short distance from the proximal end is a distinct elongate oval facet, raised on a tubercle above the general surface of the bone. This tubercle appears to give the shaft of the bone a short proximal bend toward the ulna. It then becomes nearly straight, until beyond the middle it curves again gradually toward the ulna, and at the end is moderately expanded and thickened. The distal articular surface for the ulna is indistinct, while that for the radial carpal is, as usual, elongate and convex in both directions.

In the genus *Apatornis*, the face for articulation with the humerus is nearly flat, while the ulnar articular surface is more distinct, and extended upon the side of the bone, as in *Graculus*. The shaft of the radius is hollow in both genera of *Odontotormæ*.

The following measurements will show the principal dimensions of the radius in this group:

Measurements of Radius. (*Ichthyornis dispar*, No. 1450.)

Diameter of shaft,	2.0mm
Greatest diameter of distal end,	5.5
Least diameter of distal end,	3.0

Measurements of Radius. (*Ichthyornis victor*, No. 1741.)

Length of radius,	71. mm
Greatest diameter of proximal end,	5.2
Least diameter of proximal end,	3.8
Diameter of shaft,	3.
Transverse diameter of distal end,	7.3
Least diameter of distal end,	4.

Measurements of Radius. (*Ichthyornis victor*, No. 1733.)

Greatest diameter of proximal end,	4.6mm
Least diameter of proximal end,	3.5
Diameter of shaft,	2.8
Greatest diameter of distal end,	6.1
Least diameter of distal end,	3.

Measurements of Radius. (*Apatornis celer*, No. 1734.)

Greatest diameter of proximal end,	4.2mm
Least diameter of proximal end,	3.
Diameter of shaft,	2.2

The Ulna. (Plates XXIV and XXX.)

The ulna in *Ichthyornis* is a strong moderately curved bone, somewhat trihedral proximally, but becoming more nearly cylindrical toward the distal end, where it is also less curved than in the proximal half. The surface for articulation with the humerus is placed more obliquely to the shaft of the bone than in *Sterna*, and occupies a greater proportion of the proximal end than in that genus, agreeing better in both these respects with the ulna of *Ardea.* The shaft of the bone is hollow, with thin walls, and presents faint but unmistakable evidence of the attachment of about a dozen secondary quill-feathers. The distal end of the ulna resembles that of *Ardea,* rather than that of *Sterna.*

The dimensions of the ulna in three species of *Ichthyornis* are as follows:

Measurements of Ulna. (*Ichthyornis dispar*, No. 1450.)

Length of ulna,	62. mm
Diameter of shaft,	2.6
Greatest diameter of proximal articulation,	5.0
Greatest diameter of distal articulation,	5.7
Least diameter of distal articulation,	5.0

Measurements of Ulna. (*Ichthyornis agilis*, No. 1453.)

Length of left ulna,	75. mm
Diameter of proximal end,	9.
Diameter of distal end,	8.

Measurements of Ulna. (*Ichthyornis validus*, No. 1740.)

Length of ulna,	68.5mm
Greatest diameter of proximal end,	6.5
Transverse diameter of proximal end,	6.
Diameter of shaft,	3.1
Diameter of proximal end, across curve,	6.
Greatest diameter of proximal end,	6.2

The Carpal Bones. (Plate XXX.)

The two bones of the carpus are preserved in the genus *Apatornis,* and resemble the same bones in existing *Carinatæ.* They may be compared with the corresponding bones in a Cormorant (*Graculus dilophus.*) The radial carpal has a proximal articular surface, somewhat broader than that of the Cormorant. The distal articulation, for the metacarpal, resembles considerably the same face in *Graculus,* but the inner face, articulating with the ulna, is proportionally more transverse, and shorter in the line of the length of the wing.

The ulnar carpal is less perfectly preserved, its surface being too much eroded to be certain of the limits of the articulations. The face for the ulna is, however, easily recognizable, and is comparatively large.

The Metacarpals. (Plate XXXI.)

The united metacarpal elements of *Ichthyornis* form a short and decidedly robust bone, somewhat resembling that of *Sterna*, but presenting more points of resemblance to the genus *Graculus*. It is, however, proportionally shorter and stouter than in that genus, and differs considerably in its proximal articular surface, which is plane transversely, and oblique throughout, with only one curvature. It is consequently destitute of the groove ordinarily seen at the ulnar side of this articulation, and the bone presents no trace of the depression in which this groove terminates in the genus *Graculus*.

Of the three metacarpals, the first extends to the end of the proximal one-fourth part of the bone, and is moderately robust, and, proximally, well elevated. Its distal articular surface is oblique to the axis of the bone, looking forward, and toward the palmar surface of the wing.

The second of the united metacarpals appears to form by far the greater part of the bone, as in most birds, and bears near the proximal end of its palmar surface, a distinct and well elevated tubercle. The distal half of the anconal surface of this bone bears a groove, running obliquely toward the ulnar side of the bone, passing, near its distal termination, close by the side of a distinct tubercle. A similar groove occurs in *Sterna*. At the distal end, the bone is rather suddenly expanded, and the articular surfaces, by which it is terminated, considerably resemble those of the same part in *Graculus*.

The shaft of the outer or third metacarpal is comparatively slender, as in birds generally, and is nearly cylindrical medially.

The united metacarpals in the genus *Apatornis* are much more slender than in *Ichthyornis*, but the bone is still of moderately robust proportions, when compared with the same part in modern birds of flight. Its proximal articular surface bears a resemblance to that seen in *Graculus*, differing from that of *Ichthyornis* in being grooved along its ulnar side. The groove terminates in a distinct, though shallow, pit at the base of the ulnar, or third, metacarpal.

Of the three united metacarpals, the first is shorter than in *Ichthyornis*, and hardly extends beyond the end of the upper one-fifth of the bone. Proximally, it is well elevated, extending to a height almost equal to its length. The articular face is nearly as in *Ichthyornis*.

The middle metacarpal is less robust than in *Ichthyornis*, but is still short and strong, as compared with the same bone in many living birds of flight, but does not differ greatly from that seen in *Sterna*. The tubercle near the proximal end of the palmar surface is well developed. The groove seen along the distal half of the anconal surface in *Ichthyornis* is comparatively ill defined, and the tubercle near the distal end of this surface in that genus is very rudimentary, or only faintly indicated. The distal end is much less expanded than in *Ichthyornis*, and the articular surface comparatively smaller.

The outer or third metacarpal is more slender and flattened than in *Ichthyornis*, and bears, on its palmar surface, near the proximal end, a low but distinct tubercle for muscular attachment.

The more important dimensions of the united metacarpal bones in *Ichthyornis* and *Apatornis* are given below:

Measurements of Metacarpal. (*Ichthyornis dispar*, No. 1450.)

Greatest diameter of distal end,	5.5mm
Transverse diameters of distal end,	4.0– 2.8
Diameters of shaft of second metacarpal element,	3.5– 2.2

Measurements of Metacarpal. (*Ichthyornis dispar*, No. 1730.)

Length of metacarpal,	31.5mm
Greatest diameter of proximal end,	9.6
Transverse diameter of proximal end,	3.2
Greatest diameter of distal end,	6.
Transverse diameter of larger articulation,	5.
Length of first metacarpal element,	5.2

Measurements of Metacarpal. (*Ichthyornis victor*, No. 1724.)

Length of right metacarpal,	39.5mm
Greatest diameter of proximal end,	11.2
Transverse diameter of proximal end,	4.7
Transverse diameter of shaft of second metacarpal element,	4.
Transverse diameter of shaft of third metacarpal element	1.7
Greatest diameter of distal end,	7.6
Transverse diameter of larger articulation,	5.5
Length of first metacarpal element,	7.

Measurements of Metacarpal. (*Ichthyornis anceps*, No. 1208.)

Greatest diameter of distal end,	6.75mm
Least diameter of distal end,	3.5
Transverse diameter of outer articular face,	5.
Vertical diameter of outer articular face,	2.25

Measurements of Metacarpal. (*Ichthyornis agilis*, No. 1209.)

Vertical diameter of proximal articulation,	6. mm
Transverse diameter of proximal articulation,	5.
Transverse diameter of shaft,	3.8

Measurements of Metacarpal. (*Apatornis celer*, No. 1734.)

Length of right metacarpal,	36. mm
Greatest diameter of proximal end,	8.5
Transverse diameter of proximal end,	4.
Diameter of shaft of second metacarpal element,	2.8
Diameter of shaft of third metacarpal element,	1.
Greatest diameter of distal end,	4.5
Transverse diameter of distal end,	3.2

THE WING PHALANGES. (Plate XXXI, figures 5–8 and 16–19.)

The first phalanx of the median or second digit of the wing (number 1726) is in *Ichthyornis* a robust bone, but tapers rapidly in its shaft from the proximal toward the distal end. On the ulnar side, it is, however, considerably expanded, and the thin extension is in most of the specimens thoroughly ossified, and supported on its anconal surface by two oblique ridges. Of these ridges, the first arises near the proximal end of the bone, and is only faintly indicated, or is partly confluent with the oblique margin of the expansion. It ends in a prominent thickening at the margin of the bone. The second ridge arises near the middle of the bone, and passes obliquely across the expansion, to end in a thickening, near the middle of its margin.

On each side of this ridge the bone becomes so thin as to be translucent, and in specimen number 1759, the ossification appears to have been incomplete, so that a minute foramen is left in the proximal thin portion, and a larger foramen in the distal part of the expansion. In number 1755, a small foramen exists in the distal part of the expansion only, and even this may possibly have been the result of partial crushing. The distal part of the expanded portion is thickened, and produced into a flattened hook-like process, beyond the end of the bone, but this is broken off from most of the specimens preserved.

The proximal articular surface consists of a sub-circular shallow concavity on the ulnar and palmar side, and a somewhat crescent-shaped surface. This crescent is blunt at the ends, and extends through a little more than a quarter of a circle around the sub-circular face, so as to admit only of a slight rotary motion, the joint being somewhat like the peg-and-socket articulation seen in the toes of *Hesperornis*. The shaft of the bone is flattened on the radial side, and, on the anconal surface, just beyond the middle, is a distinct scar, extending obliquely across the shaft. A similar elongated scar is seen on the palmar surface of the bone, near the distal end of the ulnar expansion.

The distal articular face is subquadrate in outline, broadest on the radial side, where it is flattened, while the ulnar portion of the face is smaller and convex, and is separated by a groove from the radial part. The palmar surface of the ulnar expansion of the bone is excavated proximally, while distally the excavation is more pronounced on the anconal surface.

The proximal phalanx of the median digit of the wing of *Apatornis* (number 1734) is comparatively much smaller than in *Ichthyornis*, and, as in that genus, the shaft tapers rapidly toward the distal end. The expanded portion on the ulnar side is about in the same proportion as in that genus, but it is less evidently strengthened by oblique ridges. It is also more nearly of uniform thickness, being barely translucent at any point, and only moderately thickened at the edge. An oblique ridge is, however, slightly indicated, passing across the expansion from near the middle of the shaft of the bone toward the outer margin, but low throughout, and indicated at the margin by only a very slight thickening. Beyond this thickening, the margin is suddenly excavated, and the terminal hook-like process, seen in *Ichthyornis*, is wanting. The articular faces resemble those of *Ichthyornis*, and there is the same distinct scar just beyond the middle of the anconal surface of the shaft, and also near the distal end of the ulnar expansion on the palmar side.

The second phalanx of the same digit is slender, and tapers from the proximal end to a blunt point distally. The proximal articular face is nearly flat, or slightly concave, sub-triangular in outline, with a prominent lobe at the radio-palmar angle of the surface. From the base of this lobe, a groove is continued a short distance upon the bone. The front or radial side of this bone, like that of the phalanx supporting it, is nearly flat. The exterior or anconal surface is excavated at the base.

The first phalanx of the third digit is imperfectly preserved in *Ichthyornis victor* (number 1775), and somewhat resembles the corresponding bone in *Graculus dilophus*, Gray. It is, however, rather more flattened proximally than in *Graculus*, and the articular surface is sub-oval. The shaft expands slightly on the radial side near the proximal end, and much more decidedly on the ulnar side a little farther along, where it reaches its greatest diameter. It then tapers rapidly, and is broken off apparently a little beyond the middle of its length.

The main dimensions of the different of phalanges described above are as follows:

Measurements of First Phalanx of Second Digit. (*Ichthyornis victor*, No. 1463.)

Length of shaft,	21. mm
Greatest diameter of proximal end,	6.8
Transverse diameter of proximal end,	5.2
Vertical diameter of proximal end,	4.2
Least diameter of shaft,	2.8
Greatest diameter of shaft,	7.6
Transverse diameter of distal end,	4.2

Measurements of same bone. (*Ichthyornis victor*, No. 1726.)

Length of shaft,	20.8^{mm}
Transverse diameter of shaft,	3.5
Greatest vertical diameter of shaft,	8.
Transverse diameter of proximal end,	5.
Vertical diameter of proximal end,	4.6
Transverse diameter of distal end,	5.
Greatest diameter at distal end,	7.

Measurements of First Phalanx of Third Digit. (*Ichthyornis victor*, No. 1775.)

Diameters of proximal articulation,	1.4–2.4^{mm}
Greatest diameter of shaft,	4.2
Length of part preserved,	8.5

Measurements of Wing Phalanges. (*Apatornis celer*, No. 1734.)

Length of first phalanx of second digit,	14. ^{mm}
Greatest diameter of proximal end,	4.2
Least diameter of proximal end,	3.
Least diameter of shaft,	2.
Greatest expansion of shaft,	5.5
Greatest diameter of distal end,	4.2
Transverse diameter of distal end,	3.
Length of second phalanx of second digit,	13.
Greatest diameter of proximal end,	3.
Least diameter of proximal end,	2.5

CHAPTER XIII.

PELVIC ARCH OF ICHTHYORNIS AND APATORNIS.

(Plates XXII, XXVIII, and XXXII.)

THE pelvic arch in the two known genera of *Odontotormæ* exhibits some interesting reptilian characters, one of which is seen also in *Hesperornis*. This portion of the skeleton is small in comparison with the pectoral arch, corresponding to the difference in size between the wings and the feet.

THE SACRUM. (Plates XXII, and XXVIII.)

The sacrum is well preserved in the type specimen of *Ichthyornis dispar* (number 1450), and appears to be composed of ten united vertebræ. The centra of these vertebræ are thoroughly coössified, and in the anterior part of the sacrum they are also considerably reduced in diameter. The anterior articular face is slightly concave. The neural spines are moderately developed in the anterior part, and are united with ossified tendons, which diverge posteriorly, and form a flattened upper surface in the median part of the sacrum. The middle part of the sacrum is much crushed below, in the present specimen. The more posterior centra are of moderate size, and the articular face of the last is depressed, and distinctly concave.

The transverse processes of the seventh sacral are well developed, and stand nearly at right angles to the axis of the sacrum. Those of the eighth and ninth are distant and divergent, those of the ninth vertebra being directed strongly backward. The anterior three pairs of transverse processes have their faces for articulation with the ilium directed outward and upward, and are supported by a shaft of greater or less length. In the region of the next three vertebræ, the sacrum has been crushed, but the processes appear to have been nearly sessile, and to have abutted almost vertically against the ilia.

The sacrum of *Ichthyornis* differs from that of the Tern in having only ten vertebræ in the coössified sacral series, while there are thirteen in *Sterna regia.* The sacrum appears also to have been somewhat narrower in the dorsal region. The strong transverse bar of bone running across between the ilia, just behind the acetabula, and formed in the Tern by the transverse processes of the ninth sacral, is in *Ichthyornis* formed by the processes of the seventh vertebra. This is followed by only three more vertebræ, instead of four as in *Sterna.* The posterior portion of the sacrum is thus seen to be much shorter than in *Hesperornis*, and the whole structure is broader, and not so perfectly coössified, indicating a correspondingly less degree of strength in the pelvic region, and less use of the legs.

In the type specimen of *Apatornis* (number 1451), the portion of the sacrum preserved is, unfortunately, crushed from a horizontal, instead of a vertical direction, as in *Ichthyornis dispar*, so that a comparison of the two is made difficult. The anterior end is, moreover, wanting, but there are clear indications of ten united vertebræ, and probably at least one more in front of those preserved. The neural spines are united with coössified tendons, and the latter do not appear to expand posteriorly over as broad a region as in *Ichthyornis.* The transverse processes preserved in this region appear to correspond with the second and third of the *Ichthyornis* sacrum. The portion of the united central column preserved presents, at its anterior end, faint indications of enlargement toward its anterior articular face, which was doubtless, as in *Ichthyornis*, considerably larger than the centra just behind it.

Of the transverse processes, the second preserved is much more robust than the one in front of it, but the four following are lost.

They correspond with only three such processes in the type of *Ichthyornis*. Behind these processes, the central portion of the sacrum is thickened below, and sends off a strong transverse process on each side, nearly at right angles with its axis. Behind this, are three pairs of transverse processes directed well backward. The second of these is preserved in the specimen, and formed a strong process for attachment with the ilium. The last pair of processes were short, and the independence of the vertebral centrum to which they were attached is indicated by a tubercular thickening at the point where the last sacral centrum has coalesced with the preceding. The posterior articular face of the last centrum is somewhat concave, and is nearly semi-oval in outline, being strongly flattened above for the neural canal.

Measurements of Sacrum. (*Ichthyornis dispar*, No. 1450.)

Length of sacrum,	26.2^{mm}
Vertical diameter of anterior end of first centrum,	3.0
Transverse diameter of anterior end of first centrum,	3.2
Least transverse diameter of centra,	1.2
Vertical diameter of posterior end of last centrum,	1.2
Transverse diameter of posterior end of last centrum,	2.0
Greatest transverse diameter of sacrum,	10.5

Measurements of Sacrum. (*Apatornis celer*, No. 1451.)

Length of portion preserved,	27.5^{mm}
Transverse diameter of last centrum at articulation,	2.5
Vertical diameter of last centrum at articulation,	1.8
Vertical diameter of sacrum, near proximal end,	7.0

The Pelvic Bones. (Plate XXXII.)

The pelvic bones in *Ichthyornis* (Plate XXXII, figures 2 and 3) are strongly coössified with each other. The ilium is obtusely rounded in front, and its antero-superior border is separated a short distance from its fellow. The pre-acetabular part of the ilium is concave externally, and considerably longer than the posterior portion. The ischium is expanded medially, and extends further back than the ilium. It is not united with the ilium posteriorly, thus agreeing with the corresponding part in *Hesperornis*. The pubis has no distinct anterior process, but the post-pubic element is elongated, and its distal portion free.

Measurements of Pelvic Bones. (*Ichthyornis victor,* No. 1732.)

Distance across pelvis between upper margins of acetabula,	20. mm
Extent of ilium, in front of acetabulum,	20.
Greatest breadth of ilium, in front of acetabulum,	8.5
Least breadth of ilium, in front of acetabulum,	5.
Height of ilium, above acetabulum,	4.
Extent of ischium, behind acetabulum,	22.5
Vertical diameter of shaft of ischium,	3.5
Greatest vertical diameter of ischium,	5.8
Transverse diameter of shaft of ischium,	1.5
Extent of pubis, behind acetabulum,	26.
Vertical diameter of shaft,	1.5
Vertical diameter of pubis, at distal end,	2.5

The pelvic bones of *Apatornis* (Plate XXXII, figure 1) are very similar in form and proportions to those of *Ichthyornis.* The pre-acetabular part of the ilium is much more extensive than the posterior portion. The acetabulum is perforate, but the foramen (*af*) is of moderate size. The ischium does not coalesce with the posterior part of the ilium, and its distal end was free, as in *Ichthyornis* and *Hesperornis,* and a few modern reptilian birds. The post-pubic element of the pelvis is longer than in *Ichthyornis,* and also much longer than the ischium.

Measurements of Pelvic Bones. (*Apatornis celer,* No. 1732.)

Length of ilium,	50. mm
Distance from front of ilium to distal end of pubis,	62.
Distance from front of ilium to distal end of ischium (approximate,	57.
Extent of pubis, behind acetabulum,	32.
Extent of ischium, behind acetabulum (approximate),	26.5

CHAPTER XIV.

THE CAUDAL VERTEBRÆ OF ICHTHYORNIS.

(Plates XXVIII and XXXIV.)

The tail in *Ichthyornis* is notable mainly for being of the modern ornithic type, thus widely differing from that of both *Archæopteryx* and *Hesperornis*, the only other two Mesozoic birds in which this organ is preserved. The tail in the genus *Ichthyornis* was comparatively short, and the terminal vertebræ were coössified.

A series of seven caudal vertebræ are preserved in one specimen of *Ichthyornis victor* (number 1732), and are figured on plate XXVIII. They pertain to the median and distal part of the tail, although not including the extreme end, a portion of the *pygostyle*, or the part formed by the united centra of the terminal vertebræ, being lost.

Of the vertebræ preserved in this specimen, the first, probably from the middle region of the tail, has in front a slightly concave articular surface, transversely oval in outline, with the upper margin nearly straight. Back of the articular face, the centrum is moderately constricted below, to expand again for the posterior face, but at the sides the centrum expands immediately to form the transverse processes. The latter are directed nearly horizontally outward and backward, and only slightly downward. They are as broad at base as the side of the centrum, but are both crushed and broken, a short distance from their origin.

The neural canal is of moderate size in this vertebra, and from its walls a pair of well developed pre-zygapophyses project forward. They extend in front of the end of the centrum by nearly half their length, and bear at the end small subcircular facets for articulation with the preceding vertebræ. These facets look nearly downward as in *Nyctea*, and the small, sessile facets on the posterior walls of the neural canal, representing the post-zygapophyses, look upward and somewhat outward. This is an interesting exception to the well known rule of the position of zygapophyses, and the attention of the writer was first called to it by his assistant in Palæontology, Mr. Oscar Harger.

The neural spine in this specimen is broken off, but is seen in section to be hollow. The posterior articular face of the centrum is slightly more concave than the anterior, and its upper outline is nearly straight.

The second caudal of the series preserved considerably resembles the preceding. As in that vertebra, the anterior articular surface is slightly concave. In outline, this surface is a nearly regular oval. On the under surface, the centrum is somewhat excavated, so as to appear hour-glass shaped, expanding posteriorly to the articulation. The bases of the transverse processes, as in the preceding vertebra, occupy the entire lateral surface of the centrum. These processes are directed strongly backward, outward, and somewhat more downward, than in the preceding vertebra. The neural canal is much as in that vertebra, or perhaps slightly smaller, and the pre-zygapophyses are well developed, and supported articular facets. They are smaller than in the vertebra in front, and post-zygapophyses are not to be distinctly seen, partly, however, it may be, from the imperfect condition of the specimen. The neural spine is broken away in this vertebra. The posterior face of the centrum is slightly concave, like the anterior, and is a little more transverse, with the upper outline nearly straight.

The third caudal preserved in the present series is rather less perfect than the two preceding it, but has the transverse processes in fair preservation. The centrum has been crushed from above downwards, but its articular faces were both concave, and it is medially constricted below, like the other vertebræ. The transverse processes have been flattened by pressure. Their bases occupy the whole lateral surface of the centrum. They are directed a little less strongly backward than in the preceding vertebra, and attain about the same length as in that specimen. The neural canal was of good size, but its walls are broken away just above their base.

The fourth vertebra in this series of caudals is very imperfectly preserved. As in the preceding vertebræ, the articular faces were both slightly concave, and the lower surface of the centrum presents the ordinary hour-glass form. The transverse processes are strong, and occupy the whole lateral part of the centrum. They stand a little less obliquely than in the preceding vertebræ. The distal ends of both transverse processes are wanting. The neural arch is almost entirely wanting, but the floor of the neural canal shows that it retained considerable size.

The fifth of the series of caudals preserved has a slightly shorter centrum than those that precede it. The articular faces are nearly circular. The anterior one is decidedly concave, the posterior very moderately so, or nearly flat. The inferior surface of the centrum is somewhat hour-glass shaped, as in the preceding vertebræ. The transverse processes, as in the other vertebræ, have a large base, occupying nearly the whole of the lateral surface of the centrum, but they taper very rapidly. They are short, and directed outward, nearly at right angles with the axis of the centrum, and somewhat downward. The under surface of the centrum presents a faint median groove extending its whole length, and at each end of the groove a low tubercle is seen on each side.

The last of this series of caudals of *Ichthyornis* consists of a portion of the united terminal vertebræ, or *pygostyle*. The part preserved consists of the first centrum and part of the second united with it; the corresponding neural arches and part of the neural spines, extending back probably to and including a part of the third spine, at which point it is broken off. The centrum preserved differs principally from those that precede it in the entire absence of transverse processes. The anterior articular face is nearly circular, but flattened in outline above, and is concave. Behind the articular face, the centrum tapers rapidly; and its entire upper surface is occupied by the neural canal. The walls of the canal rise from each side of the centrum, enclose a triangular neural canal, and are surmounted with a very short or rudimentary neural spine. Only a small part of the centrum of the second vertebra of the *pygostyle* is preserved. This is closely united with the first centrum, without trace of suture, as are also the neural arch and spine to the corresponding parts of the first vertebra.

The following measurements give the dimensions of the consecutive caudal vertebræ above described:

Measurements of Anterior Median Caudal. (*Ichthyornis victor*, No. 1732.)

Length of centrum,	3.1^{mm}
Transverse diameter of anterior articulation,	3.
Vertical diameter of anterior articulation,	2.2
Transverse diameter of posterior articulation,	3.
Vertical diameter of posterior articulation,	2.5
Diameter of vertebra, across transverse processes,	8.
Diameter of vertebra, across pre-zygapophyses,	3.6
Diameter of vertebra, across post-zygapophyses,	2.8
Vertical diameter of neural canal,	2.

Measurements of Median Caudal. (*Ichthyornis victor*, No. 1732.)

Length of centrum,	3.2^{mm}
Transverse diameter of anterior articulation,	3.
Vertical diameter of anterior articulation,	2.4
Transverse diameter of posterior articulation,	3.2
Vertical diameter of posterior articulation,	2.5
Diameter of vertebra, across transverse processes,	9.5
Diameter of vertebra, across pre-zygapophyses,	3.
Vertical diameter of neural canal,	1.6

Measurements of Median Caudal. (*Ichthyornis victor*, No. 1732.)

Length of centrum,	3.6^{mm}
Transverse diameter of anterior articulation,	3.
Transverse diameter of posterior articulation,	3.
Diameter of vertebra, across transverse processes,	11.5

Measurements of Posterior Caudal. (*Ichthyornis victor*, No. 1732.)

Length of centrum,	3.2^{mm}
Transverse diameter of anterior articulation,	3.
Vertical diameter of anterior articulation,	2.4
Transverse diameter of posterior articulation,	3.2
Vertical diameter of posterior articulation,	2.8

Measurements of Posterior Caudal. (*Ichthyornis victor*, No. 1732.)

Length of centrum,	3.4^{mm}
Transverse diameter of anterior articulation,	3.
Vertical diameter of anterior articulation,	2.6
Transverse diameter of posterior articulation,	3.
Vertical diameter of posterior articulation,	2.6
Diameter of vertebra, across transverse processes,	8.2

Measurements of First Vertebra of Pygostyle. (*Ichthyornis victor*, No. 1732.)

Transverse diameter of anterior articulation,	2.5^{mm}
Vertical diameter of anterior articulation,	2.5
Vertical diameter of neural canal,	1.5

CHAPTER XV.

LEGS AND FEET OF ICHTHYORNIS AND APATORNIS.

(Plates XXV, XXXIII and XXXIV.)

THE legs and feet in the two genera of *Odontotormæ* are comparatively small, and present no peculiar features. The remains preserved agree most nearly with the corresponding parts in modern Carinate birds.

THE FEMUR. (Plates XXV and XXXIII.)

The femur in *Ichthyornis* is a short and comparatively small bone. The shaft is slender, and nearly smooth, being destitute of the rugosites seen on the femur of *Hesperornis*. Both the articular faces present the ordinary avian type of articulation, and the shaft of the bone is hollow, with thin walls. The ratio of the fibular face to that for the tibia is about the same as in the Tern, and the general proportions of the bone, as to length, diameter of shaft, and size of articular faces, are nearly the same as in that bird. The femur of *Ichthyornis*, however, is more than half the length of the humerus, while in *Sterna* the femur is less than half as long as the humerus.

The femur of *Apatornis* is proportionally larger than in *Ichthyornis*. The shaft is hollow, with thin walls, and the whole bone is nearly smooth, as in most modern birds. There is, however, just behind the outer condyle, on the inferior surface of the bone, a well marked pit for the attachment of a ligament, and just behind the inner condyle, on the same surface, is a low tubercle. The lateral surfaces of both condyles are also slightly roughened, but not more so than in *Colymbus*. The precise length of the femur, and, of course, its length as compared with that of the tibia, cannot be determined; but the leg was evidently more strongly built than in *Ichthyornis*, while the wings appear to have been less powerful.

The femur in the type specimen of *Ichthyornis* has the following dimensions:

Measurements of Femur. (*Ichthyornis dispar*, No. 1450.)

Length of femur,	30.5mm
Diameter of head,	2.8
Greatest diameter of proximal end,	6.0
Diameters of shaft,	3.0–2.5
Transverse diameter of distal end,	6.0
Antero-posterior diameter of inner condyle,	4.0
Antero-posterior diameter of outer condyle,	4.5
Antero-posterior diameter at fibular articulation,	3.5

The Tibia. (Plates XXV and XXXIII.)

The tibia of *Ichthyornis dispar* is a slender bone of moderate length. The cnemial process is but little developed, and only slightly elevated above the articular face of the bone. The shaft was hollow, with rather thin walls, and was gently curved inward toward its distal end, rather more strongly than in the Tern. In section, the shaft was transversely oval. The fibular ridge arises just below the outer articular face, and is continued downwards until broken off by a fracture of the shaft, as seen in plate XXV, figs. 5–8. It is probable, however, that the ridge continues but a short distance farther on the shaft. The distal portion of the shaft preserved shows no trace of a fibular ridge. It is gently curved inward, and expands gradually to the articulation. Toward the distal end, the shaft becomes more flattened, and is excavated in front for the passage of tendons, which were not, however, kept in place by an osseous supratendinal bridge. The articular face has been somewhat injured by compression in the type specimen (number 1450), but seems to have resembled in general form that seen in the Tern, although of comparatively less antero-posterior diameter.

The tibia in *Apatornis* is somewhat larger and stronger than in *Ichthyornis*. The proximal end of the bone is unknown, and the upper part of the shaft is much crushed and mutilated in the specimen preserved. Distally, it is straighter than in *Ichthyornis*, and expands to about the same degree. As in that genus, there is no osseous supratendinal bridge, nor is there any apparent roughening for the attachment of the end of the fibula.

The measurements given below indicate the size of the tibia in several specimens of the *Odontotormæ*:

Measurements of Tibia. (*Ichthyornis dispar*, No. 1450.)

Greatest diameter of proximal end,	5.0mm
Greatest antero-posterior diameter,	4.5
Transverse diameter of shaft, including fibular ridge,	4.0
Transverse diameter of shaft, below fibular ridge,	2.8
Antero-posterior diameter of shaft, below fibular ridge,	2.0
Greatest diameter of distal end,	5.0
Antero-posterior diameters of distal end,	4.0–2.0–4.0

Measurements of Tibia. (*Ichthyornis dispar*, No. 1723.)

Length of tibia,	57. mm
Transverse diameter of shaft,	3.
Transverse diameter of distal end,	5.3
Antero-posterior diameter of inner condyle,	4.7
Antero-posterior diameter of outer condyle,	4.1

Measurements of Tibia. (*Ichthyornis victor*, No. 1732.)

Length of tibia,	57. mm
Diameter of shaft,	3.
Transverse diameter of distal end,	6.1
Antero-posterior diameter of outer condyle,	5.

Measurements of Tibia. (*Apatornis celer*, No. 1734.)

Transverse diameter of distal articulation,	6.5mm
Least antero-posterior diameter of distal articulation,	3.
Antero-posterior diameter of outer condyle,	5.5
Antero-posterior diameter of inner condyle,	6.
Transverse diameter of shaft,	4.

The Fibula. (Plate XXXIII.)

The fibula of *Apatornis* appears to have been as much reduced in size as in most existing birds. In one specimen (number 1734) it is a slender rod, moderately thickened above, and tapering to a point at the distal end, where its attachment to the tibia appears to have been as slight as in any living bird.

The following are the main dimensions of the fibula in this specimen of *Apatornis:*

Measurements of Fibula. (*Apatornis celer,* No. 1734.)

Length of fibula,	28. mm
Transverse diameter of proximal end,	2.5
Antero-posterior diameter of proximal end	1.
Greatest transverse diameter of shaft,	2.5

The Tarso-metatarsus. (Plate XXXIII.)

The tarso-metatarsal bone of *Ichthyornis* appears to be composed of the same number of elements, united in the same degree, as in living birds, a condition similar to that prevailing in the wing. The resulting tarso-metatarsal bone may be compared with the same bone in the Tern, which it considerably resembles, although rather more robust in proportion to its length. On the proximal end, the articular faces are slightly less excavated than in that genus. The posterior part of the upper end is imperfectly preserved, but a "calcaneal process" was present, though probably not as well developed as in *Sterna.* The anterior face of the shaft is excavated proximally, and perforated by a small foramen between the upper ends of the third and fourth united metatarsals. On the posterior surface of the bone, a shallow groove runs down from the foramen along the shaft, indicating the line of suture between these metatarsals, and a similar parallel groove behind shows the line of union of the second and third metatarsals.

On the anterior aspect of the middle metatarsal, and just below its proximal end, is a prominent tubercle, evidently for the attachment of the *tibialis anticus.* The broad groove on the anterior face of the tarso-metatarsus, over the middle element, dies out rapidly downward, and the bone tapers somewhat to near the distal end. Where the diameter is least, the section is nearly oval, but the regularity of the oval is somewhat interrupted by the shaft of the fourth metatarsal, which is indicated by a ridge running the entire length of bone. Near its distal end, it is moreover separated from the adjoining third metatarsal by a foramen which is nearly as large as in the *Tern*, but is separated by a much weaker osseous bar from the interval between the two articular ends of the bones.

Of the three distal articular faces, the middle is the largest, and most advanced. The outer or fourth stands but little back of the middle, and is directed well outward, being more oblique than in the Tern. The face of the second metatarsal is considerably behind the other two, and is more oblique than the fourth. It is also the smallest of the three faces. The three articulations are slightly more divergent and oblique than in the Tern, but they are more nearly in a transverse line than in that bird. They are also broader, with less extension vertically.

The dimensions of the tarso-metatarsal bone in three individuals of *Ichthyornis* are as follows:

Measurements of Tarso-metatarsal. (*Ichthyornis victor*, No. 1739.)

Length of tarso-metatarsal,	58. mm
Transverse diameter of shaft,	3.5
Greatest diameter of distal end,	9.
Transverse diameter of inner articulation,	3.6
Vertical diameters of inner articulation,	2.6–2.1–3.
Transverse diameter of median articulation,	2.6
Vertical diameters of median articulation,	3.8–3.1–4.
Transverse diameter of outer articulation,	2.6
Vertical diameters of outer articulation,	3.8–3.–3.4
Transverse diameter of proximal end,	7.

Measurements of Tarso-metatarsal. (*Ichthyornis victor*, No. 1464.)

Greatest diameter of distal end,	9. mm
Transverse diameter of inner articulation,	3.
Vertical diameters of inner articulation,	2.9–2.2–3.2
Transverse diameter of median articulation,	3.
Vertical diameters of median articulation,	4.–3.5–4.
Transverse diameter of outer articulation.	2.9
Vertical diameters of outer articulation,	3.9–2.8–3.2

Measurements of Tarso-metatarsal. (*Ichthyornis victor*, No. 1456.)

Greatest diameter of distal end,	9. mm
Transverse diameter of inner articulation,	2.6
Vertical diameters of inner articulation,	2.4–2.1–3.
Transverse diameter of median articulation,	2.7
Vertical diameters of median articulation,	3.4–2.8–3.6
Transverse diameter of outer articulation,	2.5
Vertical diameters of outer articulation,	3.1–2.4–3.

The Phalanges.

A single phalanx, probably from the middle or perhaps from the outer toe, is preserved in specimen number 1732, and is figured on Plate XXXIII, figure 8. The proximal articular face is divided by a median ridge, separating two not very unequal grooves. The shaft is slender and tapering, rounded above, and flattened below. It is terminated by a medially grooved distal articular face, as in ordinary birds, without any indication of the peg-and-socket articulation, seen in *Hesperornis* and some other swimming birds.

Measurements of Phalanx. (*Ichthyornis victor*, No. 1732.)

Length of phalanx,	9. mm
Vertical diameter of proximal end,	2.4
Transverse diameter of proximal end,	2.2
Vertical diameter of distal end,	1.4
Transverse diameter of distal end,	1.8

CHAPTER XVI.

THE RESTORATION OF ICHTHYORNIS.

(Plates XXVI and XXXIV.)

The preceding description of the remains of *Ichthyornis*, in connection with the illustrations given in Plates XXI to XXXIV, will make known most of the more important characters which separate these remarkable Mesozoic birds from all others, recent or extinct. The material on which the present restoration of two species of this genus are made consists of portions of more than seventy different individuals. None of these various skeletons were as complete, when found, as were several of *Hesperornis*, from the same formation. This was no doubt mainly due to the smaller size, and more fragile character, of the individual bones of *Ichthyornis*. The restoration of *Apatornis*, evidently a near ally of *Ichthyornis*, has not been attempted, as the specimens at present available for this purpose are not sufficiently numerous or complete.

In the restoration of *Ichthyornis dispar*, as given on Plate XXVI, only the remains of the type specimen are figured, as it was deemed important to show the exact material on which the genus was based. These portions are shaded in the restoration, and are of the natural size. The bones represented in outline are taken in part from other specimens of the same species, but mostly from the skeleton of the Royal Tern (*Sterna regia*, Gambel), which, after a careful comparison, seemed well adapted for completing, approximately, the restoration here presented. The position chosen is one which seemed on the whole to accord best with the remains at present known.

The restoration of *Ichthyornis victor*, on Plate XXXIV, is also of natural size, and is based on more complete material, including portions of several skeletons. The other species of the genus *Ichthyornis* did not differ widely from these in size, and this is true also of the known specimens of *Apatornis*.

In considering the skeleton of *Ichthyornis*, the anatomist is at once confronted with a strange combination of characters. The wing-bones are conclusive proof that *Ichthyornis* was a highly specialized bird, with great powers of flight. The individual bones correspond closely with those of birds living to-day. The legs and feet, also, are much like those of some modern birds. With these portions alone before him, the comparative anatomist would unhesitatingly refer the remains to the class of Birds, and would naturally conclude that they belonged to the modern type. If, however, the skull should then be found with the wings and feet, very strong evidence would be required to convince him that they were parts of one and the same bird. The jaws and teeth present reptilian characters wholly unknown in modern birds, while the base of the skull and the small brain point strongly in the same direction. The biconcave vertebræ lead *Ichthyornis* still farther away from all known birds, recent and extinct, and, if found alone with the jaws and teeth, would force any anatomist to the conclusion that he had before him the remains of a reptile.

The skeleton of *Ichthyornis*, as we know it to-day, can be interpreted only, in the light of modern science, by supposing that certain parts have become highly specialized in the direction of recent birds, while others have been derived, with but little change, from a reptilian, or even a more lowly, ancestry. In the wings, the most characteristic modern feature is the coössification of the metacarpal bones, a character universal among existing birds. In reptiles, however, and in the only known Jurassic bird, *Archæopteryx*, these bones are separate. The sternum of *Ichthyornis* is very similar to that of modern carinate birds. In the feet of *Ichthyornis*, also, the compound tarso-metatarsal is another modern feature, especially characteristic of recent birds.

If, now, we consider the skull of *Ichthyornis*, we find the avian and the reptilian characters strangely blended. The teeth are evidently a strong reptilian feature, and, before the discovery of *Ichthyornis*, were entirely unknown in the class of Birds. Their method of implantation in distinct sockets is a specialized character in reptiles, and was not shared even by *Hesperornis*, the contemporary of *Ichthyornis*. The diminutive elongated brain, also, points back to the reptiles. Other features of the skull, for example, the single headed quadrate, are shared only by the most reptilian of birds. The union of the lower jaws in front, by ligament only, is characteristic of many reptiles, and is seen in *Hesperornis*, but is unknown in all other birds.[1] The form of the skull and the obliteration of most of the cranial sutures are points of resemblance to many modern birds.

The locomotive organs of *Ichthyornis* are so similar to those of typical birds that they present no such interesting mechanical problems as were suggested by the skeleton of *Hesperornis*. In the vertebræ, however, we find a primitive form retained, and also have the key to the origin of one remarkable character in recent birds, which has hitherto remained unexplained.

While all existing birds, and all of the extinct forms so far as known, including *Hesperornis*, have the peculiar saddle-shaped vertebræ, those of *Ichthyornis*, and its near ally *Apatornis*, are biconcave. This form is seen in a few recent and in many extinct Reptiles, and in the Amphibians; but it is especially characteristic of Fishes, from which class it was undoubtedly inherited by the superior groups. This character alone indicates unmistakably a great antiquity for the class of birds.

The saddle-shaped vertebræ are certainly one of the most marked features in the skeleton of modern birds. This form is so peculiar and so constant that it has been considered by many anatomists as the best distinctive character for the class. In no other group of animals known do we find the true saddle-shaped articulation of the centra seen in the vertebræ of birds.[2]

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[1] In the Pelicans and Curlews, the rami unite late by ankylosis.

[2] An approach to this form is shown in the cervical vertebrae of the Kangaroos.

Not only do the presacral vertebræ of all existing birds exhibit this structure, but the many extinct species now known from the whole series of Tertiary deposits have the same articulation. If we knew only these fossil forms, in addition to the existing species of birds, the origin of this peculiar vertebral articulation would perhaps remain a mystery. Most fortunately, however, one of the vertebræ of *Ichthyornis* throws much light on this point, and virtually explains the difficulty.

We have seen that *Hesperornis* has the same kind of vertebræ as modern birds, while those of *Ichthyornis* are biconcave. The marked contrast between the shape of the vertebral articulation in these two genera is seen in the figures below, which show a characteristic cervical vertebra in each form. In the vertebra of *Ichthyornis* shown in figures 32 and 33, it will be seen that the articulation of the centrum is cup-shaped; while, in the corresponding vertebra of *Hesperornis*, the ends of the centrum are saddle-shaped, as in ordinary birds. Thus the distinction between the two types in this part of the skeleton is as wide as between *Ichthyornis* and any living bird.

Fig. 32.

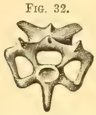

Fig. 33.

Fig. 34.

Figure 32.—Twelfth cervical vertebra of *Ichthyornis dispar*, Marsh; front view; twice natural size.
Figure 33.—The same vertebra; seen from the left side.
Figure 34.—Third cervical vertebra of *Ichthyornis victor*, Marsh; front view; twice natural size.

Fig. 35.

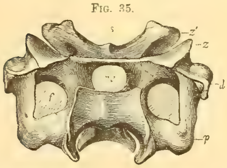

Fig. 36.

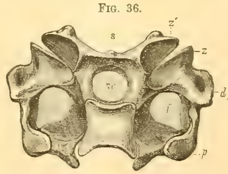

Figure 35.—Thirteenth cervical vertebra of *Hesperornis regalis*, Marsh; front view; natural size.
Figure 36.—The same vertebra; posterior view. *a.* anterior articulation; *d.* diapophysis; *p.* parapophysis; *f.* lateral foramen; *nc.* neural canal: *s.* neural spine; *z.* pre-zygapophysis; *z'.* post-zygapophysis.

To the evolutionist, who believes that birds are all closely connected genetically, this difference in structure, at first sight, offers a most serious difficulty; since hitherto we have had no hint of a transformation from the one form to the other.

In the third cervical vertebra of *Ichthyornis*, however, we catch nature in the act, as it were, of forming a new type; by modifying one form of vertebra into another. Following this clew, the connection between these widely divergent types of structure soon becomes apparent; and the development of the modern style of avian vertebra from the fish-like, biconcave form finds a ready solution. In the anterior articulation of this vertebra of *Ichthyornis* (figure 34), the surface looks downward and forward, being inclined at an angle of nearly 60° with the axis of the centrum. In vertical section, it is moderately convex, while transversely it is strongly concave; thus presenting a near approach to the saddle-like articulation. None of the other known vertebræ of *Ichthyornis* possess this character.

This highly specialized feature occurs at the first bend of the neck, and greatly facilitates motion in a vertical plane. If, now, we consider for a moment that the dominant motion in the neck of a modern bird is in a vertical plane, we see at once that anything that tends to facilitate this motion would be an advantage, and that the motion itself would tend directly to produce this modification. With biconcave vertebræ, the flexure in any direction is dependent on the elasticity of the fibrous tissue that connects them, as the edges of the cups do not slide over each other. An increasing movement in the neck of *Ichthyornis* in a vertical plane would tend to deflect the upper and lower margins of the circular cup, and to produce a vertical constriction, and at the same time to leave the lateral margins projecting; and this is precisely what we have in the third vertebra of this genus.

This modification of the vertebræ would naturally appear first where the neck had most motion, viz: in the anterior cervicals, and gradually would be extended down the neck; and, on to the sacrum, if the same flexure were continued.

Behind the axis, or where the vertical motion prevails, we find in modern birds no exception to the saddle articulation of the vertebræ in the whole cervical series.

In the dorsal vertebræ, this cause would be less efficient, since the ribs and neural spines tend to restrict vertical motion, and hence to arrest this modification. This region, then, as might be expected, offers strong confirmatory evidence of the correctness of the above explanation; for here occur, among existing birds, the only true exceptions known in the presacral series to the characteristic saddle-shaped articulation. In *Strigops* and a few other land birds; in the Penguins, the Terns, and some other aquatic birds, one or more vertebræ in the dorsal region are without the saddle-shaped articulation, and are either opisthocœlian, or imperfectly biconcave. In such instances, we can usually, if not always, detect evidence of an arrest of vertical flexure. This may lock together the posterior dorsals by their neural spines, as in *Strigops,* leaving the power of lateral flexure; or several vertebræ may be coössified, as in *Accipiter,* and some other *Raptores,* in which a stiff back is a positive advantage.

In the coössified sacral series of many birds, one or more of the anterior vertebræ have the saddle-shaped articulation. This, however, is no valid objection to the above explanation, since these vertebræ are really dorsals, and have gradually coalesced with the true sacral vertebræ.

In the caudal vertebræ of recent birds we have, in a measure, the original biconcave structure preserved, for here the motion in every direction was much restricted. The caudal vertebræ of these birds, even in the most aberrant forms, are essentially the same, and in the fossil species the articulations at least appear to follow the general rule. In *Pavo* and *Geococcyx,* the caudal vertebræ exhibit a tendency to a procœlian union. Some other forms also show unimportant modifications of the normal type of caudal articulation, but nothing to suggest a real objection to the explanation now proposed of the origin of the saddle-shaped vertebræ, characteristic of Birds.

In bringing together the above facts, and others suggested by them, the classification and development of the various forms of vertebræ appear to be somewhat as follows:

(1.) *Biconcave vertebræ* (Fishes and Amphibians); the primitive type; a weak articulation, admitting free, but limited motion. From this form, have been directly derived the other varieties, namely:

(2.) *Plane vertebræ* (Mammals); affording a stronger joint, with motion still restricted.

(3.) *Cup-and-ball vertebræ* (Reptiles); a strong and flexible joint, well fitted for general motion, and evidently produced by it. The vertebræ are procœlian when lateral motion is dominant (Serpents); opisthocœlian with varied motion (Dinosaur cervicals).

(4.) *Saddle vertebræ* (Birds); the highest type; a very strong and free articulation, especially adapted to motion in a vertical plane, and mainly due originally to its predominance.

In considering the mode of life, and habits of *Ichthyornis*, many important suggestions may be derived from its structure, as well as from the localities where the remains are found. The sharp cutting teeth of *Ichthyornis* prove, beyond a doubt, that it was carnivorous; its great powers of flight, long jaws, and its recurved teeth suggest, moreover, that it captured its prey alive. Its food was probably fishes, as their remains are found in great abundance mingled with those of *Ichthyornis.* These fossils occur in the bed of the old Cretaceous ocean in which *Hesperornis* swam. Both of these birds were clearly aquatic in habit, as shown by various points in their structure, already described, and the conditions under which their remains were deposited. In many respects, *Ichthyornis* probably resembled the modern Terns in its mode of life. The powerful wings and small feet suggest similar habits in flight, and rest. That *Ichthyornis* was provided with feathers is proved beyond question by the tubercles for the attachment of quills on the forearm.

Beside *Ichthyornis* and its allies, the only other denizens of the air at present known to have then inhabited the same region were the toothless Pterodactyles. *Ichthyornis* doubtless competed with these huge dragons for the fishes in the tropical ocean, about which they lived.

CHAPTER XVII.

CONCLUSION.

Having now described the more important characters in the structure, so far as known, of the two groups of Cretaceous *Odontornithes*, or Birds with teeth, it remains to consider what relation these birds bear to each other, and to allied members of the class; and, also, to inquire if the facts presented throw any light on the profounder question as to the origin of Birds.

In comparing *Hesperornis* and *Ichthyornis*, as the types of their respective orders, the *Odontolcæ* and *Odontotormæ*, the contrast in their principal characters is as striking as it is unexpected. *Hesperornis* had teeth implanted in a continuous groove, a low, generalized character; with, however, the strongly differentiated saddle-shaped vertebræ. *Ichthyornis*, on the other hand, had the primitive biconcave vertebræ, and yet the highly specialized feature of teeth in distinct sockets. Better examples than these could hardly be found to illustrate one fact brought out by modern science, that an animal may attain great development in one set of characters, and at the same time retain other low features of the ancestral type. This is a fundamental principle of evolution.

The more superficial characters of the absence of wings and the strong swimming legs and feet of *Hesperornis* are in striking contrast, also, with the powerful wings and diminutive legs and feet of *Ichthyornis*. These and other characters, already mentioned, separate the two birds so widely that a more detailed comparison seems here unnecessary.

It would be highly desirable to carefully compare both *Ichthyornis* and *Hesperornis* with *Archæopteryx*, the still older Mesozoic bird. This unfortunately cannot be done at present, as the two skeletons of *Archæopteryx*, now known, have not yet been fully described, nor even prepared for examination by removal of the matrix. That *Archæopteryx* belongs to the *Odontornithes*, the writer fully satisfied himself by a personal examination of the well known specimen in the British Museum. This examination was made in 1878, several years after the writer had become familiar with the American forms of toothed birds. The teeth seen on the same slab with this specimen of *Archæopteryx*, and referred to it by Evans, although imperfectly preserved, agree so closely with the teeth of *Hesperornis*, that the writer identified them at once as those of Birds, and not of Fishes. It has since been announced that the specimen of *Archæopteryx*, more recently found in Germany, also possessed teeth, although only two of small size were detected. The separate metacarpal bones, and especially the elongated tail, of *Archæopteryx*, moreover, remove it widely from the known American genera of *Odontornithes*. It will probably be found, however, that *Archæopteryx* possessed biconcave vertebræ, somewhat like those of *Ichthyornis*.

The other Mesozoic birds now known from the deposits of this country, and the few discovered in Europe, may, some or all of them, have had teeth, but their remains are too fragmentary to determine this point, or even their near affinities.

It is an interesting fact that the Cretaceous birds at present known, some twenty species or more, were all apparently aquatic forms, which are of course most likely to be preserved in marine deposits, while the Jurassic *Archæopteryx*, the only one from that formation, was a true land bird.

The Birds found in more recent formations all belong apparently to modern types, and hence present few points for profitable comparison with the *Odontornithes*. The existing birds with reptilian characters are nearly all confined to the *Ratitæ*, or Ostrich tribe. These are evidently the remnants of a very numerous group, once widely extended over different parts of the earth; and it is to the fossil forms of these birds that we must look eventually for the intermediate types between them and the less specialized Mesozoic birds.

For the present, at least, it seems advisable to regard the *Odontornithes* as a sub-class, and to separate them into three orders, according to the characters given below. These orders are all well marked, but evidently are not of equal rank. *Archæopteryx* is clearly separated much more widely from both *Ichthyornis* and *Hesperornis* than are these two genera from each other. The free metacarpals and long tail of *Archæopteryx* are significant characters. Gegenbaur and Morse have shown, however, that young birds of existing species have the metacarpals separate, and this is true for all these birds up to a certain age. Hence this character is of less importance than the presence of true teeth, since in no recent birds, young or old, have these been found. The length of tail is perhaps a character of more value, but even this is a variable feature in modern birds.

Sub-class ODONTORNITHES (or AVES DENTATÆ), Marsh.

Order ODONTOLCÆ, Marsh.	ODONTOTORMÆ, Marsh.	SAURURÆ, Haeckel.
Genus *Hesperornis*, Marsh.	*Ichthyornis*, Marsh.	*Archæopteryx*, von Meyer.
Teeth in grooves.	Teeth in sockets.	Teeth in ——— ?
Lower jaws separate.	Lower jaws separate.	Lower jaws ——— ?
Vertebræ saddle-shaped.	Vertebræ biconcave.	Vertebræ ——— ?
Wings rudimentary.	Wings large.	Wings small.
Metacarpals wanting.	Metacarpals ankylosed	Metacarpals separate.
Sternum without keel.	Sternum with keel.	Sternum ——— ?
Tail short.	Tail short.	Tail longer than body.

That the three oldest known birds should differ so widely from each other points unmistakably to a great antiquity for the class. *Archæopteryx*, *Hesperornis*, and *Ichthyornis*, are all true birds, but the reptilian characters they possess are convergent toward a more generalized type. No Triassic birds are known, and hence we have no light on this stage of the development of the class. They will doubtless be found, however, and, if we may judge from Jurassic Mammals and Reptiles, the next classes above and below Birds, the avian forms of that period would still be birds, although with even stronger reptilian features. For the primal forms of the bird-type, we must evidently look to the Palæozoic; and in the rich land fauna of our American Permian we may yet hope to find the remains of both Birds and Mammals.

The genera *Archæopteryx*, *Hesperornis*, and *Ichthyornis*, each possessed certain generalized characters not shared by the others. These characters were undoubtedly united in some earlier form, and this fact gives us a hint as to what the more primitive forms must have been, and suggests the prominent features of the ancestral type.

In the generalized form to which we must look back for the ancestral type of the class of Birds, we should therefore expect to find the following characters:

(1.) Teeth, in grooves.
(2.) Vertebræ biconcave.
(3.) Metacarpal and carpal bones free.
(4.) Sternum without a keel.
(5.) Sacrum composed of two vertebræ.
(6.) Bones of the pelvis separate.
(7.) Tail longer than the body.
(8.) Metatarsal and tarsal bones free.
(9.) Four or more toes, directed forward.
(10.) Feathers rudimentary or imperfect.

These various characters may indeed have been combined in an animal that was more reptile than bird; but such a form would be on the road toward the Birds, rather than on the ancestral line of either Dinosaurs or Pterodactyles, as feathers were not a character of these groups. With this exception, all of the characters named belong to the generalized Sauropsid, from which both birds and the known Dinosaurs may well have descended. An essential character in this ancestral type would be a free quadrate bone, since this is a universal feature in Birds, and only partially retained in the Dinosaurs now known.

The Birds would appear to have branched off by a single stem, which gradually lost its reptilian characters as it assumed the ornithic type, and in the existing Ratitæ we have the survivors of this direct line. The lineal descendants of this primal stock doubtless early attained feathers and warm blood, but, as already shown (p. 114), never acquired the power of flight. The volant birds doubtless separated early from the main avian stem, probably in the Triassic, since, in the formation above, we have *Archæopteryx*, with imperfect powers of flight.

This power of flight probably originated among the small arboreal forms of reptilian birds. How this may have commenced, we have an indication in the flight of *Galeopithecus*, the flying squirrels (*Pteromys*), the flying lizard (*Draco*), and in the flying tree-frog (*Rhacophorus*). In the early arboreal birds, which jumped from branch to branch, even rudimentary feathers on the fore limbs would be an advantage, as they would tend to lengthen a downward leap, or break the force of a fall. As the feathers increased, the body would become warmer, and the blood more active. With still more feathers, would come increased power of flight, as we see in young birds of to-day. A greater activity would result in a more perfect circulation. A true bird would doubtless require warm blood, but would not necessarily be hot-blooded, like the birds now living.

The short wings and clumsy tail of *Archæopteryx* were quite sufficient for short flights from tree to tree, and if the body were essentially naked, as now supposed, we have in this Jurassic form an interesting stage in the development of birds before full plumage was attained. Whether *Archæopteryx* was on the true Carinate line cannot at present be determined, and this is also true of *Ichthyornis*; but the biconcave vertebræ of the latter evidently suggest that this form was an early offshoot. It is probable that *Hesperornis* came off from the main Struthious stem, and has left no descendants.

These three ancient birds, so widely different from each other, and from all modern birds, prove beyond question the marvelous diversity of the avian type in Mesozoic time; and also give promise of a rich reward to the explorer who successfully works out the life-history of allied forms, recorded in ages more remote.

APPENDIX.

SYNOPSIS OF AMERICAN CRETACEOUS BIRDS.

The present synopsis contains a list of all the species of birds now known from the Cretaceous deposits of this country. As so many of these are at present represented only by fragmentary remains, and their near affinities are thus more or less uncertain, it seems advisable to arrange the genera in alphabetical order, rather than to attempt a more systematic classification. The list contains nine genera, and twenty species.

Most of the remains of American Cretaceous birds are from the Eastern slope of the Rocky Mountains. The beds in which they are found are of middle Cretaceous age, and have elsewhere been named by the writer the "Pteranodon beds," from the genus of toothless Pterodactyles (*Pteranodon*), which occurs in them. Nearly all the specimens discovered in this region were found in Western Kansas, and the remainder, in essentially the same strata, in Texas.

The bird remains found in the green-sand deposits of New Jersey are from a higher horizon, representing a division of the upper Cretaceous. These remains appear to be all distinct from those in the lower strata of the West. Some of the specimens from this region possess characters more specialized than the earlier forms; and, as neither jaws nor teeth have yet been detected, it is at present impossible to say whether the eastern species belong to the *Odontornithes.* This point will doubtless be decided by future discoveries.

All the beds in which bird remains have hitherto been found, in the American Cretaceous, are marine deposits, and the birds preserved in them appear to have been all aquatic species.

APATORNIS,[1] Marsh, 1873.

Apatornis celer, Marsh.

(Plates XXVIII–XXXIII.)

Ichthyornis celer, Marsh.—American Journal of Science, Vol. V, p. 74, Jan., 1873.
Apatornis celer, Marsh.—Vol. V, p. 162, Feb., 1873 ; Vol. V, p. 230, March, 1873; Vol. X, p. 404, Nov., 1875.
American Naturalist, Vol. IX, p. 626, December, 1875.
Geological Magazine, Vol. III, p. 50, February, 1876.
Woodward, Popular Science Review, October, 1875, p. 349.

The type specimen of this genus (number 1451) was discovered by the writer in October, 1872, near the Smoky Hill River, in Western Kansas. The remains were imbedded in the yellow chalk of the Pteranodon beds, a well marked horizon in the middle Cretaceous.

A more perfect specimen (number 1734) was found in 1877, by Mr. F. H. Williston, a member of the writer's party. The locality was near the same river, and in the same geological horizon.

Only these two specimens of the present species are known, and both are deposited in the Museum of Yale College.

BAPTORNIS,[2] Marsh, 1877.

Baptornis advenus, Marsh.

Marsh, American Journal of Science, Vol. XIV, p. 86, July, 1877.
Journal de Zoologie, Tome VI, p. 387, 1877.

The type specimen (number 1465) of the present species is a nearly perfect tarso-metatarsal bone. This specimen, although pertaining to a bird not fully adult, is in excellent preservation, and is so characteristic that it may be readily distinguished from any forms already described.

In general shape and proportions, this bone very nearly resembles the corresponding part in *Hesperornis*, but differs from it decidedly in the outer metatarsal, which at its lower end (figure 37, IV) scarcely equals the adjoining one in size and length. In *Hesperornis*, on the contrary, the outer metatarsal is more than double the size of the third. In the present specimen, the three trochlear articulations of the distal ends are nearly equal. The existence of a hallux is indicated by a small elongated depression on the inner metatarsal, a short distance above the articulation. As in the same bone in *Hesperornis*, there are no canals or grooves for tendons on the posterior face of the proximal end.

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[1] *ἀπατάω*, to deceive, and *ὄρνις*, a bird.
[2] *βαπτω*, to plunge, and *ὄρνις*, a bird.

This specimen of *Baptornis* is represented in the cuts given below:

Fig. 37.

Fig. 38.

Fig. 39.

Figure 37.—Right tarso-metatarsal of *Baptornis advenus*, Marsh; front view; natural size.
Figure 38.—Side view of same bone.
Figure 39.—Posterior view; *a.* lower tarsal bone.

The principal dimensions of this tarso-metatarsal are as follows:—

Entire length,	76. mm
Transverse diameter of proximal end,	17.
Antero-posterior diameter,	8.
Length of second metatarsal,	64.5
Length of third metatarsal,	72.
Length of fourth metatarsal,	72.
Antero-posterior diameter of distal articulation of second metatarsal,	8.5
Transverse diameter,	5.
Antero-posterior diameter of distal articulation of third metatarsal,	9.2
Transverse diameter,	6.
Antero-posterior diameter of distal articulation of fourth metatarsal,	9.
Transverse diameter,	5.5

A second specimen of *Baptornis advenus* (number 1467) appears by a comparison of the corresponding bones in *Hesperornis* to have been not quite as large as the type specimen, probably about one-fifth less in size. It was evidently a young individual. The femur is less robust than in *Hesperornis*, but considerably resembled the same bone in that genus.

Its head shows a broad surface for attachment of the round ligament. The shaft was hollow, and provided with strong rugosities for muscular attachment. The distal end was expanded, and the articular surfaces for the tibia and fibula were much as in *Hesperornis.*

The tibia in this specimen of *Baptornis* (number 1467) was a strong bone with the shaft subtrihedral proximally, becoming nearly cylindrical toward the middle, and flattened from before backward toward the distal end. The suture between the tibia and the coössified tarsal bone is still distinct, but most of the articular face is broken away. The fibular ridge is strongly developed, and was interrupted by the groove for the main tibial artery, as in *Hesperornis.* The ridge on the opposite, or inner, side of the tibia is more strongly developed than in *Hesperornis.* It also con tinues further downward, and remains sharp and distinct to near its termination.

Measurements of Baptornis advenus. (No. 1467.)

	Right.
Least transverse diameter of shaft of femur,	9. mm
Antero-posterior diameter,	8.
Greatest diameter of distal end,	21.5
Transverse diameter of tibial articulation,	14.
Transverse diameter of fibular articulation,	6.
Length of tibia (approximate),	125.
Transverse diameter below fibular ridge,	9.
Antero-posterior diameter below fibular ridge,	7.

These specimens indicate a bird about as large as a Loon, and one apparently of similar aquatic habits. The locality of the only remains at present known is in Western Kansas, in the same Cretaceous beds that contain the *Odontornithes* and *Pteranodontia.*

Both of the above specimens are preserved in the Yale Museum.

GRACULAVUS,[3] Marsh, 1872.

Graculavus velox, Marsh.

Marsh, American Journal Science, Vol. III, p. 363, May, 1872 ; Vol. V, p. 229, March, 1873.

Coues, Key to North American Birds, p. 349, 1872.

The specimens representing this species at present were found by Mr. John G. Meirs, near Hornerstown, New Jersey, in the green-sand of the middle marl bed, or upper Cretaceous.

The known remains (number 855) of this species belonged to a bird about two-thirds as large as a Cormorant. They are all in the Yale College Museum.

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[3] *Graculus*, a cormorant, and *avus*, a grandfather.

Graculavus agilis, see **Ichthyornis agilis.**

Graculavus anceps, see **Ichthyornis anceps.**

Graculavus lentus, see **Ichthyornis lentus.**

Graculavus pumilus, Marsh.

Marsh, American Journal Science, Vol. III, p. 364, May, 1872; Vol. V, p. 229, March, 1873.
Coues, Key to North American Birds, p. 350, 1872.

The specimens on which the present species was based (number 850) indicate a bird about one-third as large as the type of *Graculavus velox.* They were found in the green-sand of the upper Cretaceous, near Hornerstown, New Jersey.

All the remains at present known are in the Museum of Yale College.

HESPERORNIS,[4] Marsh, 1872.

Hesperornis regalis, Marsh.

(Plates I–XX.)

Marsh, American Journal Science, (3) Vol. III, p. 56, January, 1872; Vol. III, p. 360, May, 1872; (3,) Vol. X, p. 403, Nov., 1875; Vol. XIV, p. 85, July, 1877, Pl. V.
American Naturalist, Vol. IX, p. 625, Dec., 1875.
Geological Magazine, Vol. III, p. 49, Pl. II, February, 1876.
Journal de Zoologie, Tome IV, p. 494, 1875, Pl. XV; Tome VI, p. 385, 1877.
Coues, Key to North American Birds, p. 350, 1872.
Woodward, Popular Science Review, Oct., 1875, p. 337.
Huxley, New York Lectures, Popular Science Monthly, 1876, Vol. X, pp. 215–218.
American Addresses, pp. 50–57, London, 1877. (Restoration, from Plate XX.)
Seeley, Journal Geological Society of London, Vol. XXXII, p. 510, 1876.
Vogt, Revue Scientifique, Tome XVII, p. 247, 1879.
Dana, Manual of Geology, Plate IV, 1880. (Figures from present volume.)
Fraisse, Würzburg Physikalisch-Medizinischen Gesellschaft, 1880.

The first remains of this species discovered (number 1205) were found by the writer in November, 1870, near the Smoky Hill River, in Kansas, about twelve miles east of Fort Wallace. The geological horizon was in the yellow chalk of the "Pteranodon Beds."

The type specimen of *Hesperornis regalis* (number 1200) was found by the writer, in July, 1871. The locality was on the south bank of the Smoky Hill River, about twenty miles east of Fort Wallace. This fossil was imbedded in the gray calcareous shale, nearly in the same horizon

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[4] *ἕσπερος,* western, and *ὄρνις,* a bird.

as the one first found. The skull was wanting, but many other parts of the skeleton, including the vertebræ and the bones of the legs and feet, were well preserved. Portions of five other individuals were found by the writer on the same expedition.

The most perfect specimen of this species yet discovered (number 1206) was obtained by Mr. T. H. Russell and the writer in October, 1872. This skeleton was nearly complete when found, the skull, lower jaws, and pelvis being especially well preserved. The locality was near that of the type specimen. Another important skeleton (number 1207) was found in July, 1875, by Prof. B. F. Mudge, who was then in charge of one of the writer's exploring parties.

Other specimens of importance were obtained on subsequent expeditions by Messrs. B. F. Mudge, S. W. Williston, E. W. Guild, G. P. Cooper and H. A. Brous.

These specimens, representing some forty different individuals, were all found in essentially the same geological horizon of the middle Cretaceous. The localities are all in Western Kansas, and most of them near the Smoky Hill River and its tributaries.

The known remains of this species are all preserved in the Yale College Museum.

Hesperornis crassipes, Marsh.

(Plates VII and XXVII.)

Lestornis crassipes, Marsh.—American Journal Science (3), Vol. XI, p. 509, June, 1876.

The type specimen of this species (number 1474) consists of a nearly complete skeleton, found in the yellow chalk of western Kansas, by Mr. G. P. Cooper, in April, 1876. These remains indicate a bird considerably larger than the type of *Hesperornis regalis*, and one that may prove to be generically distinct. The characters already mentioned, especially those seen in the tarso-metatarsus, may possibly be merely sexual; although it would be strange indeed on this supposition, that no other specimens with these features should have been found.

In the present specimen, number 1474, the atlas is preserved, and is represented in the cuts below.

FIG. 40.

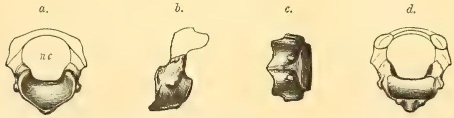

FIGURE 40.—Atlas of *Hesperornis crassipes*, Marsh; natural size. *a.* front view; *b.* side view; *c.* bottom view; *d.* back view; *nc.* neural canal.

The above named skeleton, the only one known with certainty to belong to the present species, is deposited in the Yale College Museum.

Hesperornis gracilis, Marsh.

Marsh, American Journal Science, Vol. XI, p. 510, June, 1876.
This volume, p. 99.

The specimen on which this species was based (number 1473) was found in April, 1876, by Mr. G. P. Cooper. A nearly complete skeleton (number 1679) was found in 1879, by Mr. E. W. Guild. Both specimens are from the yellow chalk, near the Smoky Hill River, in western Kansas.

The known remains of this species are in the Museum of Yale College.

ICHTHYORNIS,[5] Marsh, 1872.

Ichthyornis dispar, Marsh.

(Plates XXI–XXVI.)

Marsh, American Journal Science, Vol. IV, p. 344, Oct., 1872; Vol. V, p. 161, Feb., 1873; Vol. V, p. 230, March, 1873.
American Naturalist, Vol. IX, p. 625, Dec., 1875.
Geological Magazine, Vol. III, p. 49, 1876.
Journal de Zoologie, Tome IV, p. 494, Plate XV, 1875; VI, p. 385, 1877.
Colonosaurus Mudgei, American Journal Science, Vol. IV, p. 406, Nov., 1872.
Coues, Key to North American Birds, p. 350, 1872.
Owen, Journal Geological Society of London, Vol. XXIX, p. 520, 1873.
Woodward, Popular Science Review, Oct., 1875, p. 348.
Huxley, New York Lectures, Popular Science Monthly, 1876, Vol. X, pp. 215–218.
American Addresses, p. 54–56, London, 1877.

The type specimen of this species (number 1450) was found in 1872 by Professor B. F. Mudge, near the Solomon River, in northwestern Kansas. The bones secured are represented in the restoration of this species, Plate XXVI. Eight other specimens were obtained during the explorations carried on by the writer in the same region. All are from the "Pteranodon beds" of the middle Cretaceous.

All the remains of this species at present known are in the Museum of Yale College.

Ichthyornis agilis, Marsh.

Graculavus agilis, Marsh.—American Journal Science, Vol. V, p. 230, March, 1873.

The type of this species (number 1209) was found by the writer in October, 1872, on Butte Creek, a tributary of the Smoky Hill River, in western Kansas. The locality was in the yellow chalk, of the middle Cretaceous.

These remains are in the Museum of Yale College.

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[5] ἰχθύς, a fish, and ὄρνις, a bird.

Ichthyornis anceps, Marsh.

Graculavus anceps, Marsh.—American Journal Science, Vol. III, p. 364, May, 1872; Vol. V, p. 229, March, 1873.
Coues, Key to North American Birds, p. 350, 1872.
Marsh, This volume, p. 124.

The type specimen (number 1208) of *Ichthyornis anceps* was found by the writer in November, 1870, on the North Fork of the Smoky Hill River, about twelve miles east of Fort Wallace, Kansas. The geological horizon was in the gray shale of the middle Cretaceous. Other specimens referred to this species have since been secured from the same region.

All the known specimens are in the Yale College Museum.

Ichthyornis celer, see **Apatornis celer.**

Ichthyornis lentus, Marsh.

Graculavus lentus, Marsh.—American Journal Science and Arts, (3) Vol. XIV, p. 253, Sept., 1877.

This species is based on the lower half of a tarso-metatarsal bone (number 1796), obtained by Prof. B. F. Mudge, near Fort McKinney, Texas, in 1876. The accompanying fossils indicate that the locality was in beds of middle Cretaceous age.

This specimen is in the Museum of Yale College.

Ichthyornis tener, Marsh.

(Plate XXX, figure 8.)

The type specimen (number 1760) of the present species was found in 1879, by Mr. E. W. Guild, in Wallace County, Kansas. A second specimen (number 1766) was secured about the same time, in the same region. The locality was in the Pteranodon beds, of the middle Cretaceous.

The known remains of this species are in the Yale College Museum.

Ichthyornis validus, Marsh.

(Plate XXX, figures 11–14.)

The type of *Ichthyornis validus* (number 1740) was discovered in September, 1877, by Mr. S. W. Williston, near the Solomon River, in northwestern Kansas. The locality was in the yellow chalk of the middle Cretaceous.

All the specimens known belonging to this species are in the Yale College Museum.

Ichthyornis victor, Marsh.

(Plates XXVII–XXXIV.)

Marsh, American Journal Science, Vol. XI, p. 511, June, 1876.
Dana, Manual of Geology, pp. 466–468, Pl. V, 1880 (Restoration of skeleton, from Plate XXXIV of present volume.)

The remains on which this species was established (number 1452) were found in May, 1876, by Mr. H. A. Brous, in Wallace County, Kansas. A second specimen (number 1733) was found in 1877 by Mr. F. H. Williston, on Hackberry Creek, in Gove County, near the Smoky Hill River. More than forty other specimens have since been obtained in the same region by Messrs. S. W. Williston, E. W. Guild, and other members of the writer's parties. All these specimens are apparently from the same geological horizon in the middle Cretaceous.

All the specimens of this species at present known are preserved in the Museum of Yale College.

LAORNIS,[6] Marsh, 1870.

Laornis Edvardsianus, Marsh.

Marsh, Proceedings Philadelphia Academy, Jan., 1870, p. 5; American Journal Science, Vol. XLIX, p. 206, March, 1870 ; Vol. V, p. 230, March, 1873.
A. Milne-Edwards, Recherches Oiseaux Fossiles, Tome II, pp. 540–541, 1869–71.
Coues, Key to North American Birds, p. 350, 1872.

This species was nearly as large as a Swan. The remains (number 820) were discovered in the middle marl bed, of upper Cretaceous age, at Birmingham, New Jersey, and are now in the Museum of Yale College.

Lestornis crassipes, see **Hesperornis crassipes.**

PALÆOTRINGA,[7] Marsh, 1870.

Palæotringa littoralis, Marsh.

Marsh, Proceedings Philadelphia Academy, Jan., 1870, p. 5. American Journal Science, Vol. XLIX, p. 208, March, 1870; Vol. V, p. 229, March, 1873.
A. Milne-Edwards, Recherches Oiseaux Fossiles, Tome II, pp. 540–541, 1869–71.
Coues, Key to North American Birds, p. 349, 1872.

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[6] λᾶς, a stone, and ὄρνις, a bird.

[7] παλαιός, ancient, and τρύγγας, a shore bird.

The specimens known indicate a bird about as large as a Curlew.

The remains (number 830) were found in the upper Cretaceous green-sand, near Hornerstown, New Jersey, and are now preserved in the Yale College Museum.

Palæotringa vagans, Marsh.

Marsh, American Journal Science, Vol. III, p. 365, May, 1872 ; Vol. V, p. 229, March, 1873.
Coues, Key to North American Birds, p. 349, 1872.

The specimens preserved (number 835) indicate a bird intermediate in size between the other two species of this genus. They were discovered in the same formation, near Hornerstown, New Jersey; and are now in the Museum of Yale College.

Palæotringa vetus, Marsh.

Morton, *Scolopax*, Synopsis of the Organic Remains of the Cretaceous of the U. S., p. 32, Philadelphia, 1834.
Harlan, Medical and Physical Researches, p. 280, Philadelphia, 1835.
Marsh, Proceedings Philadelphia Academy, Jan., 1870, p. 5; American Journal Science, Vol. XLIX, p. 209, March, 1870; Vol. V, p. 229, March, 1873.
A. Milne-Edwards, Recherches Oiseaux Fossiles, Tome II, pp. 540–541, 1869–71.
Coues, Key to North American Birds, p. 349, 1872.

A smaller species, from the lower marl-bed of the same formation, found near Arneytown, New Jersey. The known remains are in the Philadelphia Academy.

TELMATORNIS,[8] Marsh, 1870.

Telmatornis priscus, Marsh.

Marsh, Proceedings Philadelphia Academy, Jan., 1870, p. 5; American Journal Science, Vol. XLIX, p. 210, March, 1870; Vol. V, p. 229, March, 1873.
A. Milne-Edwards, Recherches Oiseaux Fossiles, Tome II, p. 541, 1869–71.
Coues, Key to North American Birds, p. 349, 1872.

This species was about as large as the King Rail (*Rallus elegans*). The remains known (number 840) are from the middle marl-bed, of the upper Cretaceous. They were found near Hornerstown, New Jersey, and are preserved in the Yale College Museum.

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[8] *τέλμα*, a swamp, and *ὄρνις*, a bird.

Telmatornis affinis, Marsh.

Marsh, Proceedings Philadelphia Academy, Jan., 1870, p. 5; American Journal Science, Vol. XLIX, p. 211, March, 1870; Vol. V, p. 229, March, 1873.
A. Milne-Edwards, Recherches Oiseaux Fossiles, Tome II, p. 541, 1869–71.
Coues, Key to North American Birds, p. 349, 1872.

A somewhat smaller species than the one last mentioned, and from the same locality and formation.

The known remains (number 845) are in the Museum of Yale College.

POSTSCRIPT.

The plates of Part I of the present memoir, with their accompanying pages of explanation, were printed in 1877, and those of Part II, in April, 1878. The text of Part I was nearly all printed in 1878, and that of Part II, in the following year, or early in 1880. This delay in printing will account for the fact, that some recent publications are referred to in the Appendix, rather than in the text; and that a few of the illustrations prepared for the present volume first appeared elsewhere.

PLATE I.

PLATE I.

ODONTORNITHES.

Skull and lower jaws of HESPERORNIS REGALIS Marsh.

All Figures Natural Size. Page.

FIG. 1.—Skull; lateral view, seen from the left. Top of cranium crushed, ... 6

pm —Premaxillary.
pms—Maxillo-premaxillary suture.
t —Tooth, in position in maxillary.
an —Anterior nares.
n —Nasal bone.
l —Lachrymal bone.
of —Inter-orbital fenestra.
qj —Quadrato-jugal bone.
q —Quadrate bone.
bo —Basi-occipital.

FIG. 2.—Left lower jaw; lateral view of external surface, ... 11

t —Teeth still in place.

FIG. 3.—Left lower jaw; seen from above, ... 11

a —Groove for the teeth, with indications of sockets.
b —Groove for the reception of the upper teeth when the jaws were closed
c —Angle of mandible.

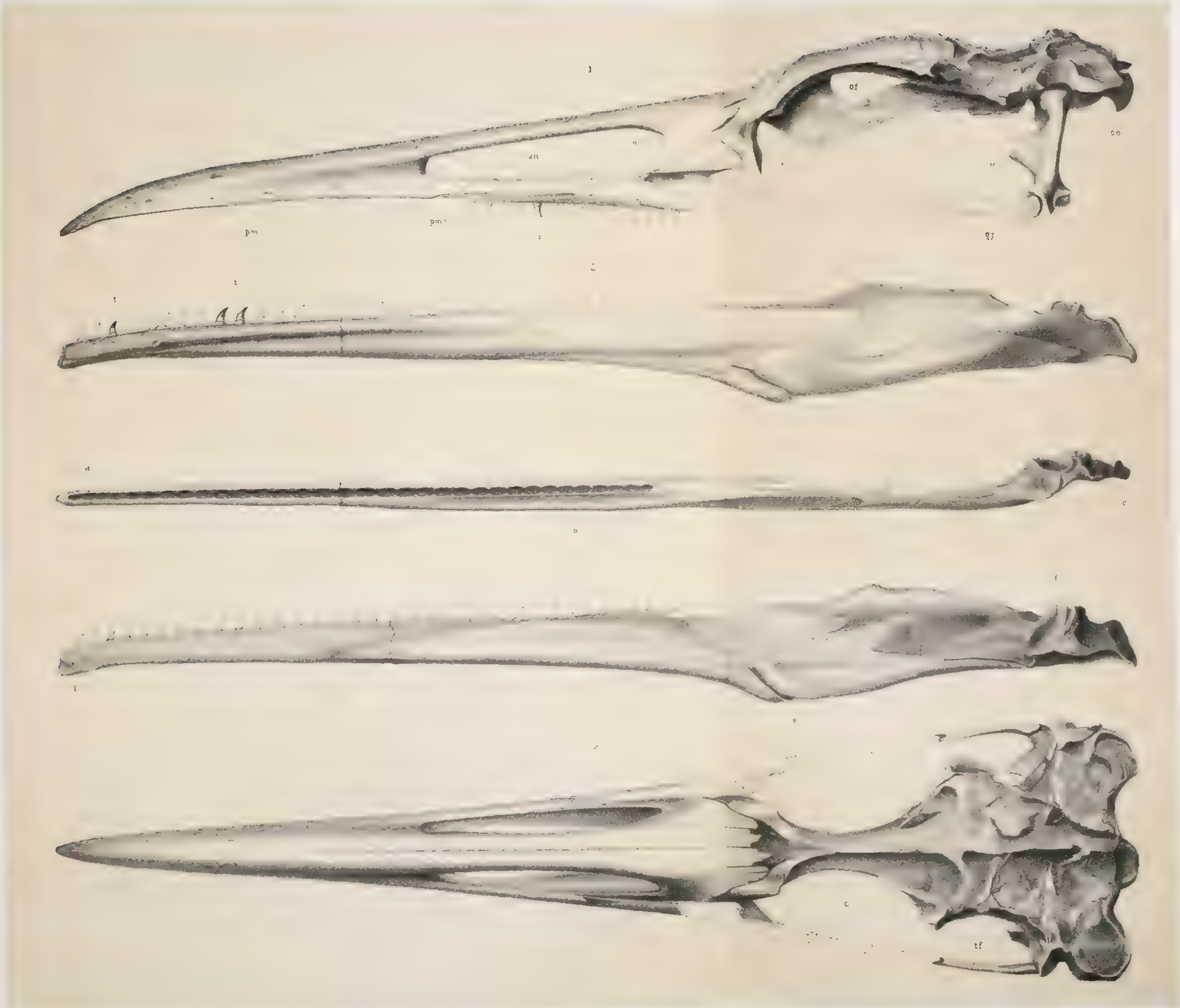
FIG. 4.—Right lower jaw; inner side, ... 11

d —Symphysial surface, showing that the rami were not coössified, but united only by cartilage.
e —Imperfect articulation between splenial and angular elements.
f —Articular surface for quadrate.

FIG. 5.—Skull; seen from above, cranium crushed, ... 6

o —Orbit.
tf —Temporal fossa.

Note.—The dotted outlines in this and the following plates represent portions wanting in the specimens described. The surface covered by oblique bars (as in figures 2 and 4) indicates portions concealed by the adhering matrix, or otherwise obscured.



F. Berger, del. E. Crisand, lith. New Haven

HESPERORNIS REGALIS, Marsh.

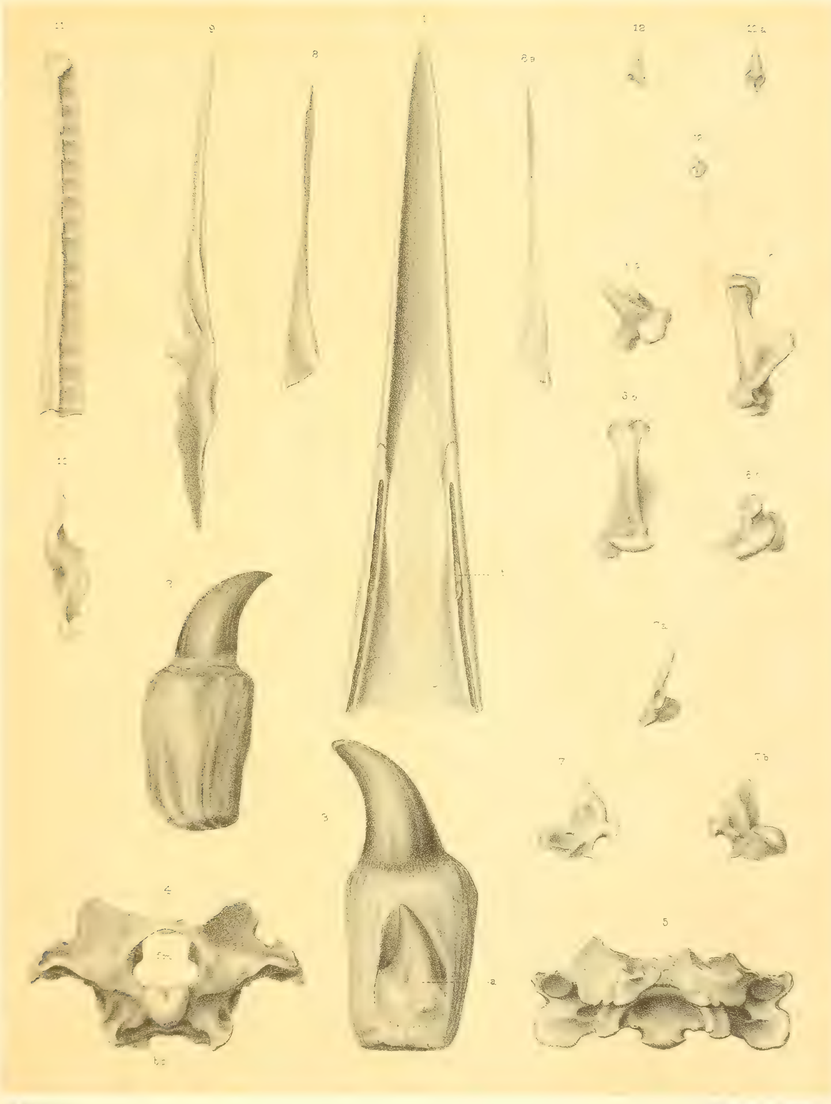
PLATE II.

PLATE II.

ODONTORNITHES.

Teeth and Skull of Hesperornis regalis Marsh.

All Figures Natural Size, except 2 and 3. Page.



HESPERORNIS REGALIS, Marsh.

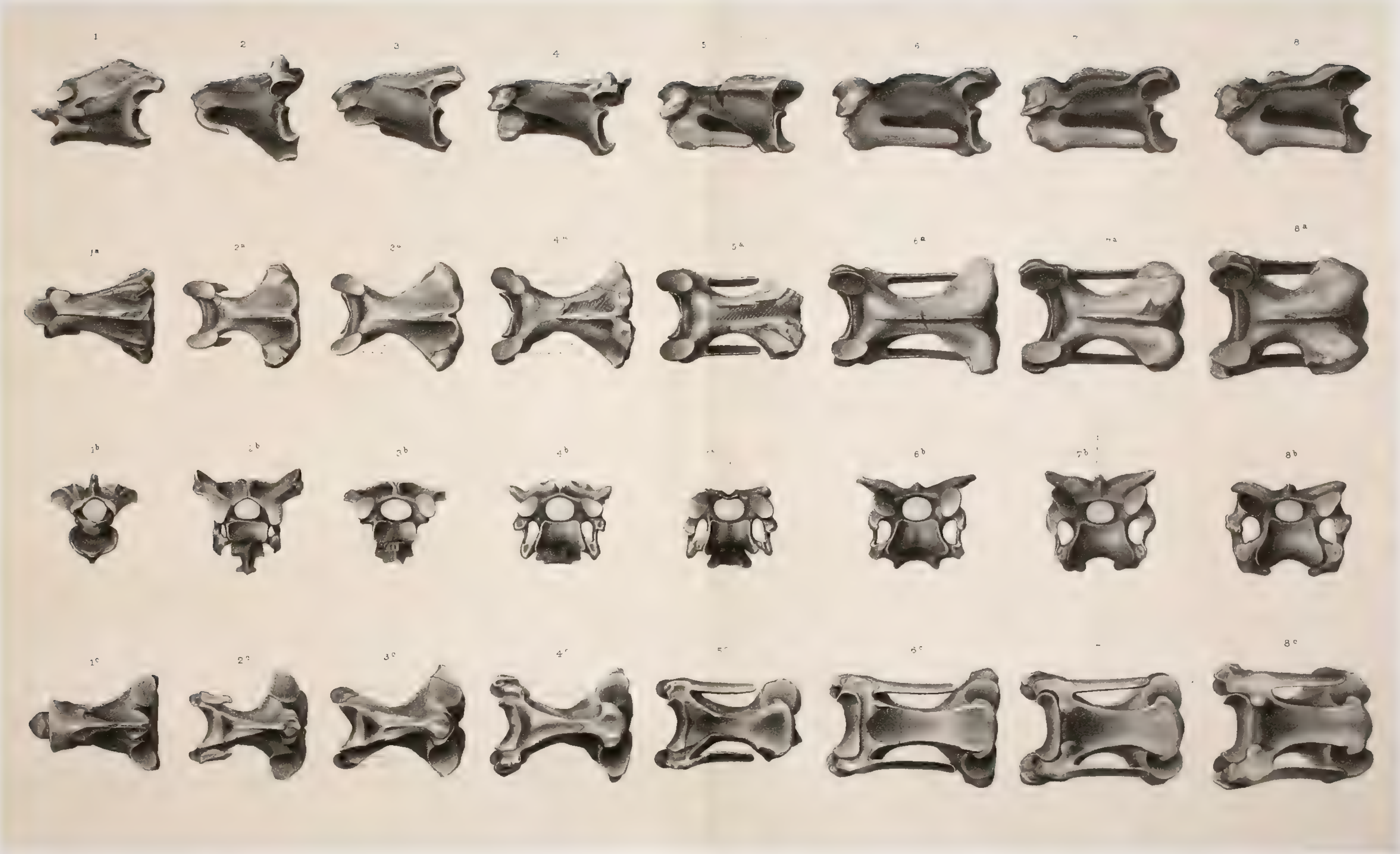
PLATE III.

PLATE III.

ODONTORNITHES.

Cervical Vertebræ of HESPERORNIS REGALIS Marsh.

All Figures Natural Size. Page.



HESPERORNIS REGALIS, Marsh

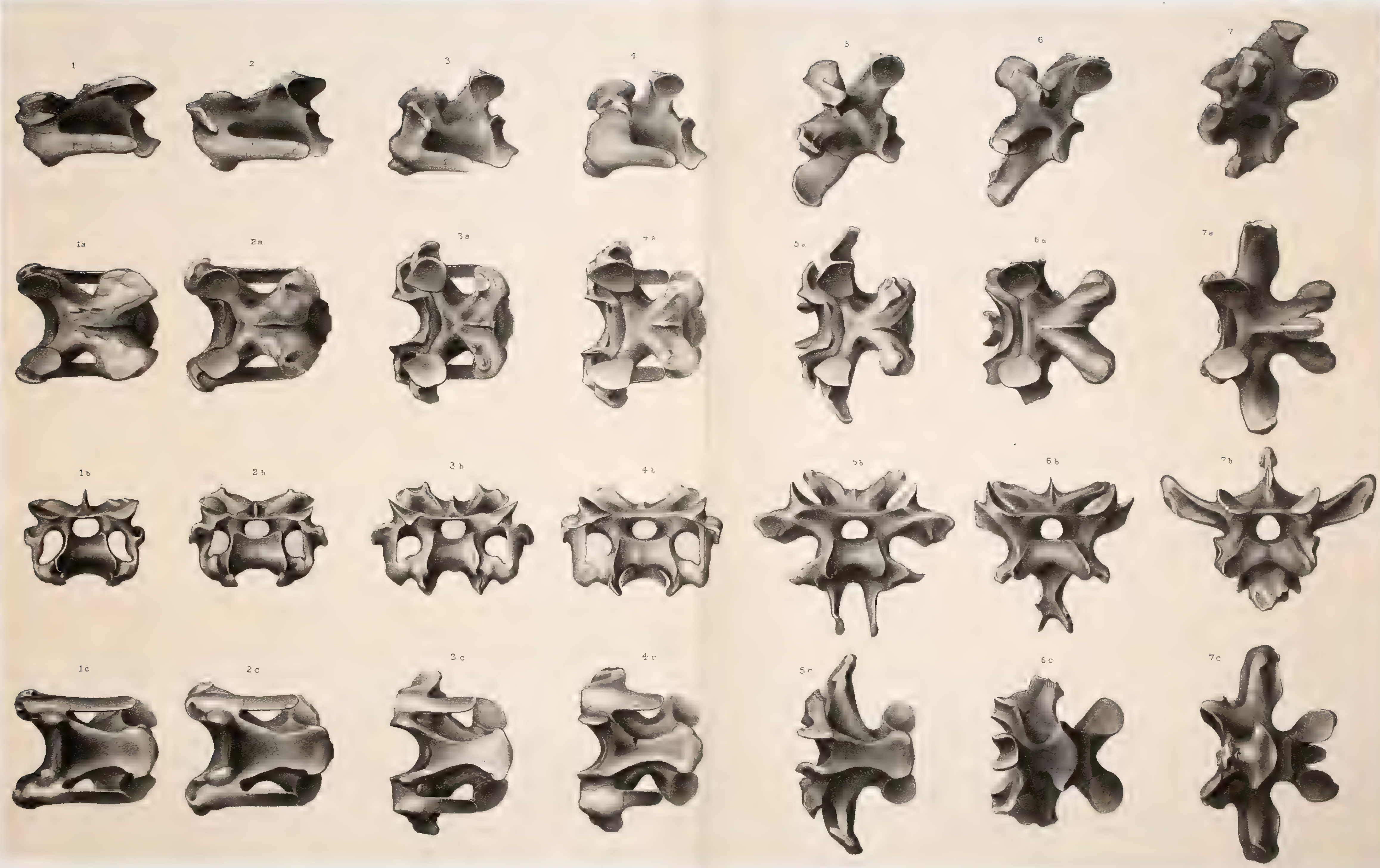
PLATE IV.

PLATE IV.

ODONTORNITHES.

Cervical Vertebræ of HESPERORNIS REGALIS Marsh.

All Figures Natural Size. Page.



HESPERORNIS REGALIS, Marsh.

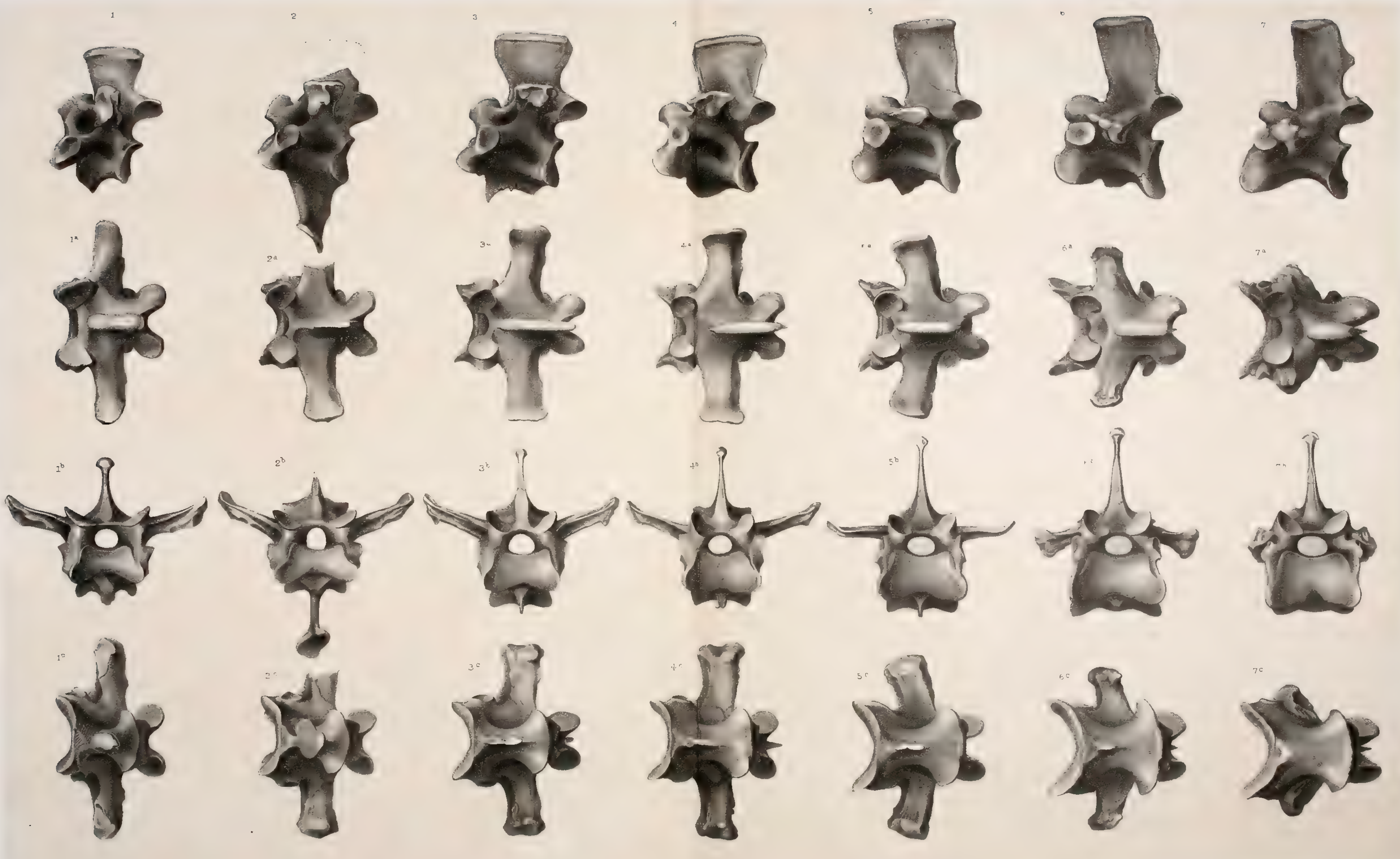
PLATE V.

PLATE V.

ODONTORNITHES.

Cervical and Dorsal Vertebræ of HESPERORNIS REGALIS Marsh.

All Figures Natural Size. Page.



F Berger, del

E Crisand lith New Haven

HESPERORNIS REGALIS, Marsh

PLATE VI.

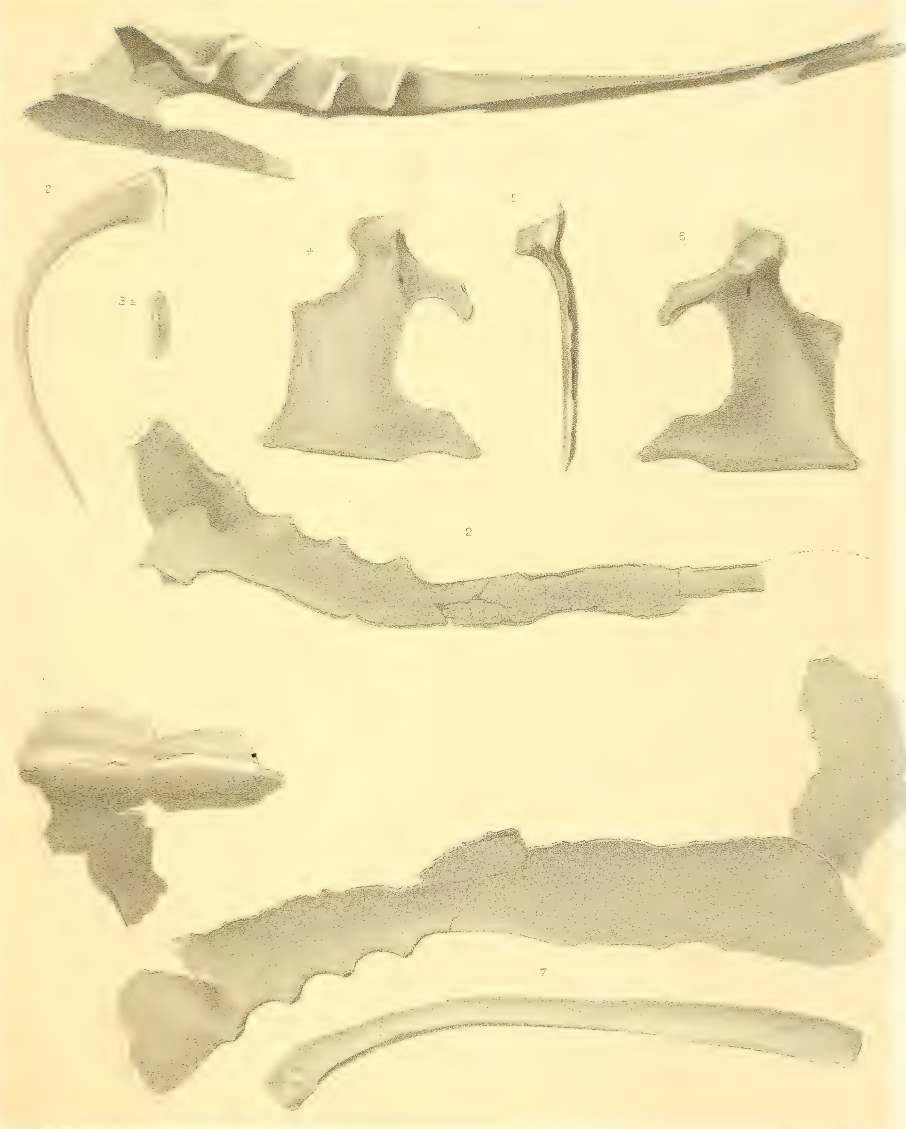
PLATE VI.

ODONTORNITHES.

Bones of Scapular Arch and Sternum of Hesperornis regalis Marsh.

All Figures Natural Size.

Page.



HESPERORNIS REGALIS, Marsh.

PLATE VII.

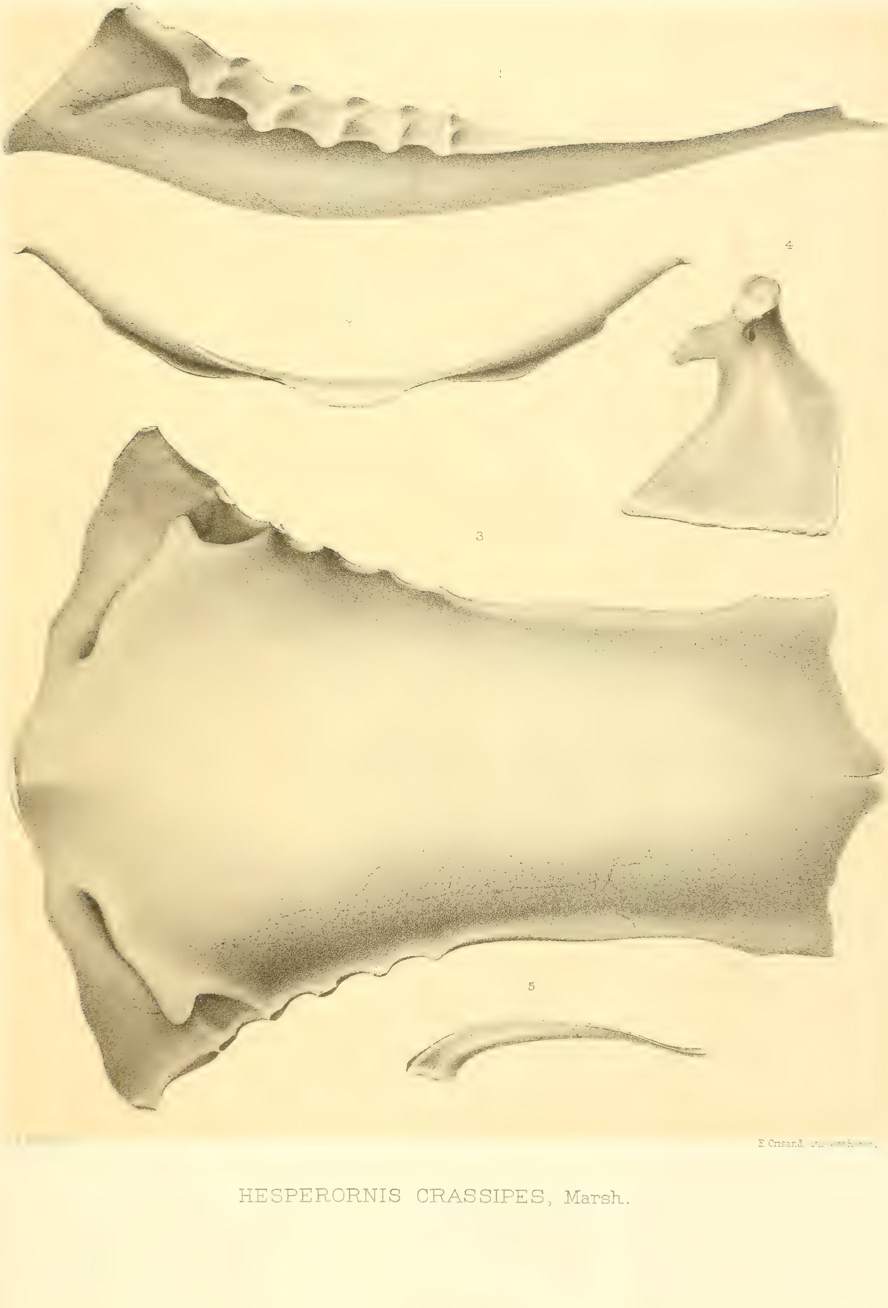
PLATE VII.

ODONTORNITHES.

Sternum, Coracoid and Clavicle of HESPERORNIS CRASSIPES Marsh.

All Figures Natural Size. Page

PLATE VII.



HESPERORNIS CRASSIPES, Marsh.

PLATE VIII.

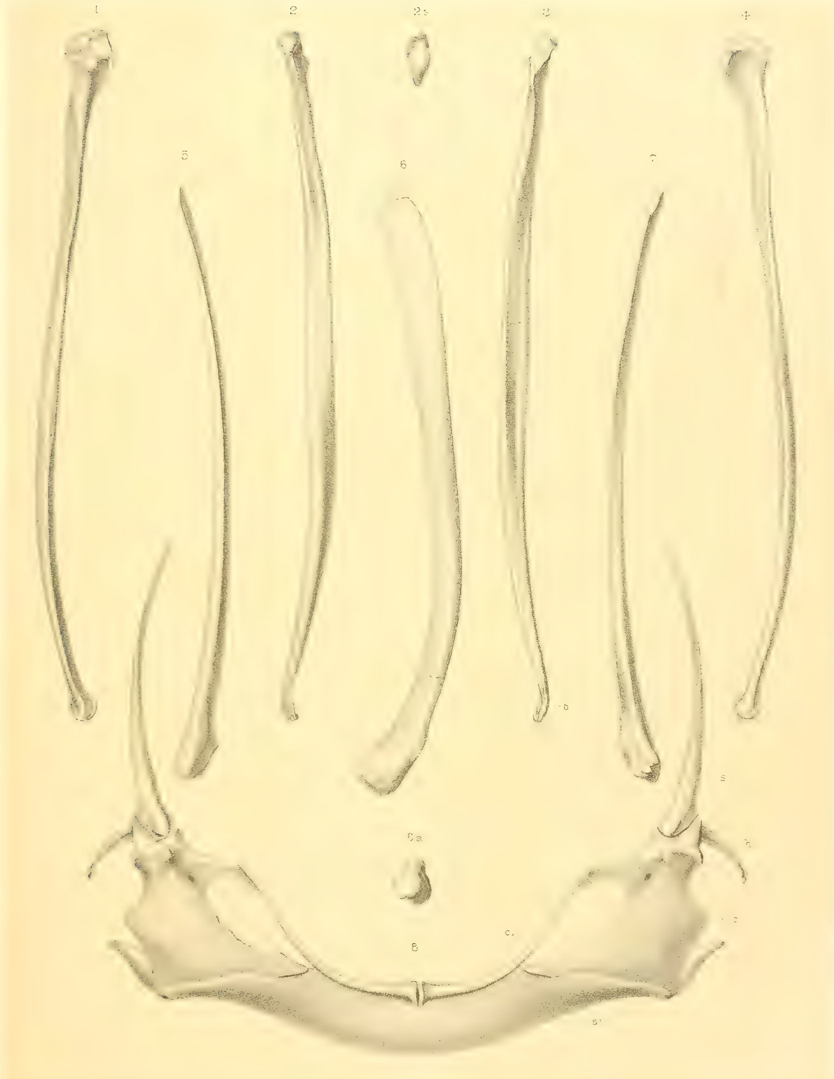
PLATE VIII.

ODONTORNITHES.

Humerus, Scapula and Shoulder-girdle of HESPERORNIS REGALIS Marsh.

All Figures Natural Size. Page.

Note.—In figure 8, portions of the scapular arch are diminished in size by the perspective. This is especially noticeable in the humerus.



HESPERORNIS REGALIS, Marsh.

PLATE IX.

PLATE IX.

ODONTORNITHES.

Ribs and Uncinate processes of Hesperornis regalis Marsh.

All Figures Natural Size. Page.

10

13

E. Crisand, lith New Haven

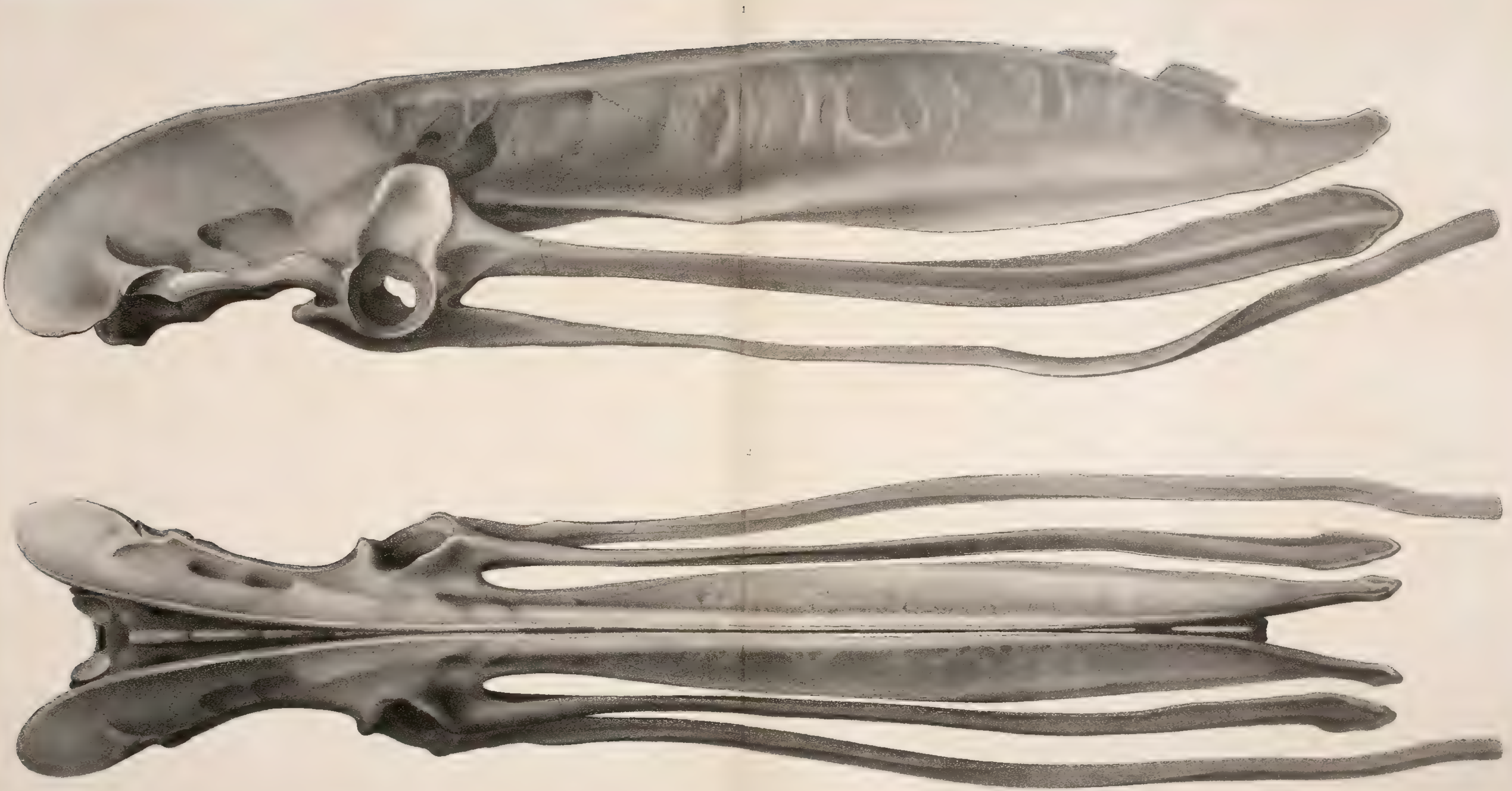
HESPERORNIS REGALIS, Marsh

PLATE X.

PLATE X.

ODONTORNITHES.

Pelvis of HESPERORNIS REGALIS Marsh.



F Berger, del.

E Crisand, lith New Haven

HESPERORNIS REGALIS, Marsh.

PLATE XI.

PLATE XI.

ODONTORNITHES.

Pelvis of HESPERORNIS REGALIS Marsh.

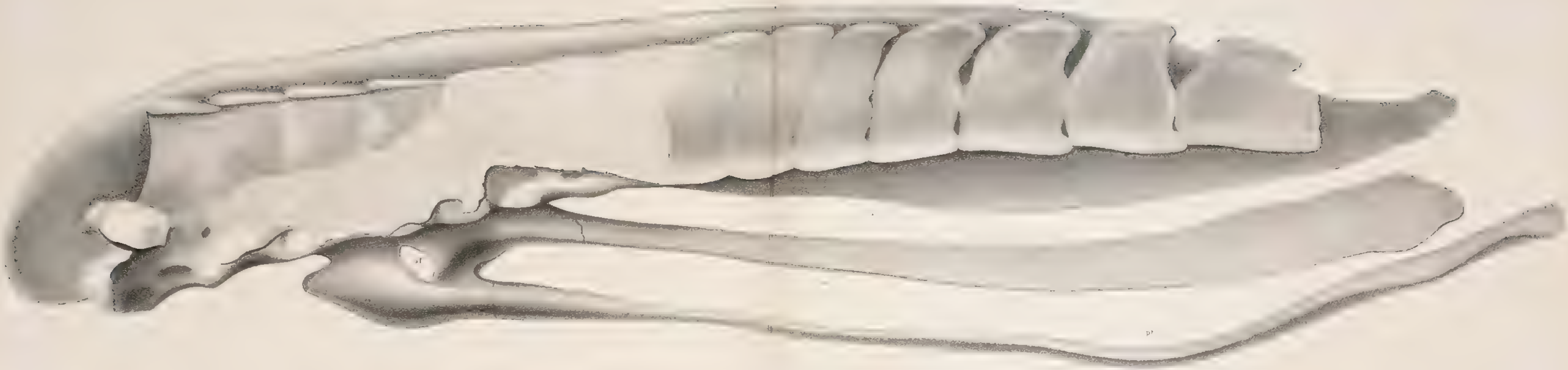
Natural Size. Page.

FIG. 1.—Left lateral view, with left pelvic bones removed; showing sacrum, and inner side of right ilium, ischium, and pubis, ---------- 69

af —Foramen in acetabulum.
il —Ilium.
is —Ischium.
pb —Pubis.

FIG. 2.—Inferior view; showing sacrum, with fourteen vertebræ in place, ---------- 69

1



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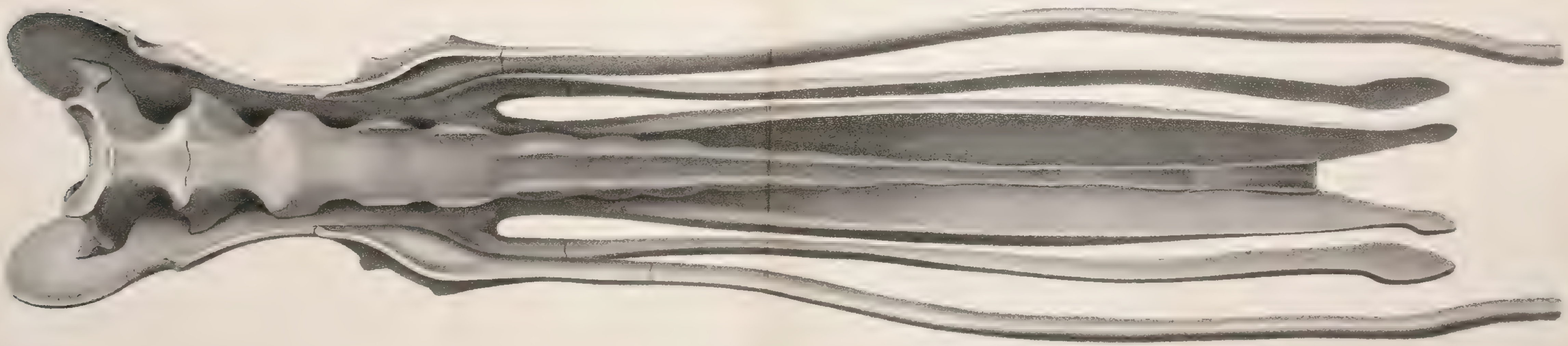


F. Berger, del. E. Crisand, lith. New Haven

HESPERORNIS REGALIS, Marsh.

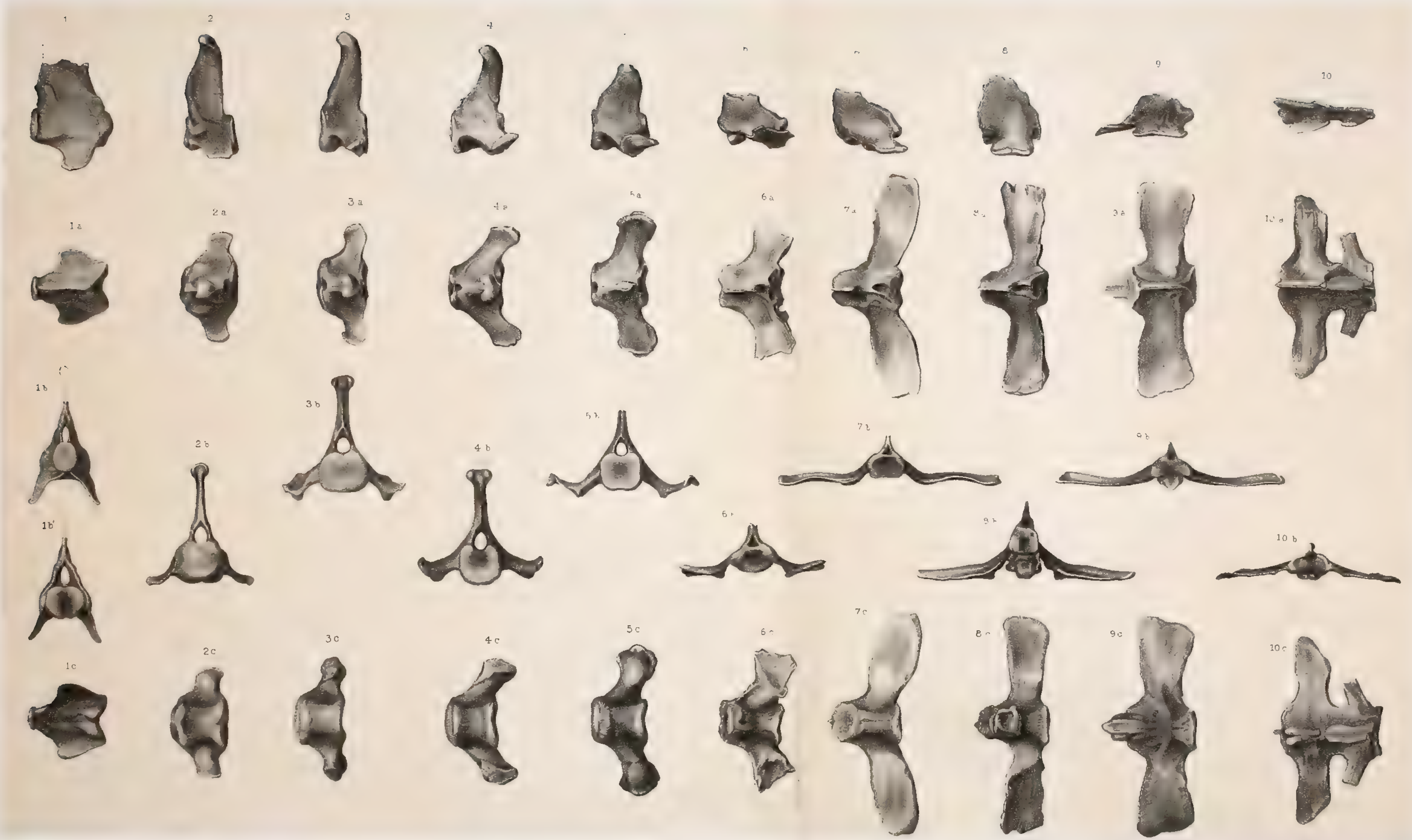
PLATE XII.

PLATE XII.

ODONTORNITHES.

Caudal vertebræ of HESPERORNIS REGALIS Marsh.

All Figures Natural Size. Page.



HESPERORNIS REGALIS, Marsh

PLATE XIII.

PLATE XIII.

ODONTORNITHES.

Femur of Hesperornis regalis Marsh.

Natural Size. Page.

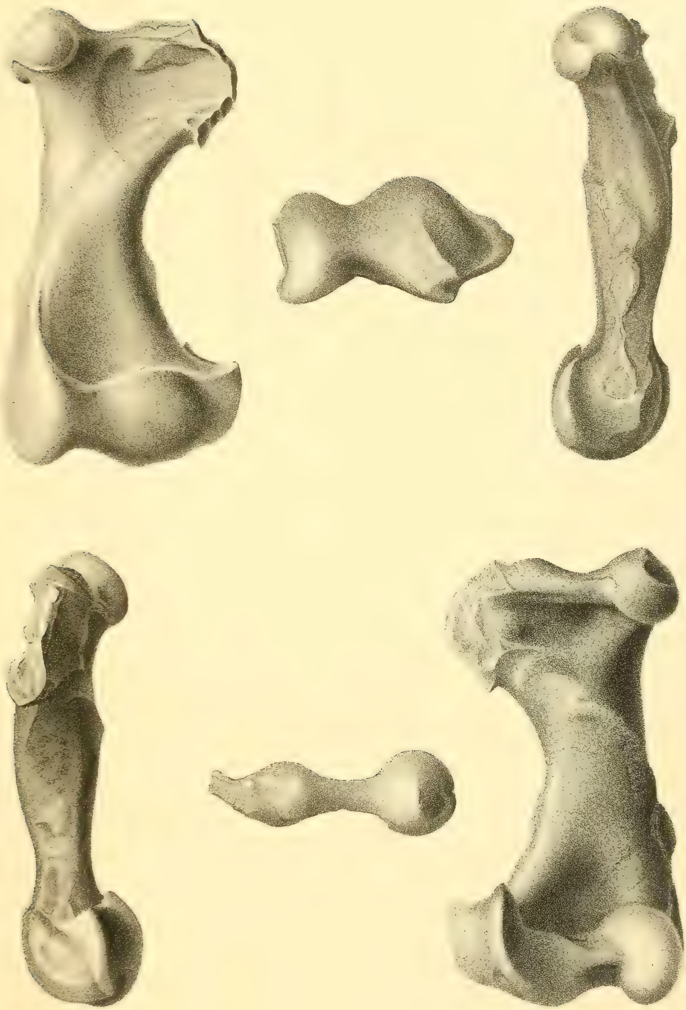


PLATE XIV.

PLATE XIV.

ODONTORNITHES.

Tibia of HESPERORNIS REGALIS **Marsh.**

Natural Size. Page.

PLATE [illegible]

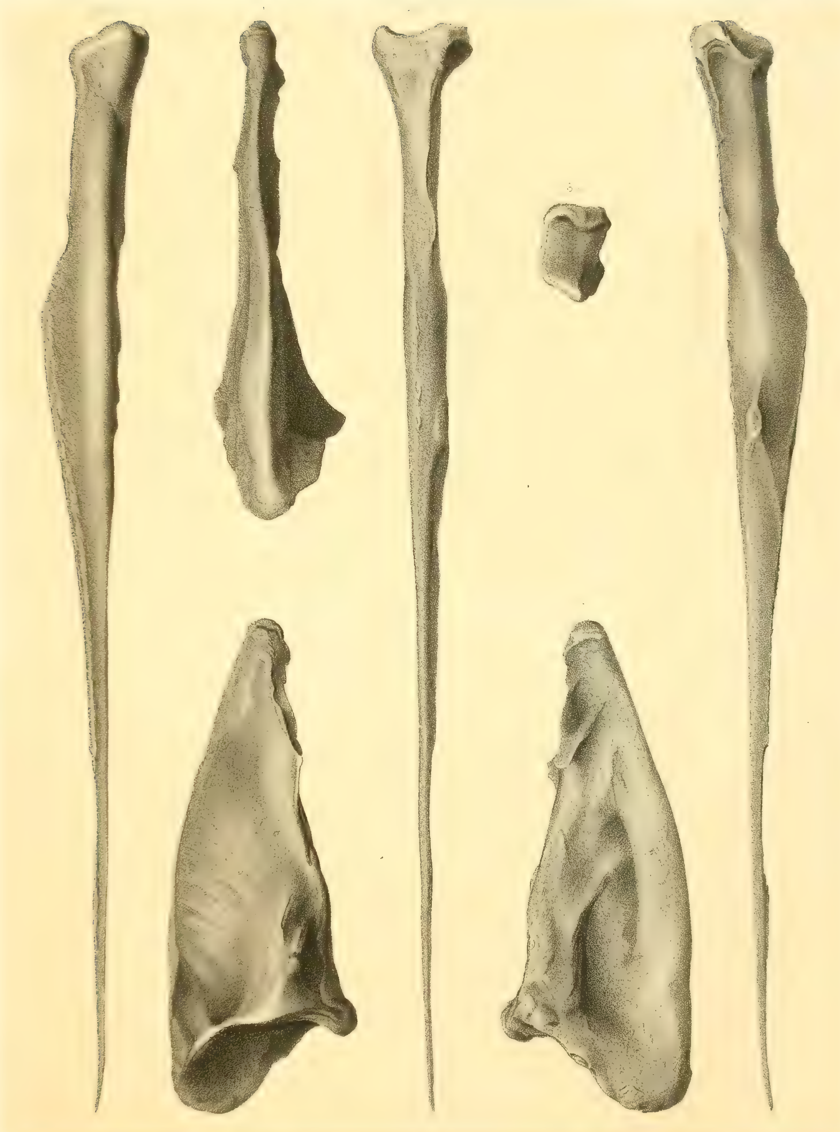
HESPERORNIS REGALIS, Marsh

PLATE XV.

PLATE XV.

ODONTORNITHES.

Patella and Fibula of HESPERORNIS REGALIS Marsh.



HESPERORNIS REGALIS, Marsh.

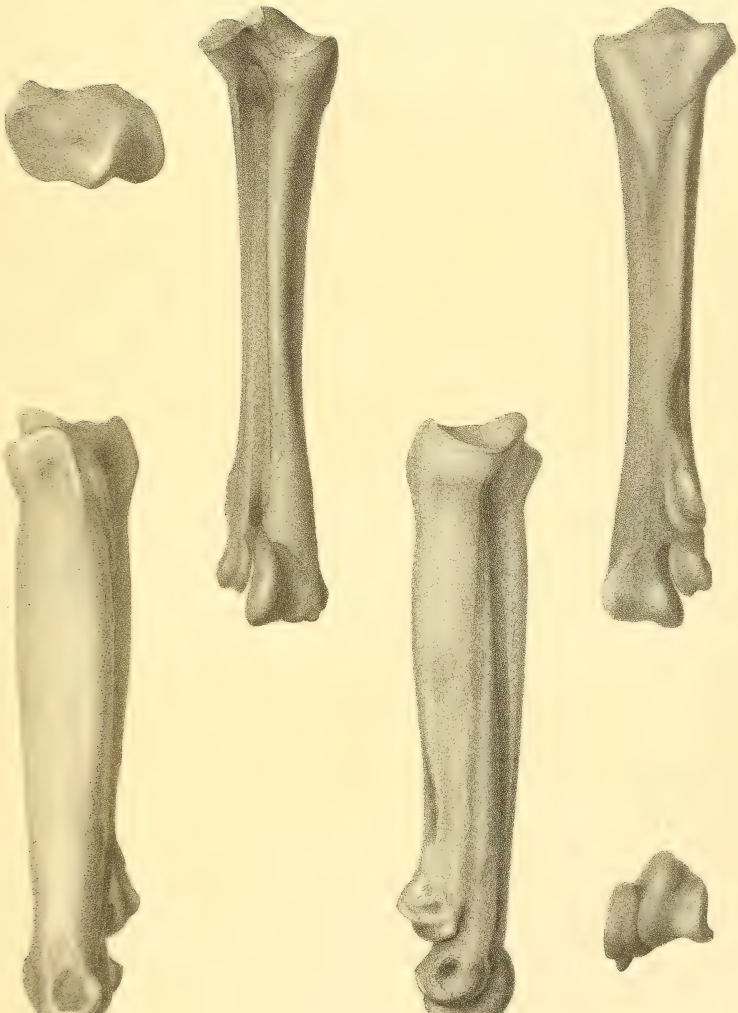
PLATE XVI.

PLATE XVI.

ODONTORNITHES.

Tarso-metatarsal of HESPERORNIS REGALIS Marsh.

Natural Size.



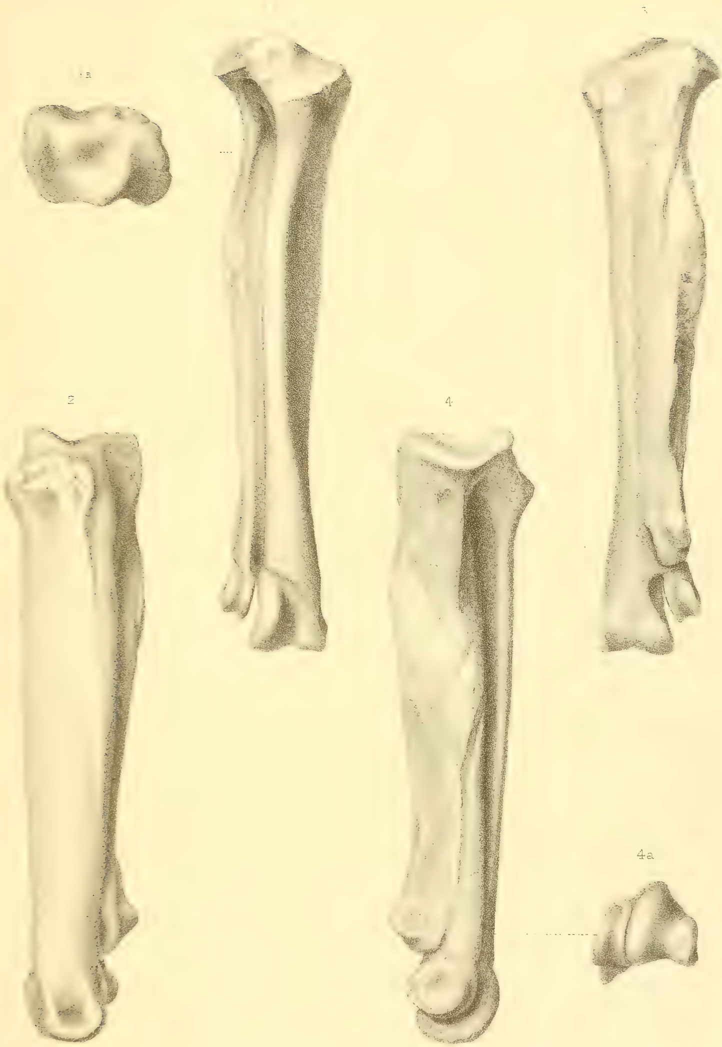
HESPERORNIS REGALIS, Marsh.

PLATE XVII.

PLATE XVII.

ODONTORNITHES.

Tarso-metatarsal of HESPERORNIS CRASSIPES Marsh.



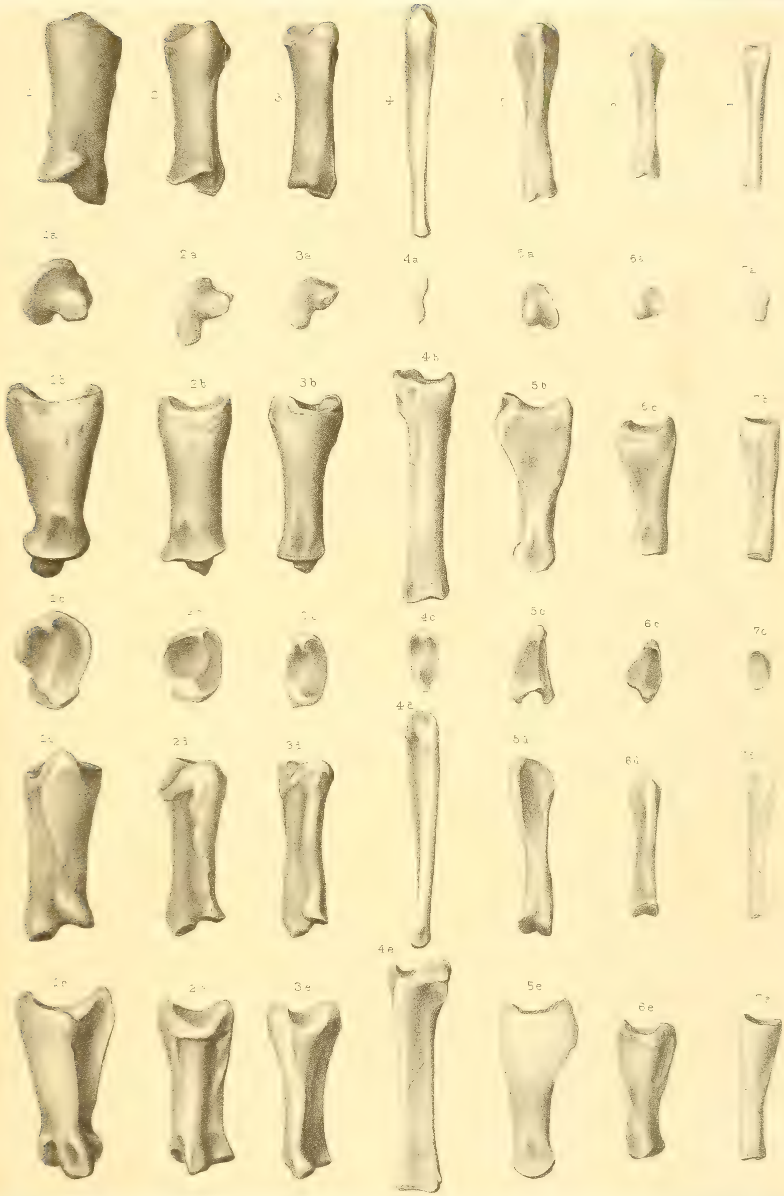
HESPERORNIS CRASSIPES.

PLATE XVIII.

PLATE XVIII.

ODONTORNITHES.

Phalanges of HESPERORNIS REGALIS **Marsh.**



HESPERORNIS REGALIS, *Marsh.*

PLATE XIX.

PLATE XIX.

ODONTORNITHES.

Phalanges and first metatarsal of HESPERORNIS REGALIS Marsh.

All Figures Natural Size. Page.

E. Crisand, lith New Haven.

HESPERORNIS REGALIS Marsh

PLATE XX.

PLATE XX.

ODONTORNITHES.

Restoration of HESPERORNIS REGALIS Marsh.

One-Half Natural Size. Page.

This restoration represents what is at present known of the skeleton of this species. The portions figured are taken mainly from a single individual (No. 1206, Yale College Museum). The only important parts wanting are the atlas, the extremity of the coccyx, and two terminal phalanges, which are restored in outline 111

F. Berger. del.

HESPERORNIS REGALIS, Marsh. ½

E. Crisand. lith. New Haven.

PLATE XXI.

PLATE XXI.

ODONTORNITHES.

Skull, Lower Jaw, and Teeth of Ichthyornis dispar Marsh.

All Figures twice Natural Size, except 2*a* and 2*b*. Page.

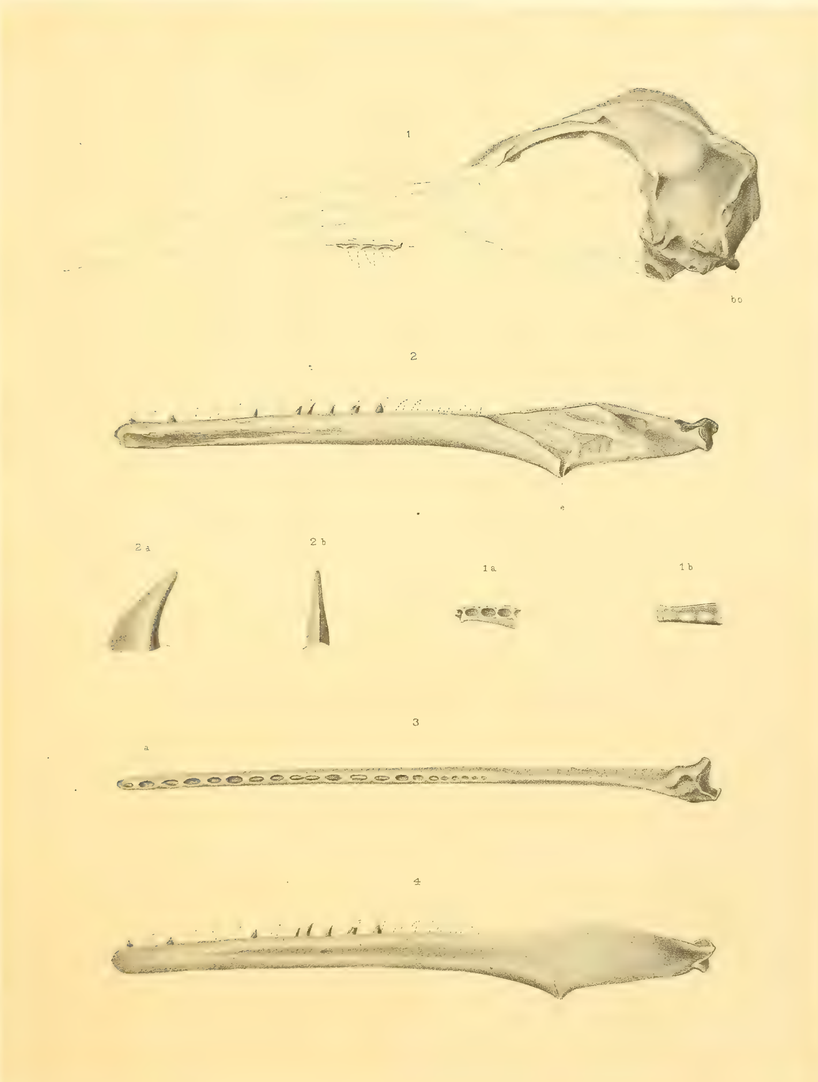
Fig. 1.—Skull; lateral view, seen from the left, restored in part from skull of a Tern, (*Sterna regia* Gambel), ... 120
bo—Occipital condyle.
1*a*—Portion of maxillary, inferior view.
1*b*—Superior view.

Fig. 2.—Right lower jaw; inner view, ... 123
t —Teeth in position.
e —Suture between splenial and angular bones.
2*a*—Tooth from lower jaw; lateral view, magnified eight diameters.
2*b*—Anterior view, magnified eight diameters.

Fig. 3.—Right lower jaw; superior view, showing distinct sockets for the teeth, ... 123
a —Socket for second tooth.

Fig. 4.—Right lower jaw; reversed, showing exterior surface, ... 123

PLATE XX



E. Crisand, lith New Haven.

ICHTHYORNIS DISPAR, Marsh

PLATE XXII.

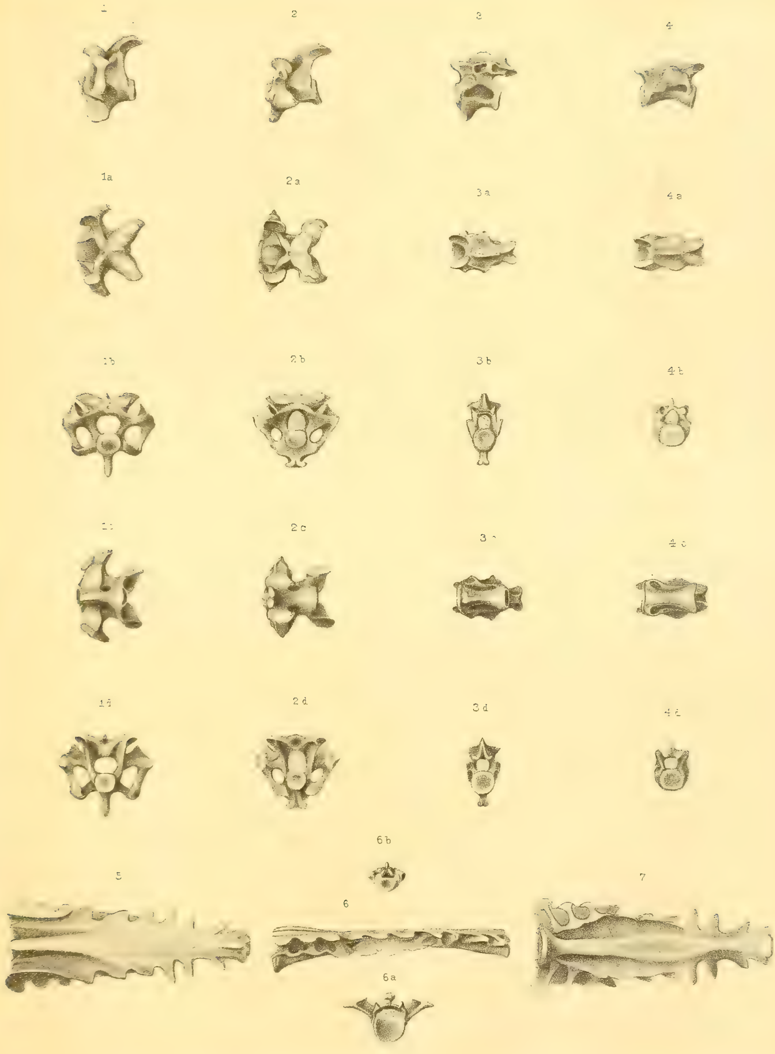
PLATE XXII.

ODONTORNITHES.

Vertebræ and Sacrum of Ichthyornis dispar Marsh.

All Figures twice Natural Size. Page.

PLATE XXII



E. Crisand, lith. New Haven.

ICHTHYORNIS DISPAR, Marsh. 2/1

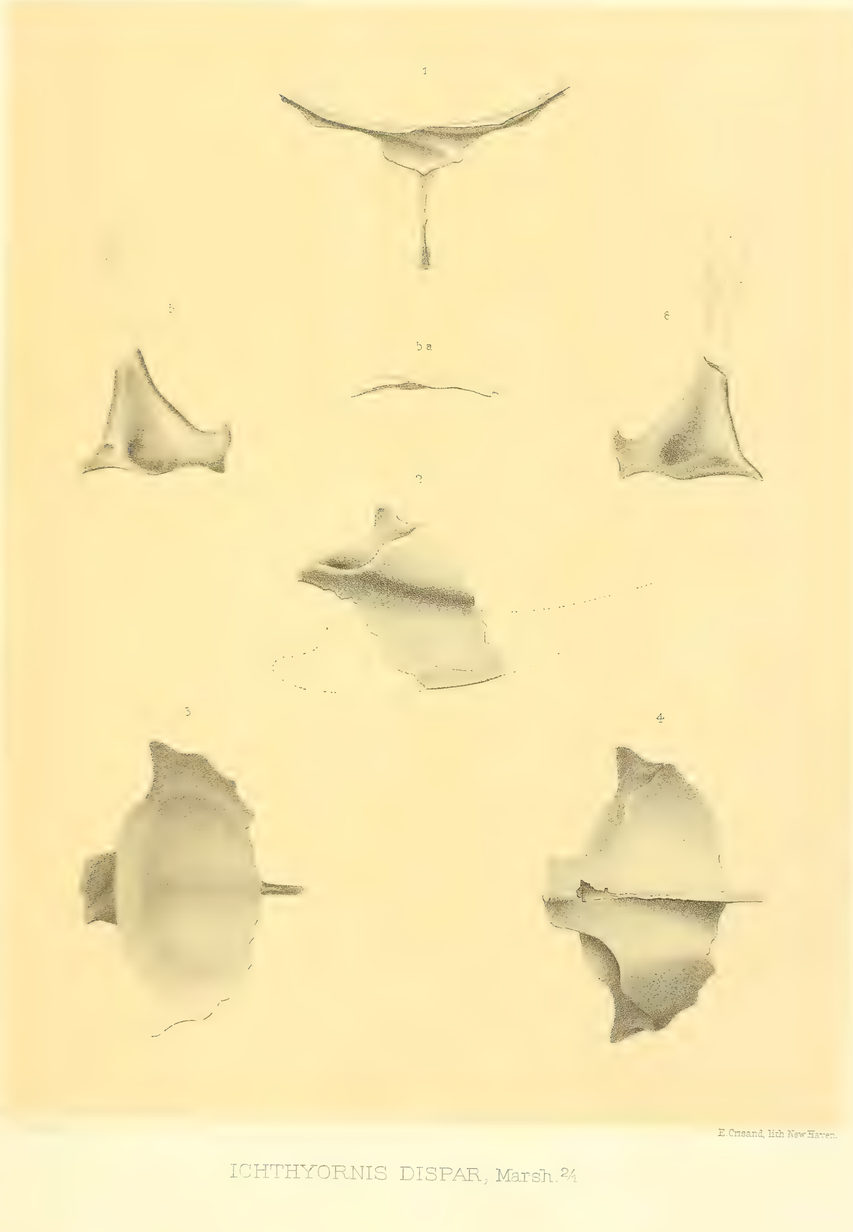
PLATE XXIII.

PLATE XXIII.

ODONTORNITHES.

Sternum and Coracoid of ICHTHYORNIS DISPAR Marsh.

All Figures twice Natural Size. Page.



E. Crisand, lith New Haven.

ICHTHYORNIS DISPAR, Marsh. 2/1

PLATE XXIV.

PLATE XXIV.

ODONTORNITHES.

Wing bones of ICHTHYORNIS DISPAR Marsh.

All Figures twice Natural Size.

NOTE.—The positions assigned to the wing bones figured separately here and in Plates XXX and XXXI are those seen when the wing is at rest, as in Plate XXVI.

E. Crisand, lith. New Haven.

ICHTHYORNIS DISPAR, Marsh. 2/1.

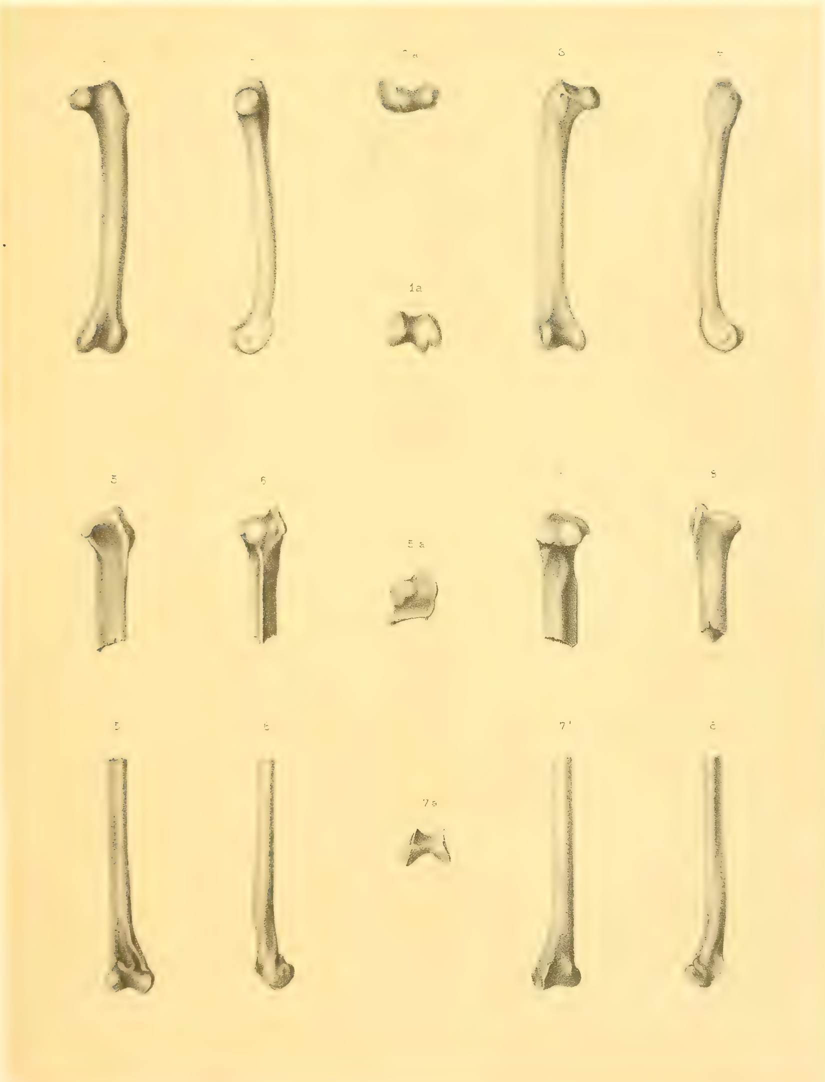
PLATE XXV.

PLATE XXV.

ODONTORNITHES.

Femur and Tibia of Ichthyornis dispar Marsh.

All Figures twice Natural Size. Page.



ICHTHYORNIS DISPAR, Marsh. 2/1

PLATE XXVI.

PLATE XXVI.

ODONTORNITHES.

Restoration of ICHTHYORNIS DISPAR Marsh.

Natural Size.

Page.

In this restoration, the shaded portions represent the parts preserved of the type specimen, (No. 1450, Yale College Museum). The portions in outline are taken in part from other specimens but mainly from the skeleton of a Tern, (*Sterna regia* Gambel.) ---------------------------------- 177

E Crisand, lith New Haven

ICHTHYORNIS DISPAR, Marsh.

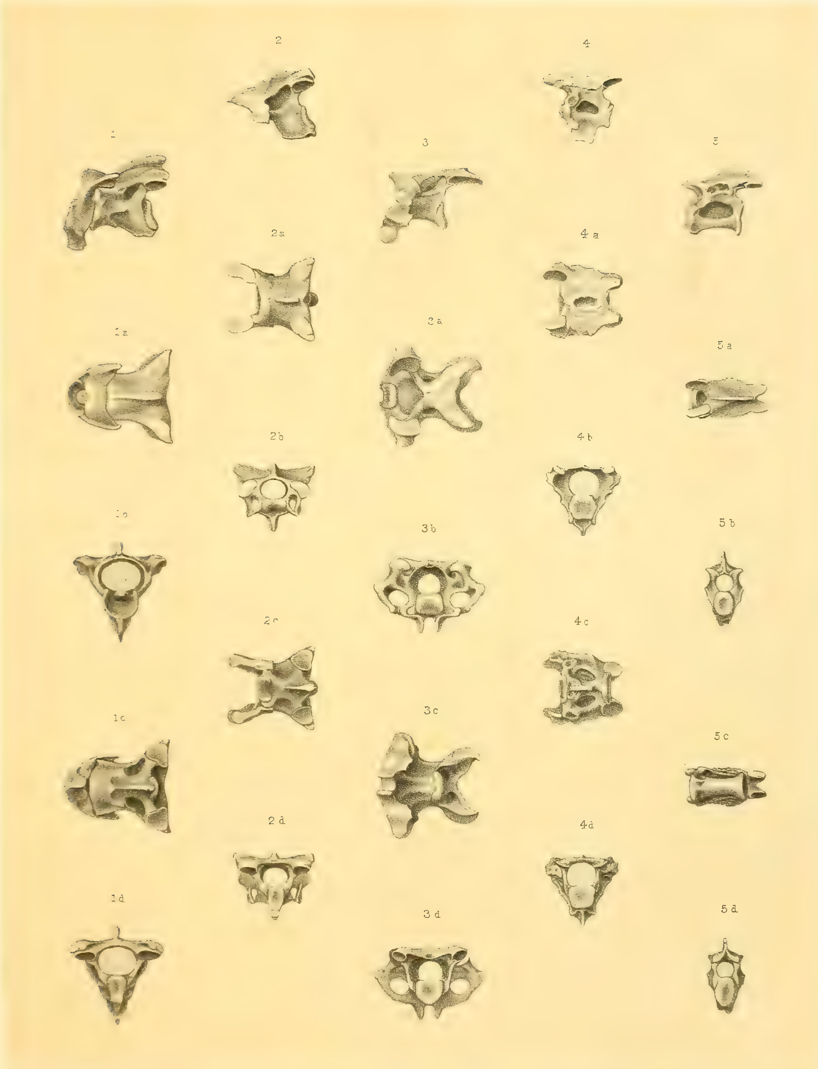
PLATE XXVII.

PLATE XXVII.

ODONTORNITHES.

Cervical and dorsal Vertebræ of ICHTHYORNIS VICTOR Marsh.

All Figures twice Natural Size. Page.



E. Crisand, lith. New Haven.

ICHTHYORNIS VICTOR, Marsh. 2/1

PLATE XXVIII.

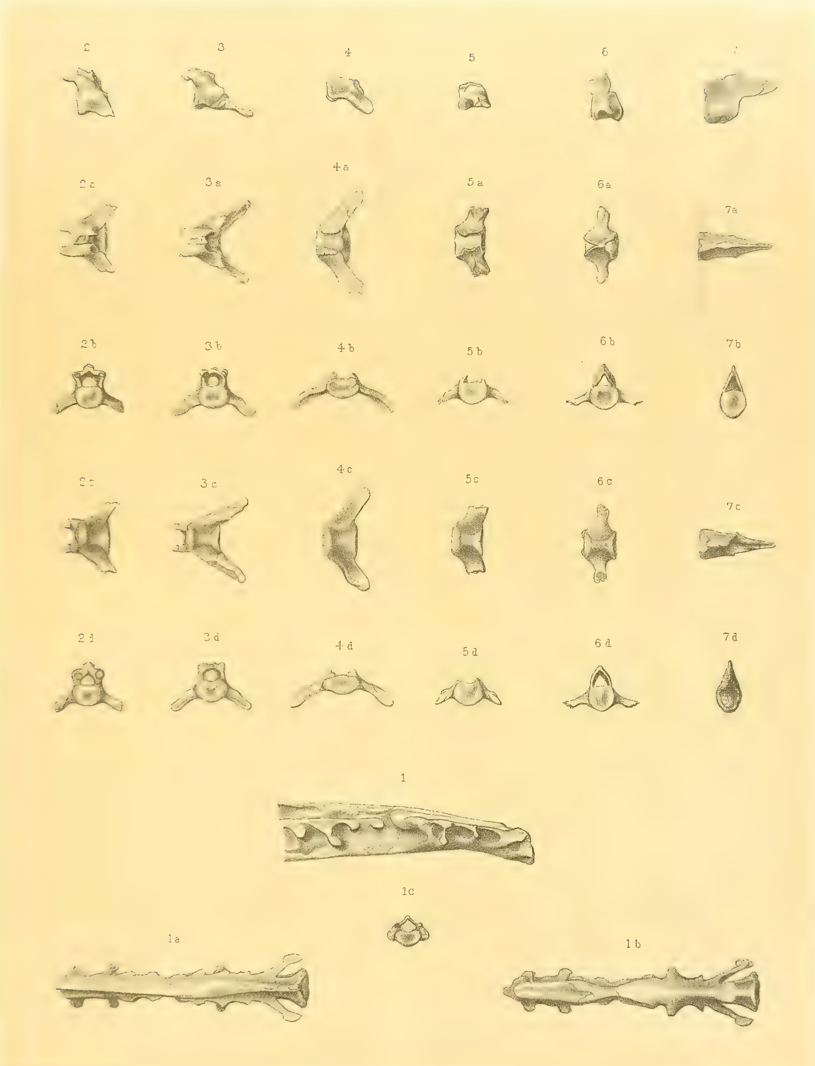
PLATE XXVIII.

ODONTORNITHES.

Sacrum of APATORNIS, and Caudal Vertebræ of ICHTHYORNIS.

All Figures twice Natural Size. Page.

NOTE.—The caudal vertebræ figured on Plate XXVIII are consecutive, and were found with the pelvis represented on Plate XXXII, figures 2 and 3.



E Crisand, lith New Haven.

1, APATORNIS. 2–7 ICHTHYORNIS 2/1

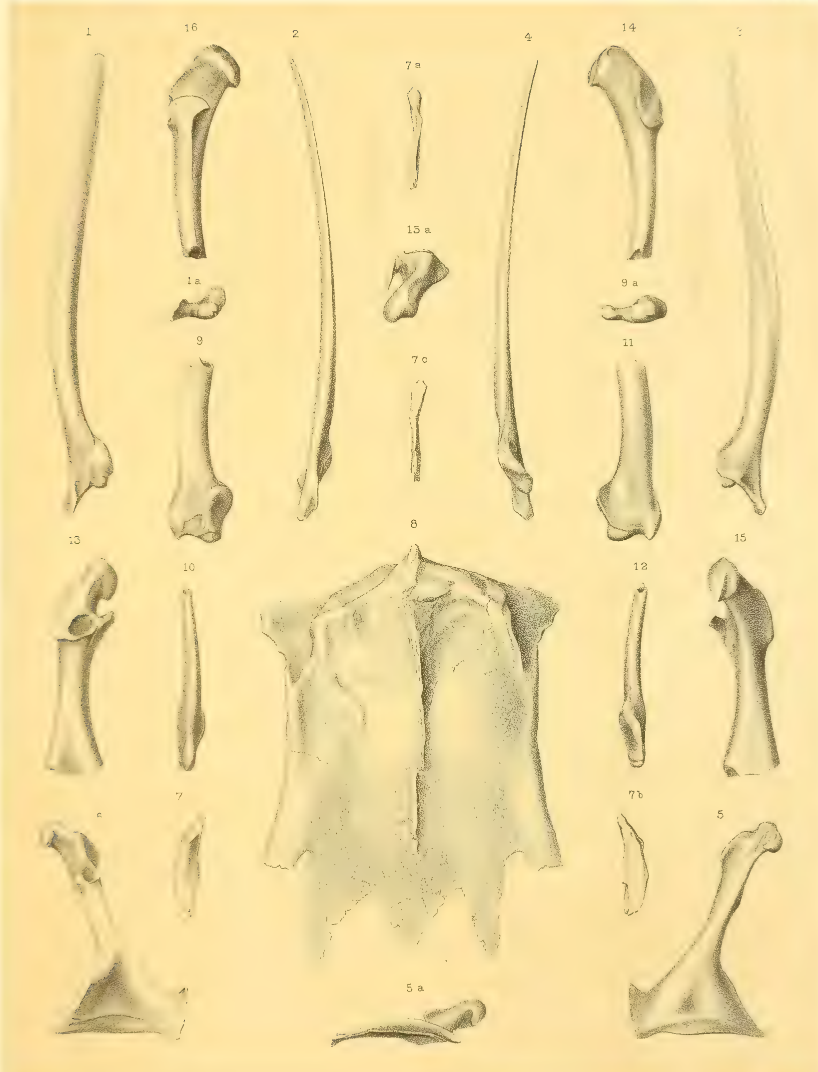
PLATE XXIX.

PLATE XXIX.

ODONTORNITHES.

Sternum and Scapular Arch of Apatornis **and** Ichthyornis.

All Figures twice Natural Size. Page.



1-8, APATORNIS. 9-16, ICHTHYORNIS. 2/1.

PLATE XXX.

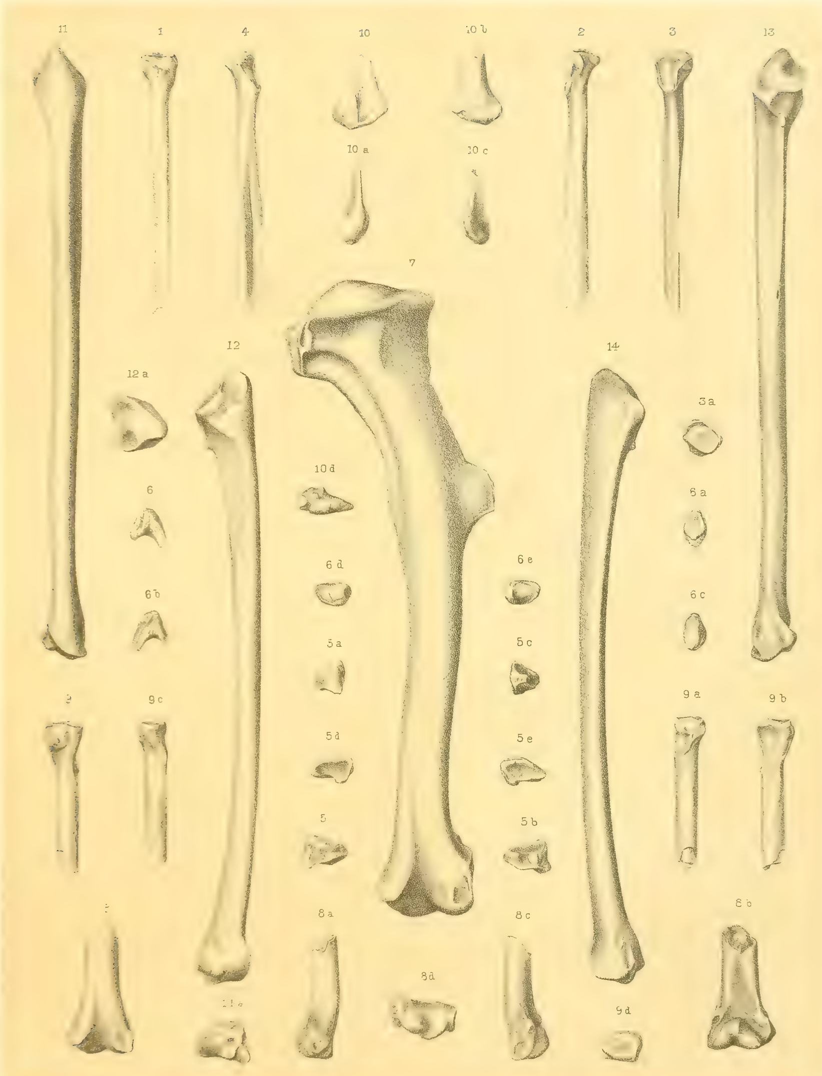
PLATE XXX.

ODONTORNITHES.

Wing bones of APATORNIS and ICHTHYORNIS.

All Figures twice Natural Size. Page.

PLATE XXX.



E. Crisand, lith New Haven

APATORNIS … ICHTHYORNIS

PLATE XXXI.

PLATE XXXI.

ODONTORNITHES.

Wing bones of Apatornis and Ichthyornis.

All Figures twice Natural Size. Page.

E. Crisand, lith. New Haven

1-11, APATORNIS. 12 19 ICHTHYORNIS ½

PLATE XXXII.

PLATE XXXII.

ODONTORNITHES.

Pelvis of APATORNIS **and** ICHTHYORNIS.

Twice Natural Size. **Page.**

FIG. 1.—Pelvis of *Apatornis celer* Marsh; lateral view, seen from the right, ... 164

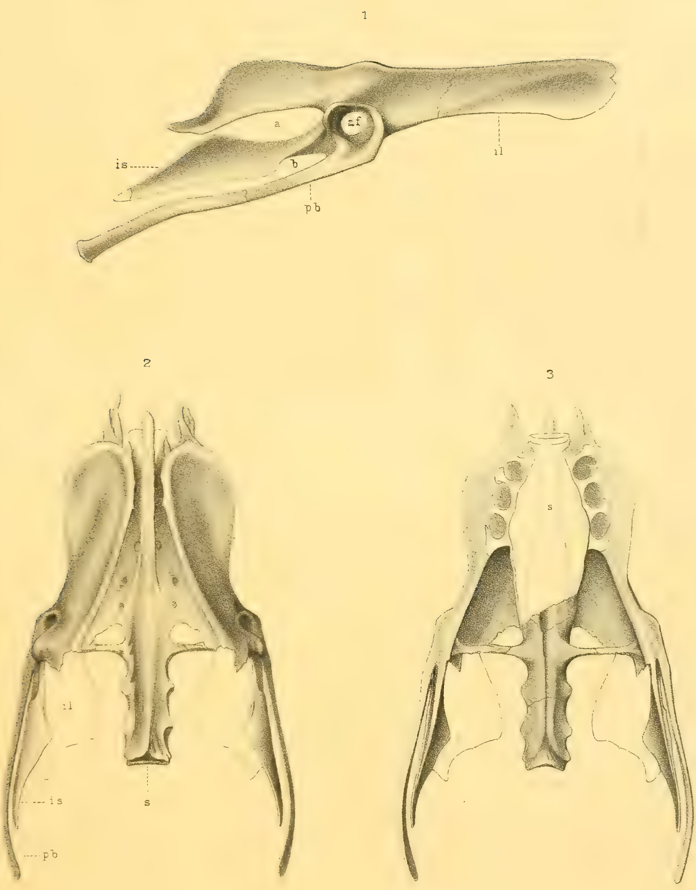
il —Ilium.
is —Ischium.
pb—Pubis.
af—Acetabular foramen.
a —Ischio-sciatic interval.
b —Obturator interval.

FIG. 2.—Pelvis of *Ichthyornis victor* Marsh; superior view, ... 163

il —Ilium.
is —Ischium.
pb—Pubis.
s —Sacrum.

FIG. 3.—Pelvis of *Ichthyornis victor*; inferior view, ... 163

s —Sacrum restored in part from sacrum of *Ichthyornis dispar*, (Pl. XXII, fig. 7.)



E. Crisand, lith. New Haven.

1 APATORNIS. $\frac{1}{1}$ 2 & 3 ICHTHYORNIS. $\frac{2}{1}$

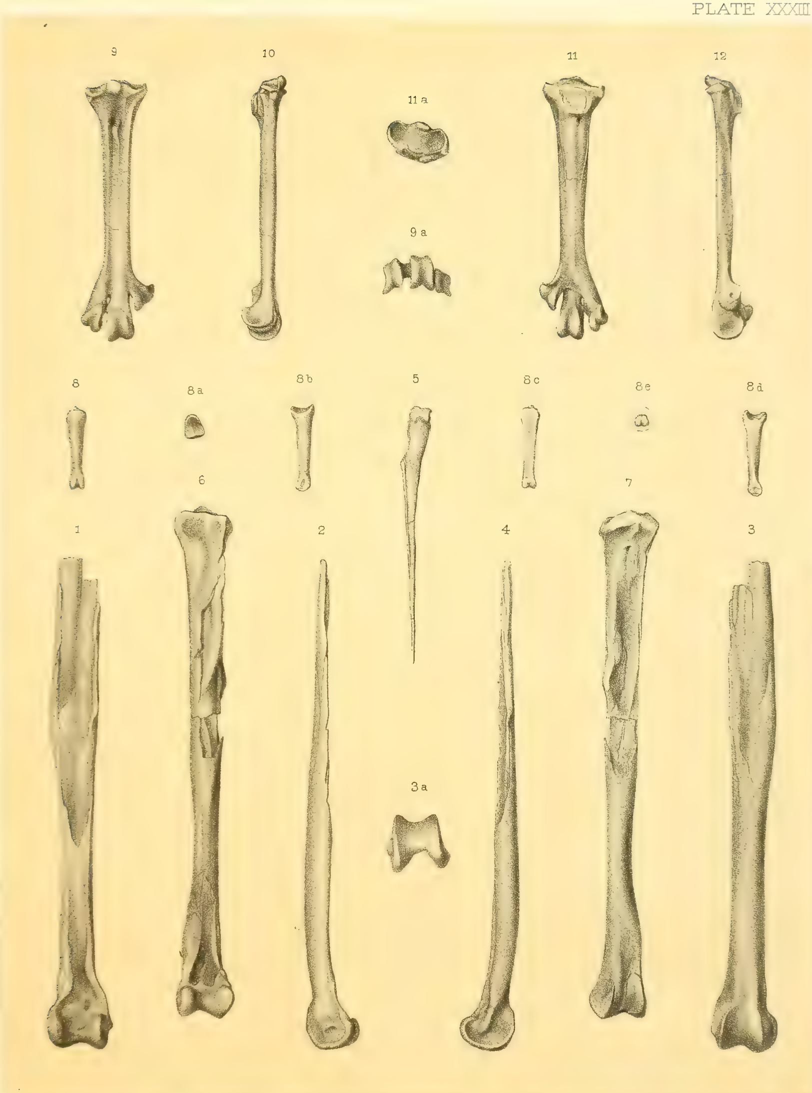
PLATE XXXIII.

PLATE XXXIII.

ODONTORNITHES.

Leg bones of Apatornis and Ichthyornis.

All Figures twice Natural Size. Page.



F. Berger del. E. Crisand, lith. New Haven.

1–5 APATORNIS 6–12 ICHTHYORNIS 2/1

PLATE XXXIV.

PLATE XXXIV.

ODONTORNITHES.

Restoration of ICHTHYORNIS VICTOR Marsh.

Natural Size.

Page.

In the restoration of this species, the shaded portions represent the parts preserved of the type specimen, (No. 1452, Yale College Museum), as well as of other individuals from the same region, and the same geological horizon. The portions in outline are taken in part from the type of *Ichthyornis dispar*, (Plate XXVI), and completed from the skeleton of a Tern, (*Sterna regia* Gambel) 177

ICHTHYORNIS VICTOR, Marsh