Article XXX. — SKULL OF TRICERATOPS SERRATUS.

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PLATE LIX.

The American Museum Expedition of 1902, under Mr. Barnum Brown and the writer, which was sent by Professor Osborn into the Laramie formation of Montana had the good fortune to secure, among other material, a fine specimen of *Triceratops serratus* Marsh. The exact locality in which the specimen was found was in the wall of Hell Creek Cañon, some twenty-five miles from the Missouri River, and one hundred and thirty-five miles northwest of Miles City, Montana. The unconsolidated sand matrix has been entirely removed from the skull, thus affording an exceptional opportunity for the study especially of the remarkably preserved palate.

Through the courtesy of Professor Charles E. Beecher the writer was permitted to study the type skulls of *Triceratops prorsus* and of *T. serratus* which are preserved in the Peabody Museum at Yale University. This confirmed the opinion already formed that the American Museum specimen is referable to the latter species. The agreement between the specimens is close, the main points of difference being the inferior size of the type specimen, which is evidently that of a younger animal, and that the median ridge of the parietal crest or frill is not so prominent in the American Museum specimen; nor are the bony projections along the ridge quite so conspicuous as in the type; but in general proportions, the form and arch of the frill, the shape of the orbit and other points mentioned by Marsh in his specific definition the resemblance is very close.

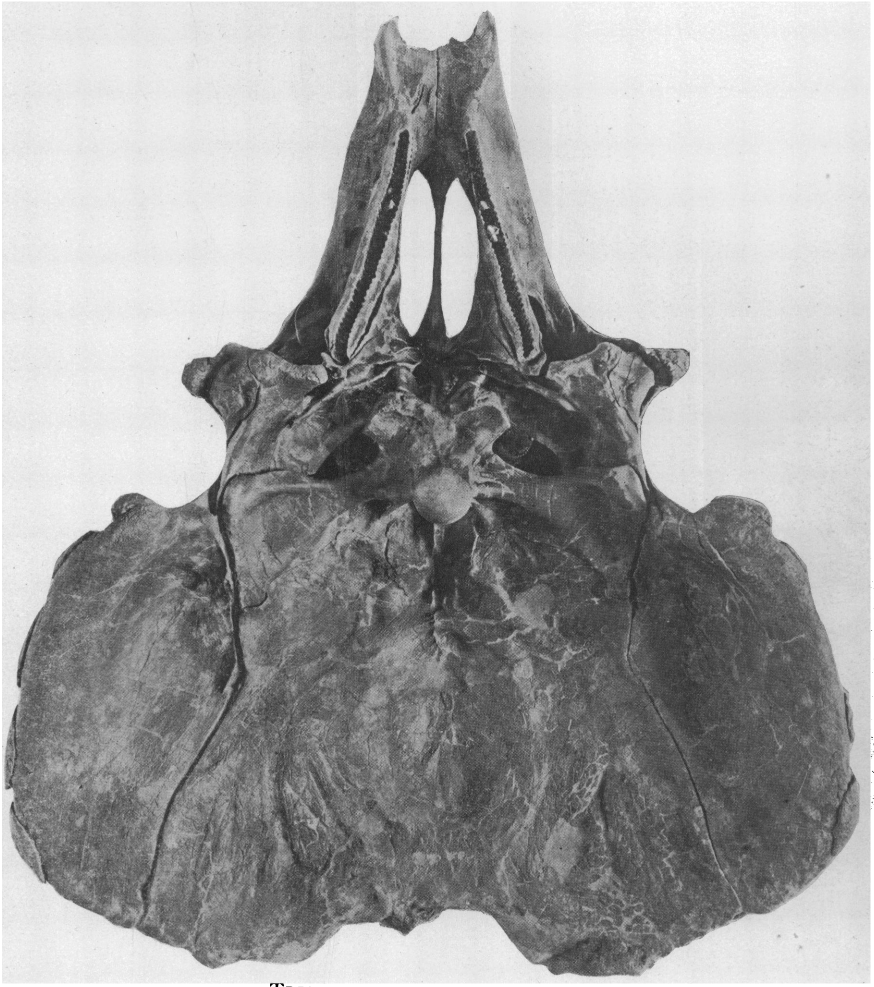
Triceratops serratus *Marsh.*

MARSH, O. C., 1890, Amer. Jour. Sci. (3) XXXIX, p. 81.
MARSH, O. C., 1890, Amer. Jour. Sci. (3) XXXIX, p. 425, pl. v, fig. 2; pl. vi, figs. 1–6.
MARSH, O. C., 1896, Sixteenth Annual Report U. S. Geol. Survey, p. 208; pl. lx, fig. 3; pl. lxi, figs. 7, 9, 10.

Materials. — The skull lacks only the distal portions of the postfrontal horn cores, the nasals and their horn core, and a portion of the premaxillary bones. The rostral bone was found displaced but a short distance to the rear on the right side of the muzzle, while on the other side lay the left mandible in perfect condition. The coössified right angular and articular, together with portions of both splenials, were found beneath the skull. One badly preserved humerus, half of another, a radius, five metacarpals, three phalanges, a fibula, and fragments of a scapula complete the list. The specimen is No. 970 of the American Museum fossil reptilian collection.

The Skull.

The condition of the sutures, the fact that the rostral bone had not ankylosed with the premaxillaries, and that the so-called epoccipital bones, the lozenge-shaped ossicles around the margin of the frill, were not sufficiently coössified with the latter to prevent the loss of some of them, give evidence that in spite of the enormous size of the animal it had not yet reached maturity. The maxillary teeth have dropped out of position with one exception, a tooth which lay deep in the alveolar channel of the right side. Other teeth, found loose in the matrix, were clearly of the upper series and are shown in position in the photograph (Plate LIX). The *rostral bone* is highly rugose, due to the impressions of blood-vessels over its surface showing it to have been closely sheathed in horn. The forward border is a full, gentle curve, while the inferior margin is straight and nearly horizontal when the bone is in position, as in most Testudinata. This, together with the form of the predentary bone, which curves upward towards the tip, would seem to indicate a cutting beak very turtle-like in aspect, as one would be led to expect from somewhat similar feeding habits, rather than the trenchant, downwardly curved, raptorial beak usually given to the restored *Triceratops*. The fact that in *Chelydra*, where the upper beak is hooked, the bone which supports it is of similar form, may be taken as corroborative evidence.



TRICERATOPS SERRATUS *Marsh.*

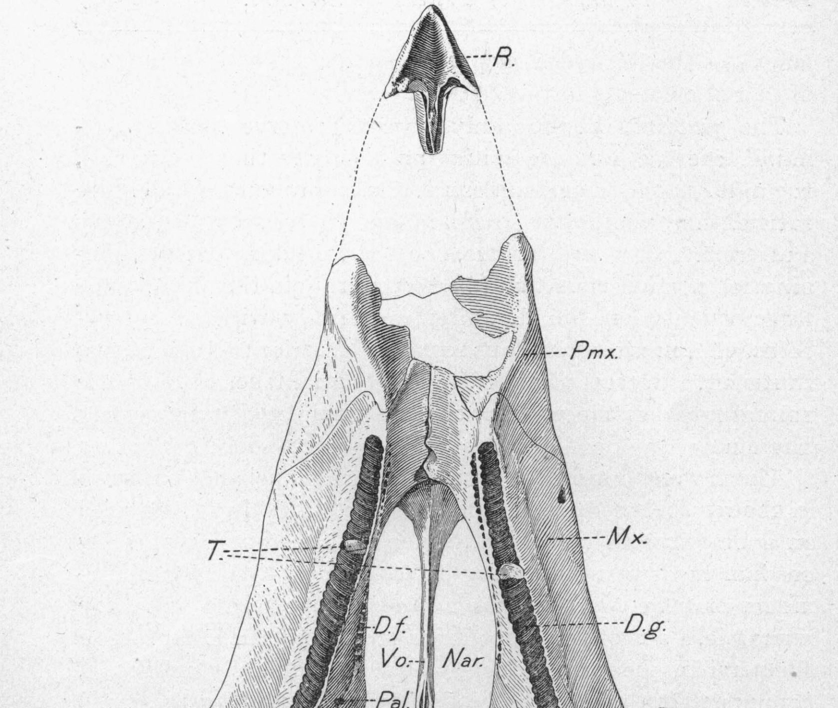
Palatal aspect of skull, with frill. × $\frac{1}{15}$. (Extreme length about 6 ft. 4 ins.).

Palatal Aspect.

The *premaxillaries* are only in part preserved. The *maxillaries* are heavy bones uniting anteriorly in the median line, in front of the narial fenestræ, by a pronounced dentate suture. Anteriorly the premaxillaries overlap them above and posteriorly they bifurcate, one limb, the dorso-lateral, running obliquely outward and backward to join the jugal, while the postero-ventral limb unites posteriorly with the pterygoids. The maxillaries thus form the anterior and about two thirds of the lateral walls of the large narial fenestræ. In the palatal face lies the alveolar channel, sculptured transversely into a number of shallow grooves, incomplete sockets in which the teeth were formed, forty in the right channel and forty-two in the left. The dental channel, is 482.8 mm. in length with an average width of 30 mm., which is somewhat less than its original measurement, owing to crushing. Other measurements may be found in the table on page 694. As in the mandible, a row of dental foramina runs along the inner face of the maxilla, one foramen being opposite each alveolar groove, through which passed the blood-vessels needful for the rapid forming of teeth in the dental magazine. The external face of the bone also bears two such foramina.

The *vomer*, or 'prevomer' as determined by Broom,[1] is a slender rod-like bone bridging fore and aft the space of the narial fenestra. Anteriorly it is dilated into a flattened rhombic expansion articulating by a squamous suture with the united maxillary bones. Passing backward there appears a median ventral keel giving the bone in its narrowest part, about the middle, a triangular section. Further to the rear the lateral edges bend downward to the level of the median keel and then rise again to their former level, where they give rise to thin plate-like expansions which are embraced at their posterior end by the pterygoid bones. Dorsally viewed the vomer is seen to become trough-like, the depression being about the width of the shaft of the bone and running the

[1] Broom, R., Proc. Linn. Soc. N. S. W., 1902, pt. 4, pp. 545–560.



Triceratops serratus Marsh. Palatal aspect of skull. × $\frac{1}{5}$. *R*, rostral bone, *Nar.*, narial vacuity, *i.pt.s.*, interpterygoid space, *D.g.*, dental groove, ? *Eus.*, Eustachian groove (?).

length of the expanded posterior portion. There is no trace of paired elements in the vomer.

The *palatines* bound laterally the posterior part of the narial fenestræ, and are somewhat triangular in shape, with the base of the triangle meeting the maxillaries in a squamous articulation somewhat overlapping the dental foramina. Posteriorly they are bounded by the pterygoids, and the anterior portion runs upward over the jaw until it ends in a large vacuity on the dorsal side. This vacuity is further bounded anteriorly and externally by the maxillary, and posteriorly by the pterygoid, and it lies above a point one third of the distance from the posterior end of the dental channel.

The *pterygoids* are large and irregular with peculiar channels, probably the eustachian canals, running obliquely from the articulation with the posterior end of the maxillaries to the median line; these channels are formed by thin, overarching ridges of bone which in their mid-length almost meet. The pterygoids form the postero-lateral margins of the narial fenestræ in the rear of the palatine bones and embrace the hinder end of the vomer. Anteriorly they are bounded by the palatine and maxillary bones and possibly by the ectopterygoids, though the last-mentioned cannot be located in this specimen[1]; the ectopterygoids are not suturally separated from the pterygoids themselves. Posteriorly the pterygoids are met by the basisphenoid and in the median line they nearly embrace the parasphenoid, or 'vomer' of Broom. Laterally they are broad and thin plate-like expansions which pass outward and backward to meet opposing processes of the quadrate, though the precise limit of the pterygo-quadrate suture is not everywhere distinct.

The *quadrates* are well developed and firmly fixed in place by the pterygoids within and the quadratojugals without. They also pass backward and upward, forming, with the quadratojugals, the lower boundary of the infratemporal fossa. Posteriorly they join the squamosals, which are widely expanded to form the lateral elements of the frill. The

[1] Marsh, O. C., Amer. Jour. Sci. (3), XLI, p. 171.

quadrate is flattened on its ventral aspect and somewhat cylindrically concave on its dorsal surface. The head is elongated transversely to a length of 147 mm., the facet which articulates with the lower jaw being somewhat saddle-shaped. The posterior end of the quadrate is embraced between the exoccipital and the squamosal bones. The *quadratojugals* are comparatively small bones lying between the quadrates and the jugals. Dorsally they extend in thin, plate-like expansions between the aforesaid bones, and in their posterior portions form part of the infratemporal arcade, almost, if not quite, meeting the forwardly extending process of the squamosals. In their ventral portion where the distance widens between the quadrates and the jugals the quadratojugals dilate into a thick, wedge-shaped mass to fill the gap. The greatest thickness is 89 mm.

The *occipital region* of the skull is rendered very massive to support the great weight of the head, the sutures between the various elements being closed. The occipital condyle is almost spherical, and has a diameter of 115 mm. It looks almost directly backward and but little downward. Anteriorly it merges into a heavy basioccipital and laterally into the exoccipitals, the limits of these three elements in the condyle itself not being discernible.

The *basioccipital* diverges into two stout limbs with heavy, rugose extremities, in front of which appear the pulley-like basisphenoid bones, the parasphenoid ('vomer') arising between the limbs.

The *exoccipitals* run out laterally to join the quadrates and squamosals, overlapping the former and firmly articulating with the latter to afford a strong brace across the entire base of the frill. They thin away posteriorly and are, together with the supraoccipital, overlain by the largely developed parietals which form the median element of the frill.

The ventral aspect of the *frill* or crest is well shown in Plate LIX, and is without vacuities of any sort, although just behind the exoccipital bones the parietals are excessively thin. Vascular impressions occur on the posterior half of the parietal bones on either side, but there is no evidence of a wide free margin sheathed with horn as in the frill of *Triceratops prorsus.*[1]

The squamoso-parietal suture is a squamous one for a short distance backward, the squamosal overlapping; but at the point where the suture bends outward it becomes a plain harmonic suture having but little strength, as is evidenced by the fact that in the specimen under consideration the squamosal bone had slipped dorsally past the parietal on the right side, while on the left the bones were flush with each other. In the type specimen of *Triceratops serratus* in the Yale University Museum both sutures, that on the left as well as on the right, have slipped. The frill thus seems to have afforded leverage to assist in moving and supporting the huge head with its weighty armament and also to have protected the neck against the assaults of enemies, but it seems hardly probable in the present species that the dorsal part could have withstood crushing blows without injury to the frill. The hinder margins of the parietals have decomposed somewhat and the marginal ossicles are here wanting, though most of them are present on the squamosals.

Dorsal Aspect.

The anterior part of the skull has been weathered off, as it formed the outcrop of the specimen, and much of the bone has been disrupted by grass roots even where it had not yet been exposed by erosion.

The *postfrontals*, with the exception of the horn cores, are entire and the underlying sinus is readily explored through the large postfrontal fontanelle (the parietal or pineal foramen of authors). This sinus is continuous with those of the horn cores and in turn with the space within the skull behind the orbits, but not with the brain case. It is more or less wedge-shaped, tapering dorso-ventrally as one goes forward, the anterior limit being just in front of the orbit. The flat roof is formed by the overlying postfrontal and frontal bones, while the sinus is laterally constricted into three chambers. The anterior chamber has a rather flat floor and is separated from

[1] Marsh, O. C. 1896. Dinosaurs of North America, pl. lx, fig. 4.

the median chamber by vertical pillar-like bones, one on either side, which serve also to support the antero-internal portions of the horn cores. The floor of the second or largest chamber is deeply excavated, and it is this chamber which communicates with the horn-core sinuses by openings in the lateral walls. The posterior chamber, lying just beneath the fontanelle, is small and round, and in the specimen in question has a small pencil-like bone running obliquely from the left lateral wall to the floor, after the manner of a flying buttress. There is no indication of a pineal foramen opening into the brain case which lies directly beneath the above sinus; hence the Ceratopsia agree with other Dinosauria in this respect. The postfrontal fontanelle closes in old animals, as in the type skull of *Triceratops prorsus*, which is that of a fully adult though comparatively small animal, and is thus analogous to that in the skull of the human infant.

The loss of the frontals and nasals from our specimen renders possible the study of the interior of the skull, the bones of which are admirably preserved, and while the entire skull gives an appearance of massiveness, the individual bones are comparatively thin, but so constructed as to brace in the most admirable manner the portions of the skull subject to strains and impact, especially beneath the horns.

The *frill* viewed from above presents much the same relative expanse of bone as is shown in the ventral aspect except that the squamosals now extend forward and upward to the base of the horn cores. Anteriorly they are bounded by the jugals, the infratemporal vacuities, and the quadrates. On one squamosal, and to a less extent on the other, a ridge for muscular attachment extends diagonally upward and backward across the posterior portion of the bone. The parietals have the same extent as in the ventral view except that here they overlie the occipital bones and articulate with the postfrontals at about the posterior limit of the horn cores. The supratemporal vacuities open forward beneath the postfrontals and above the parietals into the main sinuses of the skull. Large blood-vessels had their exit through these vacuities, their branches being deeply impressed into the surface of the parietals and to a less extent into the squamosals, thus implying a compactly fitting integument. The base, especially of the right horn core, is well preserved. It is extremely hollow, but with a shelf-like circular projection of bone running around the inner wall just above the level of the postfrontal bones without, and doubtless to aid in resisting the thrust of the latter bones when lateral pressure was brought to bear upon the horns. Around the outside base of the horn is a horizontal ridge which may have supported the base of the horny sheath. The *orbits* are nearly circular and are surrounded by a thickened ridge of bone, especially in front. The downward and outward crushing of the left horn core has partially closed the left orbit, adding to the sinister expression of the skull.

The Lower Jaw.

The left *mandible*, which is admirably preserved, consists of dentary, surangular, and coronoid, with a full magazine of thirty-nine vertical rows of teeth. On the inner face is a row of thirty-eight dental foramina, and the meckelian groove on the inferior face is wide and deep, but was covered by the thin, plate-like splenial which, though lying detached in the quarry, presents a perfect contact when placed in position. Cope [1] claims that in *Hadrosaurus* it is the splenial which contains the magazine of teeth. Whether or not this be true of *Hadrosaurus* it is certainly not true of *Triceratops*, in which the magazine is contained in the dentary in the normal manner. The teeth arise in alternate series in the successive vertical rows, only one series being in full use at one time, though those of the secondary series, arising between the teeth of the primary series, show partial wear, while in the posterior part of the jaw individual teeth of the primary set are already succeeded by tertiary teeth. The vertical worn faces of the teeth present the surface known to mathematicians as an hyperbolic paraboloid or warped surface; the whole mechanism reminding one of a slightly twisted saw with alternating higher and lower teeth. Marsh notes the fact that in the Ceratopsia the teeth are double-rooted, a feature almost unique among reptiles. This

[1] Cope, E. D., Amer. Naturalist, July, 1883, p. 775.

seems to have been brought about by the mechanical necessity of a base widened transversely to meet a lateral strain in the shearing process of mastication and the subsequent constriction of this base into an inner and outer pillar due to the crowding of the crowns of adjacent teeth set at a lower level. There could have been no lateral movement in mastication, but a chopping motion, possibly with a slight orthal movement combined with it. The food gathered by the cutting beak was probably chopped into short pieces by the teeth, being kept in the mouth by the muscular wall of the cheeks. It is doubtful whether the gape of the mouth had a posterior extent further than the anterior end of the tooth series, as otherwise the portions of food chopped off, falling outside of the lower teeth, could not have been retained in the mouth.

The alveolar grooves are equally developed in the inner surface of both inner and outer walls of the dental channel and not in the inner surface of the outer wall only as in *Trachodon* (*Hadrosaurus*) as shown by Lambe.[1] This is due to the fact that in *Triceratops* the crowns of the teeth do not form so flat a tassellated pavement when viewed from within; their position in the jaw being more nearly vertical than in *Trachodon*.

Measurements.

Length of skull (estimated)	2160 mm.
Width across frill	1578
Maxillary bones, length	672
" " length of dental channel	482.8
" " average width dental channel	30
Premaxillary bones, width at posterior end	177
Vomer, length	410
" width at anterior end	70
" width of shaft	15
Palatine bones, length	293
Occipital condyle, diameter	115
Foramen magnum, width	47
" " height	39
Basioccipital bone, width	280
Exoccipitals, distance from tip to tip	790

[1] Lambe, L. M., 1903, Ottawa Naturalist, Vol. XVII, pp. 136, 137; Osborn, H. F., and Lambe, L. M., 1902, Contributions to Canadian Palæontology, III, Part II, p. 73.

Exoccipitals, greatest fore and aft width	260 mm.
" least " " " "	147.5
Parietal bones, ventral aspect, length	808
" " " " least width	742.5
" " " " greatest "	115.4
Squamosal bones, ventral aspect, length	820
" " " " width	355
Postfrontal fontanelle, height	97
" " width	130
Infratemporal vacuity, length	130
" " height	52
Right horn core, longitudinal diameter at base	235
" " " transverse " " "	215
" orbit, length	170
" " height	115
Lower jaw, length of dentary	672.5
" " greatest depth to summit of teeth	183
" " height of coronoid	287.5
" " length of dental channel	324