# A New Specimen of *Liaoceratops yanzigouensis* (Dinosauria: Neoceratopsia) from the Early Cretaceous of Liaoning Province, China

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**Abstract: A new specimen of basal neoceratopsian dinosaur *Liaoceratops yanzigouensis* is described. The specimen comes from the Lujiatun Bed of the Lower Cretaceous Yixian Formation in Beipiao City of western Liaoning Province, and is represented by a very well preserved three-dimensional partial skull and mandible. It is also the smallest among the three specimens of *L. yanzigouensis*, and several features in the new specimen, such as the short preorbital length and the round rostroventral orbital rim, can be ontogenetically-related. The superb exposure of the palatal complex may be caused by the removing of its brain by a small predator in the contemporary Jehol Biota.**

**Key words: Dinosauria, Neoceratopsia, Early Cretaceous, Yixian Formation, Liaoning Province, China**

## 1 Introduction

Neoceratopsia is a stem-based clade including all ceratopsian dinosaurs more closely related to *Triceratops* than to *Psittacosaurus*. Compared to parrot-beaked psittacosaurs, neoceratopsians are characterized by their frilled heads and various horns in their faces. Basal neoceratopsians are an assemblage of small to medium size (about 1–3 meters long), bipedal or quadrupedal herbivores. They have been found in both Asia and North America, with one possible taxon from Australia (Rich and Vickers-Rich, 2003). The three most basal members of neoceratopsians: *Archaeoceratops oshimai* (Dong and Azuma, 1997), *Liaoceratops yanzigouensis* (Xu et al., 2002), and *Auroraceratops rugosus* (You et al., 2005), are all from the Lower Cretaceous of China.

*Liaoceratops yanzigouensis* is one of the most basal neoceratopsian dinosaurs discovered from the Lower Cretaceous Yixian Formation in Beipiao City of western Liaoning Province, northeastern China (Xu et al., 2002). It bears interesting features of both neoceratopsians and its sister group psittacosaurs, and plays an important role in our understanding of the origin and early evolution of neoceratopsians. Cladistic analysis including *Liaoceratops* shows that some neoceratopsian characters evolved in a more incremental fashion than previously known and also implies mosaic evolution of characters in early ceratopsian history (Xu et al., 2002).

The Lujiatun Bed of Yixian Formation where *Liaoceratops* was discovered is significant for its three-dimensional preservation of various fossils, including numerous dinosaurs (Xu and Norell, 2006). However, the age of the Lujiatun Bed was recently dated as 125 million years ago (He et al., 2006), almost the same as the feathered dinosaur-bearing Jianshangou Bed (Zhou, 2006), rather than as previously estimated as the lowest part of the Yixian Formation (~128 million years ago) (Xu et al., 2002).

*Liaoceratops yanzigouensis* was established on the holotype (Institute of Vertebrate Paleontology and Paleoanthropology: IVPP V12738, an almost complete skull) and the referred specimen (IVPP V12633, a juvenile skull), which have only received a preliminary description so far (Xu et al., 2002). Here, we describe a new specimen of *L. yanzigouensis* (Chinese Academy of Geological Sciences-Institute of Geology: CAGS-IG-VD-002) from the Lujiatun Bed in Beipiao City of western Liaoning Province. The new specimen is represented by a very well

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preserved three-dimensional partial skull and mandible, and is even smaller than the referred juvenile specimen (mandible length 55 mm versus 78 mm). The clearness of the sutures and smoothness of the bone surfaces are also suggestive of juvenile.

## 2 Description

The tiny specimen measures 61 mm in length as preserved (Figs. 1, 2). It lacks the skull roof, occiput, braincase and left cheek region. The skull seems to have a relatively low, flat cranium and lacks both exaggerated bosses or even conspicuous texture or ornamentation of any kind, nor is there an epijugal. The palate is superbly preserved and accessible both dorsally and ventrally. The right jaw is in articulation but the left jaw is free, allowing superb access to the dentition. The external nares are elliptical, enlarged, and dorsal in position. Retention of an external mandibular fenestra is uncommon.

### 2.1 Dermal skull roof

Rostral—The rostral is less well preserved than most elements of the skull. Its rostroventral end is not preserved, making it difficult to judge whether this bone is keeled or not. It is slightly pendant below the level of the premaxillary alveoli. An extremely gracile dorsal process ascends between the premaxillae to about the level of the first third of the rostral rim of the external nares. The caudolateral process does not seem very extensive; it is certainly shorter than the dorsal process.

Premaxilla—The premaxilla is rather simple in form, a smooth plate on the side of the face. Its suture with the maxilla follows a simple shallow smooth curve convex rostrally from the alveolar margin. The most rostral point of the curve is at the level of the ventral rim of the external naris and also of the antorbital fenestra. It rises caudodorsally to meet the nasal in a sharp point along the dorsal edge of the lacrimal. Unfortunately the premaxillary-nasal suture is not clear. The delicate rostral ascending process of the premaxilla forms a little more than half of the rostrodorsal border of the external naris. It is enclosed by the narial processes of the nasals and terminates as a sharp V on the midline a few mm caudally. There is a hint of circumnarial depression ventral to the naris; there is no well-defined rim but merely a smooth contour from the inset naris to the rostral and to the ventral margin of the premaxilla. The premaxillae form about two-thirds of a short secondary palate.

Maxilla—The maxilla has a triangular form, with its apex rostral at the summit of the premaxillary-maxillary suture. Its dorsal border runs caudoventrally, and disappears in lateral view underneath the maxillary ridge of the jugal ventral to the orbit. The triangular antorbital fossa is deeply impressed into the surface of maxilla dorsal to the facial crest. The maximum dorsal extent of the maxilla is not clear, but it does not appear to reach the prefrontal or the nasal. An ambiguous feature is a foramen between the maxilla and premaxilla. As presented for study, the specimen shows a prominent elliptical foramen along the maxillary-premaxillary suture on the right side. It measures 7 mm in height and 3 mm in width, and resembles a similar feature in *Bagaceratops rozhdestvenskyi* termed "additional antorbital foramen" (Maryańska and Osmólska, 1975). No such elliptical foramen is seen on the left side; instead, there is a much smaller irregular, sediment-filled area in a similar position. However, it seems to be lie entirely within the maxilla but it may be a natural hiatus in the bone or it may be a preservational artifact; natural edges are not evident.

The triangular antorbital fossa is sharply and deeply impressed into the maxilla. Several foramina are in evidence. One is dorsal and leads into the nasal cavity; this probably corresponds to the antorbital fenestra. It is overhung by the lacrimal and is not visible in lateral view. On the left side it is a round foramen, but on the right side it is an elongate slit. More ventrally or ventrolaterally, an opening leads from the apex of the antorbital fossa into the suborbital space. On the right side this opening is quite small but on the left side it is much larger, perhaps unnaturally so. On the left side, a third opening, rostrodorsal to the last one, has the form of a slit, and appears to enter into the nasal cavity immediately ventral to the transverse palatine wing. The larger lateral opening leads into the suborbital space.

The maxillary toothrow is somewhat inset, ventromedial to the facial crest. There are six foramina of differing sizes underneath the facial crest; the last one is the largest, adjacent to the seventh tooth. The maxilla forms the caudal third of the short secondary palate. The maxillae send rostral palatal processes medial to the premaxillary teeth, rostral to which they taper out on the midline. There are about eight dental foramina on the medial side of the maxillae a few mm dorsal to the toothrow; these are more prominent from the fifth tooth forward. The maxilla is exposed dorsally in the suborbital space between the palatine and the jugal. On each side there is an irregular opening close to the palatine. Whether natural or not, they may be indicative of maxillary sinuses.

Nasal—The nasals form a smooth broad shield dorsally, embracing the slender internarial processes of the premaxilla and expanding caudally between the two premaxillae. The caudal contact with the prefrontal is not clear.

Prefrontal—The prefrontal is situated medially and

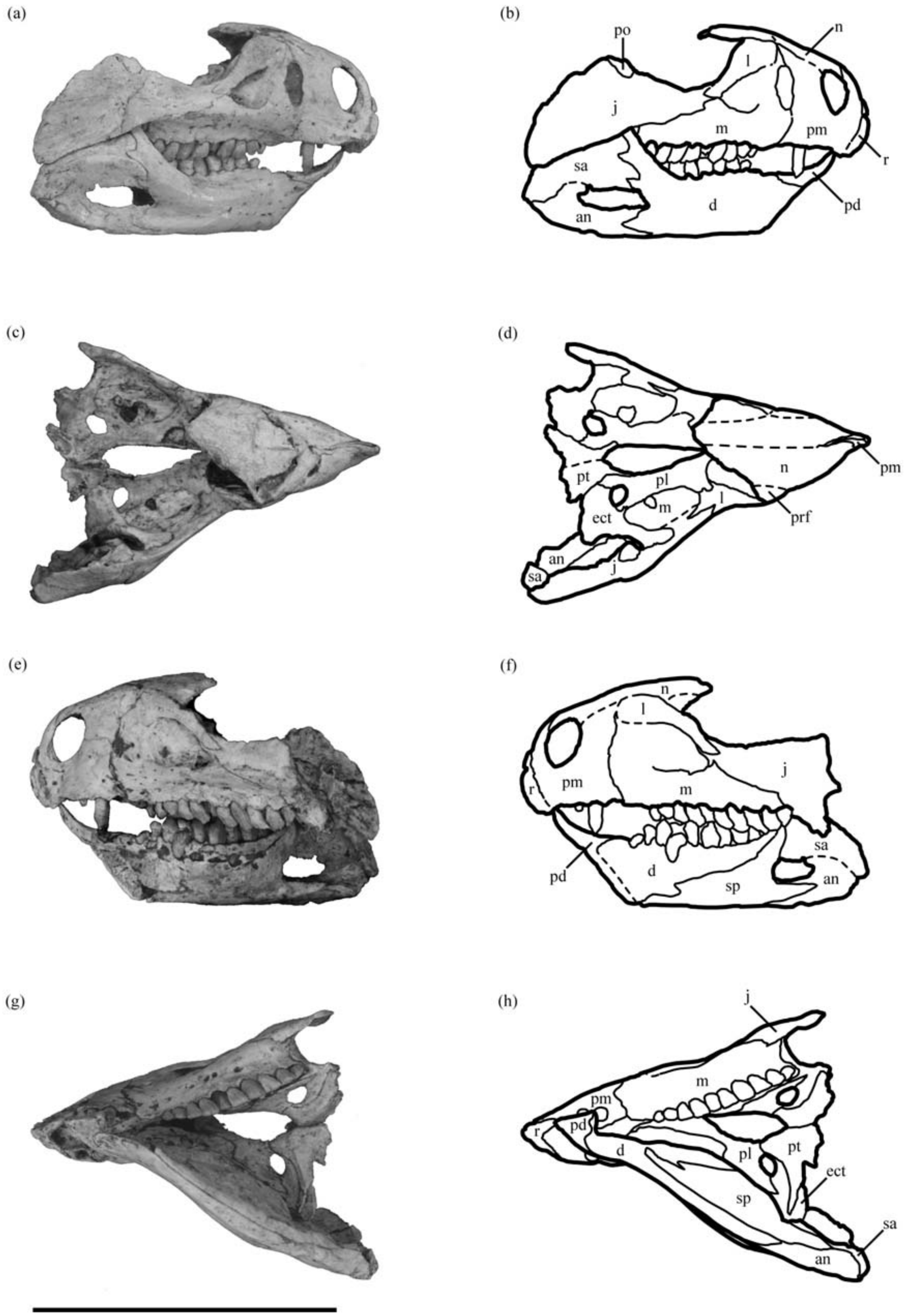


Fig. 1. Skull and right mandible of a new specimen (CAGS-IG-VD-002) of *Liaoceratops yanzigouensis* in right lateral (a, b), dorsal (c, d), left lateral (e, f), and ventral (g, h) views. a, c, e, and g: photographs. b, d, f, and h: interpretive outlines. Scale bar equals 5 cm.

Abbreviations: an – angular; ar – articular; d – dentary; ect – ectopterygoid; j – jugal; l – lachrymal; m – maxilla: n – nasal; pd – predentary; pl – palatine; po – postorbital; prf – prefrontal; pt – pterygoid; sa – surangular; sp – splenial.

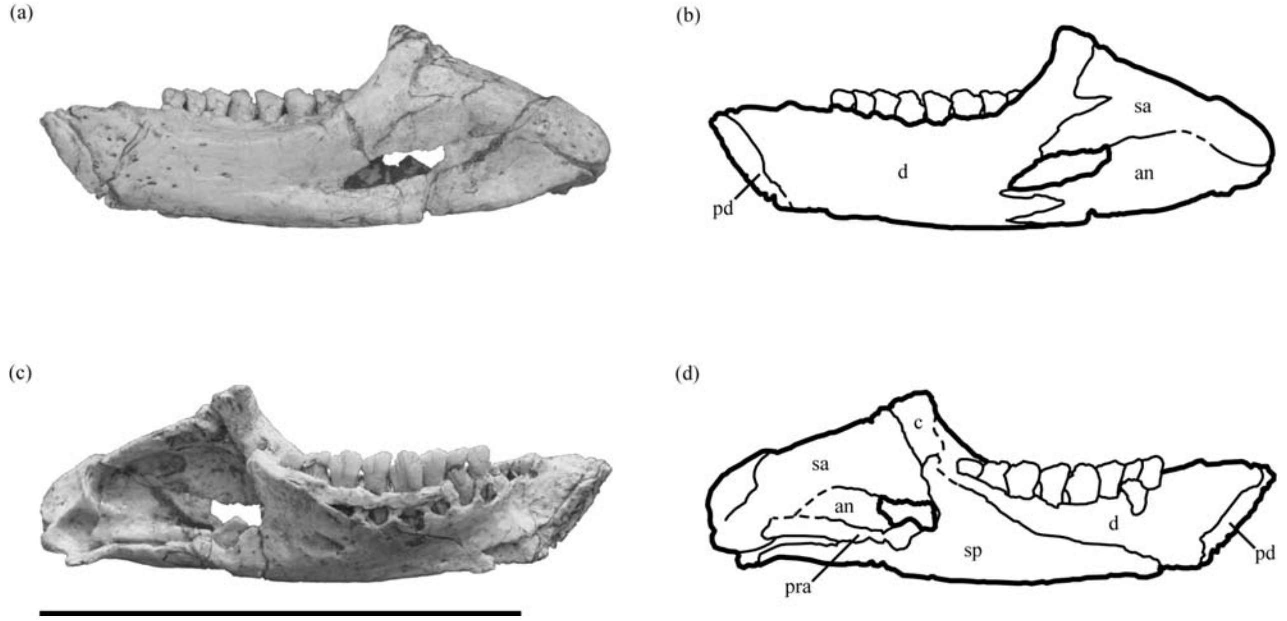


Fig. 2. Left mandible of a new specimen (CAGS-IG-VD-002) of *Liaoceratops yanzigouensis* in lateral (a, b) and medial (c, d) views. a and c: photographs. b and d: interpretive outlines. Scale bar equals 5 cm.
Abbreviations: c – coronoid; pra – prearticular. See Fig. 1 for other abbreviations.

caudomedially to the lacrimal on the skull roof, and is better represented on the left side than on the right side. Its sutural relations with the nasal and frontal are not clear.

Lacrimal—The lacrimal roofs the antorbital fossa. It is an oblique, straplike bone that extends from a wedge-shaped process on the side of the jugal rostrodorsally to the prefrontal and dorsal end of the maxilla. Its rostrodorsal end expands somewhat, but not into the fungiform expansion of *Auroraceratops* (You et al., 2005). The suture with the maxilla is not evident.

Jugal—The jugal is nearly completely preserved on the right side but only a small rostral part of the left jugal remains. The jugal is long and strongly swept back, and terminates caudoventrally in strong process. It shows only modest thickening caudally and no ornamentation. It is not clear that there was an epijugal. There is no jugal horn of any sort. Rostrally where it contacts the maxilla and the lacrimal, it barely reaches (left side) or barely fails to reach (right side) the caudal apex of the triangular antorbital fossa. The incomplete caudodorsal edge is surprisingly thin, possibly indicating overlap with the quadratojugal. The ventral border of the infratemporal fenestra does not appear to be represented.

## 2.2 Palatal Complex

With the loss of the skull roof, the palate is very well exposed both dorsally and ventrally (Fig. 1c, d). Only parts of the pterygoids remain. With the loss of the quadrates, the quadrate processes of the both pterygoids are missing.

Pterygoid—In dorsal view, the pterygoids are not very extensive. The most elevated parts are the elevated pedicles for contact with the basisphenoid and laterosphenoid. Otherwise the pterygoids are overlapped dorsally by the ectopterygoids. In caudal view the pendant compound mandibular rami are both visible, consisting of pterygoids medially and ectopterygoids laterally. The mandibular rami are rather short, and hang down only as far as the level of the dentary toothrow in the dorsal part of the mandibular fossa. In palatal view the pterygoids are seen as moderately extensive at the caudal end of the palate, and their contribution to the mandibular ramus is clear. On the right side the pterygoid is broken, but on the left side the pterygoid very nearly reaches the distal end of the ramus medial to the ectopterygoid.

Ectopterygoid—The ectopterygoid is seen most completely in dorsal view. It is shaped like a bow tie with the two expanded ends twisted in opposite planes. It also slopes caudoventrally from its attachment to the medial surface of the jugal underneath the caudoventral corner of the orbit down to the distal tip of the mandibular ramus of the pterygoid. It overlaps the caudal end of the maxilla, and its caudal border forms the rostral border of the subtemporal fossa for the mandibular adductor muscles. Rostromedially it forms the caudal border of the palatine foramen. In palatal view, exposure of the ectopterygoid is much more limited. It is seen running caudolaterally from the palatine foramen to the tip of the mandibular ramus, bounded caudally by the pterygoid and rostrally by the palatine.

Palatine—The palatines run the length of the oral cavity from the palatine foramina to the choanae (internal nostrils). They are very thin and predominantly horizontal in orientation, except along the delicate medial edge, which rolls dorsally. In between the palatines is a spacious median palatal (interpalatine) vacuity. Due to the typically close approach to the midline of the maxillae in ceratopsians, especially rostrally, the palatines are usually difficult to observe in palatal view (the more so if the mandibles are in articulation). The present specimen with the cranium missing is ideal for observing the palatines in situ.

In dorsal view the palatines are rectangular or slightly dumbbell-shaped, modestly expanded both rostrally and caudally. They are completely applied to the dorsomedial edge of the maxilla laterally. They are bounded caudolaterally by the ectopterygoid, form the rostral, lateral, and medial boundary of the palatine foramen, and sweep up caudomedially to contact the pedicles of the pterygoid, and thus are supported, at least indirectly, by the base of the braincase. The rostral end of the palatine is concave in dorsal view, and consists of two processes, named the longitudinal palatine wing and the transverse palatine wing (Osmólska, 1986). The longitudinal palatine wings sweep up dorsomedially to form blunt elevated prongs that embrace the vomers, which unfortunately are not preserved in this specimen. Rostrolaterally, the transverse palatine wings contact the thickened medial aspect of the lacrimal, and with that bone roof the antorbital foramen that enters the suborbital space. The paired choanae (fenestra exochoanalis) are situated rostral to the palatines and lateral to the vomer. The choanae enter the oral cavity rostral to the longitudinal palatine wing. As emphasized by Osmólska (1986), the choanae are situated at a high angle to the horizontal; they are seen only with difficulty in palatal view. They are situated at the rostrocaudal level of the third or fourth maxillary tooth medial to the middle of the antorbital fossa, and extend rostrally from there.

## 2.3 Mandible

The mandibles (Fig. 2) are low and gracile. They retain external mandibular fenestrae, which are asymmetrically developed: the left one smaller and more rostrally situated than the right one. All the elements of the mandibles are preserved except for the articulars.

Predentary—The predentary is not very well preserved, especially in its ventral extent. The predentary ends in an especially elongated and delicate sharp point that sweeps rostrodorsally. The predentary probably extends ventrally to the base of the dentary but does not seem to have very great caudal extent. It does not appear to have a median process separating the two dentaries, which are stabilized in shallow cotyles in each side of the predentary. The cutting surface shows little outward slope.

Dentary—The dentary is straight and parallel sided. The mandibular symphysis appears weak, with little contact between the two halves of the mandible. In lateral view the rostral end of the dentary angles sharply rostrodorsally at a 45 degree angle. Caudally the dentary sweeps dorsally into the coronoid process, where it forms a point at the apex. The contact with the surangular occurs about 5 mm caudal to the apex. Ventrally the dentary thins around the margins of the external mandibular fenestra. A lateral ridge begins on the caudal part of the dentary and continues caudally on the surangular.

The dentary-surangular suture begins dorsally on the caudal slope of the coronoid process and proceeds rostroventrally to the rostral end of external mandibular fenestra. The suture is not straight but wanders in such a way that two prongs of dentary interdigitate with the surangular. The dentary-angular contact begins near the rostroventral border of the external mandibular fenestra and reaches the ventral margin of the mandible.

Coronoid—A strap-shaped coronoid is applied to the medial surface of the coronoid process of the dentary. It sweeps rostroventrally from the apex of the coronoid process and forms the rostrodorsal boundary of the mandibular fossa.

Surangular—The surangular forms the smaller part of the coronoid process, and extends caudally as far as the jaw joint. It shows a strong longitudinal lateral ridge that is congruent with the ventral edge of the jugal. Its suture with the angular is not clear; it presumably runs caudally from the external mandibular fenestra beneath the longitudinal ridge to lie underneath the articular.

Angular—The angular composes the caudoventral part of mandible in lateral view. Its rostral margin receives the caudal prong of dentary. The dorsal border of angular forms the ventral margin of the external mandibular foramen. The ventral margin ascends caudodorsally, ending slightly rostral to the caudal end of the mandible. In ventral view, the caudal end of the angular expands both laterally and medially.

Prearticular—On the medial side of the left mandible, the prearticular is disarticulated and has fallen into the mandibular foramen. It has the form of a fairly simple rod. The articulars appear to be missing. Lacking the quadrates, the expected widths of the articular cotyles of the mandibles cannot be determined.

Splenial—The thin splenial covers much of the medial side of the mandible. It begins caudally as a slender prong lying ventral to the caudal part of the mandibular fossa. As it rises rostrally, it is congruent with the rostral edge of the mandibular fossa forming a caudodorsal process that reaches the medial base of the coronoid process adjacent to the 12th dentary tooth. The dorsal edge of the splenial comes rostrally past the series of dental foramina and descends to the ventral edge of the mandible; a slender ventral process reaches the caudal end of the mandibular symphysis (better preserved on the right side than on the left). It is probable that there was a small splenial symphysis. The ventral splenial-dentary suture runs straight down the ventral edge of the mandible and is very conspicuous.

### 2.4 Dentition

Premaxillary dentition—There are three alveoli on each premaxilla. Two teeth are preserved on the left side and one on the right side. The first tooth is set in a shallow alveolus, and appears as a low peg. The second tooth is about 5 mm tall, although on both sides a significant amount of straight cylindrical root is exposed. The bi-enameled crowns taper to a symmetrical point on each side. The third alveolus is also shallow.

Maxillary dentition—There are ten maxillary teeth, increasing in mesiodistal length from the first to the fourth. The length of the toothrow, measured along the left side, is 25 mm. The first maxillary tooth is a small, leaf-shaped peg that does not in anyway look characteristically ceratopsian. Details of crown morphology are not especially well preserved, and are best exemplified by left maxillary number 7, which is fully erupted but not yet in wear. There is a modest primary ridge shifted distally on the teeth and numerous secondary ridges, three or four mesial to the primary ridge and several distal to it. The mesial and distal edges of the teeth are recessed, and all ridges blend at the base of the tooth. There appears to be no angulation between the root and the crown. The occlusal plane is steep but not vertical. There is only a single functional tooth per tooth position. Replacement is from above.

Dentary dentition—The dentary teeth are conveniently studied on the free left jaw. The dentary toothrow includes 12 tooth positions over 28 mm. The dentary dentition is strongly inset and lies completely rostral to the coronoid process. Complete crowns are found in positions 4 through 11. The first several teeth are small; the $12^{th}$ tooth is a small peg. The tooth crowns are low and leaf-shaped, expanding from a narrow root. There is no angulation between the crown and root. The crowns are covered with thin enamel on one side only. The weak primary ridge is barely shifted mesially. The crowns are almost symmetrical. Secondary ridges are well developed. On the occlusal edge the enamel-dentine junction has a "crinkled" appearance, representing the secondary ridges in wear. The occlusal surfaces are poorly preserved and details cannot be determined. There is only a single tooth per tooth position; replacement is from below. A replacement tooth is erupting in position 5. The tooth row is gently curved, convex lingually.

## 3 Discussion

CAGS-IG-VD-002 possesses many basal neoceratopsian features, such as the retention of premaxillary teeth, absence of a nasal horn core and prominent deep triangular antorbital fossa. It can be referred to *Liaoceratops yanzigouensis* because it shares the diagnostic features of *L. yanzigouensis*, such as a common intersecting point for sutures among premaxilla, maxilla, nasal and prefrontal high on the side of the snout, and possession of several tubercles on the ventral margin of the angular (Xu et al., 2002).

Compared to the holotype and referred specimen, the several differing features in CAGS-IG-VD-002 can be explained ontogenetically. In the new specimen, the ratio between the preorbital length to the orbit length (measured from the rostroventral tip of postorbital to the caudodorsal end of the lacrimal) is 1.19 (21.2/17.8 mm), while these are 1.43 and 2.00 in the referred specimen (32.7/22.8 mm) and the holotype (64.0/32/0 mm), respectively. Therefore, the increase of the preorbital length is ontogenetically related. Along with this, the external nares and the rostral border of the antorbital fossae direct more rostroventrally than ventrally, and the rostroventral rim of the orbit becomes more angular than round. Other ontogenetically-related features include the development of a low lateral horn (in holotype), and the increase of tooth numbers (10 maxillary and 12 dentary teeth in the new specimen and the referred specimen, while there are 12 maxillary and 14 dentary teeth in the holotype).

The specimen is of taphonomic interest, as it may have been subjected to predation by a small selective feeder, either an avian or a non-avian predator (Andrews, 1990). It is well known that the Yixian Formation abounds with the remains of diverse small predators (e.g., Xu and Norell, 2006). For example, when a larger owl such as a barn owl (*Tyto alba*) or a great horned owl (*Bubo virginianus*) consumes a mouse, the victim is swallowed whole, whereas a small owl such as a screech owl (*Otus alba)* may hold the victim and dismember the carcass small bite by small bite (Dodson and Wexlar, 1979). It often begins with the head, and especially by removing the brain. This may have been the fate of the specimen under discussion. The fortuitous circumstance allows for a magnificent exposure of an important anatomical region that is otherwise rarely exposed.

## 4 Conclusions

The very well preserved three-dimensional partial skull and mandible described in this paper represents the third and smallest specimen of the basal neoceratopsian dinosaur *Liaoceratops yanzigouensis*. The superb exposure of its palatal complex, which allows a detailed examination, may have been caused by the removing of its brain by a small predator.

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