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A New Ceratopsian from the Upper Jurassic Houcheng Formation of Hebei, China

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Abstract: A new ceratopsian taxon *Xuanhuaceratops niei* gen. et sp. nov. is erected based on four fragmentary specimens collected from the Late Jurassic Houcheng Formation, Hebei Province, China. *Xuanhuaceratops* shares a number of derived features with, and is closely related to, another probable Late Juarassic ceratopsian *Chaoyangsaurus youngi*, from which it differs in only possessing a single premaxillary tooth as well as in details of quadrate and scapular morphology. We hypothesize that these two taxa represent a primitive lineage of Ceratopsia that is basal to the psittacosaurid-neoceratopsian diversity, and propose the name Chaoyangsauridae for it.

Key words: Houcheng Formation, Jurassic, Hebei, Chaoyangsauridae, Ceratopsia

1 Introduction

Although advanced neoceratopsians represent one of the best-sampled clades of dinosaurs, relatively little is known about the early evolution of Ceratopsia. Recently, primitive ceratopsians from northeastern China such as *Chaoyangsaurus youngi* (Zhao et al., 1999) and the basal neoceratopsian *Liaoceratops yanzigouensis* (Xu et al., 2002) have expanded our knowledge of early ceratopsian diversity and provided new temporal estimates for the origin of the group and its subclades.

During the 1970's a fragmentary skeleton of a small ornithischian dinosaur was found in a sandstone layer in the middle part of the Late Jurassic Houcheng Formation near the village of Yanjiagou, Xuanhua area, northern Hebei Province. This animal was briefly mentioned in the literature as "*Xuanhuasaurus niei*" (Zhao, 1985). No holotype was specified, however, and neither a diagnosis nor a description was provided, thus rendering the binomial "*Xuanhuasaurus niei*" a *nomen dubium*. Zhao (1985) considered this taxon to be a member of Chaoyangosauroidea Zhao, 1983, a paraphyletic group that he considered ancestral to Ceratopsia. Although fragmentary, the specimen displays several characters unique to Ceratopsia or ceratopsian subclades among dinosaurs. This specimen is very similar to the basal ceratopsian *Chaoyangsaurus* from neighboring Liaoning Province, but differs from it in several anatomical details and represents a closely related taxon. Subsequent field work by the authors in 2003 recovered fragments of three other individuals of the same taxon. The present paper aims to describe these specimens, and evaluate the relationships of this new taxon to other ceratopsians. The original specimen is the most complete and informative and is here designated as the holotype. Unless otherwise noted, the description is principally based on this specimen.

Abbreviations: AMNH, American Museum of Natural History, New York; BMNH, The Natural History Museum, London; IGCAGS, Institute of Geology, Chinese Academy of Geological Sciences, Beijing; IGM, Institute of Geology Mongolia, Ulanbaatar; IVPP, Institute of Vertebrate Paleontology and Paleoanthropology, Beijing; SAM, South African Museum, Cape Town.

2 Systematic Paleontology

Ceratopsia Marsh, 1890

Chaoyangsauridae *n. comb.* (Zhao, 1983)

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Xuanhuaceratops niei gen. et. sp. nov. (Figs. 1)
Xuanhuasaurus Zhao 1983 p. 300.
Xuanhuasaurus niei Zhao 1985 p. 289

Holotype: IVPP 12722, a partial skeleton comprising: parts of both premaxillae; articulated sections of the left maxilla, jugal and postorbital; the left frontal; a piece of the right postorbital; the right quadratojugal; both quadrates; parts of both pterygoids and the right ectopterygoid; glenoid regions of both mandibles; isolated section of left angular; most of the right dentary; isolated teeth, elements from all sections of the vertebral column; the left scapulocoracoid; parts of both humeri; partial left ischium; and parts of the right hindlimb including femur, sections of tibia and metatarsus.

Referred Material: IVPP V14527 and V14528; Fragmentary skull and postcranial bones and teeth of two differently sized individuals surface collected together near the middle of the Houcheng Formation near Yanjiagou/ Shisegou in summer of 2003.

IVPP V14529; parts of jaws with tooth roots collected approximately 100 m from the other two specimens.

Horizon and Locality: Houcheng Formation, probably Late Jurassic, Yanjiagou, Xuanhua Area, Hebei Province, China. The Houcheng Formation is generally considered to be Late Jurassic in age and laterally equivalent to the Tuchengzi Formation (Wang, 1998). Recent radiometric dating (Swisher et al., 2002) has shown that the upper part of the Tuchengzi dates to the earliest part of the Cretaceous, however.

Etymology: The generic name is derived from "Xuanhua", the geographic region that includes the type locality, and the suffix "ceratops", from the Greek for "horned face", as commonly used for horned dinosaur names; the species name honors Nie Rongzhen who kindly provided the authors with the specimen.

Diagnosis: Small ceratopsian closely related to *Chaoyangsaurus* (Zhao et al., 1999) based on the following unique combination of derived characters: small overlap between quadratojugal and quadrate at caudal end of enlarged infratemporal fenestra; quadrate shafts directed obliquely caudoventrally; quadrate condyles separated by deep saddle; medial face of mandibular glenoid region thickened into half-moon shaped process; external surface of dentary thickened and sculptured with pattern of anastomosing grooves and ridges. The new specimen differs from the holotype of *Chaoyangsaurus youngi* in probably possessing only a single premaxillary tooth and in the degree of sculpturing on the dentary and jugal, the rostrocaudally directed long axis of the quadrate shaft in cross section and possibly in the deeper acromion process of the scapula although the latter element is very poorly preserved in the holotype of *Chaoyangsaurus youngi*.

3 Description

Xuanhuaceratops niei is a small ceratopsian, estimated to be about a meter in length. Although all limb bones are incomplete, the preserved parts of the humeri compare to the hindlimb elements as in *Psittacosaurus*, suggesting that *Xuanhuaceratops* may have been at least facultatively bipedal as is supposed for psittacosaurs.

Skull:

The main bodies of both premaxillae are preserved, and juxtaposing the two premaxillae in ventral view shows that the premaxillary palate was shallow and lacked the outwardly flared profile seen in the deeply vaulted premaxillae of psittacosaurs and neoceratopsians. A single root of a premaxillary tooth is preserved in each premaxilla positioned below the naris. The left element shows that the tooth is surrounded by finished bone mesially and there is no trace of a second root preserved adjacent to it distally, indicating that only a single premaxillary tooth was present unlike other ceratopsians with premaxillary dentition. *Chaoyangsaurus* (IGCAGS V371) and basal neoceratopsians bear two or three teeth in each premaxilla and the alveoli are always directly adjacent to one another.

Cheek region: The caudal end of the left maxilla with adjoining parts of the jugal and ventral process of the postorbital are preserved in the holotype. The preserved maxillary section reveals saggital cross-sections of six alveoli that decrease in height and diameter toward the caudal end of the element. Laterally, the maxilla bows outward to create a cheek recess, but most of this ridge is broken and lost.

Most of the preserved external surface of the jugal is covered by a rugose pattern of small tubercles and anastomosing grooves resembling the condition in some pachycephalosaurs. The postorbital does participate in the infratemporal fenestra as in psittacosaurs, but not neoceratopsians where it is excluded by the dorsal process of the jugal.

Two postorbital fragments are preserved in the holotype. Along its rostral edge, the postorbital meets the ascending spur of the jugal along an oblique suture. The rugose pattern of small tubercles continues from the jugal onto the postorbital. Unlike the columnar and slender postorbital bar of psittacosaurs, the postorbital bar of *Xuanhuaceratops* is broad as in pachycephalosaurs and neoceratopsians.

A large fragment of the left frontal bearing part of the orbital rim, the rostral end of the supratemporal fenestra and the crista cranii is preserved. The skull table is flat rostral to the supratemporal part of the bone.

The right quadratojugal is almost complete. It is a flat

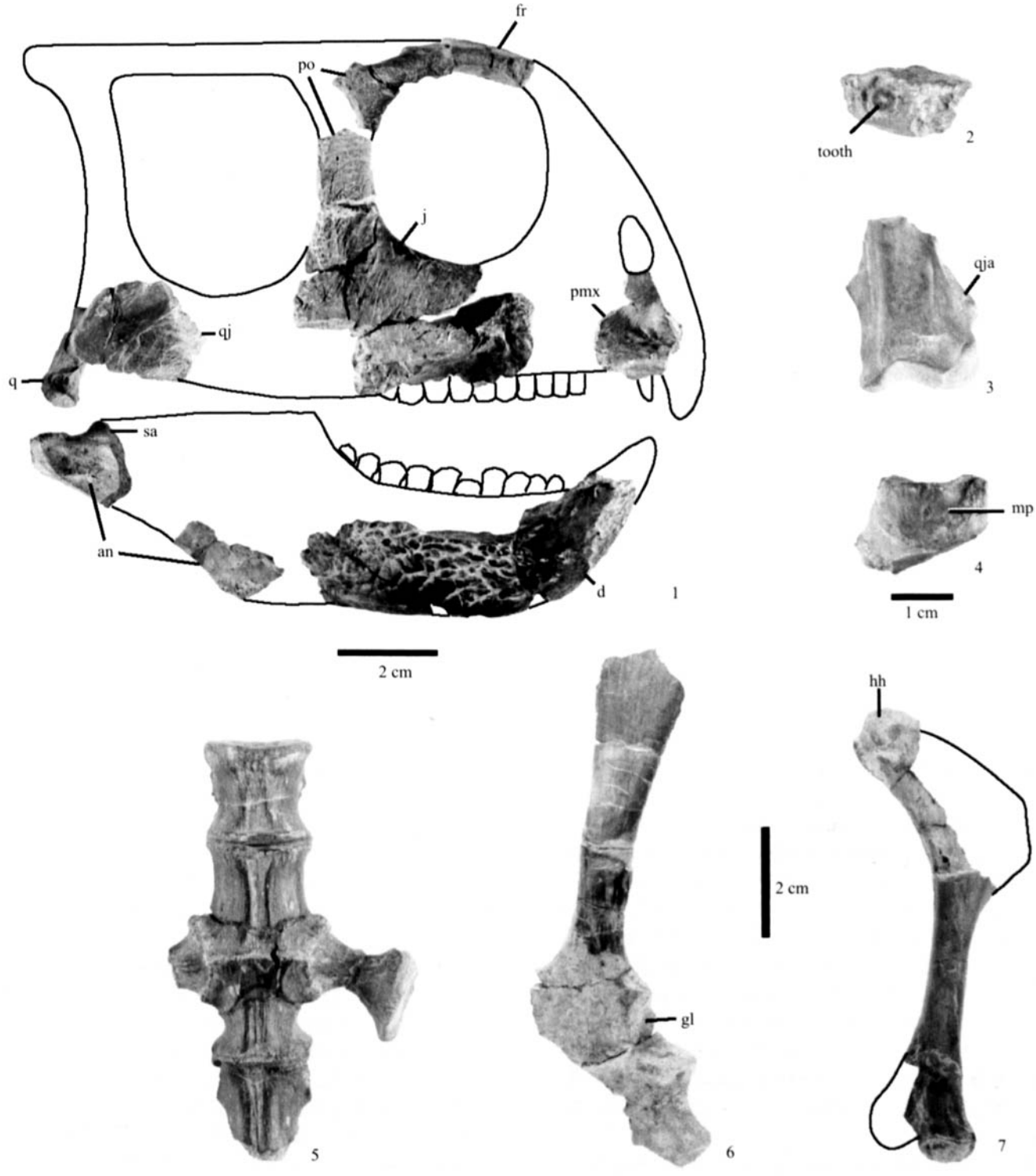

Fig. 1. Skeletal elements of the holotype specimen of *Xuanhuasaurus niei* (IVPP 12722).

1. Isolated bones of holotype skull figured in life position. Some bones from the left side of the skull such as the premaxilla, and dorsal postorbital fragment have been reflected; 2. Left premaxilla in ventral view, showing single premaxillary tooth root; 3. Right quadrate in caudal view; 4. Right mandibular glenoid in medial view, showing medial process; 5. Partial sacrum in ventral view; 6. Lateral view of the left scapula-coracoid; 7. Reconstructed right humerus in lateral view, following reflection of left proximal humerus and superimposition of distal right humerus. Scale bar for 2–4 below 4, and scale bar for 5–7 between 6 and 7. an – angular, d – dentary, fr – frontal, gl – glenoid, hh – humeral head, j – jugal, mp – medial process of articular, pmx – premaxilla, po – postorbital, q – quadrate, qj – quadratojugal, qja – quadratojugal articulation of quadrate, sa – surangular.

bone with a subtriangular profile and the rounded caudal corner fits into a small, matching depression on the lateral face of the quadrate shaft. This weak quadrate-quadratojugal overlap is unusual among ornithischians, and together with its orientation probably reflects the autapomorphic caudoventral inclination of the quadrates as in *Chaoyangsaurus* (IGCAGS V371).

The distal portions of both quadrates are preserved. In posterior view the quadrate shaft expands transversely toward the distal end and terminates in asymmetrical mandibular condyles, separated by a deep, saddle-shaped sulcus (Fig. 1-3). The lateral surface of the quadrate shaft preserves the base of a large flange that articulated with the quadratojugal just dorsal to the lateral condyle. The articular surface for the quadratojugal in *Xuanhuaceratops* differs slightly from the condition in *Chaoyangsaurus*, in the smaller degree of overlap on to the caudal surface of the quadrate shaft.

Lower jaw:

The mandibles of *Xuanhuaceratops niei* are partly preserved and comprise most of the right dentary and proximal parts of the angulars, surangulars, prearticulars and articulars (Fig. 1-1). The dentary is long, low and slightly bowed laterally with a strongly developed symphysis. A prominent groove extends along the dorsal edge of the rostral tip of the dentary for reception of the lateral process of the predentary, as in basal ceratopsians (Sereno, 1990). The middle part of the dentary is labiolingually thickened and bears irregular sculpturing on the external surface below the ridge (Fig. 1-1).

Two sections of the angular are represented including the caudal, subglenoid region of each mandible, and a more distal section close to the contact with the dentary. As in *Chaoyangsaurus*, the lateral and ventral surfaces of the angular are set at a perpendicular angle to each other. The caudal end of the surangular is preserved and forms much of the lateral cotyle of the glenoid, which is larger and shallower than the medial one. It forms the very reduced retroarticular process together with the articular (Fig. 1-1). The surangular lacks a dorsal flange that borders the glenoid laterally as in higher neoceratopsians (Makovicky, 2001).

The articular forms the medial cotyle of the mandibular glenoid, which is medially expanded in *Xuanhuaceratops* and other ceratopsians. The articular probably bears the ridge separating the two glenoid cotyla. The medial part of the glenoid is smaller than the lateral, conforming to the proportions of the quadrate condyles. Medially, the articular is deep, forming a semilunar surface below the medial edge of the glenoid (Fig. 1-4), a feature that is unique to *Xuanhuaceratops* and *Chaoyangsaurus* among ornithischians.

Dentition:

The teeth are rather simple and similar to those of *Chaoyangsaurus youngi* (Zhao et al., 1999). Because of the incompleteness of the jaws, the number of tooth positions is unknown, but we estimate no more than 10 alveoli (Fig. 1-1) based on comparisons with *Chaoyangsaurus* and psittacosaurids. Based on the fragmentary tooth roots preserved rostrally in the dentary, only a single replacement tooth was present in any alveolus.

Several teeth are preserved though none is complete. The columnar roots are very thick and roughly circular in cross section. Presumed maxillary crowns are tall and chisel-shaped and lack a distinct primary ridge. Presumed dentary crowns are wider and more fan-shaped, and a preserved complete dentary crown from one of the referred specimens has a low primary ridge as in psittacosaurs. Weak secondary ridges on the distal parts of some maxillary crowns indicate that there were a low number of denticles restricted to the apical part of the crowns as in *Chaoyangsaurus youngi* (IGCAGS V371) and *Psittacosaurus mongoliensis* (AMNH 6524; IGM 100/132). Both buccal and labial crown faces bear a thick layer of enamel.

Vertebral Column:

The vertebral column is represented mostly by isolated centra and broken neural arches in the holotype and the two associated referred specimens. Most of the preserved vertebrae in the holotype have fused neurocentral sutures suggesting that the specimen was at or near adult size (Brochu, 1996). The isolated atlas intercentrum from IVPP V14528 is low and wide, with a concave anterior and convex caudal face. Two isolated cervical centra from the holotype are laterally compressed with a low, narrow ventral keel.

Preserved dorsal vertebrae have spool-shaped centra with platycoelous cranial and caudal ends. Only one trunk vertebra of the holotype preserves the arch and has the parapophysis and transverse process positioned above the neural canal and the caudally inclined neural spine is centered above the caudal half of the centrum. The total number of elements that formed the sacrum cannot be ascertained, but a series of four coosified sacrals (Fig. 1-5) plus two isolated sacral centra that do not articulate perfectly suggest that at least seven sacral vertebrae were present in the holotype. A ventral groove extends along the ventral midline of the third and fourth sacrals, but diminishes caudad.

A single isolated cranial caudal is preserved. The ventral surface of the centrum is grooved and bears a facet for a chevron distally. The caudal ribs are positioned on the

neurocentral suture, and are horizontal and backswept.

Appendicular Skeleton:

Pectoral girdle: Most of the left scapulocoracoid is preserved (77 mm long), except for the distal ends of either bone (Fig. 1-6). The acromion is trapezoidal in shape and extends further up the scapular shaft than the glenoid. It differs from the scapula of *Chaoyangsaurus* in this respect. The scapular blade is straight in lateral aspect, and only slightly bowed transversely. The blade flares distally, but not to the degree seen in basal ornithischians such as *Lesothosaurus* (BMNH B17) and *Heterodontosaurus* (SAM K1332).

A proximal section of the left coracoid is preserved in articulation with the scapula. It is relatively thin and the base of a well-developed coracoid process extends caudoventrally from the glenoid (Fig. 1-6). A narrow groove extends caudoventrally from the glenoid lip and along the edge of the coracoid process, unlike in other ceratopsians.

Forelimb: Parts of both humeri are preserved with the holotype, and combining both yields an approximate length of ~40 mm (Fig. 1-7). The humerus was sigmoid in lateral view with the head offset from the distal condyles, which are transversely flared and anteroposteriorly flattened as in psittacosaurids.

Pelvic Girdle and Hindlimb: The acetabular part of the left ischium is the only preserved section of the pelvic girdle in the holotype. In lateral view, the iliac peduncle of the ischium is almost three times as wide as the slender pubic peduncle, but is much shorter than the latter. Fragments of the right femur, tibia and metatarsus of the holotype specimen were recovered along with femoral and shank fragments from one of the referred specimens. Unfortunately no elements are complete. Only the proximal end of the right femur is preserved. The femoral head is missing, but appears to have been oriented mediodorsally. The fingerlike lesser (anterior) trochanter adheres to the front of the femoral shaft and terminates well below the greater trochanter, and the two trochanters are separated by a narrow notch. The proximal and distal ends of the right tibia are preserved and generally resemble the tibiae of other basal ornithischians. The distal end of the tibia is tranversely expanded across the malleoli. The larger medial malleolus is deep and subtriangular in distal view. Its cranial face is slightly concave for reception of the astragalus. An astragalus is preserved with the smallest of the referred specimens and is generally typical of primitive ornithsichians, with a low pyramidal ascending process. The proximal parts of right metatarsals I–III are preserved in articulation in the holotype. The metatarsals are slender and closely appressed to each other. Metatarsal I is very slender compared to the other metatarsals and metatarsal II is mediolaterally compressed, but expanded along the plantar axis. Metatarsal III is the most complete of the preserved metatarsals, and is over 56 mm long. Its proximal end is rectangular and probably formed the widest contribution to the proximal articular surface of the metatarsus. The shaft becomes mediolaterally expanded toward the distal end. About 30 mm down the lateral face of the shaft is a large, rugose pathology with a short bone spur. Isolated pedal phalanges from the referred specimens are generally similar to those of psittacosaurids.

4 Discussion

Due to the fragmentary nature of the *Xuanhuaceratops niei* holotype, few ceratopsian synapomorphies can be observed. Among these, the presence of a strong mandibular symphysis (Sereno, 1986) and a wide ventral process of the predentary (Sereno, 2000) (inferred from the articular surface on the dentary) are observed in the holotype, and a pronounced medial expansion of the mandibular glenoid occurs in two of the referred specimens as well as the holotype.

A number of other derived character states evident in the holotype and referred specimens imply close relationship with the basal ceratopsian taxon *Chaoyangsaurus* (Zhao et al., 1999). Chief among these is the deep, ventral expansion of the medial process of the mandibular glenoid (Fig. 1-4). Although the glenoid is also medially expanded in other ceratopsians, the medial edge is relatively shallow. Another unique character state uniting the two Late Jurassic ceratopsians is the weak contact between the triangular quadratojugal and quadrate (Fig. 1-1). In most ornithischians, including psittacosaurids and neoceratopsians, the quadratojugal has an extensive overlap on to the lateral face of the quadrate. In contrast to this, the two Jurassic taxa display only a small overlap of the quadratojugal on the posterolateral face of the quadrate shaft, and the infratemporal fenestra is extended as a notch between the two bones. This unusual contact may be correlated with the autapomorphic posteroventral inclination of the quadrate shaft in *Chaoyangsaurus* and presumably also *Xuanhuasaurus*.

Another potential synapomorphy uniting the two taxa is the rugose sculpturing on the labial face of the dentary, although this is more developed in the holotype of *Xuanhuaceratops*. Pachycephalosaurs, the marginocephalian sistergroup to ceratopsians, also possess sculpturing on many dermal skull bones, but this usually takes the form of small, pointed tubercles (e.g. *Stegoceras* Gilmore[1924]). Therefore the specific type of ornamentation (anastomosing grooves separating small, rounded ridges and tubercles on the dentary) appears to be

unique to *Xuanhuaceratops* and *Chaoyangsaurus*, although the presence of sculpturing may be a marginocephalian synapomorphy.

Unique derived morphologies unite *Xuanhuaceratops* and *Chaoyangsaurus* relative to other ceratopsians and detailed comparison yields few diagnostic differences between the holotypes of both taxa. Therefore, we follow Makovicky (2002) and Makovicky et al. (2004) in hypothesizing a sistergroup relationship for the two, and we propose the name Chaoyangsauridae (modified from Chaoyoungsauridae Zhao, 1983) for this probably Late Jurassic lineage of ceratopsians. In order to achieve taxonomic compatibility with recently proposed phylogenetic classifications of Ceratopsia (Sereno, 1998), we define Chaoyangsauridae as a stem-based taxon for all taxa closer to *Chaoyangsaurus youngi* than to either *Triceratops horridus* or *Psittacosaurus mongoliensis*. Although the holotypes of *Chaoyangsaurus* and *Xuanhuaceratops* differ subtly in quadrate shaft morphology, the degree of sculpturing, and acromion process development, the principal diagnostic difference is observed in the premaxillary dentition. In *Chaoyangsaurus* each premaxilla bears a pair of juxtaposed teeth, with nearly cylindrical crowns. As discussed above, the left premaxilla of *Xuanhuaceratops* holotype displays a single alveolus along its ventral margin. Although the ventral margin is incomplete anteriorly, it is highly unlikely that a second alveolus was present, and even if were, it would be separated from the first by a diastema not present in any other ceratopsian. Although premaxillary tooth counts vary taxonomically among ceratopsians (and Ornithischia as a whole), they are intraspecifically invariant in ceratopsians for which multiple specimens exist such as *Protoceratops* (Brown and Schlaikjer, 1940) and *Liaoceratops* (Xu et al., 2002). Therefore, we consider it most conservative to regard the difference in premaxillary tooth count between *Chaoyangsaurus* and *Xuanhuaceratops* as a taxonomic one.

Figure 1-1 presents an approximate reconstruction of the life position of the cranial bones of the holotype, as determined by superimposition on to the partial, but articulated holotype skull of *Chaoyangsaurus youngi*. The temporal and occipital regions are speculative, but based on features that appear to be primitive for Ceratopsia such as an enlarged infratemporal fenestra and a short parietosquamosal frill. Skull height is also poorly constrained, but even a conservative estimate of the preserved remains dictate a short deep skull as in psittacosaurs, albeit without the vertical rostral profile and dorsally placed naris. Given the basal position of the Jurassic taxa (Zhao et al., 1999; Sereno, 2000; Xu et al., 2002), short preorbital skull length thus optimizes as the primitive condition for Ceratopsia although the vertical snout profile of psittacosaurs appears to be unique to that clade.

In northern Hebei psittacosaurids are reported from the Tujinzi Formation (Russell and Zhao, 1996), which overlies and is separated from the Houcheng Formation by the Dabeigou Formation (Gan and Zhang, 1985). In Liaoning, psittacosaurs and the basal neoceratopsian *Liaoceratops* co-occur in the lowermost Yixian Formation (You et al., 2003; You and Xu, 2005), which directly overlies the Tuchengzi Formation. Therefore *Xuanhuaceratops* and *Chaoyangsaurus* consistently predate any other known occurrences of ceratopsians including all described psittacosaurids, and are potential stratigraphic index taxa for the latest Jurassic in northern China. The presence of a second ceratopsian near the K-J boundary and basal to the psittacosaurid-neoceratopsian dichotomy (Xu et al., 2002) suggests a more diverse early history for this clade stretching into the Jurassic as predicted by Sereno (1997).

5 Conclusion

Xuanhuaceratops niei is a new small ceratopsian from the Upper Jurassic Houcheng Formation of northern Hebei. It is very similar and closely related to another Late Jurassic taxon, *Chaoyangsaurus youngi*, from Liaoning, prompting us to erecta stem based taxon Chaoyangsauridae to encompass these two taxa. *Xuanhuasaurus* illuminates important character distributions for understanding early ceratopsian evolution. It displays a rugose sculpturing of several cranial bones as in pachycephalosaurs, indicating that this feature may be primitive for Marginocephalia. A cranial reconstruction confirms that a short preorbital snout length is a primitive trait for Ceratopsia. Both Jurassic taxa predate the occurrence of more derived ceratopsians, suggesting their potential utility as index fossils.

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