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THE EARLIEST CERATOPSIAN FROM THE TUCHENGZI FORMATION OF LIAONING, CHINA

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ABSTRACT—A new ceratopsian specimen, *Chaoyangsaurus youngi* gen. et sp. nov., was collected from the Tuchengzi Formation (Middle or Late Jurassic) of Liaoning, China. Distinctive characteristics of the new species include quadratojugal overlapping posterior side of quadrate shaft; lack of a broad lateral surface of the quadrate shaft; convex posterior margin of the ventral portion of the quadrate; a ridge between the planar lateral and ventral surface of the angular. The discovery of *Chaoyangsaurus youngi* extends the record of ceratopsian from back in time from the Early Cretaceous into the Middle or Late Jurassic. Some characters of *C. youngi* may suggest a close relationship between Ceratopsia and Heterodontosauridae.

INTRODUCTION

The Ceratopsia (or horned dinosaurs) were a diverse group of dinosaurs restricted to the post-Barremian deposits of Asia and North America (Dodson, 1990). The earliest record is from the Yixian Formation, Liaoning, China, the age of which is probably early Early Cretaceous (Xu and Wang, 1998). In 1976, an ornithischian skull and some postcranial material was collected by Cheng Zhengwu from the Jurassic sediments of Liaoning Province, China. Zhao (1983) erected a new genus, *Chaoyangosaurus,* for this material and later (1985), published the binomen *C. liaosiensis.* However, this taxon was not adequately diagnosed or described, making the binomen *Chaoyangosaurus liaosiensis* a nomen nudum. In this paper, we present a detailed description of this material and propose the new name *Chaoyangsaurus youngi* together with a full diagnosis of this taxon. Although the skeleton was not articulated, the close proximity, preservation and proportions of the elements recovered strongly suggest that the material represents a single individual. This material adds to our knowledge of the earliest ceratopsian and the early evolution of the Ceratopsia.

Institutional Abbreviations—IGCAGS, Institute of Geology, Chinese Academy of Geological Science, Beijing; **IVPP**, Institute of Vertebrate Paleontology and Paleoanthropology, Beijing.

MATERIAL

The material described herein was collected from Ershijiazi, a locality in the Chaoyang Area of Liaoning Province, Northeastern China (Fig. 1). The material was recovered from the Tuchengzi Formation, a sequence of purple-grey sediments representing a river-facies that attains a thickness of approximately 876–2,908 m (Dong, 1985). There is little agreement on the age of the Tuchengzi Formation, but the current consensus suggests that it is Middle Jurassic or Late Jurassic (Dong, 1985; Wang et al., 1989; Reng et al., 1995). Recent work suggests a late Middle Jurassic age, based on the presence of the conchostracan *Mesolimnadia, Sentestheria,* and *Pseudograpta*, which can be correlated with non-marine conchostracans from Bathonian sediments in northwest Scotland (Wang, 1998). All of the material pertaining to this taxon is housed in the collections of the IGCAGS in Beijing.

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SYSTEMATIC PALEONTOLOGY

CERATOPSIA Marsh, 1890
CHAOYANGSAURUS YOUNGI, gen. et sp. nov.
(Figs. 2–7)

Chaoyangosaurus Zhao, 1983:300.
Chaoyangosaurus liaosiensis Zhao, 1985:289
Chaoyangosaurus liaosiensis Dong, 1992:94

Type Specimen—IGCAGS V371 (Figs. 2–7), the dorsal part of a skull, a nearly complete mandible, complete axis, an isolated cervical vertebra and five articulated cervicals, a fragmentary humerus and scapula.

Locality and Horizon—Tuchengzi Formation, Liaoning Province, China; Middle or Late Jurassic.

Etymology—The specific name is in memory of the founder of vertebrate paleontology in China, C. C. Young.

Diagnostic Features—Ceratopsian with weakly developed and smooth jugal boss; quadratojugal overlapping the posterior side of the quadrate shaft; lack of a broad lateral surface of the quadrate shaft; posteroventral margin of the quadrate shaft convex; rather low coronoid process with a planar top; a ridge present between the planar lateral and ventral surface of the angular.

DESCRIPTION

Skull

Chaoyangsaurus youngi is a small ceratopsian with a skull that is about 140 mm in preserved length (from tip of snout to back of quadrate). The obliteration of cranial sutures suggests that the type specimen was an adult individual. Although the dorsal part of the skull is damaged, the subtriangular shape of the skull in dorsal view is still easily recognizable, due to the lateral projection of the jugals well beyond the ventral margin of the orbits and the transverse compression of the beak-like snout. Although not fully preserved, the gentle arc of the ventral orbital margin suggests that the orbit is rather large (estimated size is about 50 mm) in comparison with the small skull size. The preorbital region of the skull is proportionately very short (estimated about 32% of the preserved skull length), and is even shorter than that of psittacosaurids (Sereno, 1990). Although the external nares are not preserved, it is possible, based on the preserved ventral tips of the nasals, to deduce that, as in psittacosaurs and *Archaeoceratops* (Dong and Azuma, 1997), the nasals extends rostroventrally below the external naris.

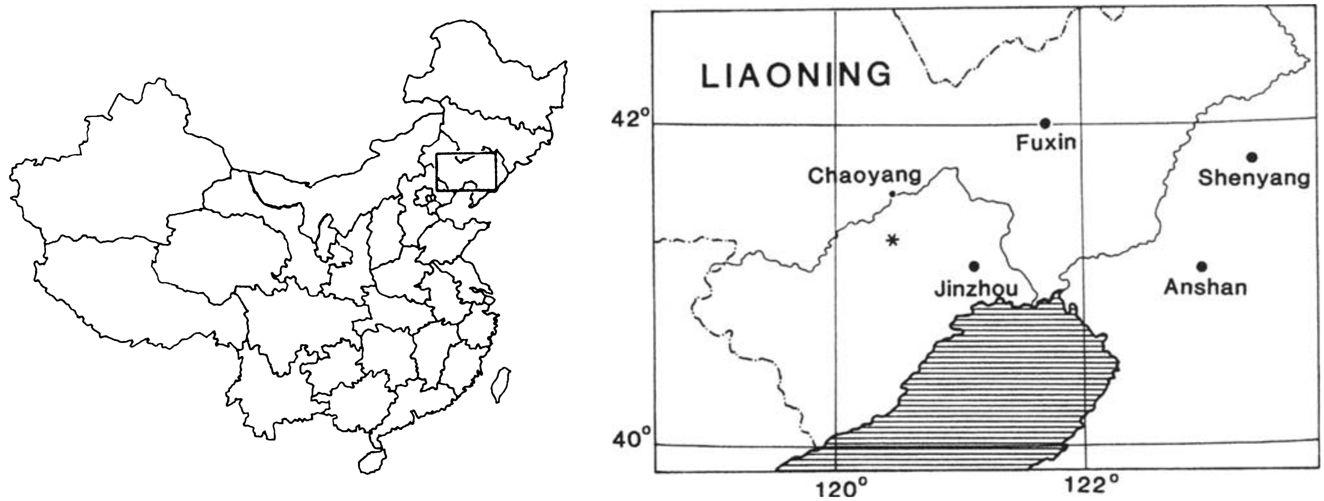


FIGURE 1. Map of type locality in Chaoyang City, Liaoning, China. * = Ershijiazi.

Dermal Skull Roof—The rostral is wedged between the ventral tips of the nasals dorsally and contacts the premaxilla posteriorly. As in psittacosaurs (Sereno, 1990), the rostral is tall and the ventral portion is transversely wide but the dorsal portion is strongly compressed. The ventral margin is edentulous but crenulate, with at least four sharp, mediolaterally compressed toothlike projections per side (Figs. 2A, 3A). The projections point anteroventrally at an angle of nearly 45 degrees from the horizontal. The most posterior projection is located slightly below the level of the ventral margin of the premaxilla. The more anterior projections are situated below this level, and the most anterior projection is more than 1 cm lower than the ventral margin of the premaxilla.

The premaxilla contacts the rostral anteriorly and the maxilla posteriorly. Although the dorsal portion of the premaxilla is broken, the preserved portion of the premaxilla suggests that it was a large bone which would have extended dorsally to form a tall, parrot-like rostrum as in all other ceratopsians. The area of the premaxilla immediately posterior to the rostrum is shallowly concave. There are two premaxillary teeth situated in the posterior part of the premaxilla (Figs. 2A, 3A), as in some primitive neoceratopsians, e.g., *Protoceratops* (Brown and Schlaikjer, 1940) and *Archaeoceratops* (Dong and Azuma, 1997). The ventral margin of the premaxilla is offset slightly below that of the maxilla.

The ventral part of the maxilla is well preserved, but the ascending process is missing. The maxilla contacts the jugal posteriorly. A nearly horizontal ridge is present near the contact with the jugal which represents the dorsal margin of the buccal emargination (Figs. 2A, 3A). In psittacosaurs an eminence rather than a ridge is present in the same position (Sereno, 1990). The maxilla is strongly emarginated dorsal to the tooth row. Immediately above the horizontal ridge, the maxilla is strongly concave, suggesting the presence of an antorbital fossa as in protoceratopsids (Dodson and Currie, 1990). Above the maxillary tooth row there are some small nutrient foramina, each of which lies above a tooth. There is a rather long and narrow caudoventral process of the maxilla which causes the tooth row to extend comparatively caudally, resembling the situation in *Heterodontosaurus tucki* (Crompton and Charig, 1962). In other ceratopsians the maxilla is nearly triangular with the anteroventral process and the caudoventral processes nearly equal in length. The tooth row of *C. youngi* extends further posteriorly such that the posterior limit of the tooth row is close to the posterior margin of the orbit. The tooth row is proportionately longer than that of psittacosaurs, though the tooth count is almost the same. The teeth are more closely packed in *Chaoyangsaurus* than in psittacosaurs due to the larger individual teeth.

The jugal (Figs. 2A, 3A) contacts the maxilla anteriorly and the quadratojugal posteriorly, and forms the ventral margin of the orbit anterodorsally. It is thickened ventrally, and the middle of the jugal flares laterally. However, this lateral projection does not have the markedly biplanar surface which develops in other ceratopsians (Sereno, 1986, 1990). The ventral margin of the jugal forms a gentle arc similar to that of many other ornithischians but rather unlike the sharply curved ventral margin seen in other ceratopsians. As in other ceratopsians (Sereno, 1990), the jugal is marginally deeper under the orbit than under the infratemporal fenestra. No clear suture separates the jugal from the quadratojugal.

The quadratojugal is broken posterodorsally. The anterior process of the quadratojugal is wedged inside a groove on the medial surface of the jugal and contributes to the ventral margin of the infratemporal fenestra. The quadratojugal is curved outward and its posterior portion is deflected medially such that it overlaps the caudal surface of the quadrate shaft. The quadratojugal is rather long axially and separates the jugal from the quadrate by a considerable distance as in psittacosaurs (Sereno, 1990) and some primitive ornithischians such as *Lesothosaurus* (Weishampel and Witmer, 1990a) and *Heterodontosaurus* (Weishampel and Witmer, 1990b).

Only the ventral portion of the quadrate is preserved (Figs. 2A, 3A, 4A). The ventral end is slightly expanded transversely to form two mandibular condyles. The lateral condyle is larger than the medial one, and they are separated by a helical groove. The two condyles curve forward and on the posterior margin of the quadrate shaft immediately dorsal to the distal condyles a prominence extends dorsally from the helical groove. The ventral shaft of the quadrate is quite unusual: the posteroventral margin of the quadrate is transversely convex rather than more or less concave or at least planar in other ornithischians (Fig. 4A). The ventral shaft of the quadrate is very thin anteroposteriorly and laterally does not extend anteroposteriorly to form a lateral surface for contacting the quadratojugal as in other dinosaurs. The quadrate is oriented posteroventrally at an angle of around 45 degrees to the rest of the skull.

Braincase—Generally speaking, the occiput is more similar in morphology to that of psittacosaurs than to those of neoceratopsians (Fig. 5A). No well-defined sutures separate the braincase elements, so it is difficult to determine the contribution of individual elements to the occipital condyle and to the margins of the foramen magnum. The preserved portion of the occiput suggests that the foramen magnum is as wide as the occipital condyle, and it is taller than wide. This is somewhat similar to the situation seen in psittacosaurs (Xu, 1997). In neoceratopsians, the transverse diameter of the foramen magnum is obviously smaller than that of the occipital condyle (Dodson and Currie, 1990). An axially oriented groove (about 6 mm) is present on the floor of the foramen magnum. This groove continues onto the dorsal surface of the occipital condyle. The occipital condyle is directed posteroventrally as in psittacosaurs (Sereno, 1990; Xu, 1997), while in neoceratopsian, such as *Centrosaurus apertus* (Lambe, 1904; Dodson and Currie, 1990), it is posteriorly directed.

The dorsally broadened pterygoid ramus of the quadrate extends anteromedially to contact the posterolaterally directed quadrate ramus of the pterygoid. The pterygoid is partially preserved (Figs. 2B, 3B, 4A). It is a rather thin bone composed of three principal rami: a posterolaterally directed quadrate ramus, a posteroventrally directed mandibular ramus, and an anteriorly directed palatal ramus. The palatal ramus is poorly exposed in the type specimen, and the mandibular ramus is broken distally. It extends posteroventrally from the lateral side of the palate toward the mandibular fossa, where it is joined laterally by the ectopterygoid. The mandibular ramus is short and robust as in ceratopsids. In psittacosaurs, the mandibular ramus develops a long straplike portion (Sereno et al., 1988). From the junction with the ectopterygoid a pronounced ridge runs along the lateral margin of the mandibular ramus toward the distal end, thus making the ramus sub-triangular in cross-section. The quadrate ramus is thickened ventrally, with a shallow groove along the ventral margin.

The ectopterygoid is a rather thick bone, especially posteriorly. It contacts the jugal and maxilla laterally and anteriorly, and is rounded posteriorly.

Lower Jaw—The lower jaw is generally similar to that of psittacosaurs except that the dorsal margin of the surangular runs backward nearly horizontally to the articulation from the coronoid region and the ventral margin of the angular and dentary curves dorsally to the articulation along the angular region. As in other primitive ceratopsians, such as *Udanoceratops* (Kurzanov, 1992), *Leptoceratops* (Brown, 1914), *Protoceratops* (Brown and Schlaikjer, 1940) and *Archaeoceratops* (Dong and Azuma, 1997), the jaw articulation is almost level with the tooth row. As in *Psittacosaurus mazongshanensis* (Xu, 1997) and *Archaeoceratops* (Dong and Azuma, 1997), the lower jaw is Y-shaped in ventral view, due to the long rostral part of the dentary forming an elongated symphysis of a constant transverse width. The symphysis is around 22 mm in length, and this broad area of contact indicates that the symphysis was immobile, of ceratopsian synapomorphy (Sereno, 1986). The external mandibular fenestra appears to be absent.

Only portions of the predentary are preserved. The ventral process is broken posteriorly. As the lower jaw is raised, the predentary closes inside the rostral as in neoceratopsians. The predentary is much longer and shallower than that of psittacosaurs. This is also the condition in neoceratopsians. Grooves on the surface of the symphysis suggest that the predentary sends a rather long ventral process under the full length of the symphysis and two short lateral processes. The ventral process was bilobate. Each lobe runs along the medial margin of the ventral surface of the dentary terminating at the rear of the symphysis (Figs. 2B, 3B). A bilobate ventral process also occurs in most ornithopods (Weishampel, 1990) and neoceratopsians (Dodson and Currie, 1990).

The labial surface of the dentary is smooth. The ventral limb of the dentary is quite broad and narrows posteriorly, its thick and rounded margin underlies the splenial anteriorly and the anterior process of the angular posteriorly. This differs from the situation in *Psittacosaurus sinensis* where the splenial reaches ventrally to the lower margin of the dentary (IVPP V738). The midsection of the dentary is laterally expanded, and the tooth row is strongly inset. Lateral to the dentition, there is a very broad buccal emargination, the lateral margin of which is a ridge which is confluent with the coronoid process posteriorly. Immediately medial to the ridge is a groove containing a row of small nutrient foramina. The coronoid process is exceedingly low as in basal ornithischians. It gradually slopes up from the mandibular ramus and is then deflected sharply to form a nearly horizontal dorsal margin. The anterior and posterior halves of the coronoid process are formed by the dentary and the surangular, respectively. In dorsal view, the coronoid process is thick anteriorly and thin posteriorly and the dorsal surface of the coronoid process is somewhat sub-triangular in shape (Fig. 4A). No coronoid bone was observed though it may be fused with the neighbouring elements.

The surangular and the angular extend past the glenoid fossa to meet at the very short retroarticular process. The angular lies along the posteroventral end of the jaw and has a small lateral exposure. Unusually, the angular possesses an exceedingly long anterior process which is wedged between the dentary and the splenial. Posteriorly, the angular twists from the anterior process to form the majority of the posterior ventral half of the mandible. The angular is divided into three planar surfaces: lateral, ventral and medial. Another unusual feature is a ridge which originates from the ridge between the dentary and anterior process of the angular, and which separates the lateral and ventral planar surfaces, setting these two planes apart by an angle of about 90 degrees. Posterior to the area of sutural contact with the dentary, the dorsal margin of the surangular extends nearly horizontally and broadens to form the glenoid fossa in combination with the articular. The dorsally directed, transversely widened glenoid fossa is divided by an oblique ridge into two concavities: a small medial one and a larger lateral one, closely matching the shape of the quadrate condyles. Glenoids of this shape were reported in *Montanoceratops* and *Bagaceratops* (Maryanska and Osmólska, 1975). Laterally, the rim of the jaw joint is buttressed by a lip-like thickening of the surangular. Posterior to the articular fossa is the exceedingly short retroarticular process. It is so poorly developed that it seems as if the retroarticular process has been lost. This is in stark contrast to *Psittacosaurus* which possess a long retroarticular process (Sereno, 1987), but similar to those of neoceratopsians (Dodson and Currie, 1990), which have much shorter retroarticular processes.

On the medial side of the mandibular ramus, the dorsoventrally deep splenial extends from near the symphysis to the mandibular fossa, contacting the angular ventrally. The narrow prearticular forms the ventral and posterior margins of the mandibular fossa, and contacts the angular and splenial ventrally.

Dentition—Premaxillary teeth are present in *C. youngi.* Both maxillary and dentary tooth rows are inset from the lateral surface of the snout and lower jaw respectively, creating a buccal recess, or cheek, lateral to the dentition as in all ornithischians (except *Lesothosaurus*) (Sereno, 1986). The tooth rows are slightly bowed medially, and the cheek teeth are packed tightly with almost no space between the crowns and exceedingly small spaces between the crowns and the alveolar border. Individual crowns are set at an angle to the axis of the tooth row, so that the anterior edge of any given crown overlaps the posterior edge of the next most anterior crown medially as in all primitive ornithischian dentitions. The crowns are oriented posteromedially. The crowns of the cheek teeth of *C. youngi* are almost as wide anteroposteriorly as the roots. In most ornith-

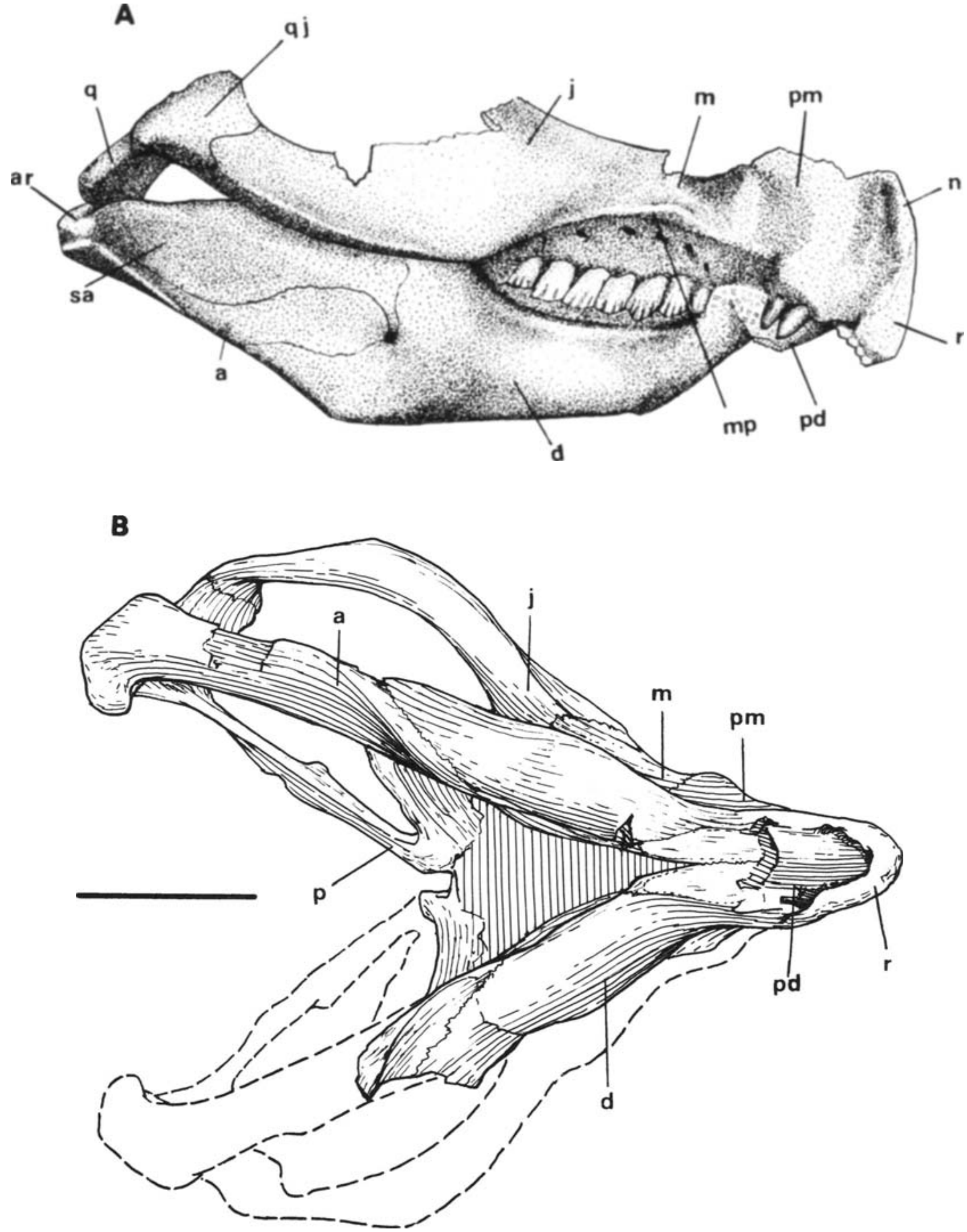


FIGURE 2. Skull of holotype of *Chaoyangsaurus youngi*, IGCAGS V371, in right lateral (**A**) and ventral (**B**) views. **Abbreviations**: **a**, angular; **ar**, articular; **d**, dentary; **j**, jugal; **m**, maxilla; **mp**, maxillary process; **n**, nasal; **p**, pterygoid; **pd**, predentary; **pm**, premaxilla; **q**, quadrate; **qj**, quadratojugal; **sa**, surangular; **r**, rostral. Scale bar equals 3 cm.

ischian, the crowns of the cheek teeth are obviously wither than the roots.

C. youngi has two simple premaxillary teeth, eight or nine transversely compressed maxillary teeth and probably eleven dentary teeth. As in all the ornithischians, the anteriormost and posteriormost one or two maxillary teeth are smaller than teeth in the center of the row and there is an increase in tooth size occurs toward the center of the tooth row. The enamel is almost equal in thickness on both sides of the tooth crown, whereas in primitive ornithopods (Crompton and Charig, 1962) and many other ornithischians, including all other ceratopsians, the enamel is distributed asymmetrically on opposing crown surfaces (Sereno, 1986). *Chaoyangsaurus youngi* possesses broad planar wear facets with self-sharpening cutting edges. The wear surfaces of a single tooth row lie in approximately the same oblique plane, on the lingual surfaces of maxillary teeth and the buccal surface of dentary teeth. This is very similar to the wear seen in psittacosaurid dentitions (Sereno, 1990). The wear

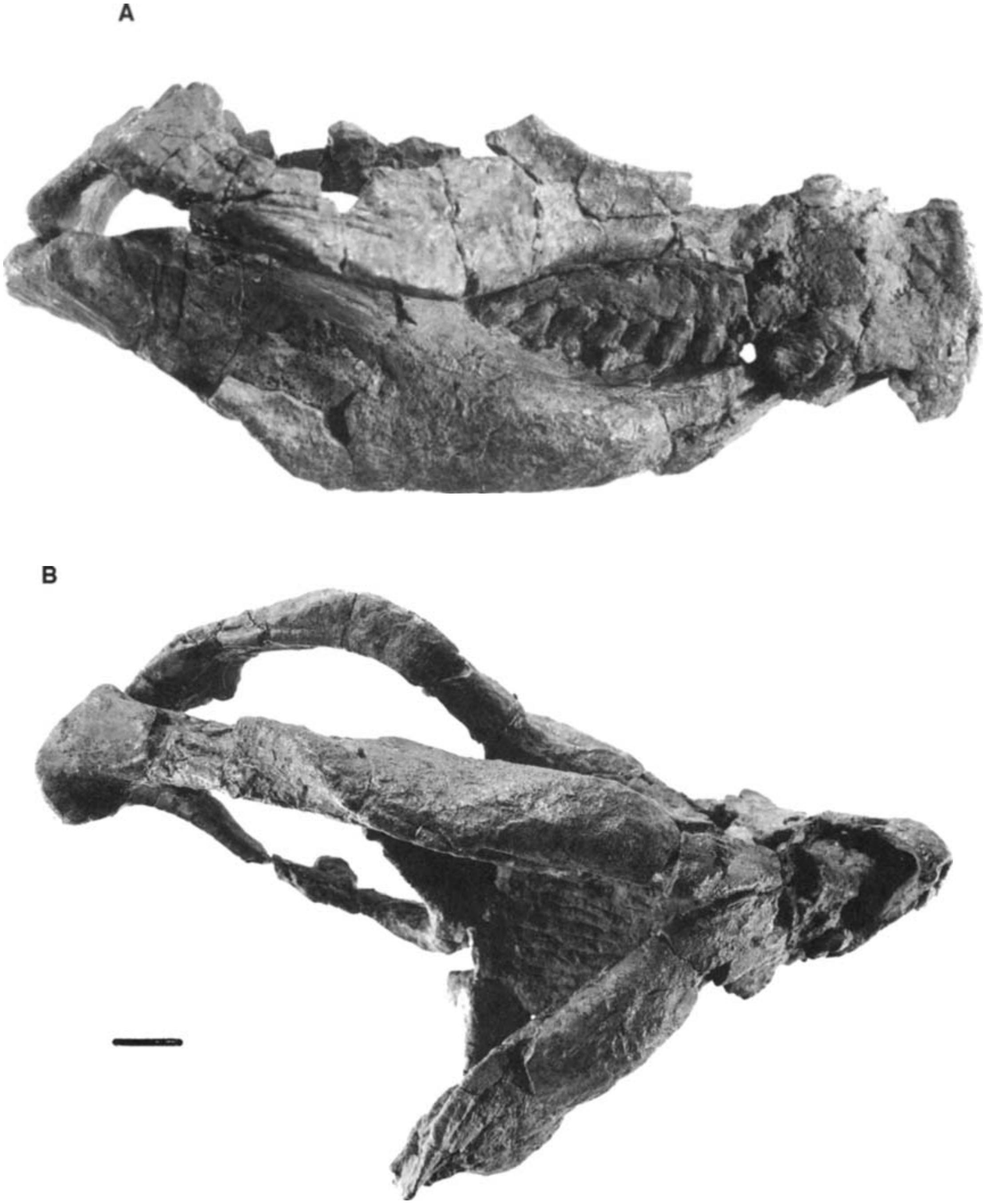


FIGURE 3. Skull of holotype of *Chaoyangsaurus youngi* in right lateral (**A**) and ventral (**B**) views. Scale bar equals 1 cm.

surface is not continuous along the tooth row. Some crowns are truncated by single wear surfaces; others are truncated by two contiguous wear facets, as in psittacosaurids.

The two premaxillary teeth are closely situated with only a small space between them (Fig. 4B). The anterior tooth is slightly larger than the posterior one. The premaxillary teeth are conical in lateral view. On close inspection, the crowns of the premaxillary teeth are transversely compressed and somewhat blade-like, with the buccal surface mesiodistally convex and the lingual surface flat. The root is almost the same width as the crown in mesiodistal diameter. There is extremely faint indication of longitudinal grooves on the right anterior premaxillary tooth but no denticles are present on any of the premaxillary teeth.

The maxillary teeth are well preserved. The buccal surface is strongly convex mesiodistally in comparison with the relatively flat buccal surfaces of the other maxillary teeth. The crowns of the maxillary teeth are chisel-shaped and very long in lateral view (Figs. 2A, 3A, 4B). Nearly all of the preserved maxillary tooth crowns are worn at the apex. The crowns are much higher than wide. There is a slight suggestion of a broad central ridge on the labial surface of the crown, offset posteriorly, and some very shallow grooves. The denticles are restricted to the distal one-third of the crown, with five and four mar-

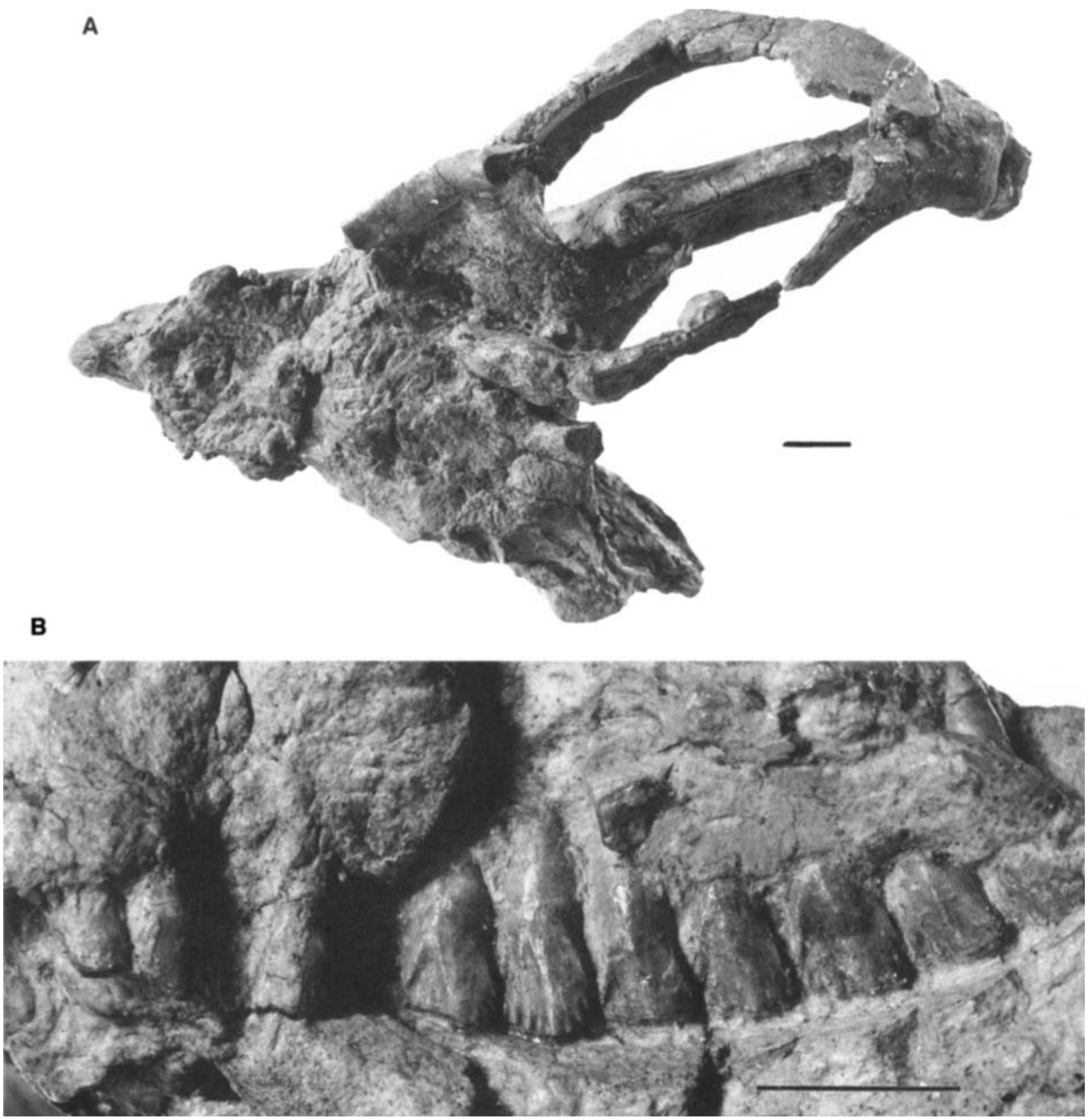


FIGURE 4. Skull of holotype of *Chaoyangsaurus youngi* in dorsal view (**A**). Premaxillary and maxillary teeth in the skull of holotype of *C. youngi* (**B**). Scale bars equal 1 cm (**A**) and 3 cm (**B**).

ginal denticles on the mesial and distal edge, respectively. The outermost denticles are the second largest, after the apical denticle, and are separated from the remainder of the crown by a very shallow groove. They extend to the base of the crown and merge with the poorly developed basal cingulum. The secondary ridges from the marginal denticles run ventrally in parallel with the longitudinal axis of the crown rather than converging toward it. The lingual surfaces of the maxillary crowns appear to be well enameled. The marginal denticles are well developed, seemingly extending further down the crown surface than on the lingual surface.

The dentary teeth are positioned medial to the maxillary teeth. The first dentary tooth is rather small and resembles the premaxillary teeth in possessing a convex labial surface. The mesial and distal edges bear very small denticles. The last dentary tooth is also small in size, with a convex labial surface and small denticles along the edge. However, rather than being conical, it differs from the first dentary tooth as its crown is compressed buccolingually and expanded mesiodistally. Dentary crowns bear centrally-directed denticles different from the nearly parallel denticles of the maxillary crowns. On both surfaces the distribution of the enamel is almost symmetrical.

Postcranial Skeleton

Vertebral Column—The axis is preserved separately, and is about three times as high as long. The centrum is slightly amphicoelous and transversely compressed, with a median ventral keel. The centrum is higher than long. The anterior articular facet is circular and the posterior one is roughly heart-shaped. The anterior articular surface is almost twice as large in area as the posterior one. The neural spine is well developed, ex-

FIGURE 5. *Chaoyangsaurus youngi* (IGCAGS V371); occiput in posterior view (**A**), axis in lateral view (**B**), and cervicals in lateral view (**C**). Scale bar equals 2 cm.

tending posterodorsally from the centrum at an angle of approximately 45 degrees (Fig. 5B), but not extending as far caudally as in psittacosaurs (Sereno, 1990; Xu, 1997) and neoceratopsians (Dodson and Currie, 1990). Posteriorly, the neural spine is forked and fused with the two postzygapophyses, making the neural spine triangular in posterior view.

Six other cervical vertebrae are preserved: one separated and five articulated (Fig. 5C). Generally speaking, the diameter of each centra are greater at either end, where a thickened rim is in contact with the margins of the next centrum. All of the centra are excavated ventrolaterally to form a median ventral keel. This is a common feature in basal ornithischians, basal thyreophorans, *Psittacosaurus sinensis* (Young, 1958) and *Psittacosaurus youngi* (Chao, 1962). The excavation and the keel run for the entire length of the centra in the anterior cervicals. In the posterior cervicals, the excavation is more strongly developed in the anterior portion of the centrum, but only weakly developed posteriorly. All of the centra are higher than wide, with the anterior end sub-triangular and the posterior end roughly heart-shaped. In lateral view, the ventral margin is longer than the dorsal one. The neural arches are almost the same height as the centra and are slightly shorter axially than the dorsal margin of the centra. The parapophyses are located below the suture with the neural arch and anterodorsal to the excavation on the thickened anterior rim. The diapophyses are situated dorsal to the suture and more posteriorly. The zygapophyses are well developed, and the prezygapophyses are longer than the postzygapophyses. The prezygapophyses point anteriorly and the two articular facets facing each other and are nearly vertical. The postzygapophyses point posteriorly and slightly laterally and have the articular facets that are directed lateroventrally (Fig. 5C). The increasing degree of tilt of the surfaces tends to restrict lateral bending but allows greater vertical movement. The neural spine is represented by a low median ridge. Below the neural spine is the very large ovoid neural canal. Its transverse diameter is nearly as wide as that of the centrum.

The proximal half of the right scapula is preserved (Figs. 6A, B, 7A, B). The proximal portion is expanded posteroventrally and possesses an anteriorly directed acromion process, a grooved sutural area for the coracoid, a notch leading to the coracoidal foramen, and the scapular contribution to the glenoid. The lateral surface of the proximal portion is concave, and the shaft is laterally compressed and is ovoid in cross-section.

The broken proximal half of the right humerus is preserved (Figs. 6C, D, 7C, D). Although most of the humeral head is missing, the lateral margin is set at an angle of about 35 degrees to the long axis of the shaft, suggesting that the proximal end of the humerus is strongly deflected medially. The deltopectoral crest is triangular in contrast to the rectangular crest of psittacosaurs (Sereno, 1990). The crest projects posteromedially rather than posteriorly as in other ornithischians. Because the crest curves medially and the medial margin of the proximal portion curves laterally, a groove is developed along the long axis of the humerus. The shaft is subtriangular in cross-section.

DISCUSSION

Autapomorphies of *Chaoyangsaurus youngi*

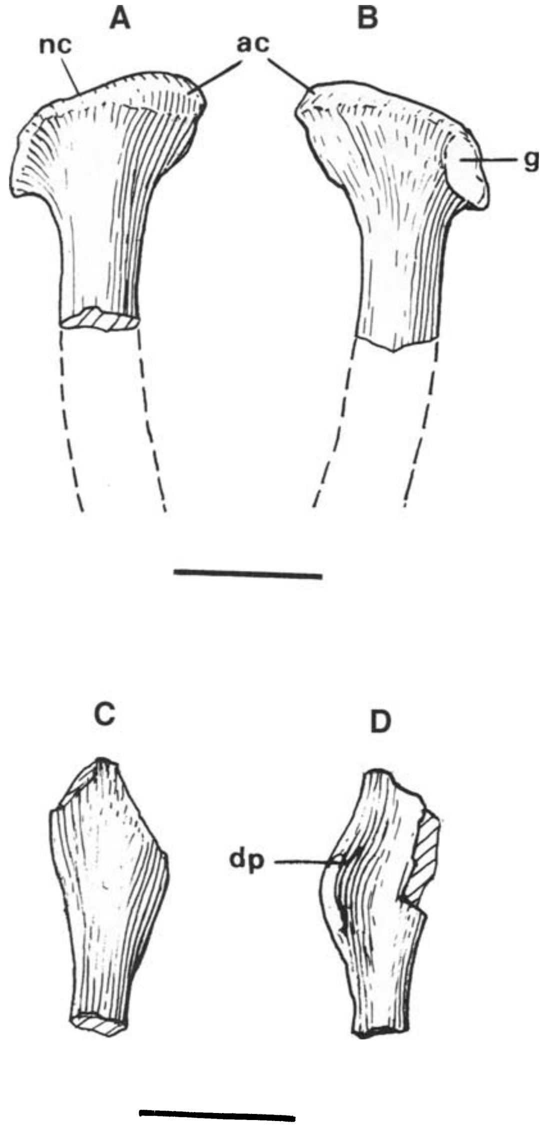
The rostral bone, jugal that flare well beyond the skull roof, deep jugal infraorbital ramus and wide predentary ventral process clearly establish that *Chaoyangsaurus youngi* is a ceratopsian. The following discussion lists five autapomorphies of *C. youngi,* which demonstrate that *C. youngi* represents a distinct species of ceratopsian.

1. Convex quadratojugal overlapping the posterior side of the quadrate shaft. Usually in dinosaurs, the lateral surface of the quadratojugal is in a plane, overlapping the lateral surface of the quadrate shaft. In *C. youngi,* the caudal portion of the quadratojugal curves medially such that it contacts the caudal margin of the shaft of the quadrate. This condition has not been reported among dinosaurs except in the basal theropod *Herrerasaurus* (Sereno and Novas, 1993).

2. Lack of broad lateral surface of the quadrate shaft. As described above, the lateral margin of the shaft of the quadrate of *Chaoyangsaurus* is very thin anteroposteriorly, and lacks the anterior ramus seen in other dinosaurs.

3. Convex posteroventral margin of the quadrate. In other ornithischians, the caudal margin, including the ventral part near the condyles, of the quadrate is concave or at least planar, while in *C. youngi,* it is apparently convex mediolaterally.

4. Dorsal margin of the lower jaw extends nearly horizontally from the coronoid process to the jaw articulation, and the ventral margin curves posterodorsally to the articulation along the angular region. This character state is similar to that of *Archaeoceratops* (Dong and Azuma, 1997), and a few other primitive ceratopsians. They have, however, never developed a hor-



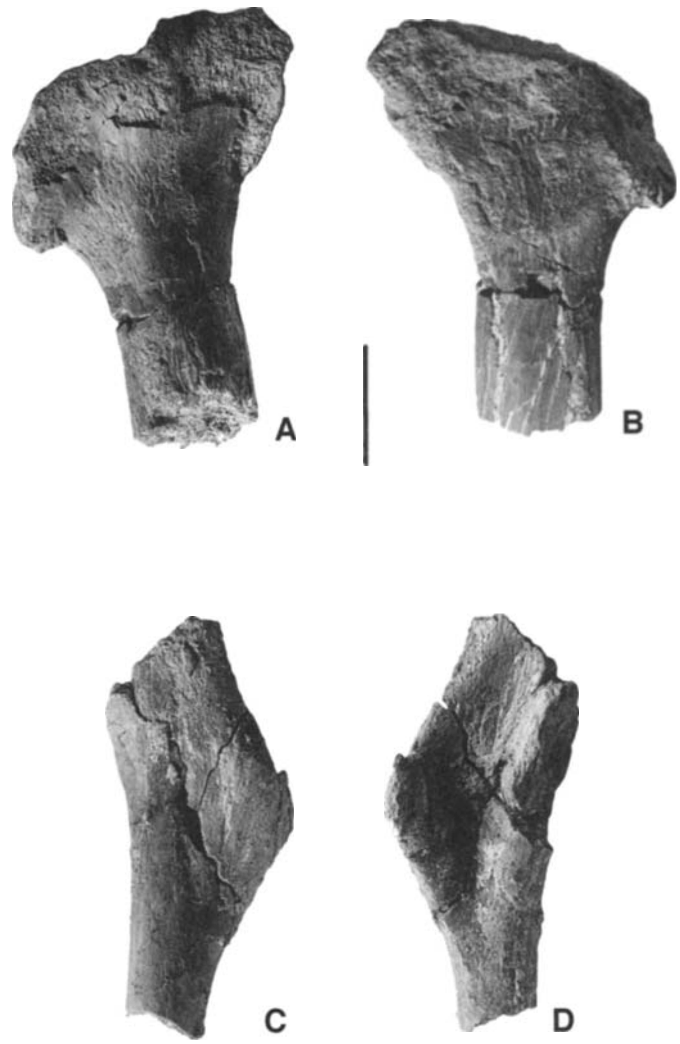


FIGURE 6. *Chaoyangsaurus youngi* (IGCAGS V371); right scapula in medial (**A**) and lateral (**B**) views, and right humerus in posterior (**C**) and anterior (**D**) views. **Abbreviations**: **ac**, acromion; **dp**, deltopectoral crest; **g**, glenoid; **nc**, notch for the coracoid foramen. Scale bar equals 2 cm.

FIGURE 7. *Chaoyangsaurus youngi* (IGCAGS V371); right scapula in medial (**A**) and lateral (**B**) views, and right humerus in posterior (**C**) and anterior (**D**) views. Scale bar equals 2 cm.

izontal dorsal margin to the coronoid process as in *Chaoyangsaurus*.

(5) A ridge present between the planar lateral and ventral surface of the angular. In *Chaoyangsaurus,* the angular has a planar lateral and ventral surface, which form a right angle. A distinct ridge is present between the two planar surfaces. In other ornithischians, the lateral and ventral surfaces of the angular usually meet to form a rounded lateroventral margin of the mandible.

Systematic Position of *Chaoyangsaurus youngi*

Chaoyangsaurus was first identified as a basal ceratopsian (Zhao, 1985) but Sereno (1997) has recently suggested that it may be a basal neoceratopsian.

As in all other ceratopsian (Sereno, 1986, 1990; Maryanska and Osmólska, 1975), *Chaoyangsaurus* has a median rostral bone at the anterior end of the snout. The rostral of *Chaoyangsaurus* is similar to that of *Psittacosaurus* (Coombs, 1982; Sereno, 1990). However, the rostral of *Chaoyangsaurus* is ill defined and in large part fused to the premaxillae, and is thin dorsally and broad ventrally in anterior view, forming a transversely convex shield that caps a triangular surface on the conjoined premaxillae. In neoceratopsians, including *Archaeoceratops* (Dong and Azuma, 1997), the rostral bone is strongly transversely compressed (Sereno, 1990). The rostral of *Chaoyangsaurus* is psittacosaur-like, therefore, rather than transversely narrow as in neoceratopsians. *Chaoyangsaurus* has a triangular-shaped head in dorsal view, due to the transverse compression of the beaklike snout and the lateral projection of each jugal, both of which are a synapomorphies of the Ceratopsia (Maryanska and Osmólska, 1975; Sereno, 1986, 1990). Compared with psittacosaurs and neoceratopsians, a few characteristics of the jugal remain in the plesiomorphic state in *C. youngi.* A lateral projection of the jugal is also present in *Het-*

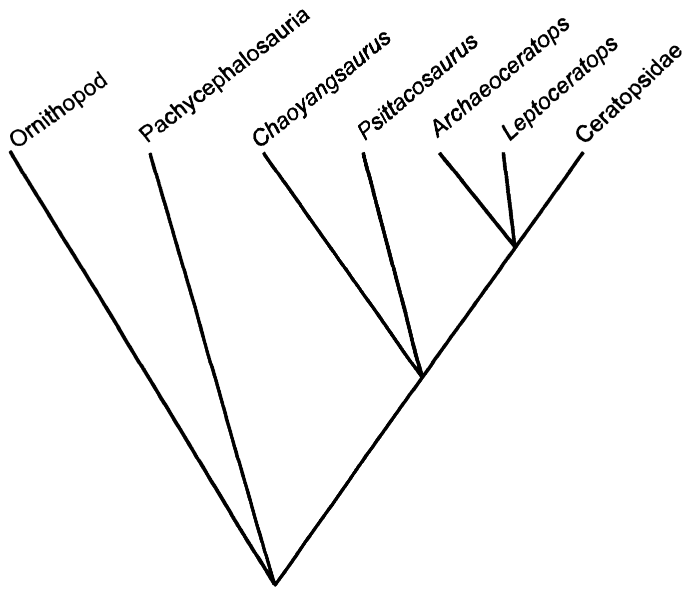


FIGURE 8. Cladogram showing the phylogenetic position of *Chaoyangsaurus youngi.*

erodontosaurus, and this character has been used to support a close relationship between heterodontosaurids and marginocephalians (Cooper, 1985). As in *Heterodontosaurus* (Weishampel and Witmer, 1990b), *C. youngi* possesses a jugal boss but lacks a crest on the lateral surface of the jugal. A dorsoventral crest divides the lateral aspect of the jugal into rostral and caudal surfaces in all ceratopsians (Sereno, 1990) apart from *C. youngi.* In ceratopsians other than *C. youngi,* another unique feature of the jugal is that the ventral margin of the jugal is angular, which is due to the abrupt inward deflection of the posterior ventral margin. In *C. youngi* the ventral margin of the jugal forms a gentle arc as in other ornithischians. *Chaoyangsaurus youngi* possesses a combination of primitive ornithischian features and a number of derived psittacosaurid and neoceratopsian features. It resembles psittacosaurs in having a tall, very short snout and a dorsally positioned external naris, but *C. youngi* is similar to neoceratopsians in having a pointed anterior end of the mandible.

In order to determine the systematic position of *Chaoyangsaurus youngi,* we constructed a data set (Appendix 1), which included a number of ceratopsian taxa, using the character data presented by Sereno (1986, 1990). A few additional characters were also incorporated into the data matrix. In order to investigate if *C. youngi* represents a basal neoceratopsian or a basal ceratopsian, we limited the ingroups to *Psittacosaurus, Chaoyangsaurus, Archaeoceratops, Leptoceratops,* and Ceratopsidae.

A phylogenetic analysis was performed using PAUP 3.1.1 (Swofford, 1993) with the dataset. All characters were unordered and trees were optimized with the use of delayed transformations. A strict consensus tree of our five most parsimonious trees has 37 steps, a consistency index (CI) = 0.757, and a retention index (RI) = 0.743 (Fig. 8). *Chaoyangsaurus* is included in the Ceratopsia on the basis of four unambiguous synapomorphies: the presence of the rostral bone (character 4), a jugal that projects well beyond the skull roof (character 12), a deep jugal infraorbital ramus (character 13), and a wide ventral process of the predentary (character 19).

This analysis was unable to resolve the position of *Chaoyangsaurus* within Ceratopsia. Three of the five shortest trees place *Chaoyangsaurus* as the sister group to *Psittacosaurus,* one places *Chaoyangsaurus* as the sister group to *Psittacosaurus*+Neoceratopsia and one supports *Chaoyangsaurus* as a member of Neoceratopsia. The *Chaoyangsaurus*+*Psittacosaurus* hypothesis is supported by four characters: preorbital region less than 40% the length of the skull (character 2), ventral border of the external naris above that of the orbit (character 3), nasal below the external naris (character 6) and a ridge (or eminence) on the rim of the buccal emargination of the maxilla near the junction with the jugal (character 11). Character 6 is also present in the recently described neoceratopsian *Archaeoceratops* (Dong and Azuma, 1997). The *Psittacosaurus*+Neoceratopsia hypothesis is supported by five synapomorphies: the vaulted premaxillary palate (character 8), dorsoventrally high maxilla (character 10), presence of a dorsoventral crest on the lateral surface of the jugal (character 14), angular jugalar ventral margin (character 15) and anteroposteriorly long neural spine of the axis (character 25). The final hypothesis, *Chaoyangsaurus*+Neoceratopsia hypothesis, is supported by three synapomorphies: short retroarticular process (character 16), upturned predentary tip (character 21) and posteriorly bifurcated predentary process (character 22).

It is interesting to note that *Chaoyangsaurus* possesses a combination of psittacosaurid and neoceratopsian features. Current data is, however, insufficient to determine the systematic position of *Chaoyangsaurus.* The morphology of the jugal is more primitive than all known psittacosaurs and neoceratopsians and we prefer the hypothesis that *Chaoyangsaurus* is the sister group to *Psittacosaurus*+Neoceratopsia. This conclusion is tentative, however, and more material is needed to determine the systematic position of *C. youngi* more precisely.

The ceratopsian fossil record is concordant with the phylogeny (*Chaoyangsaurus*(*Psittacosaurus*+Neoceratopsia)), yet stratigraphy is not always concordant with the phylogeny, and this can not be used as strong evidence in favor of this hypothesis. *Chaoyangsaurus* represents the earliest ceratopsian found to date. Psittacosaur material is mostly from late Early Cretaceous (Sereno, 1990) and the earliest record is from the early Early Cretaceous Lower part of the Yixian Formation (Xu and Wang, 1998). Neoceratopsians are almost exclusively from the Late Cretaceous, though *Archaeoceratops* (Dong and Azuma, 1997) is from the same locality as *Psittacosaurus mazongshanensis* (Xu, 1997).

Chaoyangsaurus possesses a few characters similar to those of heterodontosaurids. There is little agreement on the placement of Heterodontosauridae within Ornithischia (Santa Luca, 1980; Norman, 1984a, b; Maryanska and Osmólska, 1985; Cooper, 1985; Sereno, 1986; Gauthier, 1986; Weishampel and Witmer, 1990b). Cooper (1985) united the heterodontosaurids and marginocephalians on the basis of the prominent jugal boss. A heterodontosaurid-marginocephalian clade was supported by several similarities between *Chaoyangsaurus* and *Heterodontosaurus,* such as the long caudoventral process of the maxilla, chisel-shaped tooth crowns with denticles restricted to the apical most third of the crown. These characters suggest that ceratopsian-heterodontosaurid relationships may need reappraisal, but this work is beyond the scope of the present paper.

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APPENDIX 1

The 25 characters used in the cladistic analysis are mostly taken from the relevant literature as detailed. 0, plesiomorphic character state, 1–2, apomorphic character states.

1. Skull length (rostral–quadrate): 15% or less (0) or 20 to 30% (1), of length of postcranial skeleton (Sereno, 1986).
2. Preorbital region more than 40% (0), less than 40% the length of the skull (Sereno, 1990).
3. Ventral border of external nares below (0); above that of the orbit (1).
4. Rostral bone: absent (0); present (1) (Sereno, 1986).
5. Anteriorly keeled and ventrally pointed rostral absent (0); present (1) (Sereno, 1986).
6. Nasal above (0), below (1), the external naris (Sereno, 1990).
7. A flat subnarial margin between the narial fossa and ventral margin of the premaxilla absent (0); present (1) (Sereno, 1990).
8. Premaxillary palate, form: flat (0); vaulted (1) (Sereno, 1986).
9. Antorbital fossa present (0), absent (1).
10. Maxilla low, dorsoventral height less than (0), more than (1) two thirds of anteroposterior length (Sereno, 1986).
11. A ridge (or eminence) on the rim of the buccal emargination of the maxilla near the junction with the jugal absent (0), present (1) (Sereno, 1990).
12. Jugal that flares well beyond the skull roof: absent (0); present (1) (Sereno, 1986).
13. Jugal infraorbital ramus, relative dorsoventral width: less (0), or subequal or greater (1), than the width of the infratemporal ramus (Sereno, 1986).
14. A dorsoventral crest on the lateral surface of the jugal absent (0); present (1) (Sereno, 1990).
15. Jugal ventral margin non-angular (0) or angular (1).
16. Retroarticular process long (0); short or absent (1).
17. Parietal contribution to the caudal margin of the parietal-squamosal shelf: less than 50% (0); equal to 50% (1); much more than 50% (2) (Sereno, 1990).
18. Basioccipital contributing (0); not contributing (1), to the border of the foramen magnum (1) (Sereno, 1986).
19. Predentary ventral process, width of base: less (0), or equal to or more (1), than half the maximum transverse width of predentary (Sereno, 1986).
20. Sharp ventral keel on the predentary absent (0); present (1) (Sereno, 1986).
21. Predentary anterodorsal margin rounded (0); pointed (1) (Sereno, 1986).
22. Posteriorly bifurcated ventral process on the predentary absent (0); present (1) (Sereno, 1986).
23. Prominent primary ridge on the lateral side of the maxillary teeth absent (0); present (1) (Sereno, 1986).
24. Central of cervicals 1 to 3 not fused (0); fused (1) (Sereno, 1986).
25. The neural spine of the axis anteroposteriorly short (0); long, extending caudally to the posterior end of the centrum of the succeeding cervical (1).

APPENDIX 2

Data matrix of 25 morphological characters for two outgroups (Ornithopod and Pachycephalosauria) and five ingroups. **Character state abbreviations: 0**, plesiomorphic state; **1, 2**, derived states; **p**, polymorphic state; **?**, not preserved or unknown; **a**, unknown as a result of transformation.

	5	10	15	20	25
Ornithopod	0000a	00000	00000	00000	0p000
Pachycephalosauria	0000a	000p0	00000	00000	00000
Psittacosaurus	01110	11111	11111	01010	00001
Chaoyangsaurus	?1110	11?0?	11100	1??10	11000
Archaeoceratops	10011	11?01	01111	1??11	111??
Leptoceratops	10011	01101	01111	12111	11111
Ceratopsidae	10011	00111	01111	12111	11111