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On a New Genus of Basal Neoceratopsian Dinosaur from the Early Cretaceous of Gansu Province, China

YOU Hailu[1], LI Daqing[2], JI Qiang[1], Matthew C. LAMANNA[3] and Peter DODSON[4]

1 *Institute of Geology, Chinese Academy of Geological Sciences, Beijing 100037, China; E-mail: youhailu@sinofossa.org*

2 *Fossil Research and Development Center of the Third Geology and Mineral Resources Exploration Academy of Gansu Province, Lanzhou, Gansu 730050, China*

3 *Section of Vertebrate Paleontology, Carnegie Museum of Natural History, 4400 Forbes Avenue, Pittsburgh, PA 15213, USA*

4 *Department of Animal Biology, School of Veterinary Medicine, University of Pennsylvania, 3800 Spruce Street, Philadelphia, PA 19104, USA*

Abstract A new genus and species of basal neoceratopsian dinosaur, *Auroraceratops rugosus*, is reported based on material from the Early Cretaceous Xinminpu Group in the Gongpoquan Basin of Gansu Province, China. *Auroraceratops* is represented by a nearly complete skull and low jaws, and different greatly from all other neoceratopsians by its considerable breadth of the nasals, fungiform expansion of the dorsal end of the lacrimal, highly developed rugosity of the jugal, dentary and surangular, and inflated, striated premaxillary teeth. The finding of *Auroraceratops* adds diversity and helps elucidate the evolution of basal neoceratopsian dinosaurs.

Key words: Dinosauria, Neoceratopsia, Early Cretaceous, Xinminpu Group, Gongpoquan Basin, Gansu Province

1 Introduction

The Mazongshan area in northwestern China yields a diverse dinosaur assemblage, including members of Theropoda, Sauropoda, Ankylosauridae, Euornithopoda, and Ceratopsia (Dong, 1997; You, 2002). This assemblage is characterized by several well-established taxa, such as the basal neoceratopsian *Archaeoceratops oshimai* (Dong and Azuma, 1997; You and Dodson, 2003), the basal hadrosauroid *Equijubus normani* (You et al., 2003a), and the basal titanosaurian *Gobititan shenzhouensis* (You et al., 2003b). The dinosaur-bearing Xinminpu Group in this area is late Early Cretaceous in age, and deposited in a fluviolacustrine environment under a semiarid and subtropical climate (Tang et al., 2001).

The specimen reported here was discovered from the Gongpoquan Basin in the Mazongshan area by the Fossil Research and Development Center of the Third Geology and Mineral Resources Exploration Academy of Gansu Province. The morphology of the new specimen differs greatly from that of *Archaeoceratops*, which was recovered from the same basin, and represents a new genus and species.

2 Systematic Paleontology

Dinosauria Owen, 1842

Ornithischia Seeley, 1888

Ceratopsia Marsh, 1890

Neoceratopsia Sereno, 1986

Auroraceratops gen. nov.

Type Species: *Auroraceratops rugosus* sp. nov.

Etymology: The name refers to its status as an early neoceratopsian, but also honors Dawn Dodson (Latin “aurora” = dawn), wife of 37 years to Peter Dodson, and gracious hostess to several generations of paleontologists.

Diagnosis: As for the type and only species.

Auroraceratops rugosus sp. nov. (Fig. 1)

Holotype: A nearly complete skull and jaws. IG-2004-VD-001: Institute of Geology, Chinese Academy of Geological Sciences, Beijing, P. R. China.

Etymology: The name refers to the rugose nature of the skull and jaws.

Locality and Horizon: Gongpoquan Basin, Gansu Province, P. R. China; Xinminpu Group, late Early Cretaceous (Tang et al., 2001).

Diagnosis: A short-faced basal neoceratopsian of moderate size distinguished by great breadth of the nasals,

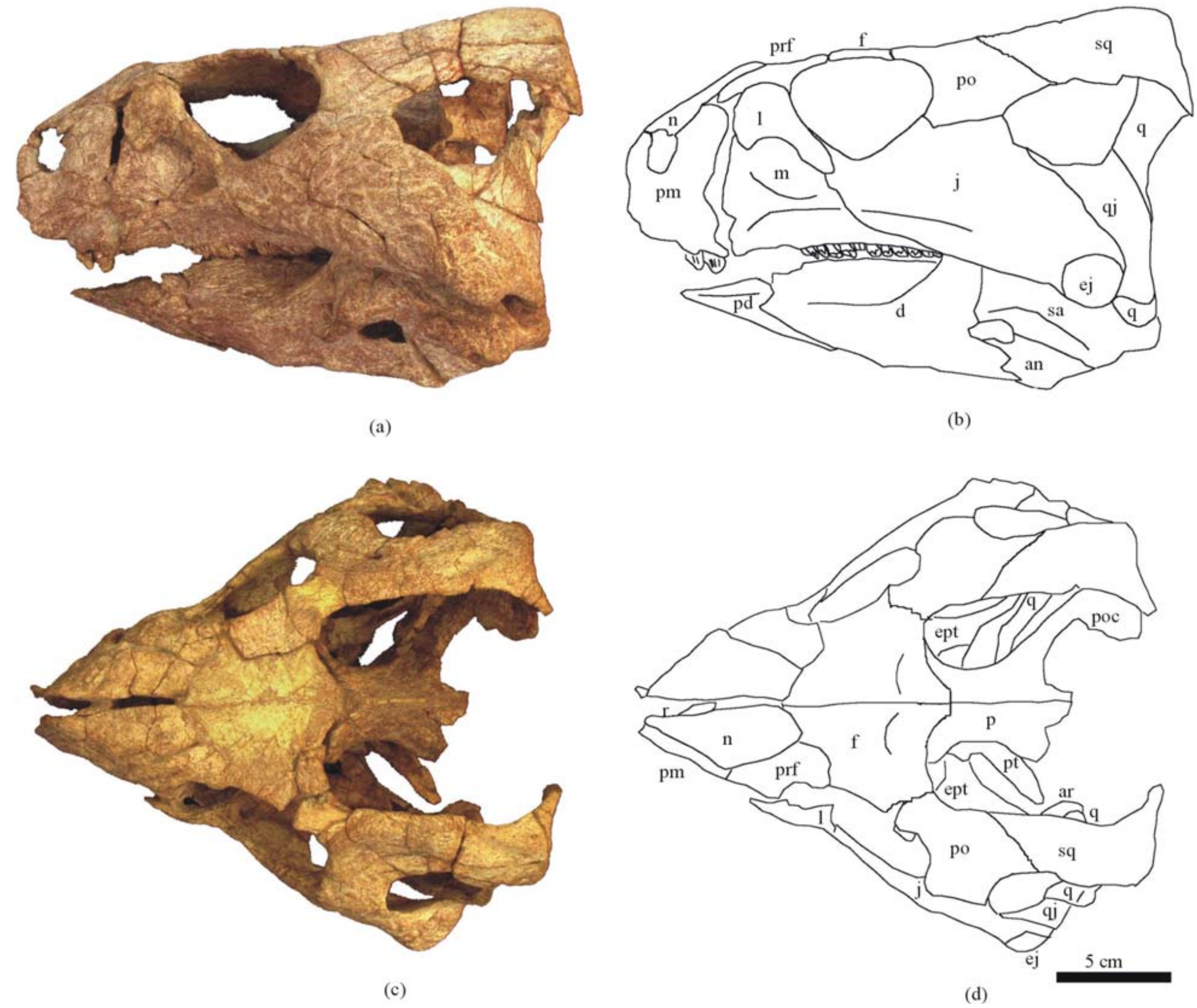

Fig. 1. Left lateral (a, b) and dorsal (c, d) views of the skull of holotype of *Auroraceratops rugosus* gen. et sp. nov. (a) and (c): photographs; (b) and (d): interpretive outlines.

Please notice the gap between the premaxilla rostrally and the maxilla and the lacrimal caudally. Abbreviations: an – angular; ar – articular; d – dentary; ej – epijugal; ept – ectopterygoid; f – frontal; j – jugal; 1 – lacrimal; m – maxilla; n – nasal; p – parietal; pd – predentary; pm – premaxilla; po – postorbital; poc – paroccipital process; prf – prefrontal; pt – pterygoid; q – quadrate; qj – quadratojugal; r – rostral; sa – surangular; sq – squamosal.

fungiform expansion of the dorsal end of the lacrimal, highly developed rugosity of the jugal, dentary and surangular, horizontal caudally directed processes of the pterygoid covering basisphenoid and basipterygoid articulation ventrally, and inflated, striated premaxillary teeth.

3 Description

The skull is exceptionally broad and relatively low. It measures 170 mm in basal and 197 mm in total length as preserved, although both the rostral bone and the central part of the short parietal frill are missing, as is the right epijugal. If palpebrals were present (as is likely), they are not preserved. The maximum width of the skull is 192 mm across the jugals (or rather from the left epijugal to the right jugal). It is thus of moderate size for an early neoceratopsian. There is very mild dorsoventral compression, as expressed in the collapse of the right antorbital fossa and distortion of the left orbit. However, there is little asymmetry of the skull.

The external nares are large, rounded and rostrodorsally located. The antorbital fenestra, though not especially large, is sharply and deeply impressed into the maxilla. The length of the subrectangular orbit is larger than its width. The infratemporal fenestra is also rectangular and is somewhat smaller than the orbit in both dimensions. The rectangular supratemporal fenestrae are elongate and relatively enormous, nearly half the basal skull length. Retention of external mandibular fenestrae is unexpected.

Some cranial sutures are difficult to discern, suggesting adult status, along with the general rugosity of the specimen. Contrarily, several elements (rostral, right epijugal) are missing and the tripartite nature of the occipital condyle is still evident, suggesting that it pertains to a subadult.

3.1 Skull

The snout is high and rounded in profile. The rostral is missing, except for a small fragment situated between the nasals. The premaxillae are large bones on the side of the face. They surround about two-thirds of the large, subcircular external nares. The premaxillary-maxillary suture ascends from the fourth premaxillary tooth to the nasal-prefrontal contact. Broad contact with the lacrimal is seen on the right side. From the prefrontal the dorsal border of the premaxilla curves forward in broad contact with the nasal. There are three or four premaxillary teeth. None is well preserved, but the third left tooth is robust, measuring at least 8 mm in diameter and 8 mm in height. It also appears to show striations. The premaxilla does not appear to contribute to the short secondary palate.

The nasals are long (66 mm, left; 61 mm, right) and very broad (24 mm). The nasal contributes about one third of the narial rim, from the rostrodorsal naris to the middle of the caudal border. The nasals have their greatest breadths at mid length, where a lateral process contacts the prefrontals and premaxillae. The nasal-frontal sutures angle rostromedially. The prefrontals are unusually prominent. They are bounded medially by the nasals, rostrolaterally by the lacrimals, rostrally by the premaxilla and caudally by the frontals. The prefrontals form the rostrodorsal rim of the orbit and a small part of the rostral part of the rim.

The lacrimal has somewhat the form of a rostrodorsally inclined rod (45 mm long on the left side), with a strongly expanded fungiform dorsal end 26 mm wide on the left. The expanded dorsal end contacts the prefrontal caudally, the nasal dorsally, and the caudodorsal process of the premaxilla rostrally. The caudoventral end of the lacrimal tapers to a blunt point that overlaps the jugal adjacent to the caudal end of the deep triangular antorbital fossa, which the lacrimal bridges. A palpebral bone was not preserved, although the thickened orbital rim could easily have accommodated one.

The frontal is broad and thin. It forms the skull table between the orbits, of which it forms the middle part of the dorsal border. The parietal is long and bears a sharp, thin (2.5 mm) dorsal ridge or keel. Caudally the parietal fanned out to form a small, thin transverse crest. The parietal is fused to the prootic-opisthotic-supraoccipital-exoccipital complex.

The maxilla is a long, irregular dentigerous bone with its apex at the rostral end, adjacent to the dorsal end of the lacrimal. The ventral border is deeply recessed, and there is a strong longitudinal maxillary ridge or facial crest, continuous with the ventral margin of the jugal caudally, which forms a facial crest that runs almost to the rostral end of the maxilla. The maxilla forms the ventral margin and medial wall of the prominent triangular antorbital fossa, which is situated ventral to the rostral part of the orbit. Twelve teeth occupy a space of 61 mm; possibly one or two more teeth lie caudal to the coronoid process of the jaw. The maxillae appear to send rostral processes medial to the premaxillae to form a short secondary palate less than 2 cm long between the premaxillary dentitions. A broken piece of bone between the maxillae appears to represent an isolated piece of vomer.

The jugal is long and strongly swept back and laterally flaring in the typical neoceratopsian form. It contacts the maxilla, reaches the caudal corner of the antorbital fossa, forms the ventral margin of the orbit and contributes a small portion of the rostroventral rim of the infratemporal fenestra. Its caudal apex extends almost as far caudally as the quadrate. The ventral edge of the jugal is rugose. The quadratojugal is a large, thick element, prominent in lateral view, whose thin dorsal edge forms the major ventral border of the infratemporal fenestra. The quadratojugal is a spacer between the ventral half of the quadrate shaft and the jugal.

The dorsal end of the quadrate curves caudally, and the shaft of the quadrate forms the caudal border of the infratemporal fenestra. In occipital view, the broad, thin pterygoid process of the right quadrate is visible, with its caudally-facing concave pocket for the quadrate process of the pterygoid. The ventral end of the quadrate shows the prominent transversely expanded double condyle so characteristic of ceratopsians (width 28 mm left; 32 mm right).

The postorbital is an important element uniting the skull roof to the cheek region. The postorbital appears to overlap the squamosal beginning at a point on the rostral third of the dorsal border of the infratemporal fenestra. The squamosal is long, in keeping with the elongation of the temporal region. However, there is absolutely no postquadrate expansion as there is in *Protoceratops* and other more derived basal neoceratopsians (You and Dong, 2003; You and Dodson, 2004).

The spherical occipital condyle is small (17 mm in diameter) and has a short neck. The tripartite nature of the condyle is clear, with the basioccipital contributing the ventral two-thirds and the exoccipitals contributing the dorsal one-third. The exoccipitals define the foramen magnum, which is round and measures 14 mm in diameter. There is a strap-like process of the exoccipital. The exoccipital measures 65 mm from the foramen magnum to the lateral extremity. The supraoccipital is recognized with difficulty, as it is thoroughly fused with the exoccipital and recognized only as low horizontal linear ridge that intersects the edge of the foramen magnum at roughly the 11 o'clock and 1 o'clock positions respectively.

The braincase is preserved in situ, and includes opisthotics, prootics and laterosphenoids. The elements are fused, and the high degree of articulation of the surrounding specimen makes the braincase difficult to study.

The pterygoids join the quadrates to the palatines and are braced by the basipterygoid processes of the basioccipital. In caudal view, the pterygoids surround the basipterygoid processes. Also visible in caudal view are the long, decurved and strongly pendant compound mandibular processes consisting of the pterygoid and ectopterygoid. They extend ventrally as far as the middle of the mandibular fossa, which they nearly contact. In palatal view, the pterygoids cover both the basioccipital and the basisphenoid as a horizontal plate. On the caudal midline the pterygoids terminate as a pair of short but conspicuous autapomorphic horizontal prongs with a spread of 10 mm.

The ectopterygoid is somewhat banana-shaped as it curves rostrodorsolaterally from the distal end of the mandibular process around the cranial border of the subtemporal fossa to the medial surface of the maxilla near the caudal end of the orbit. It has the form of a bluntly flattened rod where it contacts the maxilla. The palatines extend rostrally from the palatine foramina and are situated lateral to the rostral extension of the pterygoids and medial to the maxilla.

3.2 Mandible

The predentary is long, low, horizontal, robust and sharply pointed. The triturating surfaces of the predentary incline laterally, gently rostrally, more strongly caudally. Ventrally at the mandibular symphysis, two short prongs diverge along the axes of the mandibles. The predentary measures 66 mm in length, 39 mm in breadth, and 28 mm in depth.

The dentaries are long, straight and robust. Each dentary bears two distinct symmetrical rugosities. The more rostral one is more modest, and is situated at the midpoint of the dentary near the ventral margin. The more caudal one is quite prominent, situated near the rostral base of the coronoid process, rostrodorsal to the external mandibular foramen. External mandibular fenestrae are small and elliptical but distinct and bilateral, situated at the triple junction of the dentary, angular and surangular. The coronoid process is strong. A complete dentition exists but the teeth cannot be readily observed.

Each coronoid covers the medial face of the dentary coronoid process, the thickness of which it equals. The coronoid forms a medial plate that is broad and round dorsally, congruent with the lateral profile of the dentary, and descends towards the dentary as a narrow strap that reaches the caudal end of the mandibular ramus at the rostral end of the mandibular fossa. On the right side the intercoronoid can be seen along the caudal border of the coronoid, sandwiched between the coronoid and the dentary, approximately in the position of the dentary-surangular suture.

The suture between the dentary and surangular ascends the coronoid process roughly parallel to the caudodorsally-sloping rostral border, so the coronoid process is formed of two bones more or less equally; however, only the dentary reaches the apex of the process. There is a boss on the lateral side of the surangular at the caudal end of the mandible. The angular occupies the caudoventral part of the mandible. It underlies the surangular and articular, and shows no expansion laterally and only slight expansion medially underneath the jaw articulation. The surangular-angular suture runs caudally and slightly ventrally from the external mandibular foramen. The angular-dentary suture passes ventrally underneath the external mandibular foramen.

The articular occupies the caudomedial extremity of the mandible. The articular cotylus accommodates the medial two-thirds of the distal end of the quadrate. There is a distinct retroarticular process projecting more than 1 cm caudally on the right articular. The prearticular is applied to the medial side of the articular dorsal to the angular. On the medial side of the mandibles are seen long thin splenials that run most of the length of the mandible from the symphysis almost to the caudal end.

4 Discussion

Auroraceratops rugosus is a member of neoceratopsian dinosaurs, as clearly shown by numerous features, such as: lateral expansion of the jugal from the caudal end, straight and subcynlindrical premaxillary teeth, and prominent primary ridge on the maxillary teeth (You and Dodson, 2003; You and Dodson, 2004).

Beside *Auroraceratops*, only two other well-represented basal neoceratopsian genera are known from Early Cretaceous. One is *Liaoceratops* from Liaoning Province of northeastern China (Xu et al., 2002), and the other is *Archaeoceratops* from Gansu Province of northwestern China (Dong and Azuma, 1997). Cladistics analyses (Xu et al., 2002; You and Dodson, 2003) agree that these two taxa are successive outgroups to Coronosauria, which includes *Protoceratops*, *Triceratops*, their most recent common ancestor and all descendants. Coronosaurians include all currently known Late Cretaceous neoceratopsians (You and Dodson, 2003; You and Dodson, 2004).

Auroraceratops is a non-coronosaurian basal neoceratopsian dinosaur because it lacks the derived features of coronosaurians. Members of Coronosauria have an elongated preorbital portion, more than half of the basal

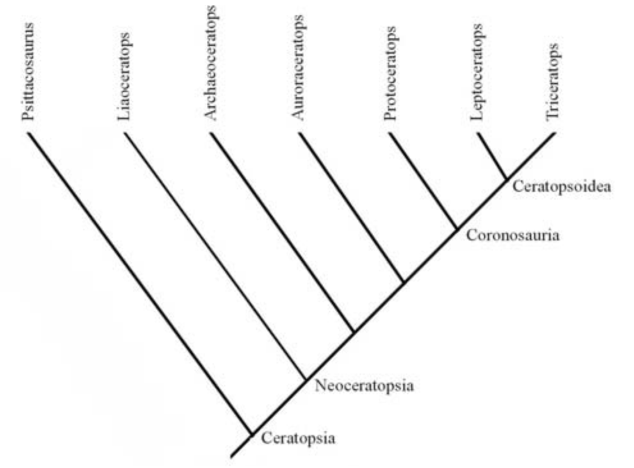

Fig. 2. Phylogenetic position of *Auroraceratops rugosus* gen. et sp. nov. as expressed in the cladogram of You and Dodson (2003).

skull length; an oval, rather than triangular, antorbital fossa; caudolaterally directed triangular supratemporal fenestra as the result of the more developed frill (You and Dodson, 2003; You and Dodson, 2004).

Compared to *Archaeoceratops* and *Liaoceratops*, *Auroraceratops* shows several derived features. The external naris is round in *Auroraceratops*, as in *Leptoceratops* (Sternberg, 1951) and members of Ceratopsidae (Dodson et al., 2004), but it is elliptical in both *Archaeoceratops* and *Liaoceratops*. The basioccipital does not contribute to foramen magnum in *Auroraceratops* as in Coronosauria, but the opposite condition exists for both *Archaeoceratops* and *Liaoceratops*. The dentary coronoid process is broad and moderately deep in *Auroraceratops* as in Coronosauria, but it is relatively narrow and low in both *Archaeoceratops* and *Liaoceratops*. Therefore, *Auroraceratops* probably represents the most derived Early Cretaceous neoceratopsians (Fig. 2).

5 Conclusions

Auroraceratops is the second neoceratopsian dinosaur from the Early Cretaceous Xinminpu Group in the Mazongshan area, Gansu Province, China, and represents the most derived Early Cretaceous Neoceratopsia. *Auroraceratops* is morphologically different from all other neoceratopsians by its considerable breadth of the nasals, fungiform expansion of the dorsal end of the lacrimal, highly developed rugosity of the jugal, dentary and surangular, and inflated, striated premaxillary teeth. The finding of *Auroraceratops* adds diversity and helps elucidate the evolution of basal neoceratopsian dinosaurs.

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