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# A New Hadrosauroid Dinosaur from the Mid-Cretaceous of Liaoning, China

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**Abstract** A new hadrosauroid dinosaur, *Shuangmiaosaurus gilmorei* gen. et sp. nov., is described based on a complete left maxilla with articulated premaxilla and lacrimal fragments, and a complete left dentary from the mid-Cretaceous Sunjiawan Formation of Beipiao, Liaoning, northeastern China. Cladistic analysis shows that *Shuangmiaosaurus* is a basal hadrosauroid, and comprises the sister taxon to Hadrosauridae. In both *Shuangmiaosaurus* and Hadrosauridae, the maxilla-jugal suture is butt-jointed, rather than finger-in-recess articulation as in other basal hadrosauroids. However, *Shuangmiaosaurus* does not possess such hadrosaurid synapomorphies as the diamond-shaped maxillary crowns with reduced primary ridges and reduced marginal denticles.

**Key words:** Dinosauria, Hadrosauroidea, Hadrosauridae, Sunjiawan Formation, mid-Cretaceous, Liaoning, China.

## 1 Introduction

In the last four years (1999–2002), dinosaur material from fossiliferous horizons of the Sunjiawan Formation near Shuangmiao Village, Beipiao, Liaoning, China has been excavated and reposited in the Liaoning Paleontological Museum (LPM) in Beipiao. Remains of theropod, sauropod, hadrosauroid, and ankylosaurian dinosaurs have been recognized in this collection (Dong, 2002). Here, a new hadrosauroid is described based on a complete left maxilla in articulation with partial premaxilla and lacrimal, and a complete left dentary.

## 2 Systematic Paleontology

**Dinosauria Owen, 1842**
**Ornithischia Seeley, 1887**
**Ornithopoda Marsh, 1881**
**Hadrosauriformes Sereno, 1997**
**Hadrosauroidea Sereno, 1986**
***Shuangmiaosaurus* gen. nov.**

**Type Species:** *Shuangmiaosaurus gilmorei* sp. nov.

**Etymology:** "*Shuangmiao*", Pinyin, means "twin temples", and is the name of the village where the specimens were excavated.

**Diagnosis:** As for the type and only known species.

*Shuangmiaosaurus gilmorei* sp. nov.

**Holotype:** LPM0165, a complete left maxilla with partial articulated premaxilla and lacrimal.

**Referred specimen:** LPM0166, an isolate complete left dentary from the same locality.

**Etymology:** In honor of C. W. Gilmore for his pioneering work on the Chinese hadrosauroid dinosaur *Bactrosaurus* in 1933.

**Locality and horizon:** Shuangmiao Village, Beipiao, Liaoning, China. Sunjiawan Formation, mid-Cretaceous.

**Diagnosis:** *Shuangmiaosaurus gilmorei* is the sister taxon to Hadrosauridae, distinguished from other basal hadrosauroids in having a butt-jointed maxilla-jugal suture.

**Description:** The holotype includes a complete left maxilla, the caudal portion of the caudal process of a left premaxilla, and part of a left lacrimal, missing its caudodorsal portion (Fig. 1). These elements were preserved in articulation. The referred specimen consists of a complete left dentary (Fig. 2). The maxilla measures 45 cm along the tooth row and is highest (10 cm) about 10 cm rostral to its caudal end. The dentary is 58 cm long from its rostral margin to the caudodorsal end of its coronoid process.

1. Premaxilla: The 12-cm long caudal portion of the caudal process of the premaxilla is preserved in articulation with the dorsal surface of the maxilla. It is approximately 4 cm high, with a flat and smooth dorsal surface. This surface reaches its greatest mediolateral dimension (6 cm) at its preserved rostral end, and articulates with the lacrimal caudally.

2. Maxilla: In lateral view, the rostralmost region of the maxilla possesses a pointed rostral process, followed by a long, dentigerous portion that gradually increases in height

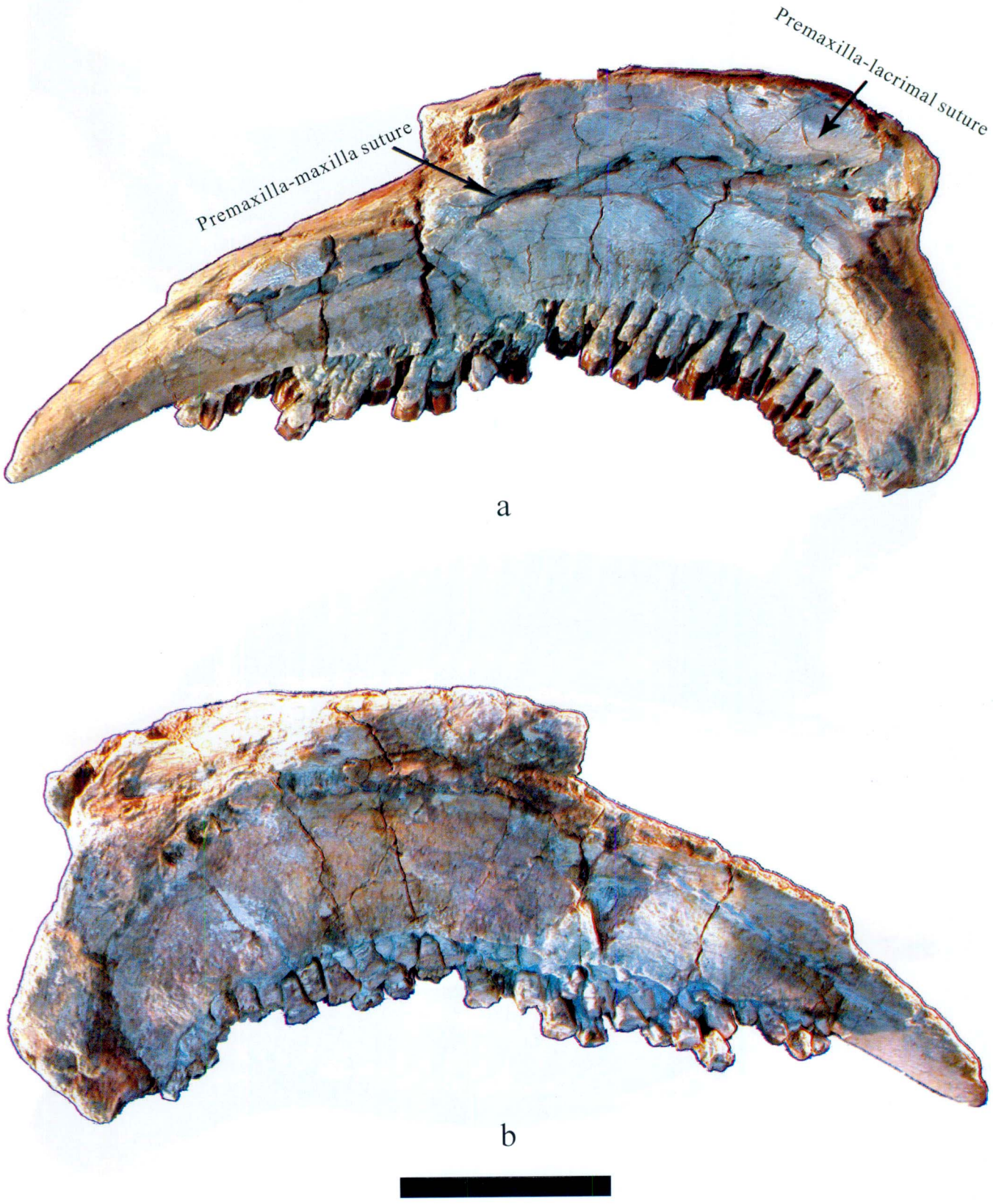


Fig. 1. Left maxilla, partial premaxilla and lacrimal of *Shuangmiaosaurus gilmorei*, gen. et sp. nov. in lateral (a) and medial (b) views. Scale bar equals 10 cm.

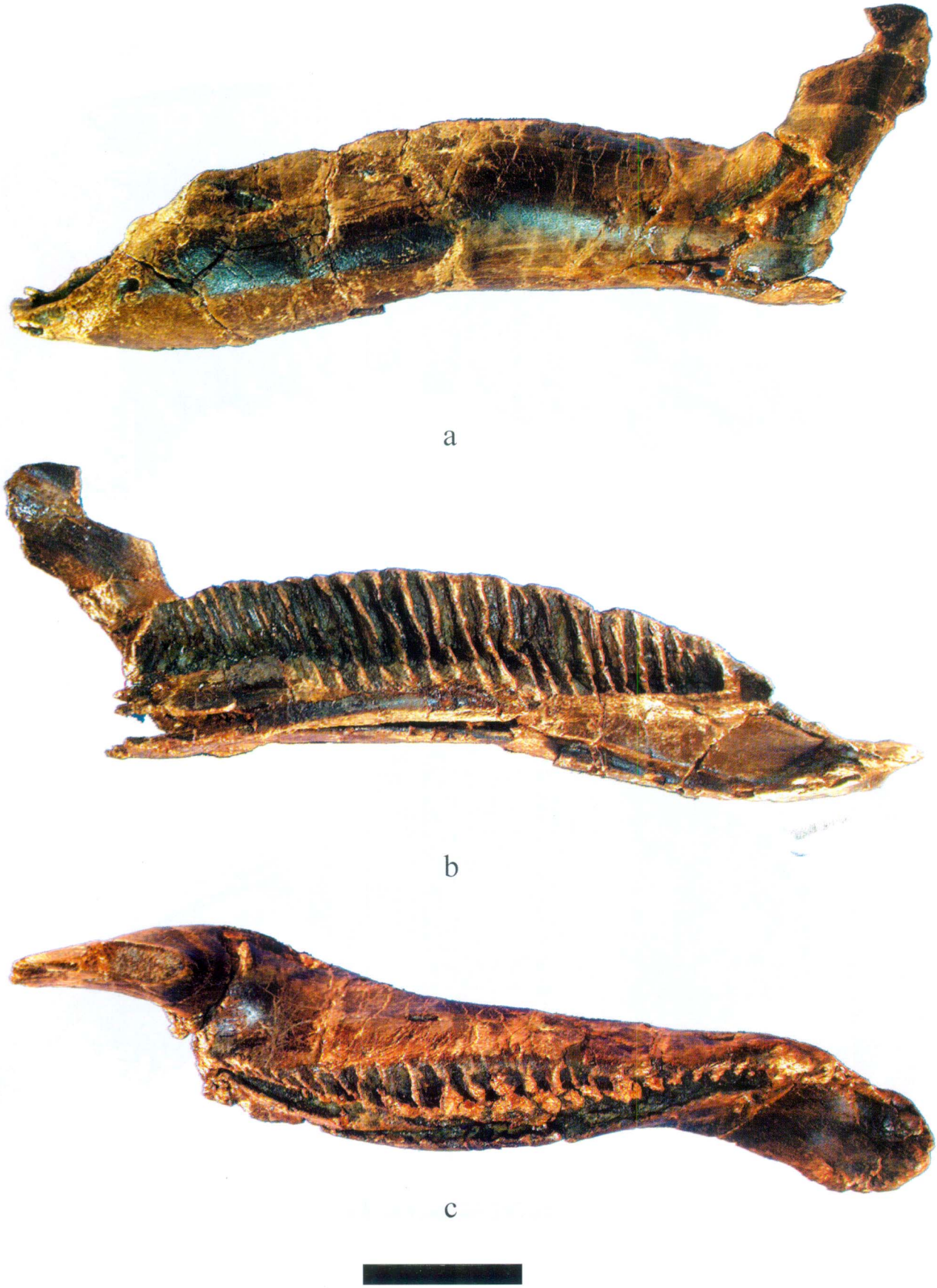


Fig. 2. Left dentary of *Shuangmiaosaurus gilmorei*, gen. et sp. nov. in lateral (a), medial (b), and dorsal (c) views.
Scale bar equals 10 cm.

**Table 1 Coding of phylogenetically informative characters in *Shuangmiaosaurus gilmorei* gen. et sp. nov., based on Norman (2002).**

| No. | Characters | 0 | 1 | 2 |
|---|---|---|---|---|
| 10 | Position of external antorbital fenestra | | On anterior dorsal margin of maxilla | |
| 11 | Dorsal process of the maxilla | | Expanded, laterally flattened plate-like structure | |
| 15 | Jugal-maxilla suture | | | Butt-jointed |
| 22 | Gap or 'diastema' between predentary and first dentary tooth | Short | | |
| 23 | Dentary ramus | Straight | | |
| 24 | Dentary ramus | Parallel sided | | |
| 25 | Coronoid process shape | Elevated, but oblique | | |
| 26 | Coronoid process position | | Laterally offset and a horizontal shelf separates dentition from coronoid process | |
| 31 | Marginal denticles | | Curved, mammillated ledge | |
| 32 | Tooth root emplacement | | | Rugose, angular-sided roots |
| 36 | Mammillary crown shape | | Elongate lozenge | |
| 37 | Ridge pattern on maxillary crowns | Very prominent primary ridge | | |

Note: Numbers correspond to character states in Norman (2002: Appendix 2).

caudally. The maxilla terminates with a robust caudoventral process.

The edentulous rostral process is 8.5 cm long and tapers rostrally. Two flanges along its dorsolateral and dorsomedial sides delimit the surface for articulation with the premaxilla. This surface is smooth, and is oriented dorsolaterally.

At the rostral margin of the alveolar portion, the maxilla abruptly increases in height, then, gradually continues to do so caudally, with both its dentigerous and dorsal margins arching slightly dorsally. The lateral surface is smooth, without foramina. The rostral one-third of the dentigerous portion has a flat and smooth dorsal surface, with a maximum mediolateral width of 5.5 cm located about 20 cm caudal to the rostramost end of the maxilla. Judging from the gently curved dorsal margin, it does not have a prominent dorsal process.

The maxilla terminates with a robust caudoventral process. In lateral view, a rugose ridge, approximately 2 cm wide, wraps the rostroventral main body, which is inset medially. In caudal view, this process bulges laterally, with a small subcircular scar on its upper half, indicating a butt-jointed maxilla-jugal articulation.

In medial view, the alveolar margin is convex dorsally, with the well-developed alveolar parapet above occupying large part of the medial surface. A series of foramina penetrate the dorsal margin of the parapet. A rugose ridge develops on the caudal end of the alveolar parapet.

3. Lacrimal: The lacrimal is block-shaped. In lateral view, its dorsal margin is slightly longer than the ventral. Its ventral half slopes ventromedially to receive the rostral process of the jugal. The antorbital foramen might exist on the dorsal surface of the maxilla, but is not visible laterally along the maxilla-lacrimal suture.

4. Dentary: The left dentary is completely preserved. In lateral view, its ramus is elongate. Its rostral end tapers slightly. Its ventral margin is slightly concave. The portion rostral to the alveolar trough is 11 cm long and 8 cm wide. This portion is not ventrally deflected, but curves medially, terminating at the weak symphysis. The predentary articulation is horizontal with a shallow trough.

In medial view, there are 27 parallel vertical tooth positions in the alveolar trough, though no teeth are preserved. Below the alveolar trough, the dentary is incised medially to border the Meckelian groove. In dorsal view, the dentary gradually widens toward its coronoid process. The coronoid process is developed caudal to the alveolar trough and separated from it by a 2-cm wide shelf. The coronoid process is tall and inclined caudodorsally, without an expanded apex.

5. Dentition: Only maxillary dentition is preserved. There are approximately 27 vertical tooth positions. In labial view, the crowns are lozenge-shaped and enameled. A prominent ridge divides the labial surface of the crown equally, and there is no evidence of subsidiary ridges. In the first three unworn teeth, the mesial and distal margins of the crown possess denticles. In lingual view, two rows of crowns are exposed and they are all worn (implying that they were functional). A coating of rugose cementum covers the root.

## 3 Discussion

Hadrosauriformes is defined as a node-based taxon including *Iguanodon*, *Parasaurolophus*, their most recent common ancestor and all descendants (Sereno, 1997, 1998, 1999). It includes two stem-based taxa, Iguanodontidae and Hadrosauroidea. In the early part of the Early Cretaceous

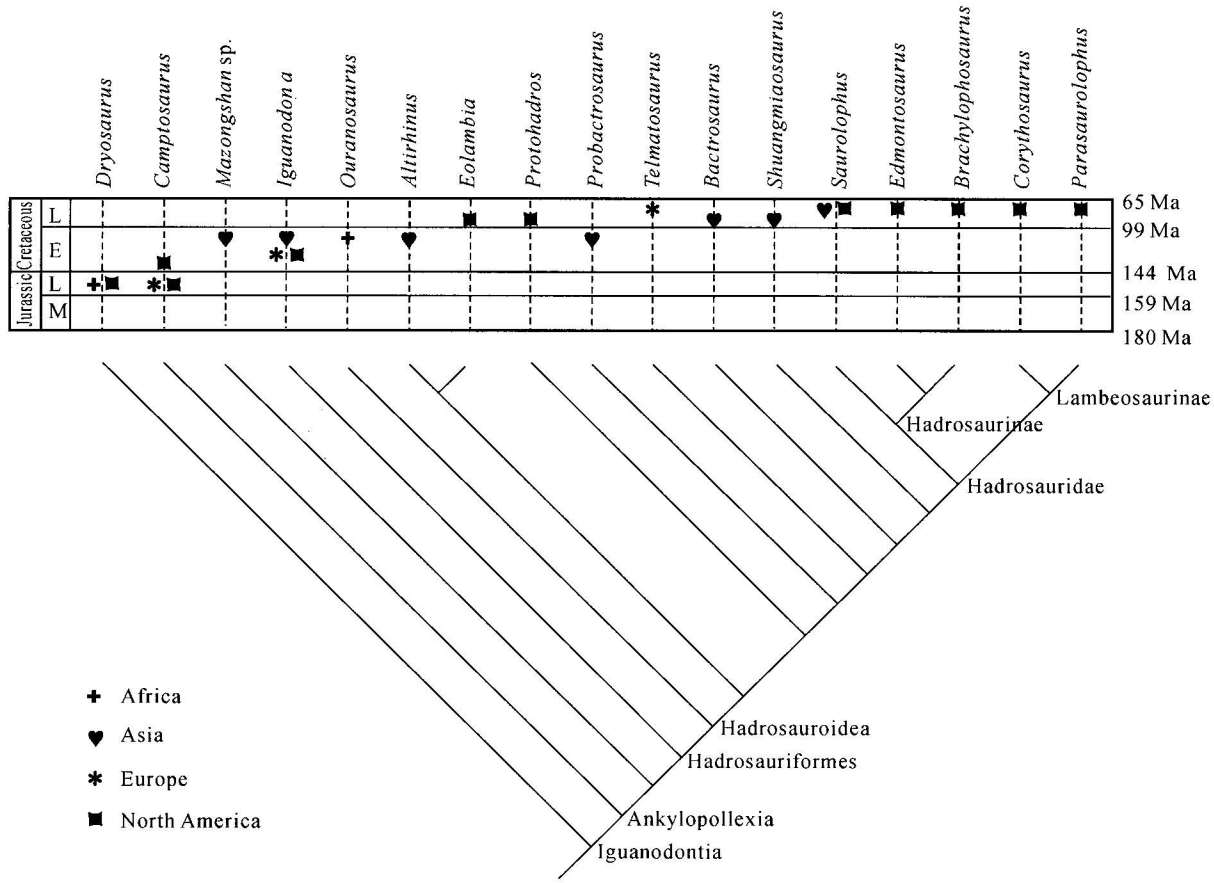


Fig. 3. Phylogenetic relationships of *Shuangmiaosaurus gilmorei*, gen. et sp. nov.
The single most parsimonious tree was recovered by the analysis of 67 unordered characters and 17 comparative taxa using the Branch-and-Bound search option of PAUP (3.1.1). The consistency index is 0.741, and the retention index is 0.876. The data matrix is based on Norman (2002), with the addition of the new taxon, *Shuangmiaosaurus gilmorei*. See Tables 1 and 2 for characters of *Shuangmiaosaurus gilmorei* and apomorphy lists, respectively.

(Berriasian–early Aptian), *Iguanodon* was the most abundant and widespread representative of Hadrosauriformes. *I. bernissartensis* has been found in the Barremian-Aptian beds of both Europe and Asia (Norman, 1980, 1996). However, from the late Early Cretaceous (Aptian–Albian) to the early Late Cretaceous, a more diverse series of genera, such as the African *Ouranosaurus* (Taquet, 1976), North American *Protohadros* (Head, 1998) and *Eolambia* (Kirkland, 1998), and Asian *Altirhinus* (Norman, 1998), *Probactrosaurus* (Rozhdestvensky, 1966; Norman, 2002) and *Bactrosaurus* (Gilmore, 1933; Weishampel and Horner, 1986; Godefroit et al., 1998), replaced *Iguanodon* as the prevailing hadrosauriform taxa. By the end of the Cretaceous, members of Hadrosauridae dominated the terrestrial ecosystems in the Northern Hemisphere (Weishampel and Horner, 1990; Weishampel and Jianu, 2000; Barrett and Willis, 2001).

In order to determine the phylogenetic relationships of *Shuangmiaosaurus*, we performed a cladistic analysis. The data matrix was based on that of Norman (2002), which contains 18 taxa and 67 characters. Of these, 12 characters are coded for *Shuangmiaosaurus* (Table 1). We used Paup 3.1.1 to analyze the character-taxon matrix, and recovered 21 most parsimonious trees. Our consensus tree is similar to that of Norman (2002), with the addition of *Shuangmiaosaurus* as the sister taxon to the Hadrosauridae. We conducted a second analysis, deleting two taxa (*Lurdusaurus* and *Iguanodon* b), and found one most parsimonious tree that refines the consensus tree above (Fig. 3). Apomorphy lists for each clade recovered in this analysis are provided in Table 2.

*Shuangmiaosaurus* is closer to Hadrosauriformes than to *Camptosaurus* (Gilmore, 1909) because it possesses elongate lozenge-shaped maxillary crowns with curved, mammillate denticles on their mesial and distal margins. Within Hadrosauriformes, *Shuangmiaosaurus* is more derived than *Iguanodon* and *Ouranosaurus* in having a dorsally placed external antorbital fenestra, a flattened dorsal process of the maxilla, a laterally offset coronoid process with a horizontal shelf, and partially cemented

**Table 2 Unambiguous apomorphy lists determined from a cladistic analysis (using PAUP 3.1.1) of 17 taxa and 67 characters.**

| No. | Characters | 0 | | 1 | | 2 |
|---|---|---|---|---|---|---|
| Mazongshan sp. + *Parasaurolophus* | | | | | | |
| 2 | Premaxillary margin | lightly ventrally offset from occlusal plane of the dentition | → | very strongly ventrally deflected | | |
| 25 | Coronoid process shape | elevated, but oblique | → | long, finger-shaped, perpendicular | | |
| 31 | Marginal denticles | simple, tongue-shaped | → | curved, mammillated ledge | | |
| 36 | Maxillary crown shape | shield-shaped | → | elongate lozenge | | |
| *Iguanodon* + *Parasaurolophus* .Hadrosauriformes. | | | | | | |
| 16 | Ventral edge of the jugal | smooth, shallow curve | → | strongly angular | | |
| 22 | Gap or 'diastema' between predentary and first dentary tooth | short | → | pronounced | | |
| 34 | Relative width of maxillary and dentary crowns | maxillary crowns approximately equal in width with dentary crowns | → | narrower | | |
| *Ouranosaurus* + *Parasaurolophus* .Hadrosauroidea. | | | | | | |
| 14 | Anterior portion of the jugal | tapering | → | expanded dorsoventrally | | |
| 24 | Dentary ramus | parallel sided | → | deepens rostrally | | |
| *Altirhinus* + *Parasaurolophus* | | | | | | |
| 10 | Position of external antorbital fenestra | between lacrimal and maxilla | → | on anterior dorsal margin of maxilla | | |
| 11 | Dorsal process of the maxilla | narrow, finger shaped process | → | expanded, laterally flattened plate-like structure | | |
| 26 | Coronoid process position | laterally offset and dentition curves into its base | → | laterally offset and a horizontal shelf separates dentition from coronoid process | | |
| 30 | Dentary enamel | thin veneer labially, thick lingually | → | exclusively lingually | | |
| 32 | Tooth root emplacement | not cemented | → | partially cemented | | |
| 40 | Replacement crowns in dentary | one | → | two | | |
| *Protohadros* + *Parasaurolophus* | | | | | | |
| 20 | Quadrate paraquadratic foramen | present | → | absent | | |
| 33 | Alveolar trough grooves | shaped by dentary crowns | → | narrow parallel-sided grooves | | |
| 39 | Occlusal surface of dentary tooth row | single tooth depth | → | multiple tooth depth | | |
| *Probactrosaurus* + *Parasaurolophus* | | | | | | |
| 22 | Gap or 'diastema' between predentary and first dentary tooth | short | ← | pronounced | | |
| 24 | Dentary ramus | parallel sided | ← | deepens rostrally | | |
| 32 | Tooth root emplacement | | | partially cemented | → | rugose angular-sided roots |
| *Telmatosaurus* + *Parasaurolophus* | | | | | | |
| 25 | Coronoid process shape | | | long, finger-shaped, perpendicular | → | markedly anteroposteriorly expanded apex |
| 27 | Surangular foramen | present | → | absent | | |
| 64 | Femur, anterior intercondylar groove | | | partially enclosed by expansion of anterior condyles | → | fully enclosed canal |
| *Bactrosaurus* + *Parasaurolophus* | | | | | | |
| 28 | Angular position | visible on lateral surface of the lower jaw | → | not visible laterally | | |
| 44 | Scapular 'acromion' | prominent on anterior margin of scapula | → | reflected laterally | | |
| 62 | Femoral shaft | distal half of shaft curved posteriorly | → | straight | | |
| 63 | Femur, 4th trochanter | | | Large, triangular | → | curved, laterally compressed eminence |
| *Shuangmiaosaurus* + *Parasaurolophus* | | | | | | |
| 15 | Jugal-maxilla suture | scarf joint | | 'finger-in-recess' joint | → | butt-jointed |
| *Saurolophus* + *Parasaurolophus* .Hadrosauridae. | | | | | | |
| 22 | Gap or 'diastema' between predentary and first dentary tooth | short | → | pronounced | | |
| 31 | Marginal denticles | | | curved, mammillated ledge | → | absent or reduced to small papillae |
| 36 | Maxillary crown shape | | | elongate lozenge | → | sub-diamond-shaped |
| 37 | Ridge pattern on maxillary crowns | very prominent primary ridge | → | reduced primary ridge | | |

Note: The character-taxon matrix is based on Norman (2002), with *Lurdusaurus* and *Iguanodon* b deleted and *Shuangmiaosaurus* added.

tooth roots. *Shuangmiaosaurus* is more highly derived than *Altirhinus* and *Eolambia* because it displays narrow, parallel-sided alveolar trough grooves, and more derived than *Protohadros* in possessing a straight dentary ramus and rugosely cemented tooth roots. One important feature, the butt-jointed maxilla-jugal suture, is shared by *Shuangmiaosaurus* and Hadrosauridae, and is not present in other basal hadrosauroids, such as *Probactrosaurus*, *Telmatosaurus* (Weishampel et al., 1993), and *Bactrosaurus*. However, *Shuangmiaosaurus* does not

possess other synapomorphies of Hadrosauridae, such as diamond-shaped maxillary crowns with reduced primary ridges and reduced marginal denticles.

Based on the phylogenetic position of *Shuangmiaosaurus*, we believe the Sunjiawan Formation to be early Late Cretaceous in age. More basal hadrosauroids, such as *Bactrosaurus* (Godefroit et al., 1998), *Protohadros* (Head, 1998), and *Eolambia* (Kirkland, 1998) are all early Late Cretaceous in age, and members of Hadrosauridae are typical of the latest Late Cretaceous. Because of its intermediate phylogenetic position, we predict an early Late Cretaceous age for *Shuangmiaosaurus* and the portion of the Sunjiawan Formation from which it came, but this age assessment remains to be bolstered by other indicators.

## 4 Conclusions

A new genus and species of hadrosauroid dinosaur, *Shuangmiaosaurus gilmorei* gen. et sp. nov. is described based on a left maxilla articulated with a partial premaxilla and lacrimal, and a left dentary. Cladistic analysis shows that *Shuangmiaosaurus* is a basal hadrosauroid, and is the sister taxon to Hadrosauridae. The Sunjiawan Formation was probably deposited during the early stages of the Late Cretaceous.

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