

Review of historical and current research on the Late Cretaceous dinosaurs and dinosaur eggs from Laiyang, Shandong (Postprint)

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Abstract

We briefly review the research history of the Laiyang dinosaur and dinosaur egg faunas and the outstanding contributions of elder paleontologists represented by C. C. Young to the research and discoveries of Laiyang dinosaurs and dinosaur eggs, and introduce the new discoveries and several research advances on the Laiyang faunas. In recent years, large-scale investigations of the strata surrounding Laiyang have discovered a series of dinosaur canyon groups developed on plains, as well as more than ten new dinosaur and dinosaur egg localities and horizons. Beginning in 2010, excavations at two fossil localities near Jingangkou Village in Laiyang yielded abundant vertebrate fossils and egg fossils dominated by Hadrosauridae, including a new saurolophine, some large theropod dinosaur fossils, and a new turtle egg fossil. The fossil-rich layers at Locality 2 exhibit typical mudflow sedimentary and bone burial characteristics. CT scanning and three-dimensional reconstruction of the peculiar crest of *Tsintaosaurus spinorhinus* revealed that its crest is a solid structure; however, other skeletal features unequivocally prove that *Tsintaosaurus spinorhinus* belongs to Lambeosaurinae, which possess hollow crests. Therefore, the currently discovered crest should not represent its true form or does not belong to the skull at all. Furthermore, re-examination of *Tanius* (1 genus, 3 species) yields the following conclusions: *Tanius sinensis* and *Tanius chingkankouensis* should be valid taxa, but some skeletal elements remain questionable and require further study, whereas *Tanius laiyangensis* is an invalid taxon.

Full Text

Preamble

Review of Historical and Current Research on the Late Cretaceous Dinosaurs and Dinosaur Eggs from Laiyang, Shandong

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Abstract

Here we briefly review the history of research on the Laiyang dinosaur and dinosaur egg faunas, summarize the contributions of C. C. Young and other elder paleontologists to the discoveries of Late Cretaceous dinosaurs and dinosaur eggs from Laiyang, and introduce new discoveries and advances in research on the Laiyang faunas. New investigations in Laiyang since 2008 have found a series of valleys developed in plains and more than ten new dinosaur or dinosaur egg fossil beds. In 2010, we began massive excavations at two localities in Jingangkou and collected abundant dinosaurs and other vertebrate fossils, such as a new saurolophine, some theropod material, and a new taxon of turtle egg. The bone beds in Locality 2 exhibit typical sedimentary and burial patterns of mudflow, and these fossil deposits are interpreted as having been carried and deposited by mudflow. Re-observation and CT scanning data of the crest of *Tsintaosaurus spinorhinus* (IVPP V 725) show that the crest is fractured and solid. However, based on re-observations of its cranial and postcranial specimens, we consider *Tsintaosaurus spinorhinus* to be a valid taxon of lambeosaurines, which have hollow crests. Therefore, the crest of *Tsintaosaurus* might not belong to the skull of this individual, and the true form of the crest needs to be confirmed in future work. We reassess the three species of *Tanius* and obtain several results: (1) *Tanius sinensis* and *Tanius chingkankouensis* are valid species of *Tanius*; (2) *Tanius laiyangensis* is invalid; (3) the sacrum and ilium of *Tanius chingkankouensis* with typical hadrosaurid features should not be referred to *Tanius*.

Key words: Laiyang, Shandong; Upper Cretaceous; Wangshi Group; Hadrosauoidea; dinosaur egg

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1 Introduction

Laiyang is located in the center of the Jiaodong Peninsula, and the well-developed terrestrial strata around Laiyang belong to the Lower Cretaceous Laiyang and Qingshan groups and the Upper Cretaceous Wangshi Group. The age of these strata ranges from 130 Ma to 70 Ma (Wang et al., 2010, 2012). The Laiyang Group consists primarily of grey and grey-green shales deposited in lacustrine environments. Abundant fossils have been recovered from the Laiyang Group, including plants, insects, conchostracans, various other invertebrates, and dinosaur tracks (Chow, 1923; Grabau, 1923; Hong and Wang, 1990; Zhang, 1992; Young, 1960; Li and Zhang, 2000, 2001). The Qingshan Group consists mainly of volcanic rocks interbedded with sedimentary rocks (Liu et al., 2011) and contains the ceratopsian dinosaur *Psittacosaurus* (Young, 1958; Zhao, 1962), pterosaurs (Young, 1958; Zhou, 2010), and the turtle *Peishanemys* (Chow, 1954a). The fossil assemblage in the Laiyang and Qingshan groups is similar to the Jehol Biota and forms the Laiyang Jehol Biota (Wang et al., 2010).

The Upper Cretaceous Wangshi Group mainly comprises fluvial and lacustrine red and gray-green siltstones and mudstones interbedded with gray and gray-green glutenites and siltstones, and is divided from bottom to top into the Xingezhuang, Jiangjunding, Jingangkou, and Changwangpu formations (Hu et al., 2001), the last of which was thought to occur only in Zhucheng and to be absent in Laiyang (Wang et al., 2012). The Jiangjunding and Jingangkou formations contain rich concentrations of hadrosauroid bones, coexisting with abundant other vertebrate bones and dinosaur eggs. More recently, Yan and Chen (2005) obtained an isotope age of 73 Ma for the Jingangkou Formation (which they called the Hongtuya Formation) based on a basalt sample from the town of Daxizhuang in Jiaozhou City. The dinosaurs and dinosaur eggs in the Wangshi Group form the Laiyang Hadrosauroid Fauna and Dinosaur Egg Fauna. Laiyang is also among the relatively few areas worldwide that are rich in both dinosaur bones and dinosaur eggs.

The earliest discoveries of dinosaur bones and dinosaur eggs in Laiyang can be traced back to the 1920s, and a golden age of exploration of the fauna took place in the 1950s. It was from Laiyang that Chinese geologists and paleontologists first reported a fossil assemblage containing Chinese dinosaurs, dinosaur eggs, pterosaurs, insects, and plants (Wang et al., 2010). Because of these discoveries, the Society of Vertebrate Paleontology of China was founded in 1984 in Laiyang. In 1951, an IVPP expedition team led by C. C. Young undertook a series of massive prospecting trips and excavations in Laiyang (Liu, 1951; Young, 1958) and found abundant vertebrate fossils including multiple specimens of the lambeosaurine hadrosaurid *Tsintaosaurus spinorhinus*, the first reasonably complete dinosaurian skeleton after the establishment of P. R. China (Young, 1958). These discoveries turned Laiyang into a focal point for the study of dinosaur and dinosaur egg fossils in China. Although dinosaurs and dinosaur eggs continued to be found sporadically in Laiyang in the following decades, no large-scale

excavations were conducted. Since 2008, however, an IVPP-Laiyang team has carried out annual field activities including massive excavations at both Young's old quarry (Locality 1) and a new quarry (Locality 2) in Laiyang. During these new field surveys, we have discovered several dinosaur and dinosaur egg localities and found abundant fossils. Here we briefly review the history of research on the dinosaurs and dinosaur eggs of Laiyang, including the contributions of Young and other paleontologists, and also introduce the new finds and research advances in Laiyang.

2 History of Discoveries of Dinosaurs and Dinosaur Eggs in Laiyang

Laiyang is an important source of Late Cretaceous dinosaurs and dinosaur eggs in China. In the last century, C. C. Young, A. Grabau, H. C. Tan, D. S. Liu, M. C. Chow, and other geologists and paleontologists conducted a series of field investigations and excavations, and abundant fossils were found, especially of dinosaurs and dinosaur eggs. The history of research on dinosaurs from Laiyang can be generally divided into three periods.

2.1 The First Period of Dinosaur Discovery in Laiyang (1920s-1930s)

Tan (1923) reported the presence of dinosaurs, fishes, insects, and plants in the Cretaceous strata of Laiyang. Grabau (1923) studied the fishes and insects, while T. H. Chow (1923) studied the plants. The dinosaur material, which had been collected by Tan, is now kept in the paleontological collections of the Museum of Evolution, Uppsala University, Sweden (PMU). Wiman (1929) described the hadrosauroid material and named it *Tanius sinensis* in Tan's honor. Buffetaut (1995) and Buffetaut and Tong (1995) referred the ankylosaurid material to *Pinacosaurus cf. grangeri*. Poropat and Kear (2013) reassessed some theropod material. In addition, H. S. Wang (1930) subsequently reported some dinosaurs from Jingangkou.

2.2 The Second Period of Dinosaur Discovery in Laiyang (1950s-1970s)

In 1950, L. H. Wang and K. Y. Kwan from the Department of Geology and Mineralogy, University of Shandong collected some dinosaurs and dinosaur eggs from the Upper Cretaceous strata around Laiyang (Chow, 1951). These specimens are now kept in the Museum of Geology at Jilin University and were reported on by Chow (1951), who identified them as hadrosaurid with Young's help. Young attached great importance to these discoveries. In 1951, he led a field expedition to Laiyang in which D. S. Liu and C. Y. Wang also participated. This team carried out massive excavations at Jingangkou (Wangshi Group) and Doushan (Qingshan Group), digging out abundant dinosaurs and dinosaur eggs (Liu, 1951; Young, 1958). Liu (1951) reported in detail on the field investigations

and excavations. Young (1954) studied the dinosaur eggs and divided them into two categories: short eggs (*Oolithes spheroides*) and long eggs (*Oolithes elongates*), proposing the preliminary classification of dinosaur eggs based on this scheme. Chow (1954b) described the microstructure of dinosaur eggshell. These early studies helped to lay the methodological and nomenclatural foundation for subsequent research on dinosaur eggs. In addition, Chow (1954a) studied the turtle fossils collected in 1951.

Young established the species *Tsintaosaurus spinorhinus* based on a complete composite skeleton and additional bones from the Wangshi Group in a monograph entitled “The Dinosaurian Remains of Laiyang, Shantung,” which was an important monograph about dinosaurs produced in the early stages of P. R. China (Young, 1958) (Fig. 1 [FIGURE:1]). The book also reported other dinosaurs collected from the Wangshi Group, including a new species of *Tanius* (*Tanius chingkankouensis*), theropods (*cf. Szechuanosaurus campi* and *Chinkankousaurus fragilis*), and some fractured bones referred to stegosaurs and sauropods (Young, 1958). These dinosaur finds revealed the basic contours of the Laiyang Hadrosauroid Fauna (Young, 1958). Young also reported *Psittacosaurus sinensis* and some pterosaur bones from the Qingshan Group (Young, 1958), which was the first report of pterosaurs from China.

Dinosaurs reported from Laiyang after this publication included another species of *Tanius*, *T. laiyangensis* (Zhen, 1976) and a pachycephalosaurid, *Micropachycephalosaurus hongtuyanensis* (Dong, 1978). In addition, there was another hadrosaurid, *Shantungosaurus giganteus* found in Zhucheng and Laiyang (Hu, 1973; Hu et al., 2001). In the 1970s, Z. K. Zhao further studied the microstructure of dinosaur eggs, erecting the two oofamilies Elongatoolithidae and Spheroolithidae based on Young and Chow’s work (Zhao and Jiang, 1974; Zhao, 1975, 1979). He was also the first to propose the current international classification of dinosaur eggs (Zhao and Jiang, 1974; Zhao, 1979).

2.3 The Third Period of Dinosaur Discovery in Laiyang (from 2008)

Since 2008, the IVPP-Laiyang expedition team has carried out a series of field investigations in Laiyang. These investigations have revealed sets of valleys that interrupt the plains dominating the landscape, and more than ten dinosaur bone and egg sites have been found in the valleys. In 2010, the team undertook massive excavations at Locality 1 (Young’s old *Tsintaosaurus* quarry) and Locality 2 (a new quarry) and collected abundant dinosaur bones. Abundant science bases and geoparks have been founded in the field area, such as the Laiyang National Geopark, a National Key Protected Fossil Locality, and a Field Observation Base of the Ministry of Land and Resources.

3 Laiyang Hadrosauroid Fauna and Dinosaur Egg Fauna

Since the 1920s, abundant dinosaur bones and other fossils have been found in Cretaceous strata around Laiyang, forming three important Cretaceous faunas: the Laiyang Jehol Fauna, the Laiyang Hadrosauroid Fauna, and the Laiyang Dinosaur Egg Fauna.

3.1 Laiyang Hadrosauroid Fauna

The Laiyang Hadrosauroid Fauna, represented by *Tsintaosaurus* and *Tanius*, is one of the most important and famous Late Cretaceous dinosaur faunas in China. Up to now, members of seven major reptile clades have been reported (Wiman, 1929; Young, 1958; Hu, 1973; Zhen, 1976; Dong, 1978; Buffetaut and Tong, 1995; Poropat and Kear, 2013). Of the seven clades, nine species in eight genera have been named (Wang et al., 2010) (Table 1), and other unnamed members represent stegosaurs, sauropods, and theropods (Young, 1958; Poropat and Kear, 2013).

Hadrosauroids consist of some basal forms, known as non-hadrosaurid hadrosauroids, and the monophyletic Hadrosauridae (Prieto-Márquez, 2010). Many hadrosaurid species have hypertrophied nasal passages associated with cranial crests, which vary widely in morphology and are important in hadrosaurid taxonomy (Ostrom, 1962; Hopson, 1975). Hadrosauridae is divided into two main clades: the flat-headed or solid-crested Saurolophinae, and the hollow-crested Lambeosaurinae (Horner et al., 2004). In recent phylogenetic analyses, *Tanius* has been recovered as a non-hadrosaurid hadrosauroid, whereas *Tsintaosaurus* and *Shantungosaurus* have been placed in Hadrosauridae as a lambeosaurine and a saurolophine, respectively (Prieto-Márquez, 2010; Zhang and Wang, 2012).

3.2 Laiyang Dinosaur Egg Fauna

Abundant dinosaur eggs were collected at the same time as the dinosaur body fossils. To date, four oofamilies, five oogenera, and eleven oospecies have been reported, forming the Laiyang Dinosaur Egg Fauna (Wang et al., 2010) (Table 2).

4 New Fossil Discoveries in Laiyang

During recent fieldwork in the Wangshi Group, several valleys were discovered in Jingangkou and Jiangjunding, which are considered to form “the Laiyang Dinosaur Valley Series,” where more than ten dinosaur bone and egg sites have been found (Fig. 2

). The dinosaur valleys generally trend nearly SN or EW, and some intersect.

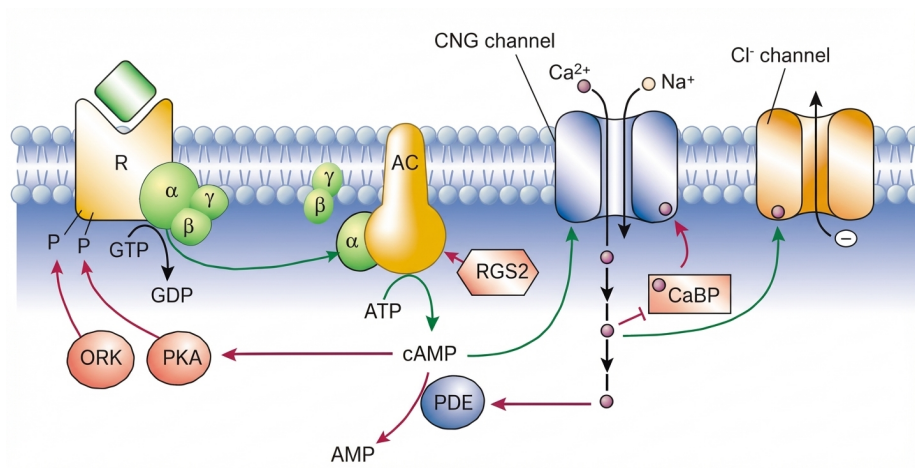


Figure 1: Figure 2

4.1 Re-excavation of Young' s Old *Tsintaosaurus* Quarry (Locality 1) and the Discovery of a New Turtle Egg

In 2010, the IVPP-Laiyang expedition team confirmed the location of the quarry where Young found *Tsintaosaurus* in 1951 (Locality 1) and reopened the quarry for further excavation. The bone-bearing beds were identified, and several isolated bones of hadrosauroids and other vertebrates were found at this site. Among these fossils, a single elongated egg is the most noteworthy. The microstructure of the eggshell is different from that seen in the eggshell of dinosaurs, birds, or crocodiles. This specimen was identified as a new type of turtle egg and named *Emydoolithus laiyangensis* (Wang et al., 2013a).

4.2 Excavations and New Discoveries in Locality 2

Locality 2 is in the eastern part of Jingangkou Village, 1 km east of Locality 1, and represents an exposure of the middle part of the Wangshi Group (Wang et al., 2012). Eight layers bearing dinosaur bones occur in a thickness of 100 m, five of which have been excavated in recent years. An on-site museum has been built in the western part of the excavation area.

The first and second fossil-bearing layers are composed of gray-green silty mudstone containing black bones. They are actually parts of a single original layer, but movement along a fault separated them. The fossils in the first layer are mainly large theropod and hadrosauroid bones and are similar to those found at the bottom of the second layer. In the middle of the second layer, large complete bones and small rounded bone fragments are mixed together, whereas the fossils in the upper part of the layer are all fractured and rounded small bones. The third, fourth, and fifth layers mainly consist of siltstones, and the fossils

in these layers are white in color. The excavations carried out in recent years have targeted the third layer, which is 1.5–1.8 m thick and contains abundant hadrosauroid bones in a normally graded vertical sequence. Near the top of this layer are small vertebrae and fractured bones, and near the bottom are large isolated bones, some of which are articulated. Abundant hadrosauroid and other vertebrate bones are found in the fourth layer, and several complete large turtle fossils occur in the fifth layer.

The strata at Locality 2 are interpreted to have been mainly formed by mudflow events because they show typical sedimentary and taphonomic characteristics expected for mudflow deposits: mudstones and siltstones with some poorly sorted gravel, most bones isolated, large and small complete bones mixed at the bottom of the layers, long axes of bones lacking consistent orientation, and a few bones oblique or vertical in orientation. The taphonomy of the bones shows that a group of live hadrosauroids was engulfed and torn apart by a sudden flood and mudflow, and the carcasses were carried a short distance and rapidly buried. However, abundant fractured and rounded small bones and plant fragments indicate these fossils were reworked before final burial. Thousands of hadrosauroid bones exposed in recent years represent at least 20–30 individuals. These can be divided into three size classes, which are tentatively assumed to represent adult, subadult, and late juvenile individuals according to studies of ontogenetic changes in the hadrosaurid *Maiasaura peeblesorum* by Horner et al. (2000).

Some of the hadrosauroid bones are referred to Saurolophinae based on the maxilla with an anterodorsal process, the jugal with a long anteroposteriorly rostral process and a shallow embayment, and the distal end of the ischial shaft without the “foot-like” process (Prieto-Márquez, 2008, 2010). These saurolophine materials belong to a new genus and species, *Laiyangosaurus youngi* in Young’s honor, based on the following autapomorphies: a prominent and narrow ridge on the lateral side of the nasal, a slightly posteriorly deflected primary ridge of the maxillary tooth, a dorsolateroposteriorly recurved retroarticular process of the surangular, a relatively shallow and rostrorodorsally directed caudal margin of the lacrimal process of the jugal, the posterior margin of the maxilla facet limited by a rostrorodorsally-oriented narrow ridge, and orbital margins that are wider than the infratemporal margins of the jugal (Zhang et al., 2017). In addition, other hadrosauroid bones would be referred to *Tsintaosaurus spinorhinus* (Lambeosaurinae) based on the humerus with a long and wide deltopectoral crest and the ilium with a deep central plate (Young, 1958; Prieto-Márquez, 2008, 2010; Zhang, 2013).

5.1 Validity of *Tsintaosaurus spinorhinus* and CT Scanning of Its Crest

Young (1958) described *Tsintaosaurus spinorhinus* based on a nearly complete composite skeleton (IVPP V 725), a separate incomplete skull (IVPP V 818), and additional postcranial materials from the Wangshi Group west of Jingangkou Village, Laiyang. *T. spinorhinus* has a rod-like, anterodorsally projected cranial crest consisting of the nasal bones and terminating in two branches (Fig. 3

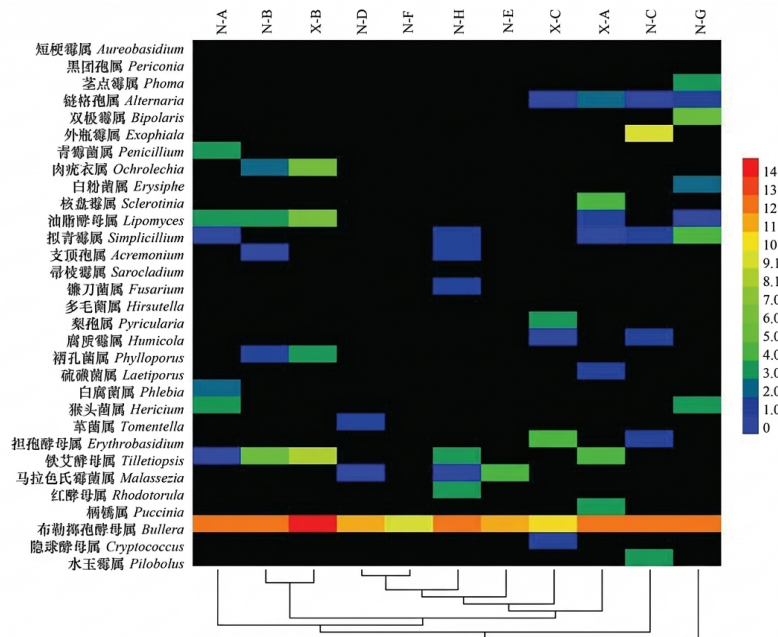


Figure 2: Figure 3

). This feature differs from the posterodorsally projected crests of other lambeosaurines, which incorporate both the nasals and the premaxillae (Ostrom, 1960; Hopson, 1975; Horner, 2004; Evans et al., 2009). Since *T. spinorhinus* was reported in 1958, it has been the subject of considerable controversy, especially regarding its crest. Some scholars have even doubted the validity of the taxon (Rozhdestvensky, 1977; Taquet, 1991; Horner and Weishampel, 1990), while some researchers believed that *T. spinorhinus* was assignable to Lambeosaurinae and most likely hollow-crested based on lambeosaurine features in the skull and postcranial bones (Maryńska and Osmólska, 1981; Brett-Surman, 1989; Buffetaut and Tong, 1993, 1995). Horner et al. (2004) confirmed that *T. spinorhinus* was a basal lambeosaurine through phylogenetic analysis. Prieto-Márquez and Wagner (2013) restored *T. spinorhinus* with a hollow posterodorsally projected crest as in typical lambeosaurines based on the skull and some

additional bone fragments.

Recently, we used a CT scanner to scan the crest of *Tsintaosaurus* (IVPP V 725) and reconstruct its internal structure (Zhang and Wang, 2012). Notably, the fracture on the root of the crest is severe. There are only several small bone fragments between the crest and the skull. The fracture surfaces on the root of the crest do not match those of the skull (Fig. 3D, E) (Zhang and Wang, 2012). Therefore, it is doubtful that the morphology of the crest of *Tsintaosaurus* is real. The cross-section of the crest shows that there are three parts along the sagittal plane (Fig. 3C). The middle part is a rectangular, long strip in our 3D reconstruction. The two lateral parts do not enclose a cavity around the middle part but instead sandwich the middle part between them. Therefore, the crest of *Tsintaosaurus* could not enclose a nasal cavity, which is divided into a pair of hollow passages in the crest of all other lambeosaurines. In addition, the middle part of the crest of *Tsintaosaurus* is also part of the skeleton, and the crest would be solid, not hollow.

However, based on our observations of the skull and postcranial bones of *Tsintaosaurus*, we consider the descriptions of the other parts of *Tsintaosaurus* by Young and other researchers to be reliable and accurate (Young, 1958; Buffetaut and Tong, 1993, 1995). *Tsintaosaurus* exhibits a series of characteristics of Lambeosaurinae, including the frontal being completely excluded from the orbital margin, upward doming on the dorsal part of the frontal, width greater than length of the supratemporal fenestra, the parietal sagittal crest being relatively short and down-curved, the anterodorsal process absent in the anterior of the maxilla, the dorsal process of the maxilla being posterodorsally extended, the symphyseal process of the dentary being medioventrally extended, the quadrate being relatively curved, and the distal region of the ischial shaft being ventrally expanded, forming a large “boot-like” process (Horner et al., 2004; Prieto-Márquez, 2008, 2010).

In conclusion, *Tsintaosaurus* is a valid lambeosaurine taxon, but the crest we examined does not appear to be the real one of *Tsintaosaurus*, or even the material might possibly not belong to the skull of this individual. However, the anterior part of its frontal and prefrontal both extend dorsally to support the crest. Given that morphology, *Tsintaosaurus* should have a hollow up-extended crest, as do other lambeosaurines. Future work will have to confirm the true form of the crest.

5.2 Validity of Three Species of *Tanius*

Three species have been placed in the genus *Tanius* (*T. sinensis*, *T. chingkankouensis*, and *T. laiyangensis*). Only the type species, *T. sinensis*, has a partial skull (Wiman, 1929), and the other two species are known only from postcranial skeletons (Young, 1958; Zhen, 1976). Therefore, the validity of *T. chingkankouensis* and *T. laiyangensis* was doubted by Buffetaut and Tong (1993, 1995).

Horner et al. (2004) suggested that *T. chingkankouensis* is a valid taxon and that *T. laiyangensis* is a synonym of *T. chingkankouensis*.

Tanius sinensis was collected in 1923 from the Jiangjunding Formation, Wangshi Group, stratigraphically below the Jingangkou Formation where *Tsintaosaurus* was found (Tan, 1923; Wiman, 1929). *T. sinensis* was described as a flat hadrosaurid based on a nearly complete skull (Fig. 4 [FIGURE:4]) and some postcranial bones (Wiman, 1929). Recently, it was referred to a valid taxon of basal hadrosauroid with a series of basal hadrosauroid features, such as the rostral process of the jugal being relatively shallow dorsoventrally, the posterodorsal border of the rostral process bearing a remarkable horizontally oriented ridge and continuing to the dorsal border of the rostral process (making a deep concave maxilla facet on the medial surface of the rostral process), and the apex of the supraacetabular process located caudodorsal to the caudal tuberosity of the ischial peduncle (Horner et al., 2004; Prieto-Márquez, 2008, 2010).

Young (1958) erected *T. chingkankouensis* based on a few postcranial bones collected in the same excavation with *Tsintaosaurus spinorhinus* at Jingangkou, Laiyang. Buffetaut and Tong (1993, 1995) considered that the ilium of *T. chingkankouensis* shows advanced hadrosaurid features. The ilium of *T. chingkankouensis* displays a characteristic of saurolophines (Prieto-Márquez, 2008, 2010) in that the apex of the supraacetabular process is located anterodorsal to the caudal tuberosity of the ischial peduncle (Fig. 5

). In addition, whether the sacra with a longitudinal ventral furrow belong to *T. chingkankouensis* is questionable because recent research suggests that the presence or absence of that ventral sacral furrow varies within species (Prieto-Márquez, 2008). Therefore, this character would not be diagnostic of *T. chingkankouensis*. However, *T. chingkankouensis* has a slightly inflated distal end of the ischium (Young, 1958), and that morphology is a characteristic of basal hadrosauroids (Prieto-Márquez, 2008, 2010). In addition, *T. chingkankouensis* has parallel dorsal and ventral margins of the distal blade of the scapula, which is similar to *T. sinensis*, but the straighter dorsal margins of the scapula differ from *T. sinensis* (Young, 1958). Therefore, *T. chingkankouensis* is a valid taxon of *Tanius*, but the ilium would not belong to *Tanius*, and there are some questions about its sacrum that will require further study.

T. laiyangensis was assigned to *Tanius* based on a broken ischium and a sacrum with a ventral furrow, similar to *T. chingkankouensis*, collected from the same site as *Tsintaosaurus spinorhinus* and *T. chingkankouensis* (Zhen, 1976). Zhen (1976) considered that the number of vertebrae of the sacrum in *T. laiyangensis* is greater than in *T. chingkankouensis*. However, the presence or absence of a furrow and the number of sacral vertebrae are not diagnostic (Prieto-Márquez, 2008, 2010). Therefore, *T. laiyangensis* is likely not a valid taxon.

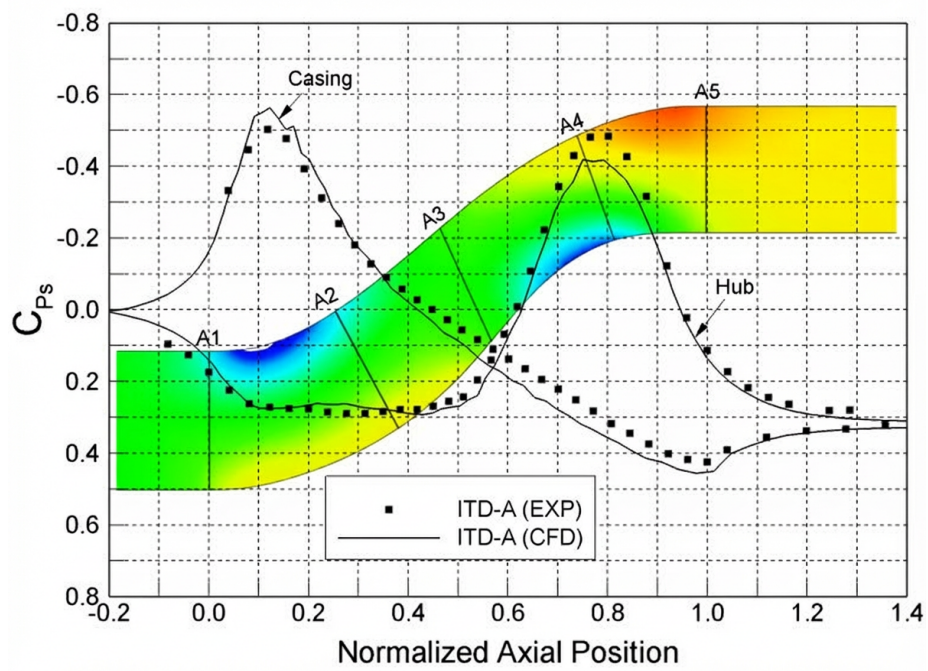


Figure 3: Figure 5

5.3 Advances in *Shantungosaurus giganteus*

Shantungosaurus giganteus was described as a giant flat-head saurolophine based on a nearly complete composite skeleton collected from the Wangshi Group at Longgujian, Zhucheng, Shandong (Hu, 1973; Hu et al., 2001). There are also a few specimens of *S. giganteus* found in Laiyang (Hu et al., 2001). Two other large hadrosaurids, *Zhuchengosaurus maximus* (Zhao et al., 2007) and *Huaxiaosaurus aigahtens* (Zhao et al., 2011), were reported from Zhucheng and were considered synonyms of *S. giganteus* (Ji et al., 2011; Hone et al., 2014).

5.4 Advances in Dinosaur Eggs from Laiyang

Liu et al. (2013) compared dinosaur eggs collected in Laiyang, Shandong Province and Changtu, Liaoning Province, and referred the eggs in Changtu to *Spheroolithus spheroides* (Young, 1954; Zhao, 1979) and *S. megadermus* (Young and Wang, 1959; Zhao, 1979), which were known only from Laiyang in prior reports. The dictyoolithid eggs are widely distributed in China and are important members of the Laiyang Dinosaur Egg Fauna. Wang et al. (2013b) re-examined the holotypes of the four oospecies of Dictyoolithidae and determined that only *Dictyoolithus hongpoensis* was valid in the oogenus *Dictyoolithus*. They established a new oogenus *Protodictyoolithus* and placed *D. jiangi* (Liu and Zhao, 2004) from the Laiyang Basin in *Protodictyoolithus* (Wang et al., 2013b).

These new discoveries and advances in recent years have enriched the diversity of the Laiyang Hadrosauroid Fauna and Dinosaur Egg Fauna. With further excavation and fossil preparation, more discoveries will be made in the future.

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