

A Decade of 21st-Century Dinosaur Research at IVPP

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In the first decade of the 21st century, a larger number of important new dinosaur specimens have come from China than from any other country. The Institute of Vertebrate Paleontology and Paleoanthropology (IVPP) has been at the forefront of the scientific effort to document and analyze these fossils, in collaboration with a wide range of other institutions in China and around the world. Recently discovered Chinese specimens, described by IVPP researchers and their collaborators, have shed considerable new light on the evolution of several important dinosaur groups and on various aspects of dinosaur biology. Some of the findings of these studies would have seemed even twenty or thirty years ago to be closer to the realm of science fiction than paleontological reality.

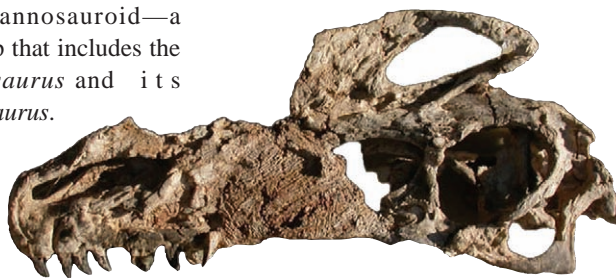
In the past decade IVPP field expeditions and research efforts have concentrated on three very different dinosaur faunas from different parts of China. First, in the Xinjiang Uyghur Autonomous Region in the extreme northwest, the Middle and Upper Jurassic rocks of the Shishugou Formation have yielded a curious assemblage of dinosaurs preserved

alongside crocodylians, turtles and other terrestrial vertebrates. Although fossils are relatively sparse in the Shishugou Formation, the Shishugou dinosaurs are of extraordinary importance because many of them represent early, relatively primitive members of groups that became far more structurally specialized and taxonomically diverse in the subsequent Cretaceous Period.

The small (about 3 meters in total body length) Shishugou predatory dinosaur *Guanlong wucaii* (Xu *et al.*, 2006a), discovered in 2002 by a joint expedition mounted by the IVPP and George Washington University in the United States, perfectly exemplifies this pattern. A number of details of the skeleton, such as fused nasal bones in the skull, show that *Guanlong* is a tyrannosauroid—a member of the group that includes the infamous *Tyrannosaurus* and its Asian cousin *Tarbosaurus*.

As well as its small size, however, *Guanlong* lacks the enlarged skull and tiny forelimbs that characterize *Tyrannosaurus*, *Tarbosaurus* and

their close relatives. Many other features confirm that *Guanlong* is a relatively primitive tyrannosauroid, a status that makes it in some ways more interesting than its larger and presumably fiercer cousins. *Guanlong* sheds light on the early stages of the evolutionary trajectory that led from more typical theropods (predatory dinosaurs) to true monstrosities like *Tyrannosaurus*. However, *Guanlong* should not be seen *only* as a transitional form. It also had important features of its own that were not shared with more advanced tyrannosauroids, most notably a striking crest of bone running down the middle of the snout. The name *Guanlong* is a direct transliteration of the Mandarin pronunciation of the



Skull of the primitive tyrannosauroid dinosaur *Guanlong wucaii* from the Jurassic Shishugou Formation of Xinjiang, China. (Photo: By courtesy of IVPP)

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characters 冠龙, meaning “crowned dragon.”

Other Shishugou taxa excavated and described by IVPP scientists and their colleagues have also been identified as early members of their respective evolutionary lineages. *Yinlong downsi*, for example, is a primitive ceratopsian or “horned dinosaur” (Xu *et al.*, 2006b), although this species is in fact so primitive that the horns that give the group its name are not yet evident. The very recently described *Haplocheirus sollers* is a primitive member of an unusual, bird-like group of theropods called the alvarezsaurids (Choiniere *et al.*, 2010). Another Shishugou theropod, *Limusaurus inextricabilis* (Xu *et al.*, 2009), proved to be a particularly important find. *Limusaurus* is not only a very primitive member of the major theropod group Ceratosauria, but is also unique among known



The small theropod *Mei long* from the Lujiatun Beds of the Lower Cretaceous Jehol Group of Liaoning, China—a dinosaur that died in a bird-like sleeping posture. (Photo: IVPP)

ceratosaurs in being toothless and probably herbivorous. Furthermore, the hand of *Limusaurus* has an unusual configuration, with digit I (the thumb) surprisingly reduced. This is a piece of evidence in favor of the controversial hypothesis that digit I eventually disappeared in theropods, so that the three fingers present in advanced theropods and their avian descendants are identifiable as digits II, III and IV (Xu *et al.*, 2009). It is virtually certain that further field and lab

research on Shishugou dinosaurs will yield additional new species and new inferences about dinosaur evolution.

The second area of concentration for IVPP dinosaur workers, the Lower Cretaceous Jehol Group of Liaoning Province in the northeast, provides an excellent and in many ways unique window on the early stages of dinosaur diversification during the Cretaceous. Many of the Jehol Group’s abundant fossil plants, invertebrates and vertebrates are found in exquisitely fine lake sediments, which frequently preserve near-complete skeletons that may even show traces of feathers and other soft tissue structures.

The rate of discovery and description of new Jehol dinosaurs have been so rapid in the past several years that it is possible to mention only a few particularly important species. *Microraptor gui* (Xu *et al.*, 2003) is a small member of the Dromaeosauridae,

a group of theropods closely related to birds. Although this species has a few unusual skeletal features, such as a strongly curved tibia, it is mainly notable for the presence of long, beautifully preserved feathers that form potentially aerodynamic surfaces on the hind limbs as well as the forelimbs (see Hone, page 92 this volume). *Liaoningosaurus paradoxus* is an ankylosaur or armored dinosaur, described by Xu *et al.* (2001) on the basis of a small juvenile specimen, with an unusual shell-like plate over the abdominal region. Whereas both *Microraptor* and *Liaoningosaurus* are known from articulated skeletons preserved on slabs of rock, so that the specimens are essentially two-dimensional, the Lujiatun Beds of the Jehol Group have yielded a number of important specimens preserved in three dimensions. Perhaps the most striking example is the tiny theropod *Mei long* (Xu and Norell, 2004), known from an exquisitely preserved individual

that appears to have died with its head tucked under a presumably feathered forelimb.

The majority of the known Jehol dinosaurs are small, with many species measuring less than a meter. Although there are notable exceptions, particularly the 7-meter plant eater *Jinzhousaurus yangi* (Wang and Xu, 2001), the unparalleled preservation of diverse small forms is probably the single greatest factor that makes the Jehol Group interesting to dinosaur researchers from the IVPP and elsewhere. Small dinosaurs are generally rare in the fossil record, and to have a large sample of them preserved alongside birds, aquatic amphibians and reptiles, early mammals, and a diverse array of fish, plants and invertebrates is extraordinary.

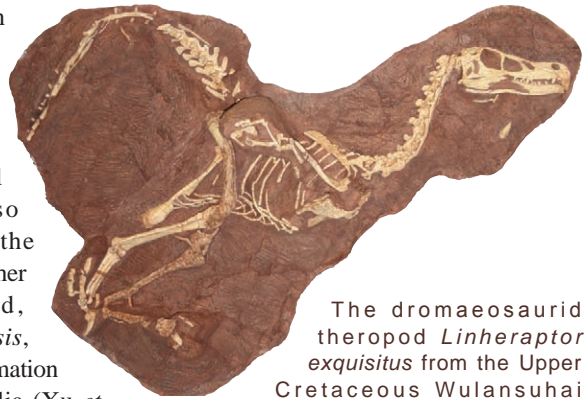
Even as ecological interpretations of this unique tableau of Early Cretaceous life continue, IVPP paleontologists have been at the forefront of research on a geologically older assemblage of less diverse but similarly preserved dinosaurs from western Liaoning and the Daohugou Locality in easternmost Inner Mongolia. These small dinosaurs date from the Late Jurassic. The most spectacular specimen yet recovered from this older fauna is an extravagantly feathered individual of *Anchiornis huxleyi* (Hu *et al.*, 2009), a close relative of *Mei*. Potentially even more intriguing, however, are two small and possibly arboreal dinosaurs assigned to the new group Scansoriopterygidae. *Epidexipteryx* (Zhang *et al.*, 2008) sports closely packed, forward-pointing teeth and long display feathers on the tail, while *Epidendrosaurus* (Zhang *et al.*, 2002) is known from a fragmentary juvenile specimen but clearly possesses a long, slender finger reminiscent to some extent of the middle digit on the hand of a living primate called the aye-aye (*Daubentonia*). The aye-aye uses its slender finger to probe for insects while foraging, and it is possible that *Epidendrosaurus* did the same.

Finally, the third area of concentration has been the Upper Cretaceous Wulansuhai Formation of western Inner Mongolia, an exceptionally prolific source of beautifully preserved dinosaurs and other vertebrates from the closing stages of the Mesozoic. In collaboration with both local paleontologists and foreign colleagues, IVPP researchers embarked on major expeditions to Wulansuhai sites north of the city of Linhe in the summers of 2008 and 2009. Ever since Chinese and Canadian paleontologists visited the same area together in 1988 and 1990, the Wulansuhai Formation has been known to contain a fauna rich in ankylosaurs, primitive ceratopsians and small theropods, preserved alongside lizards, mammals and dinosaur eggs. In many respects this assemblage is similar to that known from the famous Flaming Cliffs and other localities in the seemingly contemporaneous Djadokhta Formation of Mongolia proper.

The only Wulansuhai specimen from the recent IVPP expeditions to have so far been described is *Linheraptor exquisitus* (Xu *et al.*, 2010a), a nearly complete small dromaeosaurid that provides a

wealth of information on the anatomical characteristics of this group. However, work is ongoing and further discoveries will certainly follow. Also worthy of mention is the recent description of another Cretaceous theropod, *Gigantoraptor erlianensis*, from the Iren Dabasu Formation of eastern Inner Mongolia (Xu *et al.*, 2007). *Gigantoraptor*, which must rank as one of the most surprising finds of the past several years, is an enormous (probable body mass greatly exceeding one tonne) relative of the small, toothless, crested Mongolian theropod *Oviraptor*.

The efforts of IVPP dinosaur researchers have not been limited to the three regions discussed above. For instance, Xu *et al.* (2010b) recently described the new Cretaceous alvarezsaurid *Xixianykus* based on a specimen from Xixia County in Henan Province. Furthermore, the IVPP has seen a recent trend toward analytical studies of various aspects of the biology and evolution of extinct vertebrates, taking place alongside the important traditional



The dromaeosaurid theropod *Linheraptor exquisitus* from the Upper Cretaceous Wulansuhai Formation of Inner Mongolia, China. (Photo: IVPP)

work of describing new taxa and assessing their phylogenetic positions, and dinosaur research has been no exception. For example, Zhao *et al.* (2007) inferred the presence of gregarious behavior in juveniles of the primitive ceratopsian *Psittacosaurus*, Sullivan *et al.* (2010) documented the gradual evolution of a bird-like wrist posture in theropods, and Hone *et al.* (2010) found evidence corroborating the possibility that the dromaeosaurids of the Wulansuhai fauna sometimes fed on ceratopsians. Dinosaur research at the IVPP has moved emphatically into the 21st century—without, of course, losing sight of the Jurassic and Cretaceous in the process.

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