Exciting Fossil Discoveries Shed Light on the Origin and Evolution of Fishes and Reptiles

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Abstract: Over the last decade, numerous important vertebrate fossils have been discovered by scientists from the Institute of Vertebrate Paleontology and Paleoanthropology (IVPP) of the Chinese Academy of Sciences (CAS), which have significantly enriched understanding about the origin and early evolution of fish, amphibians, and reptiles. Particularly, researches about the origin of jawed vertebrates and origin of birds have systematically revised previous thoughts. These studies also demonstrate the globally leading role played by IVPP research teams in this field.

Keywords: vertebrates; palaeontology; evolution; fossil

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Fish, amphibians, and reptiles represent an incredibly diverse array of species that occupy nearly every ecosystem on the planet. The origin and evolution of these groups have been long-standing topics in evolutionary biology, because the early members of these clades include some of the most eye-catching species such as the dinosaurs, and many evolutionary innovations such as the powered flight.

The department of Paleoichthyology and Paleoherpetology at the Institute of Vertebrate Paleontology and Paleoanthropology (IVPP) of the Chinese Academy of Sciences (CAS) focuses on the

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origin, evolution and taxonomy of fossil vertebrates that are not closely related to mammals, including fish, reptiles and amphibians from the past half-billion years of geological time. The department boasts a team of world-class paleontologists including four Members of the Chinese Academy of Sciences who are still active in this community.

Over the past five years, this department has discovered numerous key fossils that significantly advance our understanding about the evolution history of major clades of non-mammalian vertebrates. Notably, we have led the studies on topics such as the origin and early evolution of Osteichthyes (bony fish), tetrapods, and the origin of birds and powered flight, and many of these studies have been published in prestigious journals such as *Nature* and *Science*.

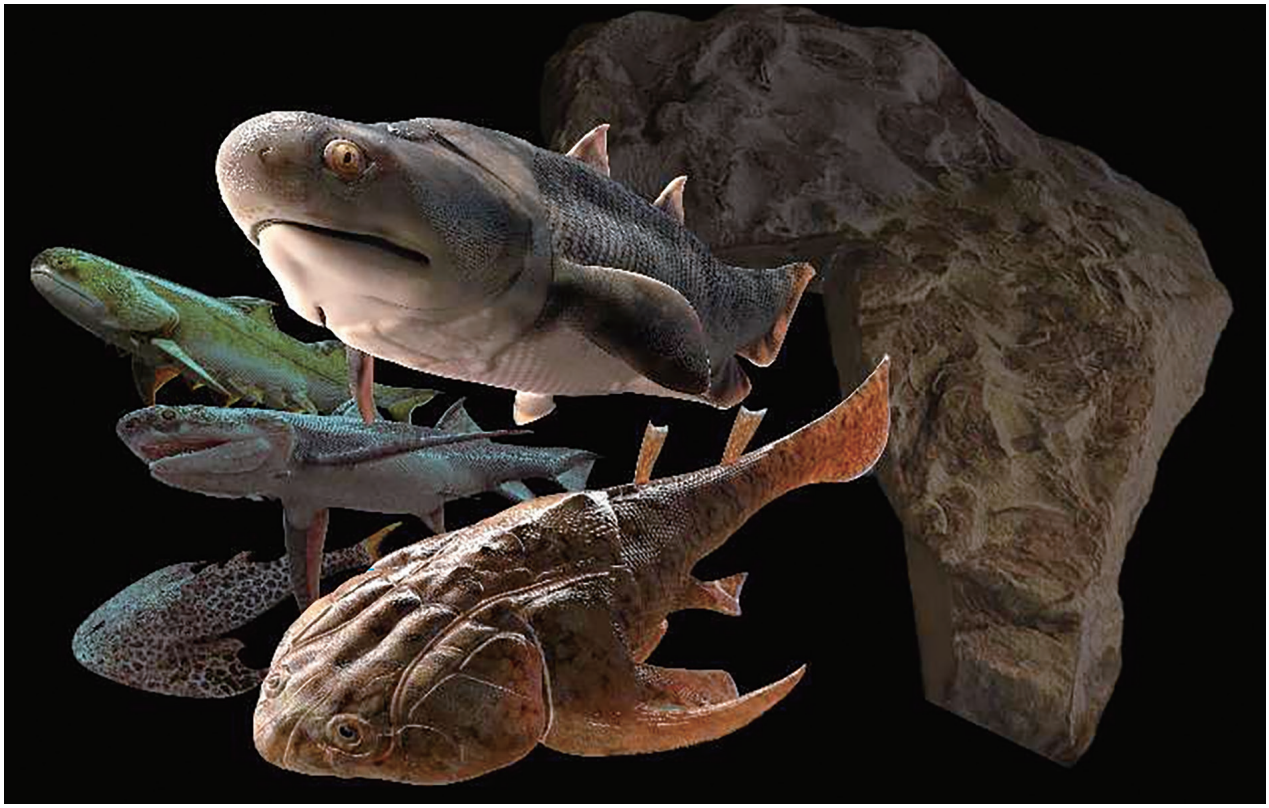
Here are some major progresses that this department has made recently:

(1) Early jawed vertebrates: The origin and rise of jawed vertebrates is undoubtedly one of the most critical evolutionary milestones in the history of vertebrates from fish to humans. However, for a long time, the scarcity of jawed vertebrate fossils before Devonian has left us with little understanding of how their body plans and key organs sequentially developed. Under the leadership of Dr. ZHU Min, a CAS Member, researchers have made significant advances in the discovery and investigation of jawed vertebrates before Devonian.

The discovery of Late Silurian (Ludlow) primitive osteichthyans and "maxillate placoderms" provide detailed fossil evidence for the origins of the gnathostome crown-group. Also, progress in our knowledge of jawless outgroup, such as the galeaspids gave hints of how key jawed vertebrate organs such as the paired nasal sacs and paired fin may already have appeared or have immediate precursors in the agnathans. The completely preserved placoderms (armourer jawed fish) and an armoured chondrichthyan from this fossil trove fills in a 14-million-year gap in the earliest fossil record of jawed vertebrates, revealing the diverse and proliferating jawed fish fauna long before the traditionally defined "Age of Fishes" (Zhu *et al*., 2013; Zhu *et al*., 2022).

(2) Marine reptiles: Based on significant marine reptile fossils

Recently discovered early Silurian (Llandovery) vertebrates from South China. Left, five new taxa; from top to bottom: ***Shenacanthus vermiformis, Fanjingshania renovata, Qianodus duplicis, Tujiaaspis vividus***, and ***Xiushanosteus mirabilis***; Right, the slab bearing the holotypes of ***Xiushanosteus*** and ***Shenacanthus***.

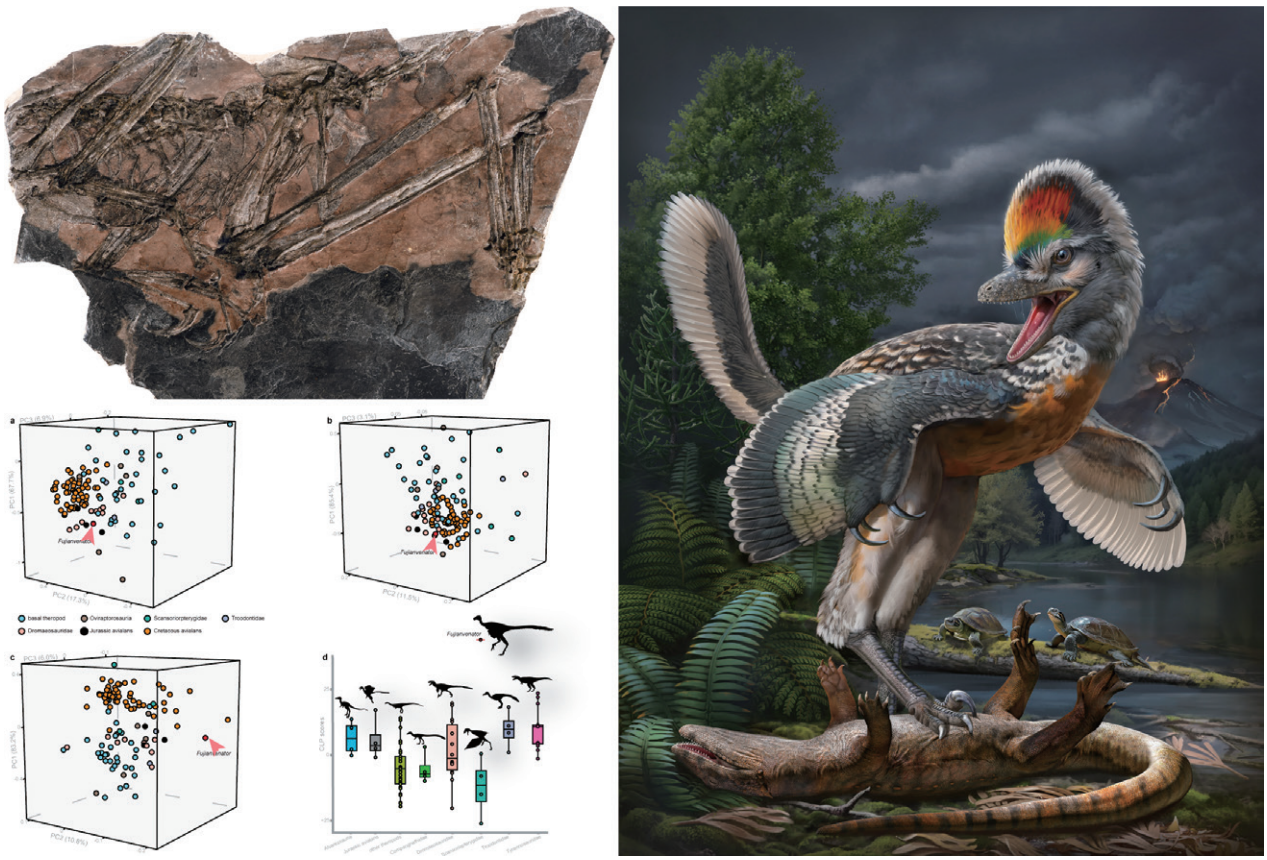


from the Eastern Tethys Ocean, now known as South China, our recent studies illuminate the origin, evolutionary radiation, and recovery of multiple secondarily aquatic reptile clades. Turtles exhibit a unique body plan among all vertebrates, with the modifications of their skulls and the origin of their shells representing some of the greatest mysteries in reptile evolution. *Odontochelys* and *Eorhynchochelys* about 230 million years ago from Guizhou, are two of the earliest known turtles (Li *et al*., 2018). These fossils reveal the reduction of temporal openings and dentition from a typical diapsid skull, and the acquisition of a carapace through rib expansion.

(3) Amphibians, squamates and choristoderes: We reported an early Eocene varanid stem from Central China (*Archeaovaranus lii*), whose holotype preserved a nearly complete skeletal and therefore provided detailed information on the cranial evolution of the varanid clade (which includes the largest lizard now living in the world, *Varanus Komodoensis*). The discovery of *Archaeovaranus* supported the hypothesis that the varanid clade originated in Asia and then spread to other part of the world (Dong *et al*., 2022).

(4) Fish fauna evolution on "Roof of the World": the rapid uplift of the Qinghai-Xizang Plateau during the late Cenozoic changed it into a habitat island isolated from an increasing complexity of less elevated environments. This makes it a laboratory similar to the Galapagos Islands for studying evolution in action. We reconstructed the evolution of the fish faunas in the Qinghai-Xizang Plateau Region since the collision of the Indian sub-continent and Eurasian continent, from the tropical fish fauna of tropical climbing perch, silurid catfish and barbine cyprinid fishes of the Eocene and Oligocene to the fauna comprising cold-adapted highly specialized snow carps and plateau loaches of the Pliocene. Our paleobiogeographical analyses also highlight the role of the Qinghai-Xi-

IVPP discovered a 150-million-year-old avialan theropod *Fujianvenator prodigiosus* and a new Jurassic fauna—Zhenghe Fauna in 2023. This fossil represents one of the stratigraphically youngest and geographically southmost members of Jurassic avialans, contributing a great deal of spatio-temporal information about early avialan diversification close to the end of the Jurassic (Life reconstruction of *Fujianvenator prodigiosus* is an artwork by Mr. ZHAO Chuang).



zang Plateau as an evolutionary junction in the dispersal history of some freshwater fishes (*e.g.*, climbing perch) via docked India from tropical Asian to African continents during the early and middle Eocene (Wu *et al.*, 2019).

(5) The origin of birds and flight: IVPP arguably represents the most active institute in this field across the world, and presents a handful of important studies that piece together how birds evolved from non-avian dinosaurs, the evolution of powered flight, feathers, and key biological features of birds. Akin to this issue, IVPP described the membranous winged scansoriopterygid theropod dinosaurs, which document a flight apparatus that was previously unknown among dinosaurs, greatly increasing the breadth of evolutionary experimentation that took place close to the origin of birds. In 2023, a joint team led by Dr. WANG Min from IVPP described and analyzed a new 150-million-year-old avialan theropod from Zhenghe Country, Fujian Province, and also named a new Jurassic fauna—Zhenghe Fauna. The new species, named *Fujianvenator prodigiosus*, exhibits a bizarre assembly of morphologies that are shared with other avialans, troodontids, and dromaeosaurids, showing the impact of evolutionary mosaicism in early bird evolution. The discovery of Zhenghe Fauna opens a new window into the Late Jurassic terrestrial ecosystem of the planet (Xu *et al*., 2023).

(6) Dinosaur eggs: Using magnetostratigraphy, cyclostratigraphy, and biostratigraphy, we establish a high-resolution geochronological framework for the fossil-rich Late Cretaceous sedimentary sequence in the Shanyang Basin of central China. Along with the dinosaur eggshell records from eastern and southern China, we find a decline in dinosaur biodiversity from the Campanian to the Maastrichtian. Our results support a long-term decline in global dinosaur biodiversity prior to 66 million years ago, which likely set the stage for the end-Cretaceous non-avian dinosaur mass extinction.

(7) Pterosaurs: Since 2005, as well as the first discovery of the Hami Pterosaur Fauna, the pterosaur research team has explored and excavated the fossil localities in Hami. They have collected abundant male and female *Hamipterus tianshanensis* specimens, which represent different ontogenetic stages associated with numerous eggs and embryos. Besides a series of phenomenal discoveries such as the most abundant male and female pterosaur fossils, the first 3D preserved pterosaur eggs, and the first 3D preserved pterosaur embryos, they, cooperating with a Brazilian team, also made some progresses in the understanding of the morphology, ontogeny, osteohistology, reproduction, and embryonic development. This pterosaur group also has reported numerous pterosaur taxa from the Middle—Late Jurassic Yanliao Biota and the Early Cretaceous Jehol Biota, establishing twelve new genera and fourteen new species since 2010 (Wang *et al*., 2017).

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