

## Introduction

# Recent advances in Chinese palaeontology

Xing Xu<sup>1,\*</sup>, Zhe-Xi Luo<sup>2</sup> and Jia-Yu Rong<sup>3</sup>

<sup>1</sup>Key Laboratory of Evolutionary Systematics of Vertebrates, Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences, Beijing 100044, People's Republic of China

<sup>2</sup>Section of Vertebrate Paleontology, Carnegie Museum of Natural History, Pittsburgh, PA 15213-4080, USA

<sup>3</sup>State Key Laboratory of Palaeobiology and Stratigraphy, Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences, Nanjing 210008, People's Republic of China

Discoveries are a driving force for progress in palaeontology. Palaeontology as a discipline of scientific inquiry has gained many fresh insights into the history of life, from the discoveries of many new fossils in China in the last 20 years, and from the new ideas derived from these fossils. This special issue of *Proceedings of Royal Society B* entitled *Recent Advances in Chinese Palaeontology* selects some of the very latest studies aimed at resolving the current problems of palaeontology and evolutionary biology based on new fossils from China. These fossils and their studies help to clarify some historical debates about a particular fossil group, or to raise new questions about history of life, or to pose a new challenge in our pursuit of science. These works on new Chinese fossils have covered the whole range of the diversity through the entire Phanerozoic fossil record.

**Keywords:** palaeontology; evolution; paleobiogeography; morphology; China

A major evolutionary pattern from the Phanerozoic fossil record is that the extinct lineages of life have a far greater morphological disparity than extant life forms. Also, many more species evolved and gone extinct in the deep times of geological history than those living today (Gould 1990; Conway Morris 1998). Palaeontology provides a unique perspective, and can make an arguably indispensable contribution to enrich our understanding of evolution by exploring the greater diversity of fossils with a vast time dimension of geological history than is afforded by living biological diversity.

Many recent and notable palaeontological contributions to evolutionary theory have come from China. A vast variety of fossils recently discovered in China could not be pigeon-holed into previously known groups; this helps to expand our knowledge of the ancient biological diversity. Because many new, exquisite fossils of known lineages are exceptionally complete, they revealed characters in unique combinations, some of which had not been 'expected' according to the received wisdom. Where to place these new fossils on the tree of life and how to interpret their way of life can influence our understanding of evolutionary history. For example, the vetulicolians from the Early Cambrian Chengjiang biotas represent a new and distinctive clade of deuterostome animals (Shu *et al.* 2001). The surprising combination of features of the enigmatic yunnanozoons has stimulated a long and passionate debate about their place on the deuterostome family tree (Chen 2008). Shu *et al.* (2010) reviewed the diverse deuterostomes

from Chengjiang with emphasis on vetulicolians and yunnanozoons, and argued that these two groups are very basal among the diverse deuterostome lineages. With well-preserved fossils from Chengjiang, Zhang *et al.* (2010) demonstrated that the lingulate brachiopods—a premier example of living fossil lineage—have long occupied their distinctive ecological niches, from the Cambrian to the Recent.

More than just the scintillating curiosities of extinct life forms, some of these fossils have raised new research questions and forced us to reconsider the previous paradigms. How can students of biomechanics and functional morphology develop new models to account for the flying function of four-winged pre-avian theropods and birds (Xu *et al.* 2003; Zhang & Zhou 2004; Chatterjee & Templin 2007)? New fossils challenge the traditional hypothesis of tetanuran theropod manual digits and promise to solve the long-debated problem of avian digital homologies (Xu *et al.* 2009). Contrary to the prevailing idea of the 1970s that the mammalian tribosphenic molar was a singular evolutionary innovation, Chinese fossils suggest that tribosphenic molars evolved homoplastically in several lineages (Wang *et al.* 1998; Luo *et al.* 2001, 2007; Luo 2007). New Jurassic mammals capable of swimming and gliding suggest that they invaded diverse ecological niches in the dinosaur-dominated ecosystem (Ji *et al.* 2006; Meng *et al.* 2006). So how did such interaction influence the terrestrial ecosystem? What are the palaeoecological implications of the earliest-known angiosperm plants that have turned out to be aquatic (Sun *et al.* 1998, 2002)?

Several research areas on China's fossils and biostratigraphy have attracted attention from the broader communities of scientists in earth science and biology, such as the studies of the Neoproterozoic animal embryos, earliest known metazoans and the Ediacaran

\* Author for correspondence ([xingxu@vip.sina.com](mailto:xingxu@vip.sina.com)).

One contribution to a Special Issue 'Recent advances in Chinese palaeontology'.

forms (e.g. Zhu *et al.* 2008), and the voluminous and exacting studies on the Permian–Triassic mass extinction and recovery (Jin *et al.* 2000; Erwin 2006). But the discoveries and studies in Chinese palaeontology have been more diverse in topics and richer in content than these noteworthy highlights. In this special issue of *Proceedings of the Royal Society B*, we invited the latest studies on important fossils and data newly collected by Chinese palaeontologists and their international collaborators. These works cover a much wider range of topics in morphology, taxonomy, phylogeny, functional analysis and palaeoecology of fossils from China.

Not surprisingly, several contributions come from the studies of dinosaurs from the well-known Jehol group and its stratigraphical equivalents of lower Cretaceous in northern China. Li *et al.* (2010) report a new tyrannosauroid with intermediate morphologies between the derived gigantic tyrannosaurids and the more basal, smaller members of this lineage, highlighting the patterns in feeding adaptation and evolution of size in tyrannosauroids. Makovicky *et al.* (2010) report a new giant ornithomimosaur, which gives an insight in the growth mechanism of gigantism that occurred in parallel in several lineages of beaked theropods. Sereno *et al.* (2010) report a new species of psittacosaurids, a group of the horned and frilled dinosaurs endemic to Asia. Their novel functional analysis on the psittacosaurid jaws suggests that psittacosaurids and the unrelated psittaciform birds have many similarities in chewing mechanism. Zheng *et al.* (2010) report an unusual dromaeosaurid with relatively short arms and small furcula, suggesting that aerodynamic capability might have evolved in the common ancestor of the paravian clade of birds, dromaeosaurids and troodontids, but was secondarily lost in several paravian taxa early in paravian evolution. This is echoed by the interesting results from Zhou *et al.* (2010a) on a primitive and toothless bird. Given the character distribution pattern across the avian phylogeny presented by the authors (Zhou *et al.* 2010a), the presence of dentition and a long skeletal tail in some basal birds would be best explained as reversals to the ancestral condition. These would provide the strongest evidence yet for the widespread and radical reversals in morphological evolution of the earliest avians.

Each contribution on fossil mammals in this issue offers a fresh insight. Hu *et al.* (2010) report on one of the earliest known eutherian mammals that is ancestral to placentals. Gao *et al.* (2010) revealed the upper tooth features for the amphilestid mammals—a group with plesiomorphic dental features for mammalian dental evolution. Ni *et al.* (2010) report a new primate from the Eocene beds of Inner Mongolia that has a close relationship to coeval primates of North America, consistent with a broader mammalian palaeobiogeography of the Eurasian–North American continents during the Eocene (Beard 1998), and supports a close relationship between dermopterans and primates, as corroborated by molecular phylogeny (Springer *et al.* 2003).

Palaeobiogeography is a topic of general interest to palaeontologists and a thread through several publications of this special issue: Zhou *et al.* (2010b) present a nice analysis on the evolutionary trends and palaeobiogeography of an Ordovician trilobite genus. Wang & Zhang

(2010a) provide new information concerning the Silurian biostratigraphy and palaeogeography based on new data from sporomorph and graptolite fossils. Sha's (2010) work on non-marine Cretaceous trigonoid bivalves provides new information concerning the palaeogeography in the Cretaceous of Asia.

The mainstay of this theme issue is on the evolutionary morphology of various fossil groups. Liu *et al.* (2010) present the skull morphology of the most primitive anomodont—a therapsid mammal-like reptile from the Permian. Lu & Zhu (2010) report one of the oldest-known onychodont fishes from the Early Devonian of South China. Its skull structures shed new light on feeding mechanisms of onychodonts and corroborate their place on the family tree of lob-fin sarcopterygian fishes, which are relevant to water-to-land transition in vertebrate history. Wang & Pfefferkorn (2010) report a new gymnosperm plant that has plesiomorphic ovulate structure but derived characters in leaves and branches, clarifying the pattern of evolution of the gymnosperm reproductive structures. Wang & Zhang (2010b) describe the rarely preserved fertile structures of a new dipteridaceous fern. Kellner *et al.*'s (2010) detailed observation on a well-preserved pterosaur specimen provides new information on the comparatively poorly known morphology of soft tissues in this extinct group. Mo *et al.* (2010) demonstrate the presence of the lepidosaurian lower temporal bar, a structure considered to be lost in lizards and snakes, in a boreoteiid lizard, and present a functional analysis on the cranial morphology of this taxon. Wu *et al.* (2010) present the newest study on the brain endocast of the Peking Man (*Homo erectus*) and brain evolution in hominins.

This special issue on *Recent Advances in Chinese Palaeontology* is limited in its selection and can only serve as a snapshot of the rapid and continuous discoveries of interesting fossils of all sorts from China. Over the last two decades, palaeontology in China has maintained a great momentum, thanks to the dedication of Chinese palaeontologists who are working with extensive international collaboration and in a favourable climate of scientific funding. In many cases, China's rapid economic development, and the spontaneous search for fossils by peasants for profit, also accelerated the pace of discoveries. New and active research is being published at faster pace and in much larger volumes than can be sampled by this special issue. We regret that we could not accommodate many equally worthy research works in this issue.

We are thankful for the interest in palaeontology of China by the editorial board of *Proceedings of the Royal Society B*, especially the previous Editor-in-Chief, Prof. W. G. Hill (Edinburgh), Prof. M. P. Hasell (current Editor-in-Chief) and Prof. R. L. Cifelli (Oklahoma, Associate Editor), who encouraged us to organize this special issue. We thank the contributing authors who not only agreed to participate, but also gave their latest works to this issue. Each contribution has gone through the standard external peer reviews of the Royal Society; we want to thank all referees for their constructive criticism and valuable input. Finally, we are indebted to Prof. W. G. Hill and Claire Rawlinson for their help to initiate this special issue, and to Ms Victoria Millen (Publishing Editor of *Proceedings of the Royal Society B*) for her support, guidance and extraordinary patience throughout the editorial process. This theme issue would not be possible without the encouragement and help provided by these great colleagues.

## REFERENCES

- Beard, K. C. 1998 East of Eden: Asia as an important center of taxonomic origination in mammalian evolution. *Bull. Carnegie Mus. Nat. Hist.* **34**, 5–39.
- Chatterjee, S. & Templin, R. J. 2007 Biplane wing planform and flight performance of the feathered dinosaur *Microaptor gui*. *Proc. Natl Acad. Sci.* **104**, 1576–1580. (doi:10.1073/pnas.0609975104)
- Chen, Y. 2008 Early cretary animals and the insight they provide into the evolutionary origin of craniates. *Genesis* **46**, 623–639. (doi:10.1002/dvg.20445)
- Conway Morris, S. 1998 *The crucible of creation: the Burgess Shale and the rise of animals*. Oxford, UK: Oxford University Press.
- Erwin, D. H. 2006 *Extinction: how life on earth nearly ended 250 million years ago*. Princeton, NJ: Princeton University Press.
- Gao, C.-L., Wilson, G. P., Luo, Z.-X., Maga, A. M., Meng, Q.-J. & Wang, R. 2010 A new mammal skull from the Lower Cretaceous of China with implications for the evolution of obtuse-angled molars and ‘amphiletid’ eutriconodonts. *Proc. R. Soc. B* **276**, 237–246. (doi:10.1098/rspb.2009.1014)
- Gould, S. J. 1990 *Wonderful life: the Burgess Shale and the nature of history*. New York, NY: W. W. Norton & Company.
- Hu, Y.-M., Meng, J., Li, C.-K. & Wang, Q. 2009 New basal eutherian mammal from the Early Cretaceous Jehol biota, Liaoning, China. *Proc. R. Soc. B* **276**, 229–236. (doi:10.1098/rspb.2009.0203)
- Ji, Q., Luo, Z.-X., Yuan, C.-X. & Tabrum, A. R. 2006 A swimming mammaliaform from the Middle Jurassic and ecomorphological diversification of early mammals. *Science* **311**, 1123–1127. (doi:10.1126/science.1123026)
- Jin, Y.-G., Wang, Y., Wang, W., Shang, Q.-H., Cao, C.-Q. & Erwin, D. H. 2000 Pattern of marine mass extinction near the Permian-Triassic boundary in South China. *Science* **289**, 432–436. (doi:10.1126/science.289.5478.432)
- Kellner, A., Wang, X.-L., Tischlinger, H., Campos, D. A., Hone, D. & Meng, X. 2010 The soft tissue of *Jeholopterus* (Pterosauria, Anurognathidae) and the structure of the pterosaur wing membrane. *Proc. R. Soc. B* **276**, 321–329. (doi:10.1098/rspb.2009.0846)
- Li, D.-Q., Norell, M. A., Gao, K.-Q., Smith, N. D. & Makovicky, P. J. 2010 A longirostrine tyrannosauroid from the Early Cretaceous of China. *Proc. R. Soc. B* **276**, 183–190. (doi:10.1098/rspb.2009.0249)
- Liu, J., Rubidge, B. & Li, L. 2010 A new specimen of *Biseridens qilianicus* indicates its phylogenetic position as the most basal anomodont. *Proc. R. Soc. B* **276**, 285–292. (doi:10.1098/rspb.2009.0883)
- Lu, J. & Zhu, M. 2010 An onychodont fish (Osteichthyes, Sarcopterygii) from the Early Devonian of China, and the evolution of the Onychodontiformes. *Proc. R. Soc. B* **276**, 293–299. (doi:10.1098/rspb.2009.0708)
- Luo, X. 2007 Transformation and diversification in the early mammalian evolution. *Nature* **450**, 1011–1019. (doi:10.1038/nature06277)
- Luo, Z.-X., Cifelli, R. C. & Kielan-Jawornowska, Z. 2001 Dual evolution of tribosphenic mammals. *Nature* **409**, 53–57. (doi:10.1038/35051023)
- Luo, Z.-X., Ji, Q. & Yuan, X. 2007 Convergent dental evolution in pseudotribosphenic and tribosphenic mammals. *Nature* **450**, 93–97. (doi:10.1038/nature06221)
- Makovicky, P. J., Li, D.-Q., Gao, K.-Q., Lewin, M., Erickson, G. M. & Norell, M. A. 2010 A giant ornithomimosaur from the Early Cretaceous of China. *Proc. R. Soc. B* **276**, 191–198. (doi:10.1098/rspb.2009.0236)
- Meng, J., Hu, Y.-M., Wang, Y.-Q., Wang, X.-L. & Li, K. 2006 A Mesozoic gliding mammal from northeastern China. *Nature* **444**, 889–893. (doi:10.1038/nature05234)
- Mo, J.-Y., Xu, X. & Evans, S. E. 2010 The evolution of the lepidosaurian lower temporal bar: new perspectives from the Late Cretaceous of South China. *Proc. R. Soc. B* **276**, 331–336. (doi:10.1098/rspb.2009.0030)
- Ni, X.-J., Meng, J., Beard, K. C., Gebro, D. L., Wang, Y.-Q. & Li, K. 2010 A new tarkadectine primate from the Eocene of Inner Mongolia, China: phylogenetic and biogeographic implications. *Proc. R. Soc. B* **276**, 247–256. (doi:10.1098/rspb.2009.0173)
- Sereno, P. C., Zhao, X.-J. & Tan, L. 2010 A new psittacosaur from Inner Mongolia and the parrot-like structure and function of the psittacosaur skull. *Proc. R. Soc. B* **276**, 199–209. (doi:10.1098/rspb.2009.0691)
- Sha, G. 2010 Historical distribution patterns of trigonoidids (non-marine Cretaceous bivalves) in Asia and their palaeogeographic significance. *Proc. R. Soc. B* **276**, 277–283. (doi:10.1098/rspb.2009.0936)
- Shu, D.-G., Conway Morris, S., Han, J., Chen, L., Zhang, X.-L., Zhang, Z.-F., Liu, H.-Q., Li, Y. & Liu, N. 2001 Primitive deuterostomes from the Chengjiang Lagerstätte (Lower Cambrian, China). *Nature* **414**, 419–424. (doi:10.1038/35106514)
- Shu, D.-G., Conway Morris, S., Zhang, Z.-F. & Han, J. 2010 The earliest history of the deuterostomes: the importance of the Chengjiang Fossil-Lagerstätte. *Proc. R. Soc. B* **276**, 165–174. (doi:10.1098/rspb.2009.0646)
- Springer, M. S., Murphy, W. J., Eizirik, E. & O’Brien, S. J. 2003 Placental mammal diversification and the Cretaceous-Tertiary boundary. *Proc. Natl Acad. Sci.* **100**, 1056–1061. (doi:10.1073/pnas.0334222100)
- Sun, G., Dilcher, D. L., Zheng, S. & Zhou, Z. 1998 In search of the first flower: a Jurassic angiosperm, *Archaeofructus*, from northeast China. *Science* **282**, 1692–1695. (doi:10.1126/science.282.5394.1692)
- Sun, G., Ji, Q., Dilcher, D. L., Zheng, S.-L. & Nixon, K. C. 2002 Archaeofructaceae, a new basal angiosperm family. *Science* **296**, 899–904. (doi:10.1126/science.1069439)
- Wang, J. & Pfefferkorn, H. W. 2010 Nystroemiaceae, a new family of Permian gymnosperms from China with an unusual combination of features. *Proc. R. Soc. B* **276**, 301–309. (doi:10.1098/rspb.2009.0913)
- Wang, Y. & Zhang, D. 2010a Llandoverly sporomorphs and graptolites from the Manbo Formation, the Mojiang County, Yunnan, China. *Proc. R. Soc. B* **276**, 267–275. (doi:10.1098/rspb.2009.0214)
- Wang, Y.-D. & Zhang, H. 2010b Fertile organs and *in situ* spores of a new dipteridacean fern *Hausmannia simensis* from the Jurassic of northern China. *Proc. R. Soc. B* **276**, 311–320. (doi:10.1098/rspb.2009.0198)
- Wang, Y.-Q., Clemens, W. A., Hu, Y.-M. & Li, K. 1998 A probable pseudo-tribosphenic upper molar from the Late Jurassic of China and the early radiation of the Holotheria. *J. Vert. Paleont.* **18**, 777–787.
- Wu, X.-J., Schepartz, L. A. & Wu, L. 2010 A new *Homo erectus* (Zhoukoudian V) brain endocast from China. *Proc. R. Soc. B* **276**, 337–344. (doi:10.1098/rspb.2009.0149)
- Xu, X., Zhou, Z.-H., Wang, X.-L., Kuang, X.-W., Zhang, F.-C. & Du, K. 2003 Four-winged dinosaurs from China. *Nature* **421**, 335–340. (doi:10.1038/nature01342)
- Xu, X. et al. 2009 A Jurassic ceratosaur from China helps clarify avian digit homologies. *Nature* **459**, 940–944. (doi:10.1038/nature08124)
- Zhang, F.-C. & Zhou, H. 2004 Leg feathers in an Early Cretaceous bird. *Nature* **431**, 925. (doi:10.1038/431925a)
- Zhang, Z.-F., Han, J., Wang, Y., Christian, C. E. & Shu, G. 2010 Epibionts on the linguat brachiopod Diandongia

- from the Early Cambrian Chengjiang Lagerstätte, South China. *Proc. R. Soc. B* **276**, 175–181. (doi:10.1098/rspb.2009.0618)
- Zheng, X. T., Xu, X., You, H.-L., Zhao, Q. & Dong, M. 2010 A short-armed dromaeosaurid from the Jehol Group of China with implications for early dromaeosaurid evolution. *Proc. R. Soc. B* **276**, 211–217. (doi:10.1098/rspb.2009.1178)
- Zhou, Z.-H., Zhang, F.-C. & Li, H. 2010*a* A new Lower Cretaceous bird from China and tooth reduction in early avian evolution. *Proc. R. Soc. B* **276**, 219–227. (doi:10.1098/rspb.2009.0885)
- Zhou, Z.-Y., Yuan, W.-W. & Zhou, Q. 2010*b* Evolutional trends and palaeobiogeography of the trilobite *Ovalocephalus* Koroleva, 1959. *Proc. R. Soc. B* **276**, 257–266. (doi:10.1098/rspb.2009.0133)
- Zhu, M., Gehling, J. G., Xiao, S., Zhao, Y.-L. & Droser, M. 2008 Eight-armed Ediacara fossil preserved in contrasting taphonomic windows from China and Australia. *Geology* **36**, 867–870. (doi:10.1130/G25203A.1)