T. rex with feathers: China's fossils are rewriting the dinosaur story

Twenty-five years ago, Chinese scientists revealed the first feathered dinosaur. Since then, they have unearthed a treasure trove of exquisitely preserved specimens that put dinosaurs in a whole new light

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By **Michael Benton**

Sinosauropteryx upended the idea that feathers are unique to birds
Julius T Csotonyi/Science Photo Library

IN OCTOBER 1996, I was in New York City attending the annual meeting of the Society of Vertebrate Paleontology at the American Museum of Natural History. The atmosphere was electric. I recall hurried encounters in hallways featuring black and white photographs and stunned reactions. Yale University's John Ostrom – the leading expert on fossil birds and dinosaurs at the time – said the images left him "in a state of shock". Another dinosaur expert, Phil Currie, then at the Royal Tyrrell Museum of Palaeontology in Drumheller, Canada, described being "bowled over".

At the centre of all the fuss was a specimen that had recently been uncovered in China. No paper had yet been published describing the animal, but Pei-ji Chen at the Nanjing Paleontology Institute had pictures, and they were jaw dropping. They showed a feathered dinosaur – the first ever seen in the West. It confirmed what Ostrom, Currie and others had long been arguing: birds are dinosaurs. As Malcolm Browne wrote in The New York Times: "Rarely are scientific findings of this possible importance presented so casually."

Chen's feathered dinosaur, later named *Sinosauropteryx*, was a shock, but nobody could predict that it was the harbinger of a deluge. Since 1996, thousands of specimens of dinosaurs and early birds have emerged from China's Jurassic and Cretaceous fossil beds, most of which are exceptionally well-preserved, including their soft tissues – and especially feathers. This has stimulated 25 years of scientific advances that have not only upended the received wisdom about feathers and birds, but also given new insights into the evolution of flight, warm-bloodedness and dinosaur behaviour.

What makes these fossils so extraordinary is the chemically unusual environment in which they formed. From about 160 million to 110 million years ago, there was continuing volcanic activity in what is now called North China, a large region north of Beijing. Some animals were buried alive under ash falls, like a prehistoric Pompeii. Many came to rest in ancient lakebeds where fine-grained sediments mixed with enough washed-in volcanic ash to make them acidic, minimising decay and scavenging. It also provided the right conditions to pickle the tougher soft tissues, including feathers, and even preserve internal organs, stomach contents and biomolecules such as proteins, lipids and sugars.

Microraptor (above and below) is one of the Chinese dinosaurs that shows flight evolved at least three times

Steve Vidler/Alamy

Before the discovery of *Sinosauropteryx*, feathers were thought to be a uniquely avian feature, one of the reasons for the huge success of birds, which now total more than 10,000 species. The Chinese fossils have comprehensively overturned this dogma. When Chen and colleagues published a paper about the fossil in 1998, they identified *Sinosauropteryx* as a compsognathid theropod dinosaur. These are distant from the ancestors of birds in the evolutionary tree, suggesting that hundreds of dinosaur species could have had feathers.

Since then, excavations in China have unearthed some 55 species each of dinosaurs and birds, including more than 30 dinosaur species with feathers. For example, even though fossils show that *Tyrannosaurus rex* had scaly skin, tyrannosauroids unearthed in China had rich feather coverings, so I think we can assume that all members of the group had feathers, at least as juveniles. Perhaps, like elephants and pigs, the young were fluffy and then lost this covering as they grew larger and had less need of insulation. Or perhaps adult *T. rex* still sported feather tufts on the head, or a Mohican-like plume down the back, to intimidate prey or rivals.

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Tyrannosauroids are theropods, the flesh-eating dinosaurs that gave rise to birds. But feathers have also been found in China among plant-eaters known as ornithischians. These specimens include the 2-metre-long beaked *Psittacosaurus* and *Tianyulong*, a 70-centimetre-long biped. *Kulindadromeus*, found in Russia in 2014, had closely packed insulating feathers over much of its body, with scaly legs and tail.

The third dinosaur group, the sauropodomorphs, which includes favourites such as the brontosaurs and titanosaurs, haven't yielded evidence of feathers. This may yet be discovered, but if it isn't, it is still likely that feathers originated with dinosaurs back in the Early Triassic, some 250 million years ago. That's because identical feathers occur in dinosaurs at opposite ends of the family tree, so their common ancestor almost certainly had them.

Feathered pterosaurs

Other animals from the period may have had feathers too. The pterosaurs aren't dinosaurs but their cousins, and they also originated in the Early Triassic. These leathery-winged flyers had a covering of bristles over their heads and bodies. In 2019, my colleagues and I identified multiple feather types in pterosaurs – some simple bristles as had been reported before, but also some that showed the same branching and structural shapes seen in dinosaurs. We called them feathers, but

others aren't so sure. Either way, the evidence suggests feathers arose long before the origin of birds.

The Chinese fossils haven't changed our thinking about when birds evolved: Archaeopteryx, which lived 150 million years ago, in the Late Jurassic, is still widely accepted as the first bird. But they have given us a much richer picture of bird evolution. Back in 1996, there was a long gap in the fossil record between *Archaeopteryx* – which had reptilian features, including jaws lined with teeth and a long, bony tail – and more modern birds dating from around 80 million years ago. This gap has now been filled with dozens of species of birdlike dinosaurs and early birds, the latter being distinguished by 30 or so distinctive traits, including specialised wrist joints to fold back the wings, hollow bones to save weight and a fused clavicle or wishbone.

Feathered dinosaurs included the plant-eating Psittacosaurus and carnivorous Sinosauropteryx (bottom)

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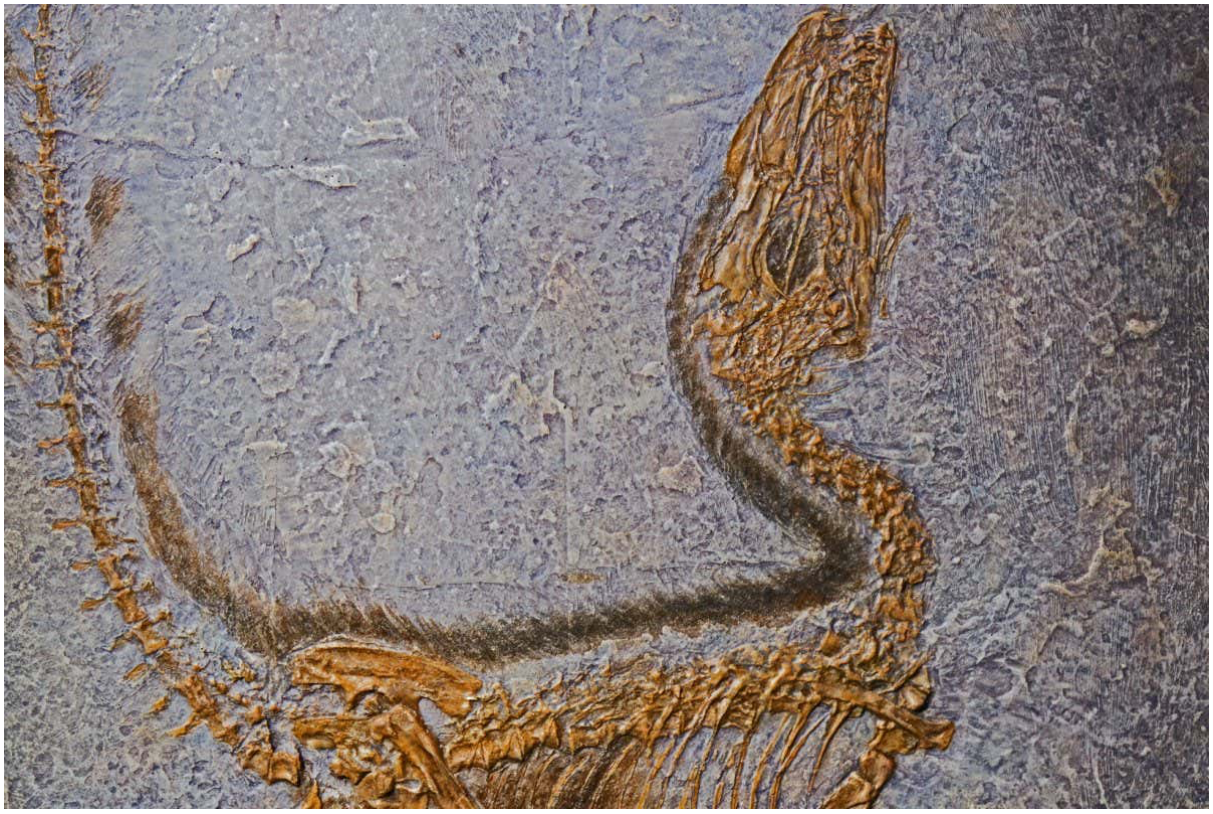
As well as enhancing our understanding of how and when birds evolved, the evidence from China leaves no doubt that birds are dinosaurs. It identifies a major new group of dinosaurs within the theropods called the paravians, which includes birds and little birdlike dinosaurs. It also reveals that many traits associated with birds have deep roots in non-avian dinosaurs. Not least of these, of course, is the feather.

The discovery of feathered dinosaurs doesn't just overturn the dogma that feathers are unique to birds, it also provides some intriguing insights into the lifestyle of the dinosaurs that sported them. Feathers have multiple functions in birds, including insulation, flight and display. The first dinosaurs certainly weren't flyers, but the Chinese fossils resolve a long-standing debate, confirming them to be warm-blooded (see "Cold-blooded no more"). Warm-blooded animals need to preserve the precious heat they generate, so insulation looks to be the reason feathers first emerged.

Display seems to have come later. We now think that the smaller feathered dinosaurs probably hopped and preened and flashed beautifully coloured head crests, tails and wing patterns to attract mates. This was true even of the short-armed, non-flying forms such as *Sinosauropteryx*, as my colleagues and I showed in 2010. If you put fossil feathers under a scanning electron microscope, you can see tiny pigment capsules called melanosomes. The pigment melanin is present in many organisms, and it takes two main forms in birds and mammals: phaeomelanin, which provides shades of ginger, and the more common eumelanin, which appears black, brown, grey or blonde depending on how densely it is packed.

Melanins are generated in the skin and enter developing hairs and feathers via the follicle, becoming encased in spherical phaeomelanosomes or sausage-shaped eumelanosomes. When we looked at feathers from the body of *Sinosauropteryx*, we saw only phaeomelanosomes – evidence that they were originally ginger, with a tail that was barred ginger and white. Other dinosaurs had red crests, black and white stripes on their wings and multicoloured mottles over the body.



As for flight, the Chinese fossils are shedding new light on that, too. In 2020, a study exploring the aerodynamics of early birds and their close relatives revealed that flight evolved not once but at least three times. To fly, a creature's wing area must exceed a critical point at which it can support the body weight. Paravians did this in various ways. *Archaeopteryx* and its kin had two feathered wings, while discoveries in China show that *Microraptor*, which lived around 125 million years ago, had four wings and its contemporary, *Yi qi*, had batlike membrane wings. This diversity has its origins around 175 million years ago when theropod dinosaurs underwent a dramatic evolutionary split in which most – like *T. rex* – became larger to overpower ever-larger herbivore prey, while the paravians shrank in size, probably in pursuit of insects, and modified their feathers for flight, camouflage and display.

Discoveries in China have immensely enriched our understanding of dinosaurs and early birds: what they looked like, their colours and mating displays, how they got around and how they are related to one another. A quarter of a century on from the astonishing revelation that dinosaurs can have feathers, fossils continue to emerge in large numbers in China. Who knows what revelations they will bring in the next 25 years.

Cold-blooded no more

Half a century ago, Bob Bakker, then a graduate student at Harvard University, made a startling suggestion: perhaps dinosaurs were warm-blooded, energetic and fast-moving like modern birds and mammals. His idea wasn't well received by other palaeontologists,

who had long reconstructed dinosaurs as slow-moving, cold-blooded reptiles. Remarkably, preserved fossils found in China over the past 25 years show Bakker was right.

The Chinese dinosaurs possess many markers of a rapid metabolism, not found in cold-blooded animals. They have air sacs within their vertebrae and limb bones, indicating a birdlike respiratory system. They appear to have had four-chambered hearts, another feature associated with warm-bloodedness. Unlike their reptilian forebears, they stood erect, with their limbs straight beneath the body, enabling them to breathe as they ran. And under the microscope, their bones look like those of birds and mammals, with evidence of fast growth and changing structure.

Even before they could fly, dinosaurs had feathers for insulation, a key requirement for warm-blooded animals to help conserve the heat they have generated. Finds in China suggest feathers emerged with the origins of dinosaurs and pterosaurs, meaning birds and their ancestors were warm-blooded at the same time mammals and their ancestors were becoming warm-blooded too.

This was the moment when life was bouncing back from the devastating end-Permian mass extinction, which wiped out more than 90 per cent of species 252 million years ago. The survivors entered a tough, arid world, and there was an evolutionary arms race as they began to build new ecosystems. This marked a huge shift in the nature of terrestrial ecosystems to the modern form with its high activity levels and increased energy use.