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Is it a bird? A critical analysis of feathered fossils

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ABSTRACT

It has long been thought that birds are descended from theropod dinosaurs with *Archaeopteryx* considered to be a classic intermediate between the two groups. The discovery of small theropod dinosaurs with 'protofeathers' in the 1990s was seen as confirmation that birds are descended from dinosaurs. More recently, many feathered theropods have been discovered in China and have been interpreted as showing how birds evolved from theropod dinosaurs. Some scientists have questioned the existence of 'protofeathers' and feathers on some of these creatures, and others have suggested that feathered theropods are birds. This critical analysis of the fossils reviews the evidence for feathered theropods and compares them to living and extinct birds. An informal classification of the feathered fossils is suggested.

INTRODUCTION

Thomas Huxley was the first person to connect birds to dinosaurs (Huxley 1870). He compared the hind limbs of *Megalosaurus*, a giant theropod, with those of the ostrich and noted 35 features that the two groups shared but that did not occur as a suite in any other animal. He concluded that birds and theropods could be closely related.

Archaeopteryx (discovered in 1861) is perhaps one of the most famous fossils (Figure 1) and is considered to be a classic intermediate between theropod dinosaurs and birds. Its iconic status as an intermediate was firmly established in the 1970s by John H. Ostrom of Yale University. Ostrom compared the skeletons of *Archaeopteryx* and the theropod *Deinonychus* and, because of the many similarities, he proposed that birds were the direct descendants of theropods (Ostrom 1976).

The discovery of small theropod fossils with 'protofeathers' in China during the 1990s and other similar creatures with feathers is now presented as confirmation that birds evolved from theropod dinosaurs. More recently, the discovery of many feathered dinosaurs in China has resulted in a revision of the significance of *Archaeopteryx* given that there are now other fossils which could be considered to be transitional forms (Mayr 2016).

Figure 1. a.The Berlin specimen of *Archaeopteryx lithographica*, collected in 1861 and on display in the Museum für Naturkunde, Berlin, Germany. Photograph by H. Raab / CC-BY-SA 3.0. **b.** Reconstruction of *Archaeopteryx*. Image by Nobu Tamura / CC BY-SA 3.0.

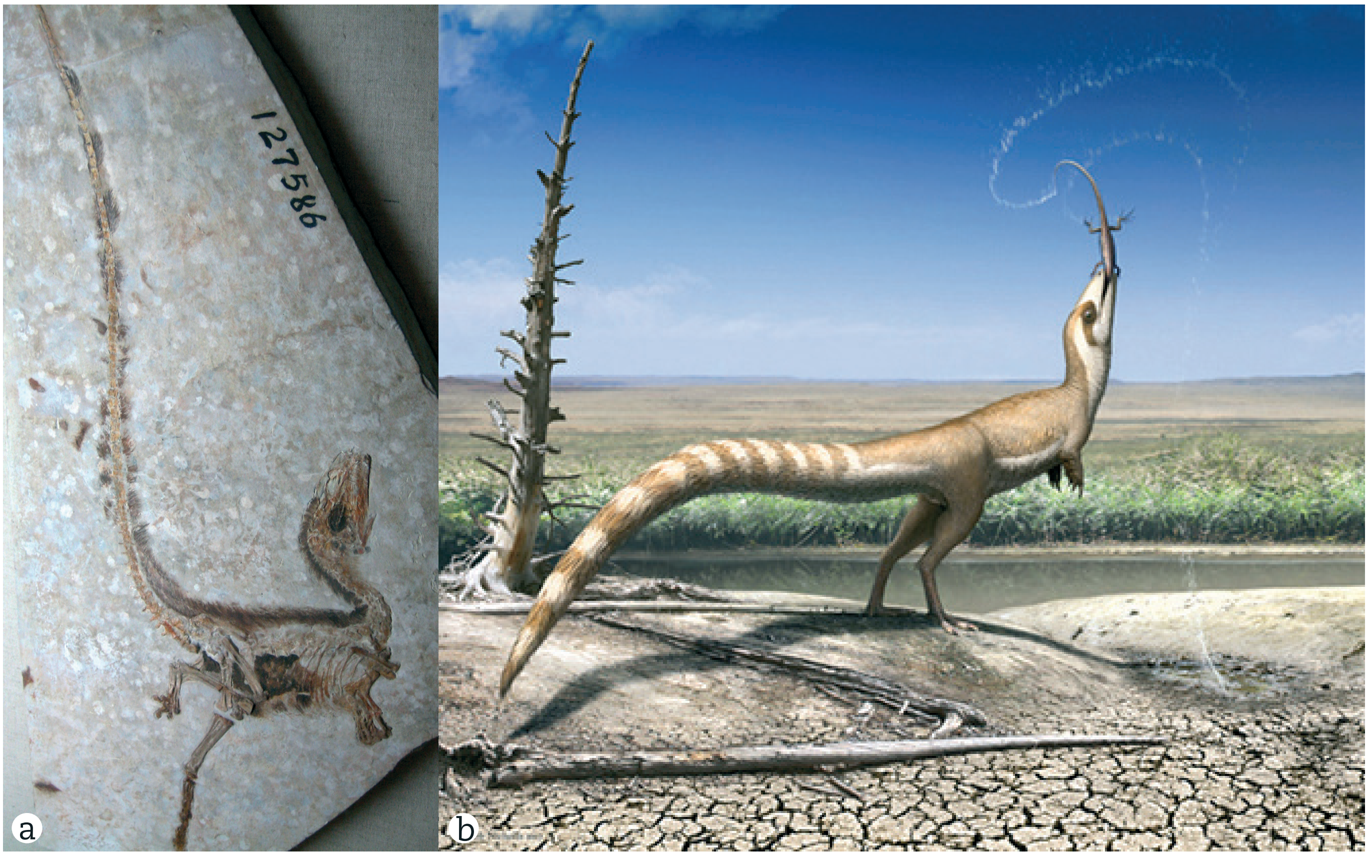

Figure 2. a. Fossil specimen of *Sinosauropteryx prima* on display in the Inner Mongolia Museum, Hohhot, China. Photograph by Sam / Olai Ose / Skjaervoy / CC BY-SA 2.0. **b.** Reconstruction of *Sinosauropteryx* preying on the lizard *Dalinghosaurus*. Image from Smithwick et al. (2017) / CC BY 4.0.

Others have responded that *Archaeopteryx* was a bird and not evidence for the evolution of birds from dinosaurs, especially as it appears earlier in the fossil record than the small theropods from which it was supposed to have evolved. Furthermore, some creation scientists have claimed that any creature with feathers must be a bird.

These fossils of feathered theropods are mainly from Jurassic and Cretaceous rocks, which – according to conventional scientists – date from 201.5 to 66 million years ago. Here we discuss the fossil evidence and suggest that it is possible to classify the feathered fossils in various broad groups.

THEROPODS

Theropods are bipedal dinosaurs which are found in Mesozoic rocks (Triassic, Jurassic and Cretaceous). Two examples are *Tyrannosaurus* and *Velociraptor*. *Tyrannosaurus* is probably the best known theropod after *Velociraptor* among the general public. It was one of the largest theropod dinosaurs (12 metres long and weighing about 10 tonnes). It had very short arms and powerful hind legs. There is no direct evidence that *T. rex* had feathers, though some tyrannosaur-like dinosaurs (e.g. *Dilong, Yutyrannus*) had them. *Velociraptor* was about the size of a turkey and had short arms and powerful hind legs. It was a running predator, with a forward-facing 'killing claw' on its foot. A *Velociraptor* forearm with quill knobs has been reported (Turner et al. 2007); therefore, it appears that *Velociraptor* had feathers.

Deinonychus was similar to *Velociraptor* but larger (over three metres in length). In the 1970s Ostrom identified a collection of features that birds and *Archaeopteryx* shared with *Deinonychus* and other theropods but not with other reptiles (Ostrom 1976). As mentioned earlier, it was on the basis of these findings that he concluded that birds are descended directly from small theropod dinosaurs.

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REVIEW OF SOME IMPORTANT FOSSILS

Many fossil theropods reported to have had 'protofeathers' and feathers have been found in the last 25 years, which evolutionists believe provide evidence that birds evolved from dinosaurs. Most of them were found in Liaoning province, China, which contains some of the foremost palaeontological sites in the world. The rock strata at these sites are part of the Jehol Group, which includes the Yixian Formation and Jiufotang Formation. The excellent level of preservation is believed to be a

Figure 3. a. Fossil specimen of *Anchiornis huxleyi* on display in the Beijing Museum of Natural History, Beijing, China. Photograph by Jonathan Chen / CC BY-SA 4.0. **b.** Reconstruction of *Anchiornis*. Image by Nobu Tamura / CC BY 3.0.

consequence of how the animals died. The area was volcanically active, and large plumes of volcanic dust repeatedly covered the area, instantly killing and burying any living thing in the area. Some of the more important Chinese theropods (often referred to as 'dino-birds') which have been reported to show evidence of 'proto-feathers' and feathers are described below. The first two reports were published in 1996 and 1997 and others have followed at regular intervals.

Sinosauropteryx

Sinosauropteryx prima was the first example of a feathered dinosaur, and was described by workers from the National Geological Museum of China (Figure 2). In 1996 they reported the discovery of this small theropod in the Cretaceous deposits of Liaoning. It was a chicken-sized dinosaur which had fringed, filamentous structures along its back and on its body surface (Ji and Ji 1996). These structures of the skin, or integument, were interpreted as precursors to feathers.

Protarchaeopteryx

The report of *Sinosauropteryx* was followed in 1997 by the report of a creature called *Protarchaeopteryx*. It apparently had short feathers on its body and longer feathers attached to its tail (Ji and Ji 1997). It has been interpreted by some as secondarily flightless.

Sinornithosaurus

Sinornithosaurus millenii is a 'basal' dromaeosaurid dinosaur which appears to have been covered with compound structures composed of multiple filaments. Furthermore, these structures are claimed to show two types of branching unique to avian feathers: filaments joined in a basal tuft and filaments joined at their bases in series along a central filament (Xu et al. 1999).

Caudipteryx

Caudipteryx is another theropod with feathers on its arms and its tail (Ji et al. 1998). It probably ran like a flightless bird (Jones et al. 2000). Its centre of gravity is forward like the centre of gravity of a bird, and it possessed feathered wings resembling those of a modern bird. It was possibly a secondarily flightless creature.

Anchiornis

This exceptionally well-preserved small theropod was found in the Jurassic Tiaojishan Formation of western Liaoning, China (Figure 3). It is claimed to have had extensive feathering, including long pennaceous feathers (feathers with a quill) (Hu et al. 2009). This creature is also claimed to shed light on the early evolution of feathers. With a reported age of 155 million years (older than *Archaeopteryx* at 150 million years) it is claimed to show a key stage of feather evolution.

Aurornis

Aurornis xui is claimed to have lived 160 million years ago in northeastern China (Figure 4). *Aurornis* is Latin for 'dawn bird'. It is believed to have traces of plumulaceous (downy) feathers, comprising a bundle of filaments joined together at the base and remaining almost parallel as they extend outwards. The feathers are preserved along the first third of the tail, above the neck and around the chest. However, pennaceous feathers are not present (Godefroit et al. 2013a).

Figure 4. Reconstruction of *Aurornis xui*. Image by El fosilmaniaco / CC BY-SA 3.0.

Xiaotingia

Xiaotingia is a theropod thought by conventional scientists to be Late Jurassic in age, which had integumentary structures which are described as faint feather impressions around the whole skeleton, including the skull, vertebral column, forelimbs and hindlimbs (Xu et al. 2011).

Eosinopteryx

Eosinopteryx is another theropod thought by conventional scientists to be Late Jurassic in age and claimed to have filamentous feathers. However, these were less extensive on the limbs and tail than in *Anchiornis* (Godefroit et al. 2013b).

Four-winged creatures

Fossils of small four-winged, long-tailed theropods have been reported since 2003. In addition to having well-developed wings, they had long pennaceous feathers attached to the legs ('hindwings'). *Microraptor* and *Changyuraptor* are two examples of these amazing four-winged creatures. However, claims that they show an earlier stage in the evolution of flight are not consistent with the fact that they are reported to be much younger than *Archaeopteryx*, which had only two wings.

In addition to having well-developed wings, they had long pennaceous feathers attached to the legs ('hindwings').

The first report of a species of four-winged, long-tailed theropod was of *Microraptor* (Xu et al. 2003). It is believed to have been a four-winged glider. *Changyuraptor* was another four-winged microraptorine (Han et al. 2014). It was found in Lower Cretaceous deposits in Jehol, China. The tail feathers were nearly 30 centimetres long (roughly 30% the length of the skeleton) and it had long, pennaceous feathers attached to the lower hindlimbs (that is, 'hindwings'). It is suggested that the long, feathered tail provides insight into the flight performance of microraptorines. The tail could have acted as a pitch-control structure reducing descent speed and thus playing a key role in landing (Han et al. 2014).

Figure 5. The pygostyle of a goose. Photograph by Marc Surtees.

Pygostylians

All living birds have a pygostyle, which is a blade-like bone at the end of a short tail (Figure 5). There are also many examples of fossils with a pygostyle, such as *Confuciusornis*, *Sapeornis* and *Yanornis*, although it was sometimes rod-like in the fossil examples. All of these birds have been found with fossil feathers.

The Cretaceous confuciusornithid birds, which had beaks made of keratin, are claimed to have lived from 120 to 125 million years ago. The first reported confuciusornithid, *Confuciusornis sanctus*, was found in the Lower Cretaceous Yixian Formation in western Liaoning province (Hou et al. 1995). Another species, *Eoconfuciusornis zhengi*, is from the Lower Cretaceous Dabeigou Formation (said to be 131 million years old) in Fengning, Hebei province, northern China (Zhang et al. 2008a).

Eoconfuciusornis and similar creatures had many features, such as the size of the deltopectoral crest of the humerus and the keel of the sternum, which show that they would have been able to fly like modern birds. *Sapeornis* was another Cretaceous bird from the Yixian Formation in western Liaoning, China (Figure 6), although it had teeth in the upper beak tip (Zhou and Zhang 2003). It also had features shared with living birds such as fused wing bones and a pygostyle.

Figure 6. Fossil specimen of *Sapeornis chaoyangensis* on display in the National Museum of Natural Science, Taichung, Taiwan. Photograph by Y.-C. Tsai / CC BY-SA 4.0.

DISCUSSION

Evolutionary sequence

Sinosauropteryx, *Protarchaeopteryx*, *Sinornithosaurus* and *Caudipteryx* are all 'younger' in evolutionary terms than *Archaeopteryx*, and this is a major problem with the claim that they represent intermediates between dinosaurs and birds. *Archaeopteryx* was found in Jurassic rocks, whereas the others were found in Cretaceous rocks. Therefore, if one accepts the assigned ages of the rocks, *Archaeopteryx* is too 'early' to be part of an evolutionary sequence from dinosaurs to birds, if *Sinosauropteryx*, *Protarchaeopteryx*, *Sinornithosaurus* and *Caudipteryx* are part of this sequence. This is the so-called temporal paradox.

However, more recent discoveries are claimed to have solved this temporal paradox (Hu et al. 2009). The discovery of long-tailed theropods such as *Anchiornis*, *Aurornis*, *Xiaotingia* and *Eosinopteryx*, which are described above, are claimed to document various stages of the evolution of birds. However, even when the fossils mentioned above (and others) are put into a sequence based on their assigned ages there is still no clear evidence of gradual evolution.

Feathers

Some reports in the scientific literature refer to the more recent discoveries as having 'filaments', 'integumentary structures' and 'faint feather impressions' which are claimed to be evidence for the evolution of feathers. Today feathers are only found on birds and are a definitive feature of birds. Therefore, the claims of feathers and 'protofeathers' on theropods are key elements of the theory that birds evolved from theropod ancestors. Some fossils which are presented as providing evidence of feather evolution include *Aurornis*, *Anchiornis*, *Xiaotingia* and *Eosinopteryx*, which have similar features and all lived at roughly the same time in the same place (northeastern China). They are also similar to *Archaeopteryx* but all were 'earlier' than *Archaeopteryx*.

It is claimed that some of these creatures had filamentous 'protofeathers' and feathers and show stages in the evolution of feathers and flight. Other fossils also claimed to have had features which show stages in the evolution of feathers include *Epidexipteryx* and *Serikornis*. *Epidexipteryx* is called a 'basal' avialan and was found in Middle to Upper Jurassic rocks. It had two pairs of elongate, ribbon-like tail feathers, but its limbs lack contour feathers for flight (Zhang et al. 2008b). It is characterised by an unexpected combination of characters seen in several different theropod groups. *Serikornis* was another theropod with a skeletal morphology suggesting that it was ground-dwelling and had no flying adaptations (Lefèvre et al. 2017). The base of the tail of *Serikornis* was covered by filaments and the end of the tail has what are claimed to be slender feathers. Thin, symmetrical feathers lacking barbules were reportedly attached along its forelimbs and hindlimbs.

A review of the literature shows that there has been considerable debate about the filamentous structures found on some specimens. In particular, the nature of the integumentary structures on *Sinosauropteryx* has been controversial, with some claiming that they are collagen fibres (Lingham-Soliar et al. 2007). However, Smithwick et al. (2017) published evidence which shows that the structures found on *Sinosauropteryx* are fibres containing melanosomes (pigment cells) and describing them as 'feather homologues'. However, in this case the use of the word 'feather' to describe what are clearly filaments, and use of the term plumage, is somewhat misleading since they do not resemble pennaceous feathers.

However, the fossils with clear evidence of feathers do not provide evidence for the evolution of feathers since they are all about the same evolutionary age

Nevertheless, reports of feathers on other theropods seem to be convincing (McLain et al. 2018). *Archaeopteryx* is the best-known example and there are many others. For example, dromaeosaurid BPM 1 3-13, which is a 'raptor' similar to *Velociraptor* and *Deinonychus*, had well-preserved feathers (Norell et al. 2002). The report of quill knobs (anchor points for ligaments attaching secondary feathers) on a *Velociraptor* forearm is consistent with the idea that it had feathers. *Caudipteryx* also had pennaceous feathers. Feathers have been found inside a piece of amber, dated conventionally to the Late Jurassic (Xing et al. 2016). This specimen shows eight vertebrae (tail bones) and feathers, which are from a creature with a long tail. *Caihong juji* was a theropod species with long arm and leg feathers and tail feathers with asymmetrical vanes forming a tail surface area even larger than that of *Archaeopteryx* (Hu et al. 2018).

However, the fossils with clear evidence of feathers do not provide evidence for the evolution of feathers since they are all about the same evolutionary age and there is no clear progression from scales to 'protofeathers' to feathers. None of this evidence comes close to explaining the origin of feathers with barbs linked together by two types of barbule to form a strong and flexible aerofoil.

What is a bird?

To make sense of these fossils we need to define what is meant by 'bird'. The need for a clear definition is illustrated by considering *Archaeopteryx*. *Archaeopteryx* had bird-like air sacs (Britt et al. 1998) as well as an 'avian' brain and inner ear (Alonso et al. 2004) and asymmetrical flight feathers (Mayr et al. 2007). However, it had more features in common with small 'bird-like' theropods than modern birds. These features include jaws with sharp teeth, three fingers with claws, a long bony tail, a hyperextensible second toe ('killing claw') and various other skeletal characteristics. Also, it should be noted that many theropods and other dinosaurs, including the massive sauropods, had air sacs. One example is *Majungasaurus atopus* (O'Connor and Claessens 2005) which had air sacs and a flow-through lung.

Classification of these creatures may be possible if 'bird' is defined as a feathered creature which in addition has *all* the following features:

- A sophisticated flow-through lung connected to air sacs
- Lightweight, air-filled bones
- Furcula (wishbone), scapula (shoulder blade) and coracoid forming a robust attachment site for the wing
- A coracoid bone with an acrocoracoid process
- A pygostyle (a terminal rod-like or blade-like tail bone)
- A brain with enlarged cerebellum and visual cortex (the avian brain).

This set of features defines a group which includes fossil birds (including all Enantiornithes) and modern birds (Neornithes). A fossil of any creature which had feathers but not all the other features listed above would by this definition not be a bird. For example, *Archaeopteryx* and many of the fossil 'dino-birds' did not have a pygostyle. Nor did they have a rigid bony 'airframe' consisting of the furcula, shoulder blade, coracoid and sternum to provide a strong flexible attachment for the wing via the humerus, which, together with the supracoracoideus pulley system, allows living birds to generate a powerful downstroke.

Created kinds of feathered creatures

It appears that there was once a greater variety of feathered creatures, including theropods, some of which could fly or at least were efficient gliders. These feathered flying theropods had long tails, two or four wings and toothed jaws. They would have been poor flyers at best, because they had no supracoracoideus pulley system to lift the wing high above the back for a long, powerful downstroke (Baier et al. 2007). This lack of power could have been compensated for by the long-tail aerofoil and, in some cases, four wings. There were also large flightless feathered theropods some of which may have been descended from smaller flying ancestors. These feathered theropods can be grouped according to lifestyle as follows:

- Flightless (e.g. *Caudipteryx*, *Protarchaeopteryx* and possibly *Epidexipteryx* and *Serikornis*)
- Two-winged gliders (e.g. *Archaeopteryx*)
- Four-winged gliders (e.g. *Microraptor* and *Changyuraptor*).

According to my proposed definition of 'bird' none of these feathered theropods were birds.

There are also numerous fossils of enantiornithine birds which have a reversed shoulder arrangement compared to living birds. Just two examples are *Concornis* from Europe (Sanz and Buscalioni 1992) and *Longipteryx* from China (Zhang et al. 2001). All enantiornithines had pygostyles, some had teeth, and many had wing claws and unfused bones in the wing, and would be birds based on the definition suggested above.

This is consistent with the observation that there was greater biological diversity in the past.

It is unclear how many different created kinds (or basic types) of feathered and non-feathered theropods there were. Further research is required to refine the creationist understanding of feathered creatures. Some studies have already been carried out, including that by McLain et al. (2018) which concluded that there were at least eight different created kinds of feathered theropods. However, much work still remains to be done before arriving at a consistent and convincing creationist classification of feathered creatures.

CONCLUSION

There appear to be many different extinct feathered, flying, gliding and secondarily flightless creatures. This is consistent with the observation that there was greater biological diversity in the past. Today, all living birds are neornithines, with a pygostyle, a toothless beak, a coracoid with an acrocoracoid process, a supracoracoideus pulley system, a keel-like sternum and fused 'fingers'. In the past, however, there was a greater diversity of created kinds of feathered creatures, not only neornithine and enantiornithine birds, but also four-winged and two-winged gliding theropods.

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