had yet been undertaken (the fossil had only come to the attention of Canadian paleontologist Phil Currie and paleo-artist Michael Skrepnick two weeks earlier), the specimen confirmed the connection between dinosaurs and birds that had been proposed on bones alone. The new dinosaur was dubbed *Sinosauropteryx*, and it had come from Cretaceous deposits in China that exhibited a quality of preservation that exceeded that of the Solnhofen limestone.

Sinosauropteryx was only the first feathered dinosaur to be announced. A panoply of feathered fossils started to turn up in the Jurassic and Cretaceous strata of China, each just as magnificent as the one before. There were early birds that still retained clawed hands (*Confuciusornis*) and teeth (*Sapeornis*, *Jibeinia*), while non-flying coelurosaurs such as *Caudipteryx*, *Sinornithosaurus*, *Jinfengopteryx*, *Dilong*, and *Beipiaosaurus* wore an array of body coverings from wispy fuzz to full flight feathers. The fossil feathers of the strange, stubby-armed dinosaur *Shuvuuia* even preserved the biochemical signature of beta-keratin, a protein present in the feathers of living birds, and quill knobs on the forearm of *Velociraptor* reported in 2007 confirmed that the famous predator was covered in feathers, too.

As new discoveries continued to accumulate it became apparent that almost every group of coelurosaurs had feathered representatives, from the weird secondarily herbivorous forms such as *Beipiaosaurus* to *Dilong*, an early relative of *Tyrannosaurus*. It is even possible that,

FIGURE 37 - A *Velociraptor* attempts to catch the early bird *Confuciusornis*. Both were feathered dinosaurs.

during its early life, the most famous of the flesh-tearing dinosaurs may have been covered in a coat of dino-fuzz.

The coelurosaurs were among the most diverse groups of dinosaurs. The famous dinosaurs *Velociraptor* and *Tyrannosaurus* belonged to this group, as did the long-necked, pot-bellied giant herbivore *Therizinosaurus* and birds. What is remarkable is that, with the exception of the ornithomimosaurs, every branch on the coelurosaur family tree contains at least one feathered dinosaur, and it is expected that fossils of even more feathered coelurosaurs will be discovered as investigations continue. This suggests that, instead of evolving independently in each group, feathers were a shared trait for coelurosaurs that was inherited from their common ancestor.[40] Most, if not all, coelurosaurs probably had some kind of feathery covering for at least part of their lives.[41]

A mix of fossil and molecular evidence hints at how feathers could have evolved. Birds are the living descendants of the coelurosaurs, and crocodylians are the closest living relatives to dinosaurs as a whole, so features shared between birds and crocodylians might have been present in the last common ancestor of both lineages (and therefore also present in dinosaurs). Both birds and alligators, for example, share the regulatory proteins sonic hedgehog (abbreviated Shh, and named for the video game character) and bone morphogenetic protein 2 (BMP2–), both of which underlie the formation of both the scales of alligators and the feathers of birds. Hence it is likely that, during the evolution of dinosaurs, these proteins were co-opted from their roles in forming the tough hides of dinosaurs into the creation of feathers.

The diversity of feather types among coelurosaurs suggests how feathers were modified once they had begun to evolve. As seen in *Sinosauropteryx*, the earliest feathers were simply tubes that grew from the skin. Once these structures evolved there would have been enough variation for them to split and become branched, something that has been observed in the downy covering of baby chickens, with each feather providing greater coverage on the animal. From there, the branching filaments could be organized along a central vane, like what is seen in *Caudipteryx* and *Sinornithosaurus*. After this point, little barbs branched off from each filament along the shaft, locking them together and stiffening the feather. This was the kind of feather needed for flight, and it is what is seen in most modern birds. That these structures are feathers and not just degraded collagen or some other quirk of fossilization is beyond reasonable doubt.

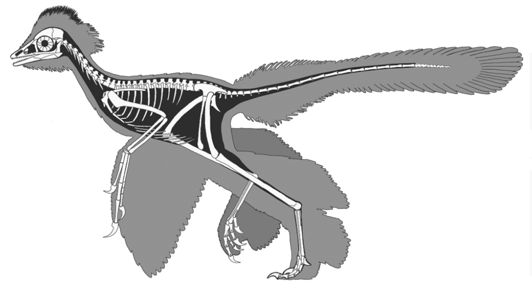
The majority of dinosaur fossils are just bones and teeth, and even fossilized skin impressions only preserve patterns, not colors.

But scientists have recently discovered that there is a way to detect some colors in the fossil record. While studying an exceptionally preserved fossil, squid paleontologist Jakob Vinther saw that its ink sac was packed with the same kind of microscopic spheres that give the ink of living squid their color. These bodies are called melanosomes, and once Vinther realized that they could be preserved in the fossil record he began to wonder what other prehistoric remains might contain them.

One of the first tests was on the forty-seven-million-year-old feather of an extinct bird from Messel, Germany (home of "Ida" and not far from the final resting place of *Archaeopteryx*). Since the feather seemed to show light and dark bands, it was a good test case to see whether the bodies were truly pigment-carrying melanosomes (in which case they would only be found in the dark bands) or were just bacterial remnants scattered all over the feather. The results were better than could have been expected. In 2009 the researchers behind the study announced that not only did the feather most certainly contain melanosomes in the dark bands, but their arrangement corresponded to a pattern seen in living birds that gives feathers a glossy sheen. This was better than just an isolated discovery. It presented paleontologists with a new technique and two teams, working independently of each other, turned to the fossilized feathers of dinosaurs to see if they, too, contained remnants of color.

The first team, lead by Fucheng Zhang, published their results in the journal *Nature* on January 27, 2010. They had turned their attention to two of the first feathered dinosaurs to be found, *Sinosauropteryx* and *Sinornithosaurus*. Feather samples from both contained two different types of melanosomes; those that created dark shades (eumelanosomes) and those associated with reddish hues (phaeomelanosomes). This allowed the scientists to speculate that *Sinosauropteryx* had a garish red-and-white-striped tail, which might have been used to signal to other members of its species.

Vinther and his team published their own findings in *Science* the following week. Building on the previous research on the fossil bird feather, they attempted to present a specimen of the recently discovered dinosaur *Anchiornis* in Technicolor. After determining the pattern of melanosome distribution throughout the feathers, they compared the arrangements to what is seen in living birds to restore the long-lost pigments. As it turned out most of the feathers of *Anchiornis* were black, but they were set off by white accents on its wings and a plume of rufous feathers on top of its head. Even though the study did not look



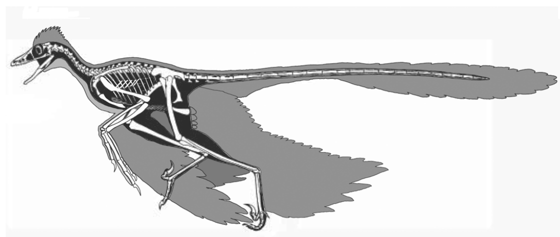


FIGURE 38 – Restorations (not to scale) of *Anchiornis* and *Microraptor*, based upon exceptional specimens that also preserved feathers. The discovery of such fossils has overwhelmingly confirmed that birds evolved from dinosaurs.

for chemical traces of color in the fossil that would have marked the presence of other shades, for the first time the researchers were able to produce an image of an entire living dinosaur.

The question of just what a feather is has become more complicated, however. Very early on in dinosaur evolution there was a split in the dinosaur family tree that resulted in the evolution of the ornithischians (containing an array of herbivorous dinosaurs such as the ankylosaurs, hadrosaurs, and ceratopsians) and the saurischians (comprised of the predatory theropods and the forebears of the gigantic, long-necked sauropods).[42] The presence of feathers in coelurosaurs alone suggested that fuzzy body coverings had evolved only once among dinosaurs within the saurischian side of the split, but at the beginning of the twenty-first century scientists found similar structures among ornithischian dinosaurs. In 2002 Gerlad Mayr and colleagues announced that they had discovered a specimen of the ceratopsian *Psittacosaurus* with long, bristlelike structures growing out of its tail and it was joined in 2009 by *Tianyulong*, another bristle-covered ornithsichian described by a team of researchers led by Zheng Xiao-Ting.

These animals were about as far removed from bird ancestry as it was possible to be while still remaining a dinosaur, yet they were covered in structures similar to the proto-feathers of *Sinosauropteryx*. Either the filamentous body covering evolved twice in two different groups of dinosaurs, or, even more spectacularly, was a common di-

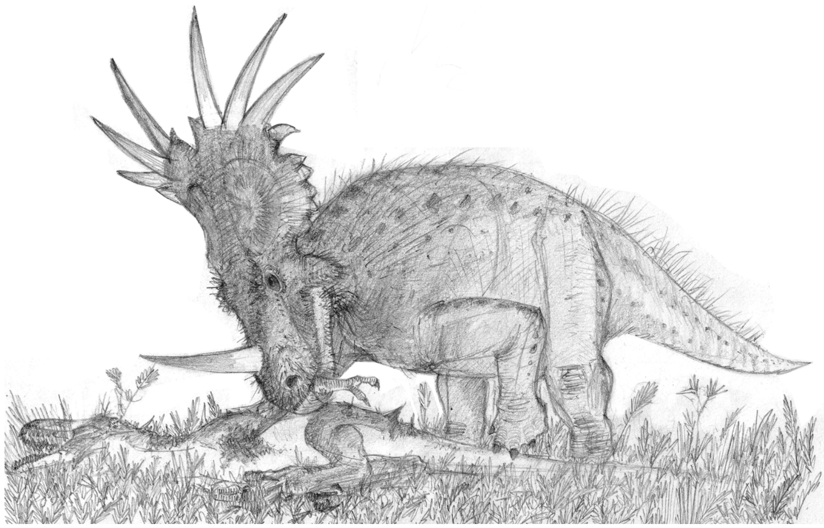


Figure 39 – A *Styracosaurus*, covered in bristles, scavenges the body of a dead tyrannosaur. The discovery that ornithischian dinosaurs like *Tianyulong* and *Psittacosaurus* had bristlelike structures growing out of their skin suggests that it is possible that many other ornithischian dinosaurs did, as well.

nosaur trait later lost in some groups. Regardless of how many times "dino fuzz" evolved, however, these structures were only adapted into true feathers among the coelurosaurs, but how flight evolved is another evolutionary mystery.

John Ostrom presented one hypothetical scenario in 1979. Inspired by his work on *Deinonychus* and *Archaeopteryx*, he proposed that the ancestors of the first bird were small coelurosaurs covered in rudimentary feathers. With their grasping hands, these tiny predators would have been adept hunters of flying insects, and their simple feathers would have provided an unexpected advantage. The feathers along their arms would have helped trap insects, and so longer feathers would have been selected for over time. Eventually these "proto-wings" would have allowed the dinosaurs a little bit of extra lift while jumping after their prey, and this shift in selection would precipitate the origin of the first flying birds.

Ostrom's "insect-net hypothesis" never truly took off, as it was marred by functional problems surrounding how feathers might be used as a net, but it did reignite an old debate about whether flight evolved from the "trees down" or the "ground up." According to the advocates of the arboreal hypothesis, small feathered dinosaurs climbed up into trees and launched themselves into the air to glide a short distance, and eventually they would be adapted to beat their wings to truly fly. The four-winged dinosaur *Microraptor*, a relative of *Deinonychus*, has most recently been taken to throw support to this idea, as it may have launched itself out of trees to glide, if not truly fly, through the forest.

Other paleontologists have preferred one version or another of the cursorial hypothesis. In this view, feathered dinosaurs ran along the ground, perhaps hopping into the air after insects or other prey, until by some mechanism they developed the ability to actually fly. In fact, feathered arms may have even made some dinosaurs better runners. A key piece of evidence for this hypothesis comes from chukar partridges. These birds are capable of flight, but if they need to escape into a nearby tree or over a natural obstacle they often run rather than fly, flapping their wings as they do so. As discovered by scientist Kenneth Dial this technique gives the birds better traction while running, so much so that they can run right up vertical inclines. As hypothesized by Dial, feathered dinosaurs could have gained a functional advantage by flapping their arms while running (be it after prey or to avoid becoming prey), and this behavior could then be co-opted to allow them to start flying.

As recognized by most working paleontologists today, however, the old arboreal versus cursorial dichotomy is no longer helpful. Much like Williston, Nopsca, and Beebe, we can create numerous plausible scenarios but, without knowing which feathered dinosaurs were the root stock from which birds evolved, any origin-of-flight hypothesis must be regarded as provisional right from the start. Even as the numerous feathered fossils have confirmed that birds evolved from dinosaurs, they have also made the relationships between those fossils and birds much more complex. At one time it seemed that *Velociraptor* and its relatives were the closest relatives of early birds, but a little-known group of recently discovered forms may be even closer.

Described in 2002, the small feathered dinosaur *Scansoriopteryx* was one of the most bizarre coelurosaurs ever found. With large eyes, a short snout, and a very long third finger, this sparrow-sized dinosaur was unlike many of its coelurosaur cousins. Its description was followed in 2008 by the announcement of a close relative named *Epidexipteryx*, a pigeon-sized dinosaur, covered in fuzz, that also sported two pairs of ribbonlike feathers on its shortened rump and a mouth full of forward-oriented teeth. Given that they may be older than the earliest birds, they could represent the kind of dinosaur birds evolved from, in which case the *Velociraptor* and its relatives would be further removed from the origin of birds than had been previously supposed.

For over a century *Archaeopteryx* was the key to understanding

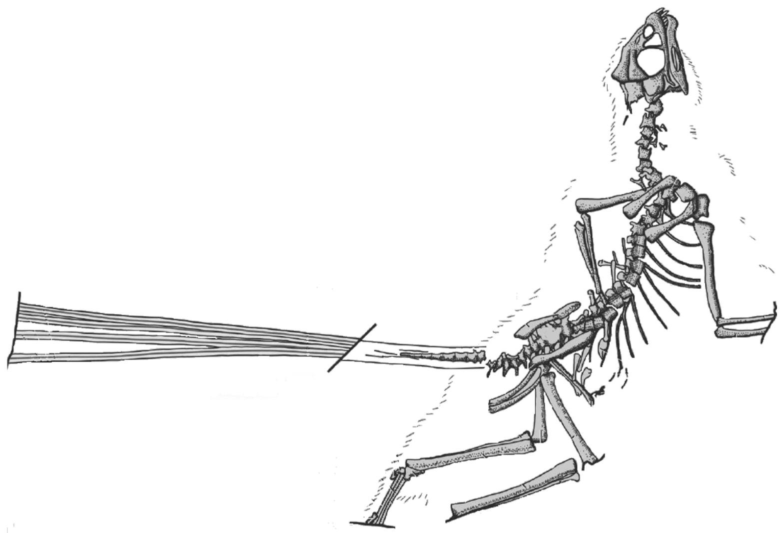


FIGURE 40 — A drawing of the skeleton of *Epidexipteryx*, denoting the "halo" of feathers around the skeleton and the pairs of elongated feathers coming out of its tail. It may be one of the closest relatives of early birds.

bird origins, as it was the oldest bird ever discovered, but as more feathered dinosaurs have been found the connection between *Archaeopteryx* and other fossil birds has become looser. As the delineation between non-avian dinosaur and bird has become increasingly blurred it has become difficult to tell what side *Archaeopteryx* falls on. As research continues, it may turn out that *Archaeopteryx* was, like *Microraptor*, a feathered dinosaur and not a true bird.

The unstable relationships of some of the feathered dinosaurs was exemplified by the redescription of *Anchiornis huxleyi* in 2009. The fossil, named in honor of T. H. Huxley's work on bird origins, had been announced the year before as the closest dinosaurian relative of birds and, at thirty million years older than *Archaeopteryx*, was especially significant. When a better-preserved specimen was found, however, the scientists realized that their initial hypothesis was wrong. *Anchiornis* was actually a troodontid, or a member of a group of coelurosaurs closely related to the famous "raptors," yet it was very similar in form to *Archaeopteryx*.

Even if *Archaeopteryx* is dethroned from the vaunted position of "earliest known bird" that Richard Owen bestowed upon it, the fact remains that birds evolved from dinosaurs, and much more than fossilized feathers supports this hypothesis. During the 1920s the explorer

Roy Chapman Andrews led a string of expeditions for the American Museum of Natural History into Mongolia's Gobi Desert to search for the evolutionary center of origin for all mammals (including humans). No evidence of a mammalian Eden was found, but the excursions did return with the ghostly white bones of the Cretaceous dinosaurs *Velociraptor*, *Protoceratops*, and *Oviraptor*, the latter of which was especially fascinating because it was found in the act of robbing a *Protoceratops* nest.

But in 1994 it was announced that the wrong dinosaur was inside the supposed *Protoceratops* eggs. Instead of an embryonic horned dinosaur, there was the miniscule skeleton of a developing theropod much like *Oviraptor*. The specimen the Andrews expedition had found was probably caring for its own eggs, not robbing the eggs of others. The discovery of several skeletons of a crested *Oviraptor* relative named *Citipati,* which were found sitting atop nests of the same kind of eggs, supported this hypothesis. Their arms encompassed the sides of the nest in a position only seen in birds, and the close relationship between *Citipati* and the feathered *Caudipteryx* opened the possibility that these dinosaurs, too, were covered in feathers that they used to regulate the temperature of their nests. This discovery of fossilized behavior dovetailed beautifully with the numerous feathered coelurosaurs, and the description of the tiny troodontid *Mei long* in 2004 also surprised paleontologists. Like the skeletons of *Citipati* on their nests, several of these dinosaurs were suddenly killed and buried while sleeping, perfectly preserved in the position in which they died. They were curled up just like slumbering birds.

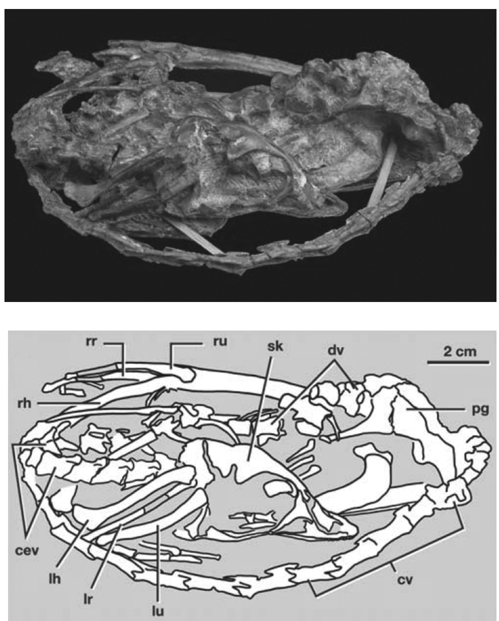


FIGURE 41 – The skeleton of the troodontid dinosaur *Mei long*, with a line drawing identifying the visible bones on the right. Abbreviations: *cev*, cervical vertebrae; *cv*, caudal vertebrae; *dv*, dorsal vertebrae; *lh*, left humerus; *lr*, left radius; *lu*, left ulna; *pg*, pelvic girdle; *rh*, right humerus; *rr*, right radius; *ru*, right ulna; *sk*, skull.

The unique breathing system seen in modern birds also appeared long before their ancestors first took to the air. As you relax reading this book you go through a breathing cycle of inhaling and exhaling. When you inhale, air enters your lungs (where oxygen is absorbed), and when you exhale the carbon dioxide-rich, oxygen-depleted air is forced out. Unlike you, however, birds lack a diaphragm and cannot inflate or deflate their lungs. Instead birds have a "one way" breathing system in which fresh air moves through their respiratory system both when the bird inhales and exhales. This is made possible by a series of anterior and posterior air sacs that can expand and contract. This is a more efficient way of getting oxygen from the air, but these air sacs also have a structural benefit. They arise from the lungs and invade the surrounding bones, thus making birds lighter. This infiltration into the bone leaves telltale hollows and indentations on bones, which have been seen in dinosaurs for over one hundred and fifty years.

It might not come as a surprise that coelurosaurs have evidence of air sacs on their bones, but other saurischian dinosaurs shared the same feature, too. This makes sense given the evolutionary history of these dinosaurs. There is no sign that air sacs were present in the ornithischian dinosaurs, but the evidence for air sacs in saurischian dinosaurs goes all the way back to one of the earliest presently known. Called *Eoraptor*, this small bipedal dinosaur was not unlike *Compsognathus*,

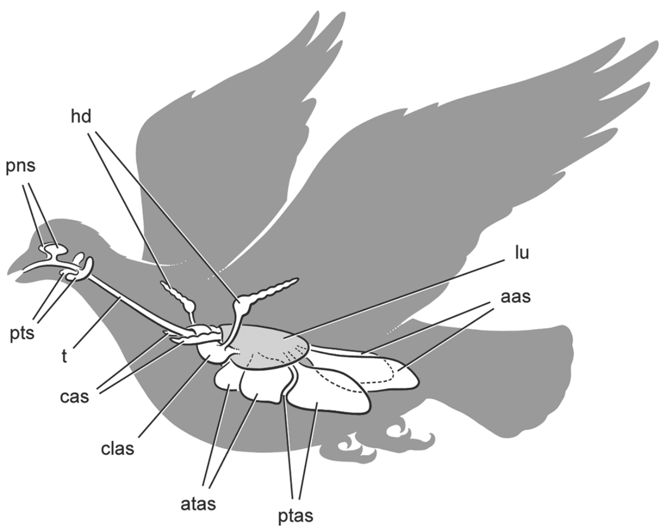


FIGURE 42 – A diagram of the air sacs inside a bird. Abbreviations: *atas*, anterior thoracic air sac; *cas*, cervical air sac; *clas*, clavicular air sac; *hd*, humeral diverticulum of the clavicular air sac; *lu*, lung; *pns*, paranasal sinus; *ptas*, posterior thoracic air sac; *pts*, paratympanic sinus; *t*, trachea.

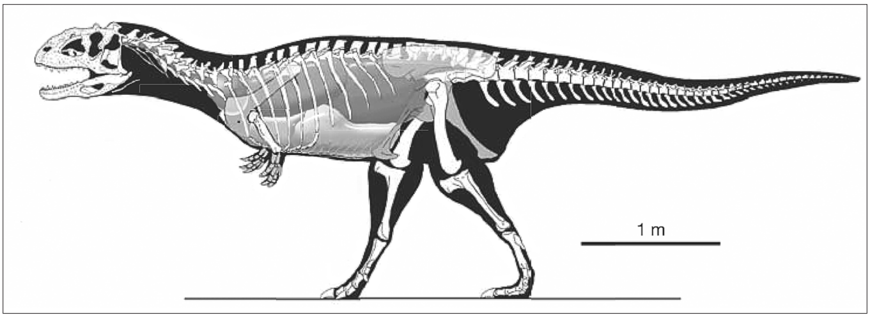


FIGURE 43 – A reconstruction of the skeleton of *Majungasaurus*, showing the placement of air sacs within the body inferred from pockets in its bones. Although *Majungasaurus* was not closely related to birds, the presence of these structures in its skeleton shows that these features were widespread among saurischian dinosaurs.

and it may be a fair approximation of what some of the earliest saurischian dinosaurs were like. Its bones were marked by indentations that indicate that it had at least some rudimentary air sacs, and later predatory dinosaurs from the coelurosaurs to the knobbly-headed abelisaur *Majungasaurus* and the *Allosaurus*-relative *Aerosteon* had even better developed air sacs.

The other great saurischian dinosaur group, the sauropods, also had bones infiltrated by air sacs. If you tried to design an animal like a 100-foot-long sauropod with thick, heavy bones in its neck, it would have been unable to lift its head. Much like a bridge, their skeletons reflect the selective pressures for strength and lightness, and air sacs allowed them to achieve this. They probably inherited this trait from their last common ancestor with the theropod dinosaurs.

While not exactly like those seen in living birds, the air sacs in many of these saurischian dinosaurs may have also provided them physiological benefits. Air sacs may have initially been selected because they lightened the skeleton, but if they provided dinosaurs with more efficient breathing (allowing them to be more active, for example) there would have been additional benefits for natural selection to act upon. Research into this area is still new, but it is clear that rudimentary air sacs appeared in dinosaurs seventy-five million years before *Archaeopteryx*, long preceding the first birds.

Some dinosaurs were even plagued by parasites that now infest the mouths of living birds. From healed wounds on skulls paleontologists have known for years that large predatory dinosaurs bit each other on the face during combat. Tyrannosaurs, especially, showed scars from such conflicts, but many *Tyrannosaurus* jaws often had holes in the lower jaw not apparently caused by the teeth of a rival. When paleontologists Ewan Wolff, Steven Salisbury, Jack Horner, and David Varricchio took another look at the jaws of tyrannosaurs that had these holes they did not find any sign of infection, inflammation, or healing that would be expected if the dinosaurs had been bitten. Bone, after all, is living tissue, and would slowly remodel itself in the wake of an injury. Instead, the holes were smooth, as if the bone was being slowly eaten away.

It seemed more likely that the holes were the result of some kind of pathology, and the researchers found that the sores were consistent with damage done by a single-celled protozoan called *Trichomonas gallinae* that infests modern birds. When inside living birds this microscopic creature causes ulcers to form in the upper digestive tract and mouth of the host, virtually identical to the damage seen in the *Tyrannosaurus* jaws. The species of protozoan that afflicted *Tyrannosaurus* might have been only a close relative of the living kind, but this was the first evidence of an avian disease afflicting dinosaurs.

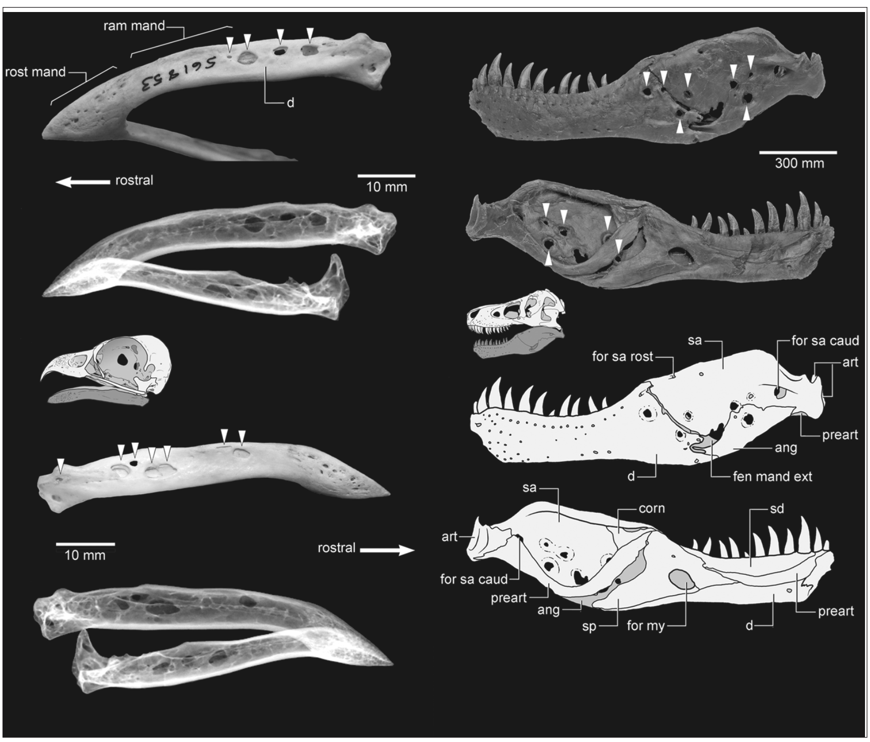


Figure 44 – The lower jaw of a hawk compared with the lower jaw of a *Tyrannosaurus rex*, both showing lesions in the bone caused by the microorganism *Trichomonas gallinae*.

Traits we think of as clearly identifying birds—feathers, air sacs, behavior, and even peculiar parasites—were present in a wide variety of dinosaurs first. Distinguishing the first true birds from their feathered dinosaur relations has become increasingly difficult. If we define birds as warm-blooded, feathered, bipedal animals that lay eggs, then many coelurosaurs are birds, so we have to take another approach.

Living birds, from kiwis to chickadees, fall within the group Aves, which also includes extinct birds like *Confuciusornis*, *Jeholornis*, *Zhongornis*, *Lonipteryx*, *Hesperornis*, and *Archaeopteryx*. Overall, Aves is the taxonomic equivalent of what are often informally referred to as "birds," but the earliest birds share many features with their closest relatives among the non-avian dinosaurs. What the closest dinosaurian relatives of birds may be, though, is presently under debate. Deinonychosaurs, the group containing both the dromaeosaurs (i.e. *Deinonychus*, *Microraptor*) and troodontids (*Mei*, *Anchiornis*), has often had pride of place as the dinosaurs nearest to birds and the group from which birds evolved. The identification of *Archaeopteryx* as a feathered dromaeosaur certainly reinforces this view, but the research describing the dinosaurs *Scansoriopteryx* and *Epidexipteryx* has placed them even closer to birds than the dromaeosaurs.

If the new analyses are supported by further evidence, *Scansoriopteryx* and *Epidexipteryx* together would make up a group called the Scansoriopterygidae and be the closest relatives to Aves. Thus, Aves plus the Scansoriopterygidae would form a group called the Avialae, with the deinonychosaurs being the next closest relatives to both groups. This placement does not reveal direct ancestors and descendants, but rather represents the group of dinosaurs from which birds arose and what they might have looked like. It is extremely unlikely that a direct line of descent from birdlike dinosaur to the first dinosaur-like bird will be found.

In his 1871 critique of evolution by natural selection, *On the Genesis of Species*, George Jackson Mivart considered the wings of birds a damning example of how Darwin's theory failed. To him a bird's wing was an atrophied organ, degenerate in the number of digits and bones in each finger. "Now, if the wing arose from a terrestrial or subaerial organ, this abortion of the bones could hardly have been serviceable—hardly have preserved individuals in the struggle for life." In other words, how could organisms have survived with half-formed wings?

What we know now about evolution has undermined Mivart's contention. The limbs of birds are only the modified limbs of dinosaurs; all the bones in the wing of a bird were present in the terrible, grasping

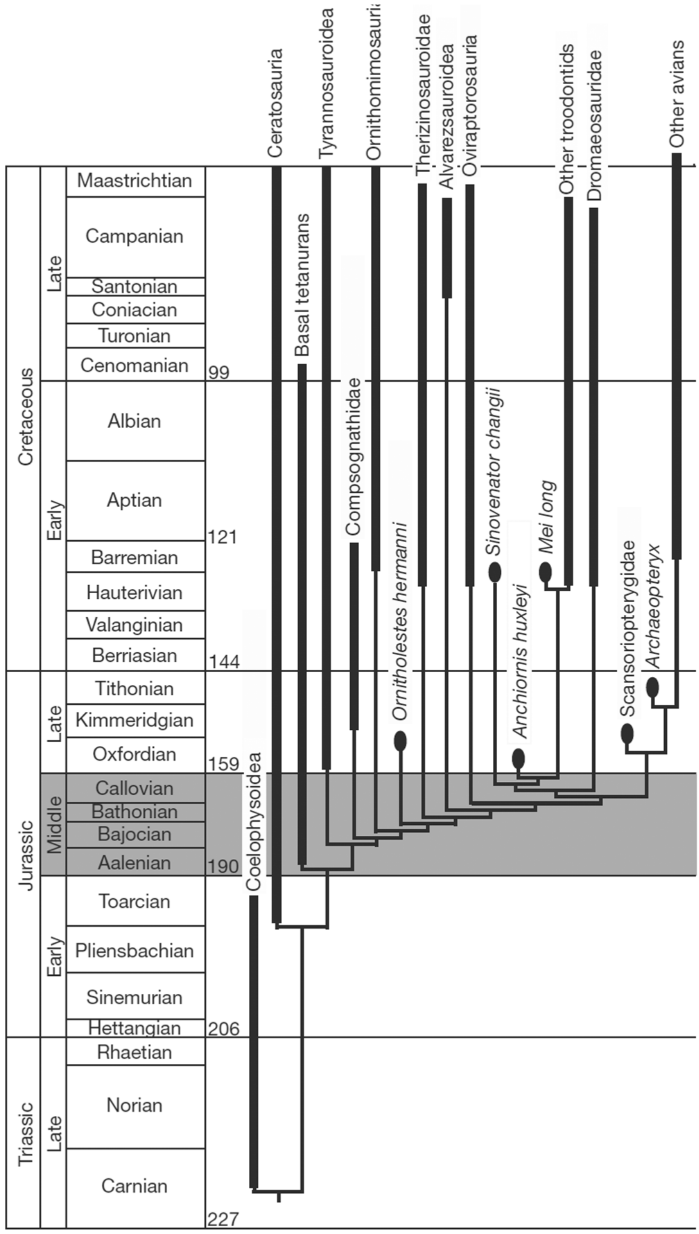


FIGURE 45 – A simplified evolutionary tree of theropod dinosaurs highlighting the relationships of coelurosaurs and birds.

hands of *Deinonyonus* and the delicate manus of *Epidexipteryx*. There is scarcely anything about a pigeon perched on a statue or a chicken you eat for dinner that did not first appear in dinosaurs, long before *Confuciusornis* flew in great flocks over what is now China. The majority of their relatives sunk into extinction sixty-five million years ago, but they are perhaps the most successful dinosaurs ever to have evolved. If you want to see living dinosaurs, you don't have to trek to a steaming jungle or isolated plateau. All you have to do is put up a bird feeder and look out the window.

But dinosaurs and birds were not the only terrestrial vertebrates evolving during the Mesozoic. The first mammals evolved alongside early dinosaurs, but they remained small creatures that lived in the corners of the world's ecosystems. The worst mass extinction ever to strike the planet had almost entirely wiped out their ancestors, making them only the remnants of a family that once flourished, but, 150 million years later, a stroke of bad luck for the dinosaurs would prove to be an unexpected boon.

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ground, but the trackway also preserved the movements of several dinosaurs together. The intricacies of the preservation and spacing of the tracks supported the idea that these dinosaurs were moving together, and it seems that at least some dinosaurs like *Deinonychus* were gregarious.

[37] Even this is an oversimplification. Some animals, like small bats and birds, have high constant body temperatures for part of the day or year but have their body temperatures affected by the surrounding environment at other times. Others, like some fish, have body temperatures that fluctuate with the environment but are maintained several degrees higher than the surrounding water.

[38] This was later reinforced by the discovery of another *Archaeopteryx* without clear feather impressions that had been labeled *Compsognathus*. What so many naturalists said was right; without feathers *Archaeopteryx* looked just like a dinosaur.

[39] Artist Gregory Paul illustrated what some of these downy dinosaurs might have looked like in his 1988 book *Predatory Dinosaurs of the World*.

[40] Other groups of predatory dinosaurs, represented by theropods, such as *Allosaurus*, *Spinosaurus*, and *Carnotaurus*, were not coelurosaurs, and to date there is no evidence that they had feathers.

[41] This is no more fantastic than suggesting that our own prehistoric ancestors were covered in hair, based upon their relationship to us.

[42] There are a number of ways to distinguish the ornithischians from the saurischians, but the easiest is to look at their hips. The ornithischians have a backward-pointed process called the pubis, while the same process in many saurischians is oriented forward (though it was secondarily rotated to point backwards in dinosaurs closely related to birds). Huxley was wrong when he thought the hips of *Hypsilophodon* represented all dinosaurs. We now know it was a type of ornithischian, unrelated to the earliest birds.

[43] Some marine reptiles, like the ichthyosaurs, had only one temporal fenestra. They differed from synapsids, however, in that they had evolved from ancestors with two such openings and the one that was retained was higher up on the skull.

[44] Today the term "pelycosaur" has fallen out of fashion because it is thought to be paraphyletic, or a group that does not contain all the descendants of a common ancestor (in this case, the therapsids). The name is retained here, however, because it allows creatures like *Dimetrodon* to be distinguished from other synapsids, and the connection between the pelycosaurs and the earliest therapsids is explained.

[45] An exception to this may be a potential early therapsid fossil from the Lower Permian called *Tetraceratops*. More complete remains will be required to determine its relationships, but if it is an early therapsid, as some paleontologists have proposed, it may indicate that the early therapsid form existed for millions of years before the adaptive radiation at about 267 million years ago. At present, though, it appears that therapsids diversified quickly after the first members of the group evolved, fitting a more punctuated evolutionary model than a "gradual" one.

[46] Interestingly, the separation of ear bones from the lower jaw of synapsids may have occurred more than once. In 2005 a team led by Thomas Rich described the jaw of an early platypus relative called *Teinolophos* that lived after the split between monotremes and other mammals but still had ear bones connected to its lower jaw. This suggests that the separation of the ear bones from the lower jaw happened once among monotremes and again in the lineage leading to the other two groups of mammals.

[47] The levels at which natural selection might work have been hotly debated in recent years. Some scientists, such as Richard Dawkins, have argued that natural selection primarily works at the level of the gene, thus rendering organisms only as gene-propagation vehicles. Scientists such as Stephen Jay Gould, however, have argued that natural selection can act on a variety of hierarchical levels, from genes to