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Dinosaurs Come to Life

Pigment cells in fossilized feathers offer the best look yet at the extinct reptiles

Feathered Dinosaurs Show Their True Colors

In the past two decades, archaeologists have found dozens of dinosaur species with well-preserved feathers, mainly in China. With the recent discovery of preserved color-pigment sacs (known as melanosomes) on these fossil feathers, scientists are starting to restore original colors and patterns one species at a time.

Ever since the word "dinosaur" was introduced in 1842, the long-lost reptiles have captured our collective imagination. Museum exhibits, illustrated books and Hollywood blockbusters such as *Jurassic Park* bring the extinct monsters to life in terrifying detail. But for the most part, the only real-life remains we have of dinosaurs are their skeletons and ambiguously colored feathers. Colorful depictions of dinosaurs have simply been educated guesses.

For decades, paleoartists have drawn inspiration for dinosaur illustrations from modern reptiles, fish and birds living in habitats similar to those of their ancient predecessors. Most artists use neutral tones commonly found in nature—brown, green, gray and black—to color their models. But a few get more imaginative. "With no specific guidelines to follow, some people can go pretty wild with colors, which risks making them unbelievable," says Gary Staab, a paleoartist who has created dinosaur models for the American Museum of Natural History in New York and the Smithsonian Institution in Washington, D.C.

Now, however, the guessing game appears to be coming to an end—at least for the estimated 20 percent of dinosaurs that were feathered. In 2008,

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Jakob Vinther, a graduate student in paleontology at Yale University, announced the discovery of fossilized dinosaur- or prehistoric bird-feather melanosomes, cell structures that synthesize and store the pigment melanin. By examining the shape and pattern of the structures, Vinther wrote in *Biology Letters*, researchers could for the first time identify dinosaur feather colors, such as the red-brown crest atop *Anchiornis*'s head or the chestnut stripes on *Sinosauropteryx*'s tail.

The findings will bring about more than better illustrations of the creatures. Paleontologists will use information about colors and patterns to investigate the animals' biology—how males and females communicated, for example, or how the dinos recognized their own kind. The research could also help explain how feathers evolved, leading to flight.

The Discovery

In 2006, when Vinther was in his first year at Yale, he examined two 150-million-year-old squid ink sacs. He was surprised to find within them preserved melanin, the same pigment that determines human skin color. The pigment cells were virtually identical in shape to those found in modern squid.

Melanin serves a variety of functions. In humans it protects skin cells from sun damage, and in birds it increases feather strength. Squid use it to scare off predators with a cloud of ink. But for Vinther, melanin's role in producing color in animals was the critical point. Could fossilized dinosaur melanosomes finally reveal dinosaurs' colors?

If squid melanin had not changed over millions of years, Vinther thought, perhaps the same would be true for birds, the descendants of dinosaurs. Modern bird-feather melanosomes are found in two shapes: elongated rods, which store black pigments known as eumelanins, and spheres, which house red-brown pigments called phaeomelanins. Different combinations of the rods and spheres on a feather, as well as the density of the structures, produce some of the colors and shades we see in today's birds.

First, Vinther needed to find out if feather melanosomes fossilize. He looked for the structures in a wreath of preserved feathers from a 50-million-year-old bird skull found in Denmark. A scanning electron microscope revealed what looked like eumelanins on the feathers. Yale paleontologist Derek Briggs, Vinther's academic adviser at the time, was doubtful. Two decades earlier, similar rodlike shapes on fossil feathers had been identified as bacteria, and throughout the 1990s Briggs had built a case for the role of these bacteria in fossilizing structures.

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Briggs suggested they examine another fossil, this one a 100-million-year-old feather with what looked like black-and-white stripes. (Dark-and-light areas can often be seen on fossil feathers, but their true colors are unknown.) The feather, found in Brazil, belonged to either a dinosaur or a prehistoric bird. Briggs and Vinther found the rod shapes only in the dark stripes; bacteria, however, would have been evenly distributed throughout the feather. The conclusion: The structures were melanosomes, not bacteria. The results, published in October 2008, sparked an international interest in "color mapping" feathered dinosaurs, or applying colors to the animals, body part by body part.

Coloring Dinosaurs

University of Bristol paleontologist Mike Benton, with his colleagues from England, China and Ireland, had spent two years examining feathered dinosaur fossils from Asia's 131-million- to 120-million-year-old Jehol ecosystem when Vinther and Briggs's findings were published. "They had shown conclusively that these structures, once passed off as bacteria, really were not," Benton says. "The potential for new paleobiological insights were clear to everyone."

That December at Bristol, the group zoomed in a little closer on the Jehol specimens and found the same rod-shaped melanosomes, as well as spherical melanosomes, on feathers from *Confuciusornis*, an ancient bird, and *Sinornithosaurus*, a non-avian dinosaur. The findings indicated that the animals had both black and red-brown colorations. Another non-avian dinosaur, *Sinosauropteryx*, exhibited only spherical melanosomes, suggesting that the dark stripes visible on bristles along its fossilized tail, as well as a feathered crest along its back, were chestnut or red-brown in color. Benton and his team published their results in the journal *Nature* last February.

Back at Yale, Vinther and his colleagues teamed up with paleontologists Li Quanguo and Meng Qingjin of the Beijing Museum of Natural History and Gao Ke-Qin of Peking University in Beijing to analyze melanosomes in fossilized dinosaur feathers from China. The researchers chose *Anchiornis huxleyi*, a recently discovered 161-million- to 151-million-year-old dinosaur, for its well-preserved feathers.

The team scraped samples from 29 points on the chicken-size fossil. They found red- or black-producing melanosomes in almost all. To determine *A. huxleyi*'s actual colors, including variations of black, brown and gray, Vinther approached biologist Matthew Shawkey of the University of Akron, an expert in modern bird plumage. Shawkey and his postdoctoral researcher Liliana

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D'Alba analyzed melanosome shape and density in black, gray and red-brown feathers from 36 species of living birds. With this information, the pair developed a statistical tool that compares dinosaur melanosomes with those of birds to determine the extinct animals' feather colors.

"With the statistical analysis, we can say with confidence for the first time 'This is a black, red or brown area,'" Vinther says. "We can also determine colors and patterns over an entire [feathered] animal and not just a single feather."

Last March, Vinther and his colleagues published their results on *A. huxleyi* in the journal *Science*. The dinosaur had a red-brown crest atop its head and similar colored flecks on the sides of its face. Its back and most of its body was dark gray or black, but the feathers on its wings and legs alternated between white and black, which created a striped pattern when seen from the side. Missing just the tail, which archaeologists didn't recover, the reconstruction is possibly the world's most realistic depiction of a dinosaur.

The two other pigments—porphyrins and carotenoids—responsible for the other colors in modern birds' plumage, such as blue and green, have not been found in dinosaur fossils, indicating that either they didn't preserve as well as melanosomes or more likely that they hadn't evolved yet. Benton says the latter theory is supported by the fact that mammals never adopted them, either.

Filling in the Blanks

Coloring dinosaurs won't just improve our image of the iconic creatures. It will also give us greater insight into how they lived. Long before dinosaurs took to the air on wings, the reptiles used variations of feathers to regulate their body temperature, repel water, and communicate.

"If you look at *Anchiornis huxleyi*, that red crest of feathers on its head—that was not used as camouflage," Vinther says. "It was used as display of some sort. We need to look at more fossils to say whether it was for species recognition or sexual display. If we see there are differences between *Anchiornis* specimens—that some have these red crest feathers and others don't—then it was probably for sexual purposes: identifying males and females. If they're all the same, they must be for species recognition," he explains.

Beyond their quest to gain knowledge of dinosaurs, Benton says, "scientists want to answer wider questions about the great success of birds. How and when did feathers emerge? How were feather styles and structures added in time, and what were the key breakthroughs that permitted a massive diversity increase?"

Most modern birds have so-called contour feathers, in which filaments branch off from a shaft. Tiny hooklike structures on the filaments hold them together in nature's version of Velcro. Vinther theorizes that this complex feather structure was sucessful because it let dinosaurs exhibit color patterns not just feather by feather, but within

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a single feather as well, which would have improved their displays. If scientists are able to find melanosomal evidence of this complex coloring, it could help prove that the aerial function of feathers—first gliding and later flying—was just a bonus.

Rewriting History

The push to color-map dinosaurs is still in the early stages, with only *A. huxleyi* completely restored. This summer, Vinther's group will unveil new dinosaur and extinct-bird restorations. Benton and his colleagues continue to color-map dinosaurs and ancient birds found in the Jehol group.

Both Vinther and Benton also think preserved skin melanosomes or melanin in the rock impressions of dinosaur fossils could one day be used to restore colors in non-feathered dinos. In the meantime, Vinther and Shawkey recently teamed up with paleontologist Julia Clarke of the University of Texas to color-map a 36-million-year-old giant penguin fossil from Peru. Instead of the black and white plumage of most of today's penguins, these ancient birds were predominantly gray and red-brown. The work, published late last year in *Science*, showed that the melanosome method can be used to restore color on a variety of fossil species, not just dinosaurs.

One group that's standing by: paleoartists such as Gary Staab. "The possibility of doing an animation or painting with more-accurate colors has everyone super-excited," he says. "We are all in this because we want to bring these fossils to life." ■

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Velociraptor
WHERE: MONGOLIA
WHEN: 99–65 MILLION YEARS AGO

Epidexipteryx
WHERE: CHINA
WHEN: 168–152 MILLION YEARS AGO

Tianyulong
WHERE: CHINA
WHEN: 145–99 MILLION YEARS AGO

Microraptor
WHERE: CHINA
WHEN: 145–99 MILLION YEARS AGO

Psittacosaurus
WHERE: CHINA, MONGOLIA AND RUSSIA
WHEN: 130–100 MILLION YEARS AGO

ANCHIORNIS
WHERE: CHINA
WHEN: 161–151 MILLION YEARS AGO

Pedopenna
WHERE: CHINA
WHEN: 176–146 MILLION YEARS AGO

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> By examining the shape and pattern of the structures, researchers could for the first time identify dinosaur feather colors.

The artist based the colors and striped patterns in this rendering of a *Sinosauropteryx* on fossilized melanosomes in the animal's tail and the feathered crest on its back.

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UTAH
LIFE ELEVATED

How to Color a Dinosaur

By studying packets of melanin pigments (melanosomes) in feathers from today's birds, Jakob Vinther, a paleontology doctoral student at Yale University, and his colleagues produced a model that can predict the colors of feathered dinosaurs. The melanosome patterns in the feathered-dinosaur fossils can be seen under a scanning electron microscope. *Anchiornis huxleyi* [above] is the first dinosaur whose color scheme has been completely decoded. Here's how they did it.

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A. Vinther's team sampled 29 areas on *A. huxleyi*, including the right hind limb [14–19], both forelimbs [1–13] and the head [25–29]. Sampling locations were chosen based on factors such as feather shape and remnants of visible patterns.

25A: Impressions of spherical melanosomes, which contain red-brown pigments

25B: Impressions of sausage-shaped melanosomes, which contain black pigments

B. The researchers looked at the shape and density of the melanosomes or their impressions at each site [right]. The presence of rod-shaped pigment sacs indicates an area was black, whereas spherical structures indicate brown or red colors.

C. The scientists input this data into a model that colorized the fossil based on comparisons with similar melanosome compositions in modern birds. A scientific illustrator used the results to make a reconstruction of the animal.

26 AND 27: Feather areas with spherical melanosomes (26) have red hues but, when both spherical and rod-shaped melanosomes (27) are present, gray colors are produced.

Jakob Vinther with specimens from Yale's ornithology collection. Bird pigments hold clues to the physical appearance of dinosaurs.

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Feathers: From Sight to Flight

Non-avian dinosaurs developed feathers roughly 260 to 230 million years ago (MYA), possibly as a form of visual communication. Color patterns may have determined dinosaurs' ability to attract mates. By the early Cretaceous period, around 145 to 99 million years ago, the evolution of feather shape had enabled early flight.

Sinosauropteryx

FEATHERS EVOLVED: 260–201 MYA
USED FOR: SIGNALING

The first feathers are threadlike bristles that endow dinosaurs with colors and stripes, like the brown-and-white stripes recently identified on the tail of *Sinosauropteryx*. These early feathers most likely play a role in signaling mates.

Caudipteryx

FEATHERS EVOLVED: 200–162 MYA
USED FOR: SIGNALING

By the early Cretaceous period, species like *Caudipteryx* bear feathers with a central shaft and vanes. The more complex structure allows for patterns within a single feather—an advantage for attracting mates and in species recognition.

Anchiornis

FEATHERS EVOLVED: 161–146 MYA
USED FOR: GLIDING

With dinosaurs such as *Anchiornis huxleyi*, feathers take on a new function, gliding. These dinosaurs have long feathers on their arms, legs and toes. Two pairs of wings and a feathered tail maximize surface area and form an optimal gliding plane.

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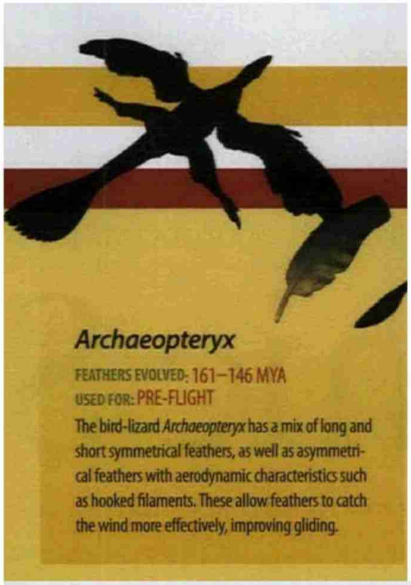
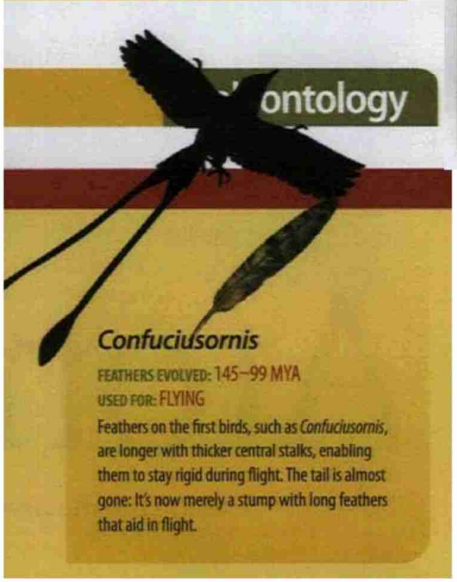


Archaeopteryx

FEATHERS EVOLVED: 161–146 MYA
USED FOR: PRE-FLIGHT

The bird-lizard *Archaeopteryx* has a mix of long and short symmetrical feathers, as well as asymmetrical feathers with aerodynamic characteristics such as hooked filaments. These allow feathers to catch the wind more effectively, improving gliding.



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Confuciusornis

FEATHERS EVOLVED: 145–99 MYA
USED FOR: FLYING

Feathers on the first birds, such as *Confuciusornis*, are longer with thicker central stalks, enabling them to stay rigid during flight. The tail is almost gone: It's now merely a stump with long feathers that aid in flight.

Empirical Evidence: Travel

Visit a Hub of Dinosaur Discovery

Dinosaur National Monument on the border of Utah and Colorado is one of North America's richest dino-fossil deposits. The exhibit houses 1,500 specimens, with some partially excavated fossils still embedded in the rocks along a trail. Go to *nps.gov/dino*.

GETTING THERE

Fly into Salt Lake City, Utah, or Grand Junction, Colorado. The monument is about a two-and-a-half- to three-hour drive from each airport.

WHERE TO STAY

There are several small hotels in the towns surrounding the monument. Or stay in one of the six on-site campgrounds. Check with park rangers regarding water availability and road conditions during off-peak seasons.

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