A Ticklish Debate

How might the feather have evolved?

By SID PERKINS

In 1861, just 2 years after the publication of Charles Darwin's *On the Origin of Species by Natural Selection*, stoneworkers exhumed a curious fossil from a limestone quarry in Bavaria. The fossil had many of the skeletal characteristics of dinosaurs, including a full set of teeth, a flat breastbone, and a long, bony tail.

But *Archaeopteryx*, which had lived about 150 million years ago, also had a wishbone, wings, and feathers nearly indistinguishable from those of birds today. Almost immediately after the find, some scientists seized upon the fossil's blend of characteristics and hailed it as the formerly missing link between ancient reptiles and modern birds. They asserted it was a perfect example of a transitional creature predicted by Darwin's insight into evolution.

Although that interpretation has never been entirely free of controversy, almost all scientists now agree that *Archaeopteryx* is the oldest known bird. A recent spate of fossil finds, replete with rare impressions of skin features, has triggered a battle of interpretations about how and when one of the most remarkable traits of birds—feathers—evolved.

Several of the recent discoveries sport modern-style feathers, just as *Archaeopteryx* does. Others, however, are covered with peculiar structures that some scientists call dino-fuzz. All are geologically younger than *Archaeopteryx*—some by tens of millions of years. That raises many difficult questions, including whether feathers and flight originally had anything to do with one another.

Until yet-undiscovered fossils reveal the precursors of feathers, scientists can only speculate on what their structures may have looked like millions of years before *Archaeopteryx* flapped onto the scene. As researchers seek to divine how feathers might have evolved, some have chosen to analyze only what's in the fossil record. Others have broadened their analyses to include evidence from modern animals.

In what can charitably be called a contentious debate, the two most strident groups of these paleontologists sometimes—okay, almost always—reach interpretations of the data that are poles apart. They defend their analyses with fundamentalist fervor and fling darts at the opinions of scientists who hold a different view.

When these guys get together, the feathers can really fly.

About 5 years ago, Paul Maderson, an evolutionary biologist at the City University of New York, set out to organize a symposium on the evolution of feathers. The idea was to bring together researchers with opinions on the issue for a reasoned, scientific debate. As it turns out, the meeting, which wasn't held until January 1999, exemplified what Maderson describes as a period of vitriolic name-calling that began in the mid-1990s.

"At that time, I knew there was disagreement [about the evolution of feathers], but I never dreamed that any scientific matter could possibly generate such bad personal behavior and such bitterness," he confesses.

Much of the paleontological passion about the evolution of feathers stems from the fundamental philosophies and the data that each faction chooses to use in its analysis.

The members of one camp of paleontologists rely on the fossil record and cladistics, the science of determining the evolutionary relationships between organisms by analyzing their shared characteristics. By looking at traits such as general body structure, the number and shape of bones, and the presence of body coverings such as feathers, these scientists can construct family trees.

The opposing group of scientists looks for relevant data beyond the fossil record. For example, they contend that studying the way today's birds grow feathers might shed light on how those structures evolved in their ancient ancestors.

Luis M. Chiappe, a paleontologist at the Museum of Natural History of Los Angeles County in Los Angeles who specializes in avian evolution, focuses exclusively on fossils and their cladistics. Scientists who do otherwise "belong to the arm-waving school of envisioning and speculating and looking for what's intuitively pleasing," says Chiappe. "Nothing's intuitively pleasing until I see it in the fossil record."

Too bad the fossil record is so sparse, laments Thomas R. Holtz Jr., a vertebrate paleontologist at the University of Maryland in College Park and a moderate in the debate. "Sampling is so spotty that the oldest known representative of [a particu-

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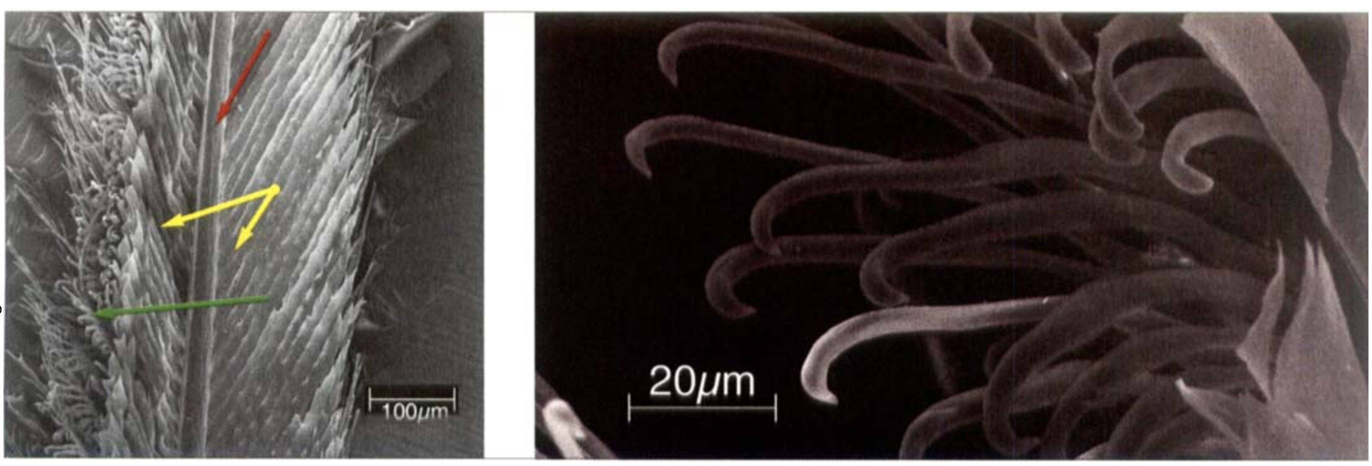

Close-up of a single barb of a chicken feather (red arrow) also reveals its barbules (yellow arrows) and hooklets (green arrow, and extreme close-up at right), which hold adjacent barbs together like Velcro.

lar group of species] probably isn't the oldest one that ever existed," he says. "It's simply the oldest one we've found so far."

Peter Dodson, an evolutionary biologist at the University of Pennsylvania in Philadelphia, opposes Chiappe's view and argues that paleontologists have to take a broad approach. He notes that the sediments around fossils and their locations—not just the fossils themselves—offer clues about how ancient animals might have lived and evolved, as well as the geographic distribution of similar animals at the time.

"I'm very unhappy and profoundly disappointed at philosophies that exclude large amounts of pertinent evidence," Dodson adds. "That's a bad way to do science."

Another argument against cladistics based solely on fossils: Looks can be deceiving, as genetic analysis of living animals attests (see box). This kind of disconnect between physical appearances and genetic relationships helps fan the debate over how feathers evolved.

Family trees: Looks versus genes

Consider that a family tree based on DNA similarities can be much different from one drawn according to body characteristics preserved in fossils (SN: 11/25/00, p. 346). Markers in the DNA of modern animals, for example, link African creatures as diverse as elephants, elephant shrews, and aardvarks to a common ancestor (SN: 1/6/01, p. 4).

Similar DNA analyses suggest that the flamingo's closest relatives could be grebes—medium-size diving birds with stocky bodies, slender necks, and small heads. These and other skeletal characteristics have led most evolutionary biologists to group grebes with loons, another diving bird, says S. Blair Hedges of Pennsylvania State University in State College. But two completely different types of genetic testing indicate that the leggy flamingo and the squatty grebe may in fact be long-lost cousins.

"The fossil record for flamingos goes back at least 50 million years, and none of their body characteristics suggests that they're related to grebes," says Hedges, who reported the DNA tree in the July 7 PROCEEDINGS OF THE ROYAL SOCIETY OF LONDON B. That DNA links flamingos and grebes "was a big surprise," he says. —*S.P.*

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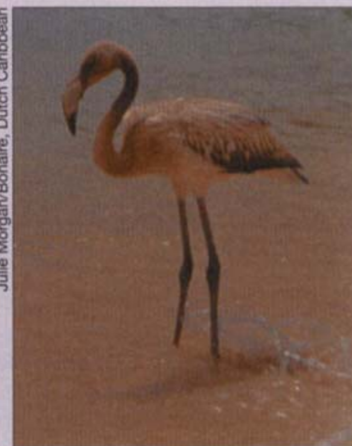

Two types of genetic analyses suggest that diving birds known as grebes, including the western grebe (left), are the closest relatives of the flamingo (right).

Feathers distinguish birds from other animals, come in many varieties, and serve many functions. They trap air near the body and help a bird maintain its body temperature. Their colors and patterns provide a means of communication or camouflage, and they can either repel water or soak it up. Also, they provide birds with an aerodynamic shape and help propel them.

Despite their remarkable diversity and complicated structures, feathers are mostly made of a single material called beta keratin. Cells that line skin follicles generate this light yet strong material, as well as the pigments that give a feather its color. In general, feathers have a long central shaft and stiff fibers, called barbs, that branch from the shaft. Barbules, smaller fibers that branch from the barbs, can sport small hooklets that lock onto adjacent barbs or barbules. This arrangement stiffens the barbs into a single, flat vane. Feathers without hooklets often have a downy appearance.

Paleontologists analyzing the skin impression of a fossil and finding follicles can't tell what varieties of feathers, if any, the animal might have grown.

"Just by looking at a follicle, you can't tell what type of feather it will produce," cautions Peter R. Stettenheim, an ornithologist who lives in Plainfield, N.H. The same follicles that generate downy feathers on a newly hatched bird can end up producing flight feathers later in the bird's life. Also, a follicle that grows a colored feather for the mating season or for summer camouflage can sprout a plume of a different color at another time of year.

A follicle's tendency toward multiple personalities has profound implications for analysis of the fossil record, says Stettenheim, whose contribution is included in the recently published proceedings of the 1999 meeting organized by Maderson. A fossil is essentially a snapshot in time, a picture of what the animal looked like at the time it died, he notes.

Most paleontologists agree that feathers like those found on modern birds have a structure that's much too complicated to have evolved more than once. Until scientists unearth fossils that are clearly the ancestors of *Archaeopteryx*, their imaginations can run wild as to what primitive feathers might have looked like.

Some paleontologists contend that feathers evolved separately from flight. In their view, plumage was an evolutionary novelty that originated in a small group of bipedal, carnivorous dinosaurs. Chiappe says that primitive feathers probably first evolved for a purpose such as communicating with potential mates and adversaries or moderating an animal's body temperature. Only later did these precursors to feathers gradually assume a more modern form, as the evolving structures became useful for locomotion and eventually full-fledged flight.

Computer-based aerodynamic analyses show that even flightless theropod dinosaurs with feathers could run faster if they flapped their wings, Chiappe notes. Primitive feathers probably helped dinosaurs make quick turns, which might have helped them catch prey or escape predators, he adds. Then, dinosaurs passed along the innovation to birds.

Contrast this so-called from-the-ground-up theory of the evolution of flight with a from-the-trees-down concept. In the latter, feathers and the ability to fly evolved simultaneously.

In one of these theories, the scales on small reptiles became stubby projections. A rough skin would have been beneficial to small tree-dwelling reptiles because it would smooth the airflow over the body as the animals jumped away from predators, says Dominique G. Homberger, an evolutionary biologist at Louisiana State University in Baton Rouge. Smoother airflow translates into less aerodynamic drag and therefore an ability to jump farther.

Animals that garnered this small yet distinct advantage would have been most likely to survive. That could have driven the evolution of such stubby scales into elongated filaments, which eventually evolved into feathers.

Primitive forms of feathers need not have served all the functions that a modern bird's feathers serve, Homberger says. It was only necessary that such structures conveyed some small benefit to the ancient reptile. When fossils of the ancestors of *Archaeopteryx* finally come along, they may help reveal the origin of feathers, Homberger notes.

The search is on for just those fossils, but finding specimens that answer important questions is usually a matter of luck, says Holtz. Conditions must be just right for an animal's remains to be preserved, and that's particularly true for the small, lithe creatures that might have been the ancestors of birds.

The calm waters of a lake or lagoon would be required, because the rough-and-tumble conditions in a river or stream would probably tear apart the delicate skeleton of a small animal, he notes. Also, only the fine-grained sediments typically washed into calm waters would capture the detailed microstructure of any primitive feathers covering a dead animal's body. Finally, the water would have to have held little oxygen, thus checking the population of bottom-dwelling bacteria or other organisms that otherwise would have consumed the animal.

Most paleontologists agree that all they need to do is find the fossils that formed somewhere in the world under just these conditions long before *Archaeopteryx* winged its way through Bavarian skies. At that point, they might have the first bird's direct ancestor and the means to end a fierce scientific debate. □