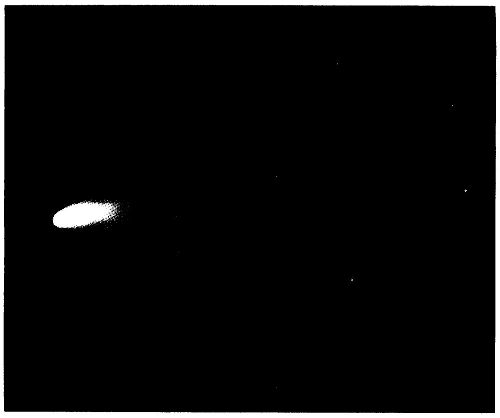


Chilly childhood. Traces of argon indicate that Hale-Bopp formed near Neptune's orbit.

Stern and a half-dozen collaborators launched a sounding rocket 300 kilometers above the White Sands Missile Range in New Mexico to study Hale-Bopp on 29 March 1997, within a day of its closest approach to the sun. The rocket carried a small telescope and a spectrograph that Stern aimed at the comet for just 5 minutes, using a joystick and radio telemetry. In the complex spectrum of sunlight reflected by the comet, the team found a pair of faint wiggles at ultraviolet wavelengths characteristic of argon. "Hale-Bopp was such a boomer that there was just enough argon for us to detect," Stern says.

The implication, he maintains, is that the comet arose between the orbits of Uranus and Neptune, where temperatures in the embryonic solar system hovered around 40 kelvin. That places tighter limits on Hale-Bopp's cradle than research by Mumma and others in 1997 with the Extreme Ultraviolet Explorer satellite, which found that neon was depleted in Hale-Bopp by a factor of at least 25 compared with the sun. If all of Hale-Bopp's neon burned off, its birthplace must have been warmer than 25 kelvin (*Science*, 5 September 1997, p. 1488).

Recent models by SwRI planetary scientist Harold Levison and colleagues suggest that Jupiter, Saturn, Uranus, and Neptune each may have injected comparable numbers of comets to the Oort Cloud. However, the solar system's disk of gas and dust was so much warmer near Jupiter that all of Hale-Bopp's argon would have wafted into space if it spent much time there, Stern says. "This comet must have been in a deep freeze," he says, until some slight perturbation—perhaps from a passing star—nudged it inward from the Oort Cloud relatively recently.

That scenario is feasible, says planetary scientist Jonathan Lunine of the University of Arizona, Tucson. However, he warns that comets may have undergone chemical processing after their birth. Such modifications could have changed the original gas contents of comets in ways that astronomers still don't understand. "We cannot yet say that the comet formed at 20 or 30 kelvin just because we see argon," he says. Stern notes that even if such changes occurred, the presence of argon shows that the comet's interior never rose above 40 kelvin, pointing to a quick exit from the solar system.

Astronomer Lucy McFadden of the University of Maryland, College Park, and others had hoped to see argon from Halley's Comet in 1986 with a shuttle mission, but the Challenger explosion foiled those plans. Stern's team produced "a very high return for a cost-effective observation," she says. "These are remarkable results."

–**ROBERT IRION**

PALEONTOLOGY

Feathers, or Flight of Fancy?

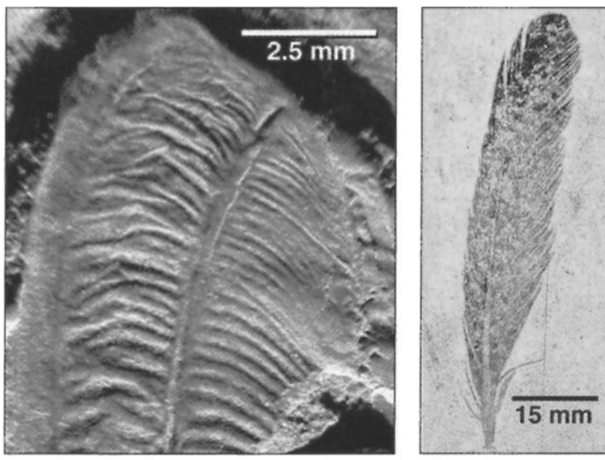
A controversial paper aims to turn avian origins on its head. But mainstream paleontologists say "put up or shut up"

Longisquama insignis never asked for all this fuss. Some 220 million years ago, the squat, mouse-sized reptile eked out an unassuming existence in what is now central Asia, gobbling Triassic insects and minding its business. But *Longisquama* was marked by destiny: Sprouting from its spine were at least six vanelike appendages up to 12 centimeters long—features unlike anything known to have graced a reptile before or since. Scientists disagree whether the creature used its plumes for gliding; they may have been a sexual display. Now, after decades in a Russian research institute, the appendages have propelled *Longisquama*'s fossilized remains from relative obscurity and thrust it dead center into a bitter debate.

On page 2202, a team led by John Ruben of Oregon State University in Corvallis describes *Longisquama*'s curious appendages in the greatest detail yet. In a radical interpretation of the fossil evidence, the authors argue that the appendages are feathers much like those of modern birds. Outside the paper, Ruben and his iconoclastic band go much further, touting the fossil as "an ideal bird ancestor." That conclusion has infuriated paleontologists—not just because it challenges the prevalent theory that birds evolved from theropod dinosaurs, but because they say it does so in an unscientific way.

The minority of scientists who reject the dinosaurian origin of birds are elated by the new description of *Longisquama*. "It's almost too good to be true," says Storrs Olson, curator of birds at the Smithsonian Institution, who did not contribute to the paper. "This is a bigger step forward to understanding the origin of birds than *Archaeopteryx*"—the 145-million-year-old fossil bird whose teeth, scales, and other primitive features forged an unequivocal link between birds and reptiles. The dinosaur advocates' response to this new nontheropod ancestor to birds? "Nonsense." "Nuts." "Rubbish"—not to mention several unprintable comments.

The fossil causing the flap was discovered decades ago in an ancient lake bed in what is now Kyrgyzstan. The Russian paleontologist Alexander Sharov published the first description in 1970. Since then, the specimen has remained at the Russian Academy of Sciences' Paleontological Institute in Moscow, where few Western paleontologists have had a chance to examine it. Ruben and his graduate student Terry Jones first saw it in early 1999, when *Longisquama* was touring the United States as part of a privately sponsored fossil show. After the tour ended, Russian paleontologists brought the fossil to Larry Martin's lab at the University of Kansas, Lawrence, where they examined it with



Birds of a ...? Some argue that *Longisquama*'s appendages (*left*) were feathers, like those of the fossil bird *Archaeopteryx (right)*.

CREDITS: (LEFT TO RIGHT) RICHARD WAINSCOAT/UNIVERSITY OF HAWAII INSTITUTE FOR ASTRONOMY; T. D. JONES *ET AL*.; L. CHIAPPE, NATURAL HISTORY MUSEUM OF LOS ANGELES COUNTY

Ruben, Martin, Alan Feduccia of the University of North Carolina, Chapel Hill, and others.

What riveted their attention was the creature's plumage. Previous workers had described the long, thin appendages as scales (the name *Longisquama* means "long scale"), but to Ruben and colleagues they bore a breathtaking resemblance to bird feathers. For example, they note that *Longisquama*'s appendages have a central shaft with narrow ribs that extend out to the edges, roughly comparable to barbs on a feather. And near the spine, the shafts have wide, tubular bases, similar to the hollow calamus of modern feathers. The calamus grows from the circular epidermal ring around a follicle in a developmental pattern unique to feathers—a pattern Ruben thinks that the base of the shafts in *Longisquama* shares. "It had to have developed in a follicle," he says. "There's no other way to do it."

In short, Ruben and colleagues conclude, *Longisquama* was a feathered creature. That's important, Ruben says, because he and most other scientists think structures as specialized as feathers must have evolved only once, almost certainly in some ancient member of a vast group of creatures called archosaurs. Archosaurs include birds, dinosaurs, pterosaurs, crocodiles, and less well known animals, all of which share a unique pattern of openings in the skull.

But if only one branch of the archosaur family developed feathers, which one was it? Theropod dinosaurs, most paleontologists say, citing numerous skeletal similarities that link them to birds. Ruben disagrees. If a nondinosaurian archosaur—*Longisquama*—had feathers, he says, then it's difficult for him to picture dinosaurs' evolving them independently and turning into birds. On the other hand, "I can easily imagine avian evolution going through a *Longisquama*-like stage," Ruben says.

When paleontologists hear statements like that, they reach for their entrenching tools. The problem, they say, is not that the authors of the *Longisquama* paper are presenting a rival hypothesis about bird origins; it's that they aren't really stating a hypothesis at all. Simply arguing that *Longisquama* is birdlike is not enough, says paleontologist Kevin Padian of the University of California, Berkeley. You must be able to show that it is more closely related to birds than something else, such as theropod dinosaurs, he says.

To make such comparative evolutionary arguments, mainstream biologists and paleontologists in North America use computer-generated family trees called cladograms. First they choose anatomical characters, such as the length of digits or the presence of openings in the skull. Then they tabulate which animals do or don't have them, and run the resulting matrices through computer programs that rank the possible evolutionary lineages in order of simplicity. The most parsimonious cladogram is the one that requires the fewest evolutionary changes. Other things being equal, that family tree, or phylogeny, is the one that scientists prefer. "This gives us an explicit, repeatable, falsifiable basis for conducting our studies," says John Merck, a paleontologist at the University of Maryland, College Park.

But to the chagrin of their opponents, Ruben and others who object to the dinosaurian origin of birds don't argue that way. Instead of postulating cladistic relationships, Merck charges, Ruben and others present fossil evidence that they say suggests something other than dinosaurs might have given rise to birds, but without fleshing out alternative scenarios that others can test. "They're not playing the game," says Tom Holtz, a theropod expert at the University of Maryland, College Park. "Just saying 'This might have something to do with bird origins' doesn't give us something that's falsifiable."

For Padian, *Longisquama* is the last straw. "If you think this is where birds came from, where is your cladistic analysis?" he demands. "Where's your falsification of the dozens of cladograms that put birds right in the middle of theropod dinosaurs?"

Unnecessary, Martin says. "We don't have to do a cladogram. We can tell you right now that all the characters we found on the specimen were consistent with it being related to birds." As for the many cladograms that demonstrate a dinosaurian origin of birds, Martin charges that they are riddled with characters based on mistaken anatomy—in other words, "garbage in, garbage out" on a massive scale.

But anatomy may prove to be the Achilles' heel of the *Longisquama* paper. The evidence for feathers is marginal at best, says *Longi*-skeptic Rick Prum, curator of ornithology at the University of Kansas's Museum of Natural History and one of the scientists who saw the fossil while it was in Kansas. "I think they've documented through careful observation that the bases [of the appendages] are cylindrical," Prum concedes. Still, that doesn't mean they grew like feathers, he says, stressing that "everything else about these structures has nothing to do with feathers." What they really look like, Prum believes, is ribbed membranes. Feathers tend to fray at the edges, he notes; *Longisquama*'s plumes are fused. Near the base, where the appendage emerges from the skin of the beast, the ribs extend from the shaft backward toward the body, rather than toward the tip as a feather barb does. In one place, where two plumes cross, the one on top shows the clear imprint of the one underneath—something a feather wouldn't do. "The more you look at these things," Prum says, "the less they are like feathers."

Ruffled. Most paleontologists sharply reject the idea that a creature like *Longisquama*, not dinosaurs, led to birds.

CREDIT: T. D. JONES *ET AL.*

Some paleontologists even doubt whether *Longisquama* is an archosaur. Hans-Dieter Sues, an archosaur expert at the Royal Ontario Museum in Toronto who has studied the specimen firsthand, points out that cracks in the skull make it impossible to find two key diagnostic features: an opening in the lower jaw and an opening in front of the eye socket. Sharov included them in a sketch accompanying his original description of *Longisquama*, but others who have examined the fossil have been far less confident that they are there.

But even paleontologists who dismiss any connection between *Longisquama* and the origin of birds still find it an intriguing fossil. "Wherever *Longisquama* fits on the tree of life, it's a remarkable reptile from an extremely interesting time in vertebrate history," Holtz says. Prum points out that no modern animals have such long, membranous scales. Even if they have nothing to do with feathers, he says, "these structures are quite bizarre and fascinating. I want to know what they are."

–**ERIK STOKSTAD**