PALEONTOLOGY

# Lung Fossils Suggest Dinos Breathed in Cold Blood

When John Ruben first laid eyes on a high-quality photo of the so-called "feathered" dinosaur from China last year, he was stunned. It wasn't the featherlike structures that riveted his attention—he dismissed them as collagen fibers (see sidebar)—but the theropod dinosaur's innards, which were outlined in the slab of stone. "My eyes popped out," recalls Ruben, a respiratory physiology expert at Oregon State University in Corvallis. "I realized that here was the first evidence in the soft tissue that theropods had the same kind of compartmentalization of lungs, liver, and intestines that you would find in a crocodile"—and not in a bird.

To prove that notion, Ruben and his graduate students sectioned crocodiles and other reptiles and found that their lung structures resembled the images of several flattened fossil dinosaurs from China. On page 1267, Ruben uses this lung evidence to argue not only that dinosaurs were incapable of the high rates of gas exchange needed for warm-bloodedness, but also that their bellowslike lungs could not have evolved into the high-performance lungs of modern birds. Thus, he challenges two of the reigning hypotheses concerning dinosaurs: that they were warm-blooded and that they gave rise to birds.

Coming hot on the heels of another controversial paper that concludes that digits in bird wings could not have developed from dinosaur forelimbs (*Science*, 24 October, p. 666), Ruben's report is part of a "one-two punch to the dinosaur origins of birds hypothesis," says paleontologist James Farlow of Indiana University–Purdue University in Fort Wayne. But while many dinosaur experts say they welcome Ruben's novel approach, few are willing to embrace his conclusions so far. "This is exactly the kind of research we need," says Lawrence Witmer, an evolutionary biologist at Ohio University College of Osteopathic Medicine in Athens. And it's definitely weakening the case for warm-blooded dinosaurs. But many researchers, including Farlow and Witmer, think there's persuasive evidence that birds are descendants of dinosaurs. Says Farlow: "[This] is like a breath of fresh air, but it's going to ruffle a lot of feathers."

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**Short of breath.** Ruben (left) says dino lungs were inefficient.

To test whether dinosaurs were really endotherms—warm-blooded animals able to generate their own heat—Ruben and graduate students Terry Jones and Nick Geist have sought to identify the signatures of endothermy, such as a scroll-like structure in the nose, in the bones of living animals. They have argued that dinosaurs lack such structures (*Science*, 30 August 1996, p. 1204). But what they really needed was improbable—a look at a dinosaur's lungs to see if they were efficient enough to power a warm-blooded animal.

The improbable happened last year, however, when Ruben saw photos of several specimens of *Sinosauropteryx*, a small, meat-eating dinosaur from the 120-million-year-old Yixian formation in northeastern China. The fine silt from an ancient lake preserved the animals' soft structures, including a clear "silhouette of the lungs" of one dinosaur, says paleontologist Larry Martin of the University of Kansas, Lawrence, who has seen the fossils.

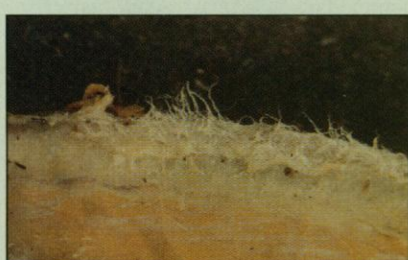
When Ruben looked at the photos, it was "immediately apparent" to him that the dinosaur's lungs were arranged in a way that closely matched that of crocodiles. The theropods had two major cavities—the thoracic cavity containing the lungs, liver, and heart; and the abdominal cavity containing intestines and other organs. These were completely separated from each other by the diaphragm, as is the case in croco-

## Plucking the Feathered Dinosaur

Exactly 1 year ago, paleontologists were abuzz about photos of a so-called "feathered dinosaur," which were passed around the halls at the annual meeting of the Society of Vertebrate Paleontology (*Science*, 1 November 1996, p. 720). The *Sinosauropteryx* specimen from the Yixian Formation in China made the front page of *The New York Times*, and was viewed by some as confirming the dinosaurian origins of birds. But at this year's vertebrate paleontology meeting in Chicago late last month, the verdict was a bit different: The structures are not modern feathers, say the roughly half-dozen Western paleontologists who have seen the specimens.

The stiff, bristlelike fibers that outline the fossils lack the detailed organization seen in modern feathers, says Alan Brush, an ornithologist at the University of Connecticut, Storrs, who specializes in feather structure. Brush was part of a "dream team" sent to China this spring by The Academy of Sciences in Philadelphia to view the fossils.

But just what the structures are—and whether they link birds and dinosaurs—is still under debate. Noting that the outline of the dinosaur skin is hard to discern in the fossilized stone, another dream team member, paleontologist Larry Martin of Kansas University, Lawrence, thinks the structures are frayed collagenous fibers beneath the skin—and so have nothing to do with birds. Zoologist John Ruben of Oregon State University in Corvallis dissected a sea snake's tail to show that such fibers can indeed look feathery (see photo). Others, including Brush and Philip Currie, a paleontologist at the Royal Tyrrell Museum of Palaeontology in Drumheller, Canada, describe the bristlelike fibers as "protofeathers"—fibers that may be hollow and made of the same kind of keratin as feathers.



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**Feathered friend?** Collagen fibers in a sea snake's tail resemble feathers.

Meanwhile, Ji Qiang, director of the Chinese Geology Museum in Beijing, insists that the fibers are "obvious primitive feathers." But a paper in press at *Nature* by another group of Chinese researchers doesn't make that claim, says Currie. Measuring the width of the fibers under a scanning electron microscope or testing whether they're made of collagen or keratin could resolve the debate. Some of these tests are under way, Currie adds. –A.G.

diles. Birds have no such separation.

In living crocodilians, the function of this separation is to provide an airtight seal between the cavities. Then, when the diaphragmatic muscles contract, they pull back the liver and create negative pressure in the thoracic cavity, allowing air to fill the bellows-type lungs. Birds don't need such a separation between the cavities, because air in their lungs moves one way through millions of tiny air passages, drawn by the expansion and contraction of air sacs throughout their bodies.

Birds' flow-through lung system has plenty of surface area and is especially efficient at exchanging oxygen for carbon dioxide. (Mammals have yet another system that allows efficient gas exchange.) The bellowslike reptilian lung, however, provides much less area for gas exchange, and reptiles cannot absorb oxygen at the high rates needed to sustain intense activity. Ruben also showed that theropods and crocodiles share a distinct hip structure, linked to muscles that help bring air into the bellowslike lungs. All in all, says Ruben, it's "pretty solid evidence that theropods could not have had a modern, high-performance avian-style lung ... and were stuck with an unmodified, bellowslike lung." Says Martin: "Support for the hot-blooded dinosaur hypothesis now has the rigidity of a marshmallow." The evolutionary implications are even more far-reaching. Ruben argues that a transition from a crocodilian to a bird lung would be impossible, because the transitional animal would have a life-threatening hernia or hole in its diaphragm. "There may well be a relationship between dinosaurs and birds, but it's not the linear relationship you see in museum displays," he says.

Ruben's analysis is "another nail in the coffin of the warm-blooded dinosaur theory," says paleontologist Peter Dodson of the University of Pennsylvania, Philadelphia. But many other researchers say his case is not airtight. They point out that Ruben relied on photos showing a lung outline that is little more than "smudges on rock," says Witmer. What's more, Ruben's inferences are based on a flattened, two-dimensional fossil. "You would expect some deformation when the organs squish out," says Witmer, who suggests, only half-jokingly, that Ruben flatten his alligators with a steamroller for comparison. And the evolutionary transition from the actual theropod lung, rather than the modern crocodilian analog, might be easier.

Indeed, even if Ruben's analysis of lung structure holds up, it would have to be weighed against "a mountain" of other evidence supporting the dinosaurian origin of birds, says Farlow. Still, he finds Ruben's findings of a crocodilian-type lung for theropods "compelling." Fortunately, the Yixian formation is so rich in fossils that more specimens of *Sinosauropteryx* are likely to turn up. And if the same lung structure appears in enough fossils, Ruben's case will gather considerable weight.

**–Ann Gibbons**

ASTRONOMY

# Galactic Disk Contains No Dark Matter

By studying the movement of stars in the disk of our Milky Way galaxy, two teams of French astronomers have concluded that what you see is what you get: The mass of the visible stars appears to account for all the material in the galactic disk. These findings, derived from data gathered by the European astrometric satellite Hipparcos, imply that the main body of our galaxy contains no "dark matter"—invisible material that astronomers believe accounts for up to 90% of the mass of the universe. "These studies confirm that the dark matter [presumed to be] associated with the galactic disc in fact doesn't exist," says Honc-Anh Pham of the Paris Observatory at Meudon, whose doctoral thesis forms one of two studies that came to this conclusion. Instead, both groups argue, the dark matter must be lurking in the galactic halo, a large, spherical region encircling the galaxy containing dust, gas, and globular clusters of very old stars.

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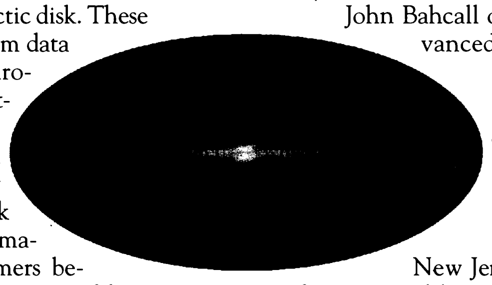

**No more than meets the eye.** Visible stars seem to account for all the mass in the galactic disk.

Pham studied the movements of 10,000 stars to get a fix on the gravitational forces pulling them around. She inferred from these movements that the local mass density in our galaxy is 0.11 solar masses per cubic parsec. (A parsec corresponds to 3.26 light-years.) A separate team, led by Michel Crézé of Strasbourg Observatory, reports in a forthcoming issue of *Astronomy & Astrophysics* that from a study of a smaller group of 100 stars they found an even lower value, 0.076 solar masses per cubic parsec. These values are close to estimates of the mass density of visible stars in the galactic disk and leave little room for dark matter. The new results confirm some earlier estimates, made before Hipparcos data became available, but they are much lower than values obtained by John Bahcall of the Institute for Advanced Study in Princeton, New Jersey, using velocity data from ground-based astrometric observations. He concluded that the local galactic density is between 0.15 and 0.20, enough to accommodate 30% to 50% dark matter.

Astronomers have long surmised that dark matter provides some of the gravitational glue required to hold galaxies together: Most galaxies rotate so fast that they would fly apart if their visible stars provide the only sources of gravity. The stars in galaxies also orbit in a peculiar fashion: Unlike planets in the solar system, stars in the outer reaches of galaxies move as fast as those nearer the center. This suggests that the galaxies' mass must be spread out and not concentrated in the core, as it is in the solar system.

Astronomers can estimate the total mass in a galaxy like our own from the forces needed to hold it together, but without an accurate knowledge of the mass density of the galactic disk, they could not tell how much of the dark matter resides in the disk and how much in the halo, Crézé says.

Crézé and his Strasbourg colleagues Emmanuel Chereuil and Olivier Bienaymé, and Christophe Pichon of the University of Basel in Switzerland, looked at the Hipparcos data for 100 stars in a sphere of radius 125 parsecs around the sun. Hipparcos, launched in August 1989, cataloged over 4 years the precise position and motions of more than 100,000 stars. The team analyzed the distribution of the motions of their sample of "tracer" stars in the direction perpendicular to the galactic disk to assess the amount of gravitational pull dragging them back toward the galactic plane. Herwig Dejonghe of the University of Ghent in Belgium compares their method to "looking at a sample of high jumpers and deducing the mass of the Earth from the height they reach."

Pham's approach was somewhat different: Her larger sample within a sphere with radius 250 parsecs consisted of just one type of star, known as F-type, which are old and so have dissipated some of the motion associated with their births in swirling clouds of gas. From their distance from the galactic plane and their proper motions, she obtained her value of the local galactic density.

The results were welcomed by Michael Merrifield of Britain's Southampton University, who with his colleague Robert Olling has argued from observations of the shape of the galactic disk, that all the dark matter in the galaxy should be found in a round halo. "We actually have run calculations ... our [galactic] model with the round halo corresponds exactly to the kind of numbers they get," Merrifield says.

**–Alexander Hellemans**

*Alexander Hellemans is a writer in Naples, Italy.*