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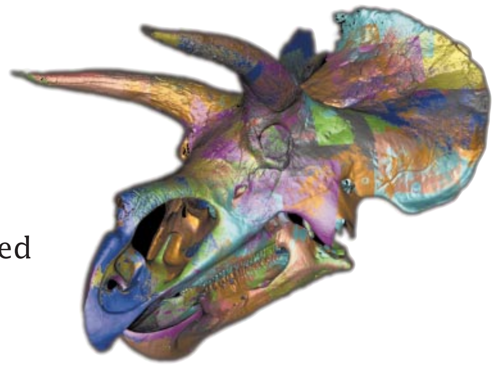
A Makeover for an Old Friend

Time and technology revamp a dinosaur classic

By SID PERKINS



Try standing in a corner for nearly a century, being breathed on and gawked at by millions of noisy tourists. You'd likely have tired bones, too.

In 1998, when Smithsonian Institution conservators took a close look at the fossils in Dinosaur Hall, they were astonished by the sad state of the *Triceratops*. The ancient glue used to harden the bones in the 93-year-old, 8-foot-high display was deteriorating, and the evaluators worried that the ancient relics were on the verge of falling apart.

What started out as a crisis for one of the most popular exhibits at the National Museum of Natural History in Washington, D.C., quickly turned into an opportunity for researchers. As the display was dismantled so that the fossilized bones and bone fragments could be cleaned and conserved, researchers applied the latest technology to learn more about how the *Triceratops* stood, walked, and maybe even ran.

Laser scans and other high-tech imaging of the bones have enabled the scientists for the first time to construct digital paleontological models that may resolve an ongoing debate about the animal's posture. Accurate scale models of the fossils have already revealed new information about how the bones fit together.

Next year, these data and nearly a century's worth of paleontological findings will be incorporated into a renovated exhibit at the Smithsonian. It will undoubtedly have scientists and museumgoers alike looking at these old bones in a new way.

With a large frill on the back of its skull and its trademark three horns—one small rhino-style horn on the nose and a long one pointing forward from above each eyebrow—*Triceratops* is one of the most familiar dinosaurs. In fact, says Ralph E. Chapman, a paleontologist at the Smithsonian, a survey would probably show *Triceratops* among the top 20 most recognized animals, period—right up there with dogs, cats, elephants, and people.

A lot of this familiarity stems from the prevalence of the dinosaur's image in modern culture. *Triceratops* has often appeared in children's literature and in movies, including 1925's *The Lost World* and 1993's *Jurassic Park*.

Smithsonian Institution/NMNH

Researchers used laser scans to generate three-dimensional digital models of the fossil bones that were included in the 1905 *Triceratops* mount.

Many of the popular ideas about how the dinosaur looked derive from the Smithsonian's original mount of the *Triceratops*, which was unveiled in 1905. Curators put the exhibit together from the bones of perhaps 20 different dinosaurs that paleontologists had collected in the 1880s and 1890s at six sites in eastern Wyoming. Chapman says the exhibit was the first attempt at an accurate, full-scale reproduction of the animal.

Despite having parts from so many animals, the 25-foot-long *Triceratops* that stood in the Smithsonian for nearly a century was far from complete—and it was far from perfect. For example, Chapman says, only a dozen or so of the bones in the mount's spine were real. The others, built out of plas-

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ter by the museum, were modified versions of the vertebrae at hand. The best skull available in 1905, the one that ended up in the exhibit, came from an animal now recognized to be a young adult that wasn't fully grown.

If the bones on display had suddenly sprung to life, they would have walked with a severe limp, if they could have walked at all. One humerus—the single bone in the upper forelimb—was much longer than the other because the two bones came from different animals. Furthermore, none of the *Triceratops* fossils found before 1905 included rear feet, so museum personnel attached feet from duck-billed dinosaurs instead.

None of these imperfections kept the tourists away. Chapman estimates that at least 100 million museumgoers have visited Dinosaur Hall since the *Triceratops* took up residence there, and this popularity has been part of the problem. The vibrations from the footfalls and voices of those visitors, the daily temperature and humidity changes associated with their breathing, the construction of a subway near the museum in the 1960s—all have contributed to the deterioration of the exhibit.

Moreover, the glues and other chemicals used to harden the bones after they were excavated didn't prove up to the task of preserving the specimens perpetually. Recent computerized tomography scans indicate that even some of the *Triceratops* fossil bones that appeared okay upon first inspection in 1998 show signs of internal damage.

The original *Triceratops* mount was disassembled last year, and its bones have been stabilized with new hardeners and other improved preservation techniques. They'll remain a vital part of the Smithsonian's collection. A few of these bones will return to Dinosaur Hall next year as part of the new display, but the others will be stored so that researchers can pore over them.

The most exciting aspect of the conservation effort, Chapman says, is the technology that the researchers are using to construct the *Triceratops* that museumgoers will see in the new exhibit.

Before the original mount was disassembled, researchers used lasers and other optical devices to scan the exhibit from several different angles and produce a three-dimensional digital record of how the bones fit together. Then, the scientists scanned each of the 200 or so bones to create computer models that have data points spaced as little as 0.1 millimeter apart, says Chapman.

In all, the digital dinosaur takes up nearly 20 gigabytes of computer space, enough room to store 50,000 books of text. The file representing the skull alone has nearly 20 million data points, he notes. These electronic models could ease the sharing of scientific data. For example, rather than ship a casting of a particular bone to other interested scientists, the Smithsonian could instead just send them a digital file.

The digital versions of the fossils have been the cornerstone of the effort to renovate the *Triceratops* exhibit. For example, what will appear to be the bones in the new mount in many cases will be plaster casts of plastic

Smithsonian Institution/National Museum of Natural History

Compared with the original 1905 mount (left), the renovated Triceratops that will go on display in the Smithsonian's Dinosaur Hall early next year will have more-erect front legs—perhaps similar to the position shown at right.

models created with a process known as stereolithography. This technique is widely used by manufacturers to produce prototypes of automobile parts and aircraft components. The Smithsonian's current effort has pioneered use of the method in paleontology, Chapman says.

In the first step of the stereolithography process, a computer converts the digital model of a solid object into a stack of thin slices. Then, the computer sends this information, one slice at a time, to an ultraviolet laser beam.

The beam paints the slice's shape on a platform just beneath the surface of a vat of liquid polymer that hardens when struck by the light. After the thin layer of resin hardens, the computer drops the platform slightly and the laser draws the next layer of the object—a process repeated until the entire part is fabricated.

The casts in the new exhibit, which will be exact plaster replicas of the polymer parts—or, in some cases, direct casts of the original bones—will offer a number of advantages, Chapman says. They will be lighter, easier to handle, and sturdier than the original fossils, and they'll be able to withstand the environmental conditions of the exhibit hall. If a cast is somehow damaged, researchers can always produce another one from the digital model.

The casts can be drilled so that an internal framework supports them instead of unsightly external cradles and scaffolding. Internal support will enable model assemblers to make the mount look more like a skeleton and to put the *Triceratops* in a more lifelike pose.

The digital models of the dinosaur will also permit the museum to perform a little corrective surgery. In the computer, changing the size of a bone is as simple as making a few keystrokes. Bones that are missing, or those of poor quality, can be replaced by computer-generated mirror images of actual fossils from the other side of the old composite skeleton. For example, the left side of the 1905 mount had more original ribs than the right side did, while the right side had more original leg bones than the left did.

To reflect the appropriate size of a fully grown adult, the skull in the new *Triceratops* exhibit will be 15 percent larger than that in the previous one. Most importantly, the new mount will have the proper feet. They'll be made from casts of fossils, borrowed from another museum, that were unearthed long after the Smithsonian's *Triceratops* was put together.

Although Chapman says the new exhibit will be "less real" in the sense that its individual bones will be plaster representations of actual fossils, he points out that the updated *Triceratops* will more accurately depict what the living dinosaur looked like. Museumgoers will still be able to see real fossils in the new exhibit, he adds, but those bones will be enclosed in sealed cases to protect them from harmful changes in humidity.

The *Triceratops,* which Chapman describes as "one of the neatest animals that's ever been around," lived in parts of western North America when what is now the Great Plains lay beneath a warm, shallow sea. Fossils of the dinosaur have been found in sediments that were deposited between 73 million and 65 million years ago along the lush coastal plains that stretched between central Colorado and southern Saskatchewan.

One of the dominant herbivores long before grasses evolved, *Triceratops* used its turtlelike beak and bladelike teeth to graze on flowering shrubs, palm fronds, and small trees. Several instances of parallel sets of fossil footprints and bone beds that contain multitudes of remains of closely related dinosaurs suggest that *Triceratops* probably traveled in herds and possibly even migrated, Chapman says.

From variations in characteristics such as length and orientation of the brow horns among the fossils of individual animals, paleontologists at one time distinguished up to 16 different species of *Triceratops*. As researchers discovered more fossils, Catherine A. Forster noted that much of the variation fell within a bell curve and became convinced that there were probably just two species.

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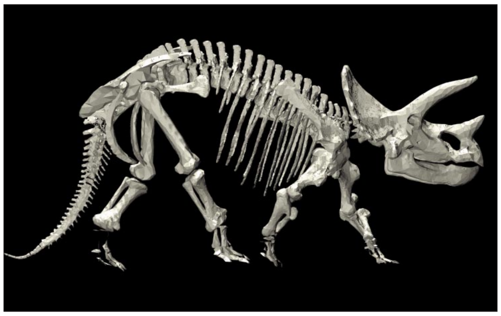
"Every little difference between animals doesn't signify a new species," says Forster, a paleontologist at the State University of New York at Stony Brook.

Dinosaurs of the more common of the two *Triceratops* species that Forster recognized had a shallower snout, larger brow horns, and a smaller nasal horn than members of the other species did. Some researchers, such as Gregory S. Paul, an independent paleontologist in Baltimore, argue that these physical differences in size and shape could merely represent differences between male and female animals of a single species.

Although such sexual dimorphism was common among dinosaurs—even in species related to *Triceratops*—no one has published data that prove that any *Triceratops* species was sexually dimorphic, says Chapman.

Forster says that additional specimens or further analysis of old data might show that sexual dimorphism, rather than two species, is the more likely explanation of the differences.



Smithsonian Institution/NMNH

Scientists have assembled the computer models of individual bones into a digital composite. Animated versions of the digital Triceratops are available through links at the Web site http://www.nmnh.si.edu/paleo/dino/trinew.htm.

Another mystery still to be solved about *Triceratops* is its stance. In the original Smithsonian exhibit, the composite animal stood with its front feet outside its shoulders in a sprawling, somewhat crocodile-like configuration. Chapman says, however, that crocodiles aren't necessarily a good model for this dinosaur because paleontologists now know that *Triceratops* evolved from ancestors that walked on two legs.

In the new exhibit, the front legs will have a more erect orientation. Researchers are still working to determine the precise configuration they'll choose for the bones. Chapman says the digital models of the leg bones are proving invaluable for the ongoing reconstruction. The paleontologists have experimented with 1/6-scale plastic models of the bones, which are easier to move and position relative to one another than the original fossils or the full-scale models are.

"With the [small-] scale models, you really get a feel for how the joints should fit together," he says. "With real-size bones that weigh 70 or 80 pounds apiece, you can't just flip them around in the air to see how they fit."

Using small pieces of a computer mouse pad to simulate cartilage in a small model of the front-knee joints, the scientists found that the *Triceratops* could lock its knees, just as cows and horses do when they sleep standing up.

The massive, 6-foot-long fossil head had been much too heavy and too delicate for curators to manipulate easily. But with the computer model, they discovered that the animal's head, which swiveled on a huge ball-and-socket joint that Chapman likens to a "big, bony trailer hitch," was remarkably well balanced. Also, the analysis revealed that the head was much lighter—only about 800 pounds—than scientists had expected.

The digital modeling of their *Triceratops* offers the Smithsonian researchers a variety of possibilities. For example, detailed analysis of the pathways of blood vessels through the skull might reveal whether thin spots in the dinosaur's frill have a function or are simply areas where the frill didn't get much blood flow and therefore couldn't nourish bone.

The computer has also allowed the Smithsonian researchers to animate the models to see how *Triceratops* might have walked. Their first attempts are crude, Chapman notes, but he says

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future versions will have "more flex in the spine, more movement in the joints, more everything." After that, he says, the next step is to add muscles "to see if the model ties itself in knots when it walks."

Paul says that when the front legs of *Triceratops* are arranged so they reproduce the footprints found in fossil trackways attributed to the dinosaur, the legs are almost fully erect, with the elbows pointing slightly outward. In this configuration, which Paul notes is common among large mammals such as rhinos, the shoulder joint rotates so that each limb moves nearly straight forward and backward when the animal walks.

Triceratops, therefore, wasn't a lumbering animal, he contends—instead, it could move significantly faster than an elephant and probably could run as fast as a rhino. He estimates it could trot at between 25 and 30 miles per hour and may even have been able to gallop. Analysis of the strength of the leg bones supports this idea, he claims.

"There's a mythology that because these animals were large, they had to be slow," Paul says. "Elephants are slow merely because they're designed that way."

Although digital modeling offers scientists new ways to study fossils, it poses thorny problems. The ease of sharing vital paleontological data may open the door for a number of unauthorized uses, such as the manufacture of marketable reproductions and toys.

If money is to be made from the data, however, the Smithsonian would like for it to defray some of the high costs of the *Triceratops* exhibit renovation. The intellectual property rights associated with the new digital models could be a valuable asset, says Richard H. Benson, chairman of the Smithsonian's department of paleobiology.

"We still need to work out the details of how we'll share the data with the affiliates of the museum versus how we'll share the data for educational purposes," says Benson. "The potential is obvious."

"Everybody and his brother wants one of these scale-model miniatures," Chapman notes. "I know I'd like one at home." □