National Science Foundation
WHERE DISCOVERIES BEGIN

A SPECIAL REPORT

AT LOW EBB

STUMBLING ACROSS A DINOSAUR

PUTTING THE PIECES TOGETHER

SOME ANSWERS MORE QUESTIONS

At Low Ebb

As the many paleontologists supported by the National Science Foundation can attest, spotting fossil remains is only the first step in accurately recreating a creature that has been dead for many millions of years. Categorizing it and eventually concluding you've found something new requires far more than the ability to recognize an ancient bone lying on a frozen beach.

A map of Antarctica showing the locations of recent dinosaur finds on the Antarctic Peninsula and near the Beardmore Glacier.

Credit: Alex Jeon, National Science Foundation

In late November 2003, Judd Case, a professor of biology at Saint Mary's College of California, and James E. Martin, curator of vertebrate paleontology at the South Dakota School of Mines and Technology, boarded the Laurence M. Gould, NSF's polar research vessel. They were expecting to return to Vega Island off the Antarctic Peninsula, the portion of the continent that juts northward toward South America where several years earlier, they had found the remains of a duck-billed dinosaur during a joint U.S.-Argentine expedition.

This time, a return to Vega Island was not to be. Ice conditions would not allow the inflatable boats to ferry the researchers from the ship to shore. "We weren't able to get to where we knew fossils would be," Martin said. "The only possible place left to do anything was James Ross Island."

On a Ross Island peninsula called the Naze, Martin hoped to find the remains of marine reptiles such as plesiosaurs, on which he is an expert. Making matters worse, they were forced to camp at a spot four miles away. "That in itself was interesting," Martin remarked of the regular hikes across shore ice, "because some days our trail had floated away."

Except on the occasional sunny day, the team worked in snowy whiteouts and other poor weather reminiscent of conditions endured by the shipwrecked crew of Sir Ernest Shackleton's vessel Endurance, who in 1915 were stranded not far from the fossil expedition.

Their spirits, Martin conceded, were at low ebb.

"I was probably happier than Judd was because I thought, 'At least we'll get some good marine reptiles,'" he said. "But, absolutely, we really were not doing well at all. We'd spent a lot of money and time and all we'd found was a marine vertebra."

Then, on Dec. 12, 2003, everything changed.

By Peter West

While Case and Martin were uncovering their carnivorous dinosaur, a research team led by William Hammer of Augustana College was braving the harsh conditions thousands of miles away near Antarctica's Beardmore Glacier. Hammer's team discovered fossils of a primitive sauropod, a plant eater.

Credit: Andy Sajor, National Science Foundation

Case and Martin's research team found the theropod bones on this rocky slope of Comb Ridge at the tip of the Naze peninsula.

Credit: National Science Foundation

Stumbling Across A Dinosaur

That day, Case almost literally stumbled across something that didn't seem to fit with the other finds the team was making.

"I had worked myself away from the main group and was following up a slope. I started to see a lot of golf ball size rocks that were round and smooth," he said.

Most likely, the stones had been swallowed by marine reptiles to digest their prey, similar to the stones found in the gizzards of modern birds. After the reptiles died, the stones had settled on an ancient ocean bottom in the animals' corpse.

"Expecting to run into marine-reptile bones, I came across a bone that represented something quite different. It had rounded ends and a groove on it," Case said. "I didn't think it was from a marine reptile because of what I've learned from Jim. I didn't think this is what a marine reptile looks like."

Case then showed his find to Martin, expecting to be convinced they were bones of an extinct ocean creature. "Jim is very good at being skeptical," he noted.

Case, Martin and their colleagues pored over the bone, trying, in a sense, to make its characteristics fit into their preconceived notions.

"We knew we were working in what were once relatively deep marine waters. And we were trying to make it into everything that might be marine reptile," Martin said. "Initially, we were trying to make it anything but a dinosaur."

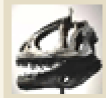
But as the research team scoured a roughly 40-square-meter (50-square-yard) area, finding a tooth here and a jawbone there, they became more and more convinced the animal they were reconstructing was in fact a dinosaur.

"We just kept going and going until we couldn't find anything more. Until we felt we had really covered the area," Martin said. And gradually, the accumulated evidence showed their predator was a dinosaur.

"As we began to find more pieces throughout that afternoon, Jim said, 'You know, I've only seen these things in meat eating theropods'," Case said. And theropods, or "beast-footed" dinosaurs like Tyrannosaurus rex and smaller carnivores, were not known for frolicking in the deep ocean.

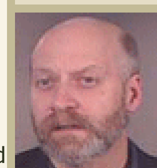
By Peter West

Skulls and Bones

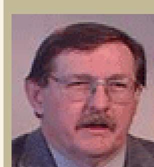


NSF supports paleontologists hunting around the globe for the skulls and bones of dinosaurs and other ancient creatures. >> more

Video Q & A



Judd Case, *Saint Mary's College of California*



James E. Martin *South Dakota School of Mines & Technology*

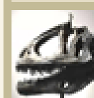
Credit: Dena Headlee, National Science Foundation video

- Where was the dinosaur discovered?
- What was so unique about this find?
- How did you search for other bones once the first discovery was made?

Skulls and Bones

Antarctic dinosaur hunters Judd Case and James Martin eventually pieced together enough evidence to conclude they had uncovered an entirely new species of carnivorous dinosaur related to the enormous meat-eating Tyrannosaurs and smaller and swifter velociraptors that terrified movie-goers in the film *Jurassic Park.*

Video



Skull cast of *Cryolophosaurus elliotii.* In 1991, William Hammer led the team that discovered *C. ellioti*, the first dinosaur found on Antarctica, proving that dinosaurs lived on all of the continents.

Credit: Maryland Science Center, Baltimore

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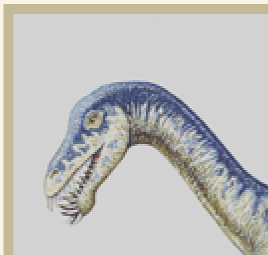
The same week Case and Martin found their meat eater, a team led by William Hammer of Augustana College found what they believe to be the pelvis of a primitive sauropod, a four-legged dinosaur similar to better-known creatures such as brachiosaurus and diplodocus. Field analysis of the bones suggests the new plant eater was nearly seven feet tall and up to 30 feet long.



Reconstruction of the body of Masiakasaurus knopfleri, based on fossils recently discovered in Madagascar. Total body length: 1.6-2.0 meters.

Credit: Bill Parsons

Like Case and Martin, who discovered a duck billed hadrosaur in 1998, Hammer is an Antarctic dino veteran. In 1991, Hammer led the team that discovered *Cryolophosaurus ellioti*, the first dinosaur found on Antarctica, proving that dinosaurs lived on all of the world's continents.

Beyond Antarctica, NSF supports the expeditions of paleontologists hunting around the globe for the skulls and bones of dinosaurs and other ancient creatures locked within the Earth. In Madagascar, for example, an NSF-supported team of researchers from New York, Minnesota and Utah has turned up several dinosaur firsts over the years.

The team discovered the fossilized remains of a bizarre, dog-sized predatory dinosaur, *Masiakasaurus knopfleri*. This six-foot-long, 35-pound theropod is notable for its extremely specialized teeth and jaws.

The skull bones and head of Rapetosaurus krausei as it may have looked in life.

Credit: Mark Hallett, State University of New York at Stony Brook.

The team's Madagascar digs also uncovered the first nearly complete skeleton ever found anywhere of a member of the titanosaur family of sauropods. The skeleton of *Rapetosaurus krausei* gave scientists the first view of a titanosaur from head to tail.

Most recently, the team uncovered a nearly complete dinosaur skull, the first ever found on Madagascar, that of *Majungatholus atopus,* a 30-foot-tall distant cousin of *Tyrannosaurus rex.* Later, the team fingered *Majungatholus* as the first clear-cut dinosaur cannibal.

Artistic rendering of *Majungatholus atopus* feeding on another of its species. *Majungatholus* roamed the plains of northwestern Madagascar 65 to 70 million years ago. Evidence found in tooth-marked bones indicates that *Majungatholus* was a cannibal. Other evidence indicates that *Majungatholus* also fed on the remains of sauropods, including *Rapetosaurus krausei*.

Credit: Demetrios M. Vital

By David Hart

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Putting the Pieces Together

Having found all of the pieces that they could, including portions of the animal's legs and feet and teeth and jawbones, both Case and Martin tentatively agreed they had found the remains of a meat-eating dinosaur, although "everything was working against that conclusion," Martin noted.

The location, for example, had been covered in fairly deep water when the creature was alive. They later theorized that the animal's body floated out to sea after it died.

Also, at the apex of the food chain and representing a very small percentage of living creatures, predators in nature are less likely to leave any physical trace of their passing.

According to Martin, "the skeleton appears to have been eroded ... every bone we collected was broken."

On the island, the researchers had already moved from the collecting stage of their investigation to analysis, trying to confirm what they reluctantly believed was true.

"In some cases, we sat down early with all the bones spread out, and began to put things together that looked like they belonged together," Case said.

They also referred to figures in a book that happened to be in camp. "The photos helped us to identify some of the bones," he said.

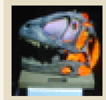
Martin noted that even though the bones they found were fragmentary—"This wasn't Jurassic Park, where they blew the dust off that complete skeleton"—the evidence was sufficient to make a serious analysis. "We got the two best ends of the animal for identification: the head and feet. In this case, foot bones, claws and teeth."

Later, aboard ship and headed back to the United States, the scientists laid the bones out on a large piece of paper in one of the ship's labs in the positions they would have held in life. They were beginning to answer a question even larger than whether the creature was a dinosaur: Was it just new to the region or was it new to science?

Every bone collected by Case and Martin's team was broken, suggesting the skeleton had eroded out over some time. They suspect that the meat eater floated out to sea after it died and may have become a meal for a large marine reptile.

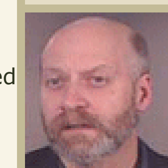
Credit: Judd Case

New Looks, Old Bones



Uncovering the bones of a dinosaur may be physically demanding, but it is by no means the end of the discovery process. >> more

Video Q & A



Judd Case, *Saint Mary's College of California*

Credit: Dena Headlee, National Science Foundation

What did you find?

What do you believe happened to the dinosaur when it died?

What have you learned about the animal from looking at the bones?

Requires Real Player

Video

An artist's conception of the fate of the carnivorous dinosaur recently discovered in Antarctica by Case and Martin's research team.

Credit: Trent L. Schindler, National Science Foundation

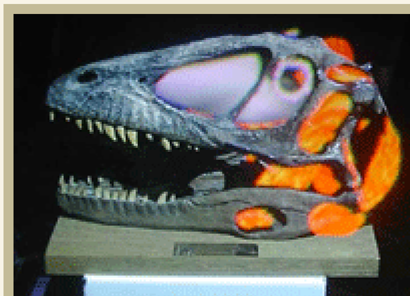
View Video
Requires Real Player

By Peter West

Ken Dial, a professor of vertebrate morphology, holds an adult chukar partridge in his flight lab at the University of Montana. Dial's study of young birds suggests full-fledged flight may have evolved from two-legged dinosaurs that used wing-like forelimbs to propel themselves rapidly up steep inclines.

Credit: K.P. Dial, University of Montana

New Looks at Old Bones



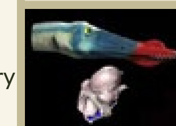
Paleontologists and computer scientists joined forces to paint fossils with digital flesh and create dynamic models that reveal how dinosaurs may have looked, walked and attacked prey. Here the physical skull of Deinonychus, a meat-eating dinosaur, is placed inside a 3-D display and then augmented with reconstructed soft-tissues, including paranasal air sinuses and bony eye rings.

Credit: Oliver Bimber, Bauhaus University, Germany; Stephen M. Gatesy, Brown University; Lawrence M. Witmer, Ohio University; Ramesh Raskar, Mitsubishi Electric Research Laboratories, Massachusetts; L. Miguel Encarnação, Fraunhofer Center for Research in Computer Graphics, Rhode Island

Uncovering the bones of a dinosaur may be physically demanding, but it is by no means the end of the discovery process. Detailed analysis of the bones often requires years of painstaking effort or the development of new tools and techniques. Here are just a few examples of NSF's support for scientists taking a new look at old bones.

Oregon State University scientists studied a well-preserved fossil of a meat-eating dinosaur and found clues to a number of dinosaur debates. They suggested that, although dinosaurs were in fact cold-blooded, they could have bursts of high energy and speed. The same study concluded that birds are most likely not descended from any known family of dinosaurs.

Video



Researchers from Ohio and Texas used CAT scans to peer into the heads of two ancient flying reptiles called pterosaurs. This animation demonstrates the relationship of head orientation to the inclination of the lateral semicircular canals (shown in blue) of the pterosaur *Anhanguera santanae.* When the semicircular canals are brought to a normal, near-horizontal position, the long axis of the head turns downward, a position ideally suited for hunting in flight.

Credit: Trent L. Schindler, National Science Foundation video

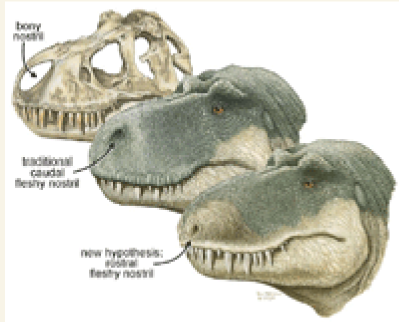
View Video
Requires Real Player

Researchers from Ohio and Texas used CAT scans to peer into the skulls of two pterosaurs, flying reptiles that lived alongside dinosaurs. In their examinations of the passageways and chambers inside the skulls, they found key structures to be specialized and enlarged, a discovery that could revise views of how vision, flight and the brain itself evolved.

But old bones are not the only source of new information about dinosaurs. NSF has also supported studies of modern creatures that provide insights into dinosaur physiology and behavior.

For example, a study of skulls from more than 65 surviving dinosaur relatives—including crocodiles, birds and lizards—challenged the conventional view of dinosaur nostrils. Dinosaurs may have had larger nasal passages than had been thought, which could lead to greater understanding of their respiratory functions.

And a study of young birds provided a possible solution to the riddle of how full-fledged flight evolved. Based on videotapes of young birds flapping their way up ramps, University of Montana researcher Kenneth Dial proposed that two-legged dinosaurs may have used their forelimbs as wing-like structures to propel themselves rapidly up steep inclines.



Changing the nostril position in Tyrannosaurus rex affects how scientists understand the extinct creatures' respiratory functions. The traditional view (middle) has the nostril located more to the rear of the head. A new restoration (bottom) based on Lawrence Witmer's study reflects a more forward position of the nostril. The skull is shown at top.

Credit: W. L. Parsons, under the direction of L. M. Witmer

By David Hart

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The team led by William Hammer believes this pelvis, exposed on the rock where it was preserved, belongs to a previously unknown plant-eating dinosaur. According to Hammer, "We have so few dinosaur specimens from the whole continent compared to any other place, that almost anything we find down there is new to science."

Credit: William Hammer

Some Answers, More Questions

The answer lay not, as one might expect, in 21st century scientific tools such as DNA analysis, because, Case noted, "the genetic material that one would use for such a comparison is all gone," turned to stone like the bones themselves.

Instead, a more venerable method was used to decide they had found something never before seen by science—searching the literature in specialized repositories, such as, in this case, the one at University of California, Berkeley, and comparing the physical evidence they had with characteristics of specimens that had already been described. They made comparisons between their partial skeleton and those of animals from the three known major groups of meat-eating dinosaurs.

"You get more and more specific about 'where does this best fit?' but you've got to start with the major categories first," Case said. "The vast majority of the bones we're finding are from the lower legs, the ankles and the feet. So then you can say, 'If you have this suite of bones, you belong in this group.' We could begin to eliminate groups that way."

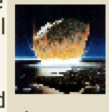
"The group it seems to fit in best is one held together by their general primitive theropod characteristics," he added.

Eventually, Case, Martin and their team were certain they had found a new creature previously unknown to science.

But as is often the case in scientific research, new-found answers brought new questions. Questions that likely will have to wait for another day, and perhaps a different expedition, to answer.

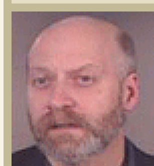
"One of the surprising things is that animals with these more primitive characteristics generally haven't survived as long elsewhere as they have in Antarctica," Case said. "For whatever reason, they are still hanging out on the Antarctic continent. Why is this group still here when in other places other groups have displaced them? We don't know.

The Ultimate Question



NSF has supported many efforts to collect evidence that shines light on the most hotly debated question about the monster creatures.
>> more

The Ultimate Question



Judd Case, *Saint Mary's College of California*

Credit: Dena Headlee, National Science Foundation

- What kind of dinosaur was it?
- How big was this dinosaur?
- What have you since learned about what the Antarctic environment must have been like 70 million years ago?

Requires Real Player

By Peter West

National Science Foundation
WHERE DISCOVERIES BEGIN

The Ultimate Question

Many theories have been proposed for the mystery behind the dinosaurs' ultimate displacement. Perhaps an asteroid impact, perhaps an upsurge in volcanic activity caused their extinction. How about a little (or a lot) of both? NSF has supported many researchers in their efforts to collect evidence that shines light on what may be the most hotly debated question about these monster lizards.

Nature remodels the coastline. An artist's depiction of the asteroid impact 65 million years ago that many scientists say is the most direct cause of the dinosaurs' disappearance.

Credit: Don Davis, NASA

The leading theory holds that an asteroid impact 65 million years ago is the most direct cause of the dinosaurs' disappearance. In 1996 and 1997, two teams of scientists supported in part by NSF's Ocean Drilling Program found evidence to tie the asteroid impact, which left the Chicxulub crater off the coast of Mexico's Yucatan peninsula, to the catastrophic extinction.

One team, led by Kenneth Miller of Rutgers University and also supported by NSF's Continental Dynamics Program, identified layers of dissimilar plankton fossils separated by a layer of debris produced by the impact. In another area of the Atlantic, the second team, led by Richard Norris of Woods Hole Oceanographic Institution, found a layer of impact debris almost 7 inches thick.

Answering the question of whether an asteroid or comet struck the earth, UCLA's Frank Kyte found fossilized bits of the guilty asteroid itself. The tiny rock fragment showed the original meteorite had a rocky composition like asteroids, and not like comets.

But was a single asteroid enough? Other research suggests that dinosaurs were having a really bad geological era.

The fossil record of clams and ammonites, according to one research team, shows the Chicxulub impact accounts for only 50 to 75 percent of the extinctions at the time. Other factors, including a precipitous drop in sea level before the asteroid struck, caused the rest of the extinctions.

Painting an even bleaker picture with an alternate theory, Gerta Keller of Princeton University has collected, with NSF support, evidence for volcanic eruptions over half a million years, and perhaps repeated asteroid impacts, as the real dinosaur killers.

Gerta Keller of Princeton University has collected, with NSF support, evidence of volcanic eruptions over half a million years, and perhaps repeated asteroid impacts, as the real cause of the dinosaurs' extinction. Rather than using dinosaur bones, however, Keller studies one-celled organisms, called foraminifera, some species of which evolved rapidly through geologic periods and whose fossils serve as a timeline by which surrounding geologic features can be dated.

Credit: Denise Applewhite, Princeton University

But aside from the dinosaurs unlucky enough to be caught in the impact zones of massive asteroids or trapped in the path of volcanic lava flows, there remains the question of the "kill mechanism" that caused worldwide extinctions, even while mammals and other species survived.

Climate change is the leading suspect. However, a team of NSF-supported climate scientists has argued that neither asteroids nor eruptions could inject enough long-lasting debris into the stratosphere to affect global climate on the scale needed for mass extinction.

But perhaps "hypercanes" could. A computer model by Richard Rotunno of the National Center for Atmospheric Research, Kerry Emanuel of the Massachusetts Institute of Technology, and three other scientists showed how hypercanes—theoretical superstrong hurricanes—could have arisen after asteroid impacts or undersea eruptions heated swaths of ocean, generating storms with wind speeds approaching the speed of sound and vast sheets of stratospheric clouds that could alter radiation patterns and perhaps trigger ozone depletion.

By David Hart