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SOCIETY FOR SCIENCE & THE PUBLIC
FEBRUARY 4, 2017

Babies Change Mom's Brain

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Dino DOOMSDAY

SPECIAL REPORT

The fiery end of the dinosaurs and the new world that followed

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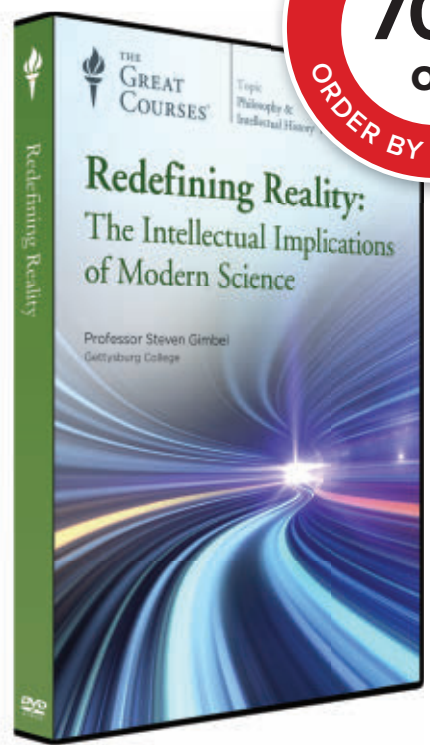

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ScienceNews

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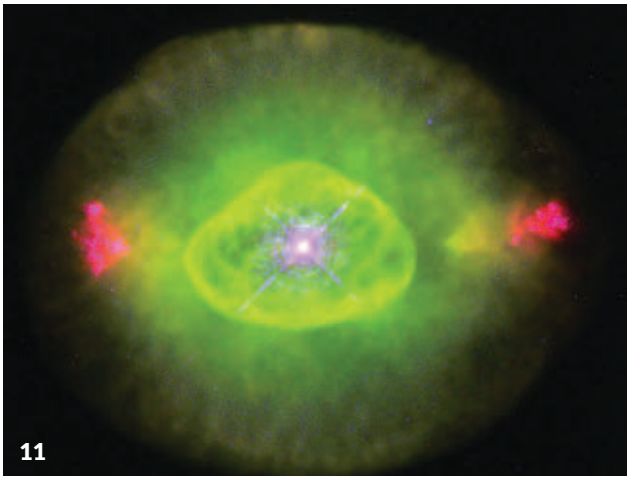
Special Report

DINO DOOMSDAY

News



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Departments

SOCIETY UPDATE
Introducing the 2017 Regeneron STS Scholars

COVER When the Cretaceous-Paleogene extinction ended dinosaur domination, mammals got a new lease on life. *Nicolle Rager Fuller*

CLOCKWISE FROM TOP: UTAKO KIKUTANI; COURTESY OF HACHETTE BOOK GROUP; B. BALICK, J. ALEXANDER, A. HAJIAN, Y. TERZIAN, M. PERINOTTO, P. PATRIARCHI, NASA

Endings make way for new beginnings for Earth and *SN*

Life on Earth has survived at least five major extinction events, but it is the dinosaurs' mass die-off that most captures our imagination. It appears to have been a dramatic one, as Thomas Sumner writes on Page 16. A fiery asteroid impact carved out a chunk of what's now below the Caribbean Sea, killing many animals instantly. Far more species slowly dwindled, with debris from the impact blocking the sun and altering the climate worldwide. A new twist, Sumner reports, is growing evidence of the planetary reach of long-lived eruptions that created the massive Deccan Traps in present-day India. The volcanic spew broadly coincided with the asteroid strike 66 million years ago, and some think it might have had a significant or even a leading role in the extinction. Others disagree, but the story of the dinosaurs' final days certainly continues to grow more complex and intriguing the more we learn.

No matter the cause, it's clear that some living things managed to get by and eventually to thrive (hello, mammals and birds). In her article on Page 22, Meghan Rosen examines new details about what survived and how. Working backward from later animals, some scientists are profiling the kinds of traits that would have been useful in an apocalypse, with some interesting results. Seed-cracking beaks, for example, might have given some avian ancestors an edge over dino relatives with teeth.

On Page 26, Susan Milius makes the excellent point that we now know that not all dinosaurs died out. Some live on as birds. It's something that I, having learned otherwise as a child, still sometimes overlook. Evolving thinking about the end of the dinosaurs makes the story a little messier, a little less easily summarized to schoolchildren. But it does more clearly reveal life's ebbs and flows, and both its vulnerability and resilience to unimaginable planetary insults. Even widespread destruction can lead to the blossoming of new life. Even when we think the dinosaurs are all gone, we find some that have been here all along, beside us.

Writing about endings and new beginnings is fitting for me personally as I prepare this issue, the last under my direction as Editor in Chief. After more than nine years at *Science News*, I am pursuing a new opportunity on the West Coast, closer to my family, the Pacific Ocean and my beloved chaparral. Although my staff at first looked as if an asteroid were falling when I told them of my departure, this will be a much more peaceful transition. *Science News* is a vigorous enterprise, in print and online, thanks to the Society's leadership under Publisher Maya Ajmera and to readers like you who continue to support the important journalism we do. Our team of experienced science journalists remains devoted to bringing you the latest news from a broad range of scientific fields. It has been humbling to learn from them — and from those of you who have reached out to me — during my time here. This team will continue to thrive, especially since Elizabeth Quill has agreed to step in as acting Editor in Chief. Quill has done a fantastic job on a number of projects, including our year-end issue and series of e-books. She certainly has the talent and dedication — the beak that can crack seeds, if you will — to lead *Science News* to its next great evolution.

— Eva Emerson, Editor in Chief

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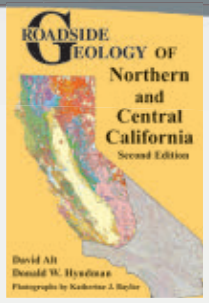
SANDY SCHAFFER

GEOLOGIC ROAD TRIP OF THE MONTH



EXCERPT FROM
Roadside Geology of Northern and Central California
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ISBN 978-0-87842-670-6

POINT REYES NATIONAL SEASHORE

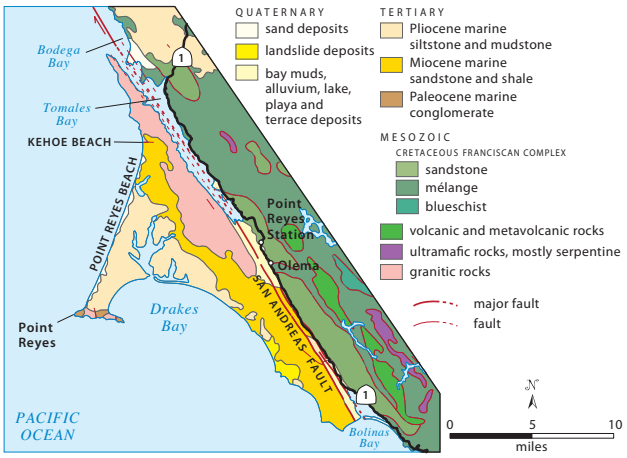
Point Reyes Peninsula is an afterthought of tectonics, a scrap of granite dabbed at the last moment onto the coast of northern California. According to most geologists, it lurched at least 270 miles north along the San Andreas and San Gregorio faults. It is still moving.

The fundamental bedrock of Point Reyes is granite. Watch for it in small, weathered outcrops beside the road and in the woods along the west side of Tomales Bay. Bold outcrops of granite make up the towering sea cliffs that buttress the extreme tip of the peninsula, around the Coast Guard station. You can also see granite at the north end of the peninsula, at Tomales Point and in the cliffs at Kehoe Beach. Look carefully to see that each of these areas has its own distinctive kind of granite. Age dates show that all crystallized about 82 million years ago, during late Cretaceous time.

Elsewhere, the granite lies beneath sedimentary rocks. The oldest are sandstone and conglomerates of the Point Reyes Formation that cover the granite at the tip of the peninsula. They were laid down during Paleocene time, about 60 million years ago, probably in deep water. Most of the others were deposited in shallow seawater between 20 and 5 million years ago, during Miocene and Pliocene time. They make up the long line of pale sea cliffs that face south across the sheltered waters of Drakes Bay.

Point Reyes Beach

The northwest wind builds the waves into heaping rollers as it drives them across thousands of miles of open ocean to burst onto Point Reyes Beach. They curl around the rugged granite cliffs at the extreme tip of the peninsula, focusing their energy into enormous breakers.



Point Reyes National Seashore.

Granitic rocks (foreground) and the Laird Sandstone of middle Miocene age (background) at Kehoe Beach. (38.162846, -122.949591)

Siltstone cliffs of the Purisima Formation at Drakes Bay are prone to rockfall. Note the dust rising from falling rocks in the center of the photograph. (38.029519, -122.954273)

The sand on Point Reyes Beach consists mostly of small red and green pebbles of chert, bits of Franciscan radiolarian cherts. That is surprising because no Franciscan rocks exist on the peninsula, and Tomales Bay separates the beach from those east of the San Andreas fault. The waves may wash some of those colorful pebbles across the shallow north end of the bay, but it is easier to imagine that most of them washed down the coast and onto the beach at a time when Tomales Bay did not exist.

Drakes Bay

The same great waves that crash so heavily onto Point Reyes Beach stretch themselves thin as they wrap around the end of the peninsula to lap gently onto the long curve of shoreline along Drakes Bay on its south side. The soft beaches are made of sand eroded from the white cliffs that rise above them.

Long tradition maintains that Sir Francis Drake and his crew beached their ship in Drakes Bay to spend the winter of 1579 overhauling it before they started across the Pacific Ocean. The long row of white cliffs reminded Drake and his crew of the white cliffs of Dover. Those more famous cliffs are in chalky Cretaceous limestone; these are pale siltstone laid down in shallow seawater during late Miocene time. They contain fossil bones of seals and sea cows, among other water beasts. Many geologists correlate the pale siltstone in the cliffs at Drakes Bay with the Purisima Formation of the Santa Cruz Mountains and along the coast between Martins Beach and Pescadero Point.

Excerpt from the February 4, 1967 issue of *Science News*

50 YEARS AGO

Heroin cure works

[T]he drug methadone appears to have fulfilled its promise as an answer to heroin addiction. Some 276 hard-core New York addicts ... have lost their habits and none have returned to heroin — a 100 percent success rating. Methadone, a synthetic narcotic, acts by blocking the euphoric effect of opiates. Addicts thus get nothing from heroin and feel no desire to take it.

UPDATE: The U.S. Food and Drug Administration approved methadone as a treatment for opiate addiction in 1972 but quickly recognized that it was no panacea. That same year, policy makers worried that methadone would produce addicts — as patients got high off the treatment itself (*SN: 10/28/72, p. 277*). Methadone can be deadly: In 2014, 3,400 people died of methadone overdoses. Although methadone is still used, drugs such as buprenorphine and naltrexone, have joined the treatment arsenal for opiate addiction.

This 75-million-year-old hatchling fossil of the dinosaur *Protoceratops andrewsi* was found in Mongolia. Fossilized *P. andrewsi* embryos reveal dinos had reptilelike incubation times.

RETHINK

Dinosaur eggs were slow to hatch

Dinosaurs might live on today as birds, but they hatched like reptiles. Developing dinos stayed in their eggs three to six months before emerging, far longer than previously suspected, researchers report online January 3 in the *Proceedings of the National Academy of Sciences*.

With few clues to dinosaurs' embryonic lives, scientists assumed that young dinosaurs shared modern birds' swift incubation period, which ranges from 45 to 80 days for eggs in the size range of dino eggs. A reptile egg generally takes about twice as long to hatch as a bird egg of similar size, says lead author Gregory Erickson, a paleobiologist at Florida State University in Tallahassee.

But counts of growth lines on the teeth of rare fossilized dinosaur embryos from two species, *Protoceratops andrewsi* and *Hypacrosaurus stebingeri*, suggest a longer trajectory like that of reptiles, say Erickson and colleagues at the University of Calgary in Canada and the American Museum of Natural History in New York City. These lines, laid down daily on teeth, can be used like tree rings.

The longer incubation time might have worked against dinosaurs, Erickson says. Guarding a brood of eggs for many months could put parents at risk of attack. And a species hit by environmental catastrophe (see Page 16) would have a harder time bouncing back. — *Laurel Hamers*

SCIENCE STATS

Humans' stuff vastly outweighs humans

Have you ever felt weighed down by your material possessions? The boundless variety of stuff that humans manufacture — tractors, buildings, ballpoint pens, Hello Kitty backpacks — has serious heft: 30 trillion metric tons, a new study estimates. That's about 50 kilograms for every square meter of Earth's surface. The human-made "technosphere," all the manufactured goods around today, surpasses the natural biosphere in mass and variety, geologist Jan Zalasiewicz of the University of Leicester in England and colleagues report online November 28 in *The Anthropocene Review*. Books alone, at about 130 million titles, surpass the estimated 8.7 million eukaryotic species on Earth. The technosphere is one measure of how humankind is reshaping the planet (*SN: 10/15/16, p. 14)*, the researchers note. — *Thomas Sumner*

506
million metric tons
Approximate combined mass of all living humans

30,000,000
million metric tons
Estimated mass of the technosphere

SOURCE: J. ZALASIEWICZ *ET AL/THE ANTHROPOCENE REVIEW* 2016

THE -EST

Tomatillos go way back

Two tiny tomatillo fossils have kicked the origin of nightshade plants back to the age of dinosaurs.

Finding 52-million-year-old fossils suggests that the nightshade family originated even earlier, tens of millions of years before scientists had suspected, researchers report in the Jan. 6 *Science*.

Nightshades include roughly 2,500 species of plants, from tomatoes to eggplants to tobacco. Previous estimates had dated the family to some 30 million to 51 million years ago. And scientists had suggested that tomatillos arose even more recently, just 10 million years ago.

Paleontologist Peter Wilf and colleagues have nixed that timeline. They uncovered the roughly 2-centimeter-tall fossils from an ancient lake in what is now Patagonia. Each fossil preserves the delicate, tissue paper–like sheath that typically covers a tomatillo's central berry, like a candle inside a paper lantern. In one fossil, evidence of a berry (now turned to coal) still remains.

"This is like an impossible fossil," says Wilf, of Penn State. "That you could preserve something this delicate — this little papery structure, it's unheard of."

A 52-million-year-old fossil of a tomatillo, the oldest known, includes the plant's papery outer sheath and remnants of the berry, which has since turned to coal.

The outer structures may keep tomatillo berries dry — and afloat. "You've got an umbrella and a life raft," Wilf says. And it's built right in.

The fossils represent a new species of tomatillo, called *Physalis infinemundi*, Wilf and colleagues at Cornell University and the Paleontological Museum Egidio Feruglio in Argentina report. *Infinemundi* is Latin for "at the end of the world."

Fifty-two million years ago puts these tomatillos deep in the Southern Hemisphere during the final days of the supercontinent Gondwana, before Antarctica split from Australia and the southern tip of South America. — *Meghan Rosen*

FOSSIL: P. WILF/PENN STATE; WORMS: P. GONZALEZ/STANFORD UNIV. (LARVA, JUVENILE), CHRIS PATTON/STANFORD UNIV.

This marine acorn worm spends its larval phase as a "swimming head" (top left) before metamorphosing into a juvenile (top right), according to new genetic analyses. Adult worms (bottom) can grow to about 40 centimeters long.

HOW BIZARRE

Acorn worms have a head for swimming

Certain marine worms spend their larval phase as little more than a tiny, transparent "swimming head." A new study explores the genes involved in that headfirst approach to life.

A mud flat in Morro Bay, Calif., is the only known place where the acorn worm *Schizocardium californicum* is found. After digging up the creatures, Paul Gonzalez, an evolutionary developmental biologist at Stanford University, raised hordes of the larvae at Stanford's Hopkins Marine Station in Pacific Grove, Calif.

Because a larva and an adult worm look so different, scientists wondered if the same genes and molecular machinery were involved in both phases of development. To find out, Gonzalez and colleagues analyzed the worm's genetic blueprint during each phase, the team reports in the Jan. 9 *Current Biology*.

Genes linked to trunk development were switched off during the larval phase until just before metamorphosis. Most of the genes active in the larvae were associated with head development, Gonzalez says.

The larvae hatch from eggs laid on the mud. When tides flood the area, the squishy, gel-filled animals use hairlike cilia to swim upward to devour bits of algae. "They're feeding machines," Gonzalez says. He speculates that being balloon-shaped noggins, rather than wriggling noodles, may help the creatures float and feed more efficiently.

After about two months of gorging at the algae buffet, the larvae, which grow to roughly 2 millimeters across, transform and sink back into the muck. There, they eventually grow a body that can stretch up to about 40 centimeters. — *Emily DeMarco*

News

BODY & BRAIN

Pain promoter also acts to relieve it

New experiments may lead to better treatments for people

BY RACHEL EHRENBERG

A protein that sounds the alarm when the body encounters something painful also helps put out the fire.

Called $Na_v1.7$, the protein sits on pain-sensing nerves and has long been known for sending a red alert to the brain when the body should feel pain. Now, experiments in rodent cells reveal another role for $Na_v1.7$: Its activity triggers the production of pain-relieving molecules. The study, published in the Jan. 10 *Science Signaling*, suggests a new approach to pain management that takes advantage of this protein's dual role.

The findings suggest that when opiates are given for certain kinds of pain relief, targeting $Na_v1.7$ as well might lessen the need for those pain relievers, says neuroscientist Munmun Chattopadhyay of Texas Tech University Health Sciences Center El Paso. That could reduce opiate use and associated side effects.

The new research also solves a puzzle that has frustrated researchers and pharmaceutical companies alike. People with rare mutations in the gene for making $Na_v1.7$ feel no pain. That discovery, made more than a decade ago, suggested that $Na_v1.7$ was an ideal target for controlling pain. If a drug could block $Na_v1.7$ activity, some kinds of pain might be eradicated (*SN: 6/30/12, p. 22*). Yet drugs designed to do just that didn't wipe out people's pain.

"It seemed so obvious and simple," says study leader Tim Hucho, a neuroscientist at the University Hospital Cologne in Germany. "But it was not so simple."

Then in 2015, researchers reported that mice and people with nonfunctioning $Na_v1.7$ not only felt no pain, but they also made higher than normal levels of pain-relieving opioids naturally produced by the body. When these researchers, led by John Wood of University College London, gave the opiate-blocker naloxone to a woman with the rare pain-eradicating mutation, she felt pain for the first time.

"It was astonishing," says Hucho, who collaborated with Woods and others on the new research.

Pain-sensing proteins like $Na_v1.7$ prompt nerve cells to send electrical signals. But in this case, $Na_v1.7$ was influencing a nonelectrical process — somehow cranking up the activity of genes in charge of making in-house opioids. "It turned the whole field upside down," Hucho says.

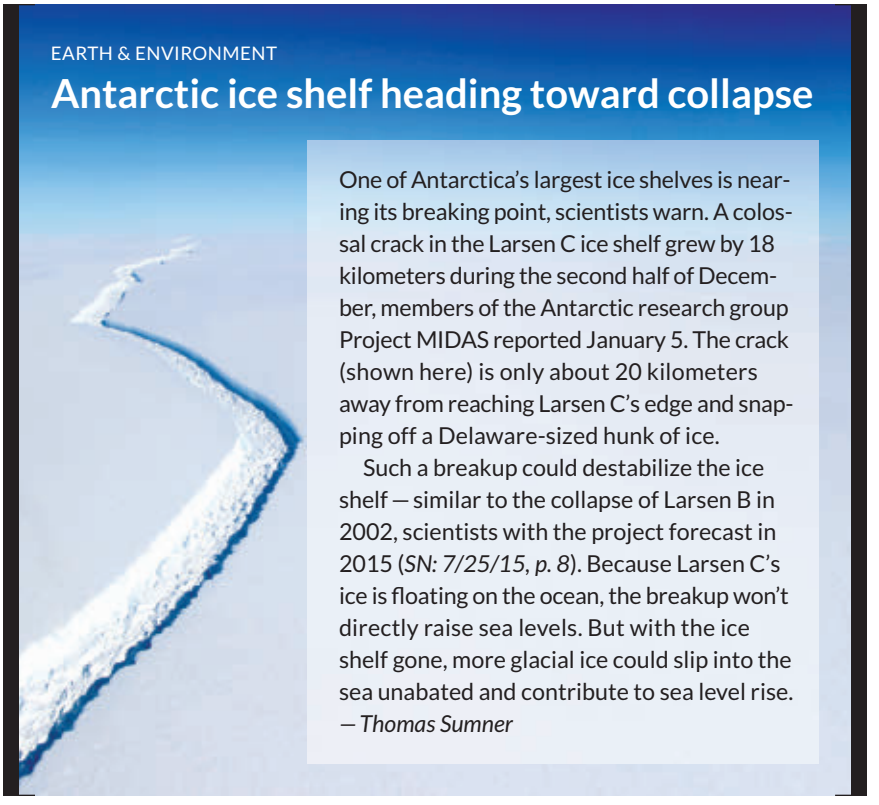
An investigation of rat and mice nerve cells reveals the tug-of-war between $Na_v1.7$'s pain-promoting and pain-relieving powers. Cells with nonfunctioning $Na_v1.7$ have amped up activity in the cellular machinery that kicks off pain relief, Hucho and colleagues report. They suggest that $Na_v1.7$ acts like the axis point in a playground seesaw. When the pain-promoting side is dialed down, the pain-relieving side becomes more dialed up than usual, and cells make more of their in-house opioids.

When opiates are given for pain, the body typically gets used to them and increasing amounts of the drugs are required to have an effect. Yet in the rodent cell experiments, this desensitization didn't happen. The cellular machinery that interacts with the body's opioids remained sensitive, even with the uptick in the production of these pain relievers.

Taken together, the results suggest that rather than trying to push down on one side of the seesaw to stop pain, a better approach might be moving the axis at the seesaw's center, Hucho says. Such a shift would tip the scales toward in-house opioid production, while also dialing down pain promotion. Much more work is needed before the finding will translate into treating pain in people. But the study's experimental design will make it much easier to explore which cellular players might be manipulated, the researchers say. For example, for some types of pain, a small amount of opiates might offer pain relief when taken with a $Na_v1.7$ blocker. ■

EARTH & ENVIRONMENT

Antarctic ice shelf heading toward collapse



One of Antarctica's largest ice shelves is nearing its breaking point, scientists warn. A colossal crack in the Larsen C ice shelf grew by 18 kilometers during the second half of December, members of the Antarctic research group Project MIDAS reported January 5. The crack (shown here) is only about 20 kilometers away from reaching Larsen C's edge and snapping off a Delaware-sized hunk of ice.

Such a breakup could destabilize the ice shelf — similar to the collapse of Larsen B in 2002, scientists with the project forecast in 2015 (*SN: 7/25/15, p. 8*). Because Larsen C's ice is floating on the ocean, the breakup won't directly raise sea levels. But with the ice shelf gone, more glacial ice could slip into the sea unabated and contribute to sea level rise. — *Thomas Sumner*

JOHN SONNTAG/NASA

BODY & BRAIN

Pregnancy alters a mother's brain

Loss of gray matter may aid in caring for a baby, study shows

BY LAURA SANDERS

Pregnancy seems to change nearly everything about an expectant mother's life. That includes her brain. Pregnancy selectively shrinks gray matter to make a mom's brain more responsive to her baby, scientists report December 19 in *Nature Neuroscience*.

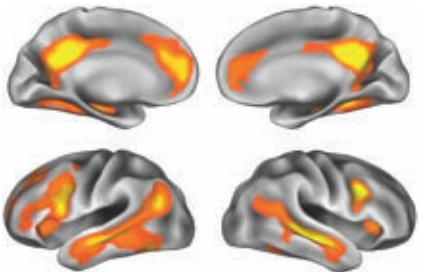
"This study, coupled with others, suggests that a woman's reproductive history can have long-lasting, possibly permanent changes to her brain health," says neuroscientist Liisa Galea of the University of British Columbia in Vancouver.

Researchers performed brain scans of 25 women planning to get pregnant with their first child. More scans were performed about two months after the women gave birth. Pregnancy left signatures so strong that researchers could correctly predict whether women had been pregnant based on the brain changes.

Women who had given birth had less gray matter in certain regions of their brains compared with 20 women who had not been pregnant, 19 first-time fathers and 17 childless men. These changes were still evident two years after pregnancy.

"Reductions in gray matter are not necessarily a bad thing," says study coauthor Elseline Hoekzema, a neuroscientist at Leiden University in the Netherlands. A similar reduction happens during adolescence, a refinement that is "essential for a normal cognitive and emotional development," says Hoekzema, who, along with colleagues, did most of the work at Universitat Autònoma de Barcelona.

Further experiments suggested the changes make women more responsive to their infants. The regions that shrunk the most — parts of the frontal and temporal cortices as well as the midline — are thought to be involved in understanding other people's mental perspectives.



After pregnancy, women had less gray matter volume (highlighted) in some regions of the brain (four views shown), a change thought to reflect neural refinement.

Selective shrinkage may indicate that these regions become more specialized, helping a mother better care for a baby.

Regions that changed the most showed large responses to photos of a woman's infant. And moms whose brains changed the most scored higher on a questionnaire about attachment to their babies.

The changes may be caused by pregnancy hormones such as estrogen and progesterone, says neuroendocrinologist John Russell of the University of Edinburgh, who wasn't involved in the study. The extreme hormone drop that comes during birth may also reshape the brain. ■

GENES & CELLS

Protein detects when lungs fill with air

Mechanical sensor helps regulate breathing, mouse study finds

BY RACHEL EHRENBERG

Scientists investigating what keeps lungs from overinflating can quit holding their breath.

Experiments in mice have identified a protein that senses when the lungs are full of air. This protein helps regulate breathing in adult mice and gets breathing going in newborn mice, researchers report in the Jan. 12 *Nature*.

If the protein plays a similar role in people, exploring its activity could help explain disorders such as sleep apnea or chronic obstructive pulmonary disease.

Researchers knew that feedback between the lungs and brain maintains normal breathing. But "this research gives us an understanding at the cellular level," says neonatologist Shabih Hasan of the University of Calgary in Canada. "It's a major advance."

Called Piezo2, the protein forms channels in the membranes of nerve cells in the lungs. When the lungs stretch, the channels detect the distortion caused by the mechanical force of breathing and spring open, triggering the nerves to send a signal.

A team led by neuroscientist Ardem Patapoutian discovered that the channels send signals along three pathways. Mice bred to lack Piezo2 in a cluster of nerve cells that send messages to the spinal cord had trouble breathing and died within 24 hours of birth. Newborns missing Piezo2 channels in nerves that communicate with the brain stem via a structure called the jugular ganglion also died.

Mice lacking Piezo2 in the nodose ganglion, a structure that also links to the brain stem, lived to adulthood. But their breathing was abnormal and a known safety mechanism in their lungs didn't work. Called the Hering-Breuer reflex, it kicks in when the lungs are in danger of overinflating. Normally, Piezo2's signal prevents potentially harmful overinflation by temporarily halting breathing. Known as apnea, this cessation of breathing can be dangerous in other instances.

Previous work in mice by Patapoutian, of the Scripps Research Institute in La Jolla, Calif., and colleagues found that Piezo2 channels play a major role in sensing touch. The channels also function in proprioception, the sense of where body parts are in relation to each other.

Two recent studies by different groups have found that people with mutations in a *Piezo2* gene also have problems with touch, proprioception and, in one study, breathing. Although small, the studies suggest that investigating Piezo2 in people could shed light on breathing disorders and other problems. ■

OSCAR VILARROYA

HUMANS & SOCIETY

Foragers first settled Tibetan Plateau

Hunter-gatherers may have moved into area before farmers

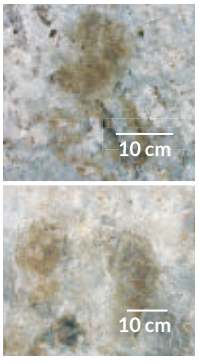
BY BRUCE BOWER

People hunted and foraged year-round in the thin air of China's Tibetan Plateau at least 7,400 to 8,400 years ago, a new study suggests. Permanent settlers of the high-altitude region might even have arrived as early as 12,000 to 13,000 years ago.

Three lines of dating evidence indicate that humans occupied the central Tibetan Plateau's Chusang site, located more than 4,000 meters above sea level, at least 2,200 years earlier than previously thought, say geologist Michael Meyer of the University of Innsbruck in Austria and colleagues. Their report, published in the Jan. 6 *Science*, challenges the idea that the Tibetan Plateau lacked permanent settlers until farming groups arrived around 5,200 years ago.

"Hunter-gatherers permanently occupied the Tibetan Plateau by around 8,000 years ago, which coincided with a strong monsoon throughout Asia that created wet conditions on the plateau," Meyer says.

These people hunted animals such as wild yaks and foraged for plants, including berries from sea buckthorn shrubs, in nearby river valleys at elevations more than 3,600 meters above sea level, Meyer suspects. These residents must have lived there year-round because brief summer forays to Chusang would have been difficult for people living below 3,300 meters above sea level, he adds. Even when mountain passes were clear of heavy snowfall and expanding valley glaciers, round trips from low altitudes to the central Tibetan Plateau would have taken 41 to 70 days, Meyer's team estimates.



Fossil prints (including this handprint, top, and two footprints, bottom) suggest people settled the Tibetan Plateau earlier than thought.

Chusang was discovered in 1998. The site consists of 19 human hand- and footprints on the surface of a fossilized sheet of travertine, a form of limestone deposited there by water from a hot spring.

The new age estimates for Chusang come from three measures: the decay rate of forms of radioactive thorium and uranium in travertine sampled in and around the prints; determinations of the time since quartz crystals extracted from the travertine were last exposed to sunlight; and radiocarbon measures of sediment and microscopic plant remains found on the travertine slab's surface.

Signs of long-term camping at Chusang have yet to turn up, but extensive excavations have not been conducted, Meyer says. His group found chipped rocks and other debris from stone-tool making at two spots near Chusang's hot springs. These finds are undated.

Previous work has suggested that hunter-gatherers occasionally reached

GENES & CELLS

Vital enzyme adapted to cooling Earth

Scientists re-create evolutionary history of adenylate kinase

BY LAUREL HAMERS

Like lifelong Floridians dropped into a Wisconsin winter, enzymes accustomed to warmth don't always fare well in colder climes. But ancient heat-loving enzymes forced to adapt to a cooling Earth managed to swap out parts to keep chemical reactions going, scientists report online December 22 in *Science*.

By reconstructing an enzyme as it might have looked billions of years ago (*SN: 6/11/16, p. 16*), the work "helps to explain the natural evolutionary history of life on this planet," says biochemist Yousif Shamoo of Rice University in Houston. The findings question the idea that enzymes must sacrifice stability to become more active.

Enzymes are catalysts that jump-start chemical reactions inside living things. Most work only within a specific temperature range. Too cold, and they can't get going. Too hot, and they lose their shape — and by extension, their function.

Life may have started in warm environments like hot springs or hydrothermal vents, so the first enzymes probably worked best in those toasty temperatures, says study coauthor Dorothee Kern, a biochemist at Brandeis University in Waltham, Mass. But gradually, Earth cooled. For life to continue, enzymes had to shift their optimal temperature range.

Kern and colleagues looked at the evolutionary history of the enzyme adenylate kinase. Some version of this protein is found in nearly all life-forms.

The researchers used a technique called ancestral sequence reconstruction to figure out what the set of genes that code for the enzyme might have looked like at different points in the last 3 billion years. The scientists edited *E. coli*'s genes to make the bacteria produce those probable ancient enzymes and then looked at how the reincarnated molecules held up under different temperatures.

"These very old enzymes were way more lousy at low temperatures than anyone expected," Kern says. But over time, natural selection favored enzymes that worked better at cooler temperatures, she found. The genes accumulated mutations that swapped some amino acid building blocks in the enzymes, ultimately lowering energy demands. That let the enzymes move essential reactions along at a pace fast enough for life to survive.

There wasn't a disadvantage to also working well in heat, so the enzymes didn't immediately lose their heat tolerance. Some became what Kern calls

MARK ALDENDERFER

the plateau's northern edge by about 12,000 years ago, and again from about 8,000 to 6,000 years ago, says archaeologist Loukas Barton of the University of Pittsburgh. The new dates may not point to permanent residence, he says. The early arrivals probably spent a single summer or a few consecutive years at most on the plateau, Barton says. "That would not constitute a peopling of a region any more than our 1969 visit to the moon did."

Archaeological finds indicate that human populations expanded on the Tibetan Plateau between around 5,200 and 3,600 years ago, Barton says. Those groups cultivated barley and wheat at high altitudes and herded domesticated sheep and perhaps yaks, he says.

Before that time, Chusang might have supported year-round occupation, says archaeologist David Rhode of the Desert Research Institute in Reno, Nev. But the site could easily have been occupied seasonally, he says. Unlike Meyer, Rhode estimates that Chusang was about a two-week walk from some lower-altitude campsites. "That's not far at all for a human forager," Rhode says. ■

"superenzymes" — working fast and catalyzing reactions at low temperatures while remaining stable at high ones.

That finding goes against a widely held assumption that an increase in activity — which would allow an enzyme to keep trucking at the same speed at lower temperatures — typically comes with a corresponding decrease in stability.

That was a logical assumption: Like chilly fingers struggling to tie shoelaces, enzymes generally get stiffer and don't work as well when the temperature drops. To up their activity, they'd need to increase their flexibility. That could make them less stable at higher temperatures and more likely to lose their shape. Now, it seems that some enzymes can have the best of both worlds.

Scientists in the lab have engineered generalist enzymes that work across a wide temperature range, Shamoo says. But this work shows it might have happened in the real world. ■

E. OTWELL

MATTER & ENERGY

Carbon can exceed four-bond limit

Chemists confirm links to six other atoms in unusual molecule

BY LAUREL HAMERS

A molecule originally proposed more than 40 years ago breaks the rules about how carbon connects to other atoms, scientists have confirmed. In this unusual instance, a carbon atom bonds to six other carbon atoms. That structure, mapped for the first time using X-rays, is an exception to carbon's textbook four-bond limit, researchers report in the Jan. 2 *Angewandte Chemie*.

Although the idea for the structure isn't new, "I think it has a larger impact when someone can see a picture of the molecule," says Dean Tantillo, a chemist at the University of California, Davis who wasn't part of the study. "It's super important that people realize that although we're taught carbon can only have four friends, carbon can be associated with more than four atoms."

Atoms bond by sharing electrons. In a typical bond, two electrons are shared, one from each atom. Carbon has four such shareable electrons of its own, so it tends to form four bonds to other atoms.

But that rule doesn't always hold. In the 1970s, scientists made an unusual discovery about a molecule called hexamethylbenzene that has a flat hexagonal ring made of six carbon atoms. An extra carbon atom sticks off each vertex of the ring, like six tiny arms. Hydrogen atoms attach to the ring's arms. And leftover electrons zip around the middle of the ring, strengthening the bonds and making the molecule more stable.

When the scientists removed two electrons from the molecule, leaving it with a positive charge, some evidence suggested it might dramatically change its shape. It seemed to rearrange so that one carbon atom was bonded to six other carbons. But the researchers didn't experimentally confirm that structure.

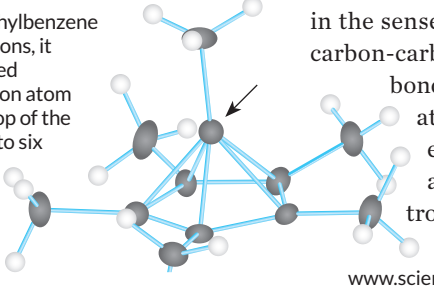
Now, a different lab has revisited the question. Making this charged version of hexamethylbenzene is a challenge: It's stable only in extremely strong acid, says study coauthor Moritz Malischewski, a chemist at the Free University of Berlin. And the experimental details in the old study were a bit fuzzy. But after some tinkering, he managed to create the charged molecule. He and coauthor Konrad Seppelt crystallized it with some other molecules and then used X-rays to get a 3-D map of the crystal structure.

The X-ray experiment confirmed what scientists had suggested in the 1970s: When hexamethylbenzene lost two electrons, it reordered itself. One carbon atom jumped out of the ring and took a position on top, turning the flat hexagonal ring into a five-sided pyramid. The carbon on top of the pyramid was indeed bonded to six other carbons — five in the ring below and one above.

"This molecule is very exceptional," says Malischewski. Though scientists have found other exceptions to carbon's four-bond limit, this is the first time carbon has been shown associating with this many other carbon atoms.

When Malischewski measured the length of the molecule's bonds, the top carbon's six bonds were each a bit longer than an ordinary carbon-carbon bond. A longer bond is generally less strong. So by picking more partners, that carbon has a slightly weaker connection to each one.

"The carbon isn't making six bonds in the sense that we usually think of a carbon-carbon bond as a two-electron bond," Tantillo says. The carbon atom has only four shareable electrons, so it spreads itself a bit thin by sharing electrons among the six bonds. ■



When hexamethylbenzene loses two electrons, it forms a five-sided pyramid. A carbon atom (arrow) at the top of the pyramid bonds to six other carbons instead of just four.

ATOM & COSMOS

Fast radio burst's home identified

Astronomers trace repeating signal to distant, tiny galaxy

BY CHRISTOPHER CROCKETT

A mysterious, recurring blast of cosmic radio waves finally has a home address. For the first time, astronomers have definitively traced a fast radio burst back to its source: a faint galaxy about 2.5 billion light-years away. The finding confirms a decade-long suspicion that these outbursts originate well outside our galaxy, although the mystery about what's causing them remains unsolved.

"Now with the first proven distance, we can see how remote and how bright the source must be," astrophysicist Sarah Burke-Spolaor of West Virginia University in Morgantown said January 4. For roughly five milliseconds, the burst outshines all the stars in its own galaxy and rivals the luminosity of blazing disks of gas that swirl around supermassive black holes, said Burke-Spolaor, one of the researchers involved with the discovery.

Fast radio bursts have stumped astronomers since the first one was reported in 2007 (*SN: 8/9/14, p. 22*). Since then, 17 more bursts have been detected by several radio telescopes around the world. In nearly every case, the outburst lasted just a few milliseconds and was never seen again. Only one, first detected at the Arecibo Observatory in Puerto Rico in 2012, has been seen multiple times.

Most radio telescopes can provide only a fuzzy idea of where on the sky a burst comes from. But the repetitive nature of the 2012 burst, dubbed FRB 121102, gave astronomers a heads-up for where to point the Very Large Array, or VLA, a network of radio dishes near Socorro, N.M., to capture a sharper image.

"We have imaged the burst itself with the VLA and pinpointed where it is on the sky," said Shami Chatterjee, an astrophysicist at Cornell University. Over the span of six months, the VLA detected nine outbursts coming from the same direction as previous repetitions. A persistent glow of radio waves also comes from the same spot. Further observations with the Gemini telescope in Hawaii revealed that the radio outbursts coincide with a faint galaxy. By measuring how much the expansion of the universe has stretched the light coming from the galaxy, the researchers were able to estimate the distance to the source of the burst.

The findings also appear in the Jan. 5 *Nature* and in two papers in the Jan. 10 *Astrophysical Journal Letters*.

"Without a doubt, this is a landmark event," said Duncan Lorimer, an astrophysicist at West Virginia University who discovered the first radio burst roughly a decade ago but was not involved with these studies. "There's no question about the validity of the result."

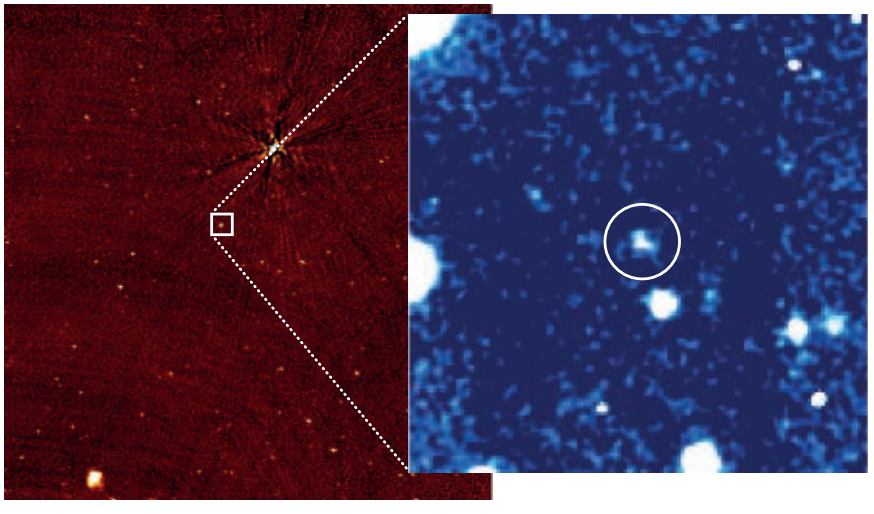
The host galaxy is tiny. "We're barely able to distinguish it from a star," said project member Shriharsh Tendulkar, an astrophysicist at McGill University in Montreal. It has roughly one-thousandth as many stars as the Milky Way and is less than one-tenth as wide. "That's weird," Tendulkar said. One favored explanation for fast radio bursts is that they come from neutron stars, the dense cores left behind after a massive star explodes. But if neutron stars are responsible, then astronomers expect to find bursts in places with lots of stars, he said.

Tracing FRB 121102 back to a dwarf galaxy doesn't rule out neutron stars as a source. The gas in dwarf galaxies is more pristine — with relatively low amounts of elements heavier than helium — than in other locales such as the Milky Way. Such gas makes it easier for massive stars to form. More heavyweight stars lead to more neutron stars, which could lead to more radio bursts.

Some of the new data, however, also suggest that the source sits near a supermassive black hole, indicating that perhaps the radio blast is somehow connected to gas and dust swirling down the black hole's gravitational throat.

"We've made this huge breakthrough in getting the distance, and it still doesn't want to let its identity be known," Lorimer said.

With a host galaxy in hand, astronomers can now point telescopes covering a broad range of the electromagnetic spectrum — from radio waves to gamma rays — at the galaxy to learn more about the burst's home. One thing that researchers will look for is whether the burst has a steady beat; all the detections so far have appeared randomly. If the signal has a regular period, then something that is spinning (like a neutron star) might be the culprit. Pinpointing more radio bursts and seeing if they also originate in dwarf galaxies could help researchers figure out if this object is unusual or typical of all radio bursts. ■



A persistent source of radio waves (radio image, left) sits at the same position on the sky as a repeating fast radio burst. That led astronomers to discover a faint smudge of visible light (right) — the burst's home galaxy, about 2.5 billion light-years away.

H. FALCKE/*NATURE* 2017

MEETING NOTES

Some pulsars lose their steady beat

A pair of cosmic radio beacons known as pulsars keep switching off and on, suggesting that there might be vast numbers of undiscovered pulsars hiding in the Milky Way.

Pulsars are rapidly spinning neutron stars, the ultradense cores left behind after massive stars explode. Like lighthouses, pulsars sweep a beam of radio waves around the sky. Astronomers see them as steady pulses of radio energy.

But at least two in the Milky Way seem to spend most of their time turned off, Victoria Kaspi, an astrophysicist at McGill University in Montreal, reported January 4. One, first detected at Arecibo Observatory in Puerto Rico in 2011, pulses only about 30 percent of the time. Another, also discovered at Arecibo, laid down a steady beat just 0.8 percent of the time when observed in 2013 and 2015. Then starting in August 2015, it abruptly jumped to being on 16 percent of the time for several months.

When sending out pulses, these pulsars seem to behave like any other pulsar, Kaspi said. "You wouldn't know that they have this dual personality." Researchers don't yet know why some pulsars behave this way. But Kaspi said that it's probably tied to changes in their magnetic fields, which astronomers think help control the radio beacons.

These two intermittent pulsars join three others that had been previously observed in the Milky Way. Given that most of these five spend much of their time off, Kaspi said, astronomers might be missing a large population of pulsars in the Milky Way. — *Christopher Crockett*

Earliest galaxies got the green light

Green was all the rage a couple of billion years after the Big Bang.

Galaxies in the early universe blasted out a specific wavelength of green light, researchers reported January 7. It takes stars much hotter than most stars found in the modern universe to make that light. The finding offers a clue to what the earliest generation of stars might have been like (*SN: 10/1/16, p. 25*).

Some nearby galaxies and nebulae produce a little bit of this hue today. But these early galaxies, seen as they were roughly 11 billion years ago, produce an overwhelming amount. "Everybody was doing it," said Matthew Malkan, an astrophysicist at UCLA. "It seems like all galaxies started this way."

Malkan and colleagues used the United Kingdom Infrared Telescope in Hawaii and the Spitzer Space Telescope to collect the light from over 5,000 galaxies. In all of these galaxies, the team found, one wavelength of green light — now stretched to infrared by the expansion of the universe — was twice as bright as light from the typical mix of stars and gas seen in galaxies today.

The green light comes from oxygen atoms that have lost two of their electrons. Knocking off two electrons requires harsh ultraviolet radiation, possibly from lots of extremely hot stars — each roughly 50,000° Celsius. The sun, by comparison, is a paltry 5,500° at its surface.

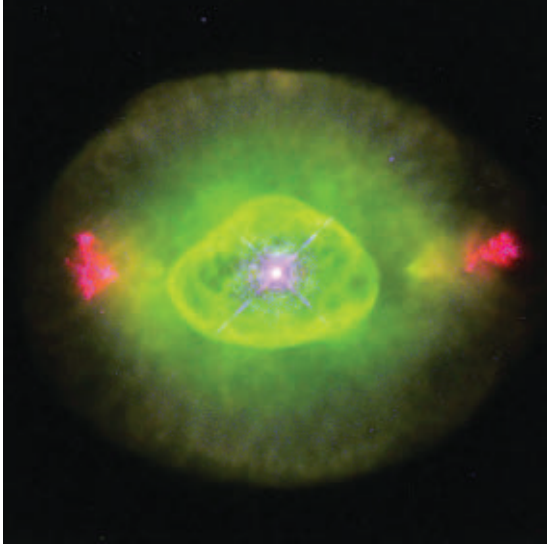
"Stars must have been much hotter than most energetic stars familiar to us today," Malkan said.

How they got so hot — perhaps via unusual abundances of chemicals or just piling on lots of mass — is unsettled. — *Christopher Crockett*

Milky Way's black hole may hurl galactic spitballs our way

The gargantuan black hole at the center of the Milky Way is a little like an unruly kid hurling spitballs. But unlike a child's

Blobs of gas roughly the mass of Jupiter (illustrated) could form near the black hole at the center of the Milky Way and shoot into intergalactic space.



Galaxies in the early universe emitted lots of green light, such as seen in this nebula (NGC 6826) in the Milky Way.

arsenal, these spitballs are roughly the size of a planet and can travel fast enough to shoot out of the galaxy. Some might even zip right by our solar system.

Stars that pass too close to the black hole can be shredded by its intense gravity. Previous simulations have shown that within these strands of stellar debris, gas can clump back together into balls roughly the mass of Jupiter that are then launched away at several thousand kilometers per second. What happens to these blobs was unknown.

About 95 percent are launched so fast that they escape the gravity of the Milky Way and fly into intergalactic space, Eden Girma, an undergraduate student at Harvard University, reported January 6. Girma and astrophysicist James Guillochon of the Harvard-Smithsonian Center for Astrophysics developed computer simulations to figure out the fate of these galactic spitballs. Those that don't escape get stuck in orbits just a few hundred light-years from the black hole.

Of those that do fly away, some could pass through our cosmic neighborhood, getting as close as about 700 light-years, Girma said. Detecting them won't be easy. With no internal heat source, the blobs would emit only a trickle of infrared light. The best bet, she said, is to catch one as it passes between Earth and a distant star. The starlight, magnified by the gravity of the projectile, would momentarily brighten and betray the blob's presence. — *Christopher Crockett*

FROM TOP: B. BALICK, J. ALEXANDER, A. HAJIAN, Y. TERZIAN, M. PERINOTTO, P. PATRIARCHI, NASA; MARK A. GARLICK/CFA

LIFE & EVOLUTION

Overlooked mass migration spotted

Trillions of arthropods fly over United Kingdom annually

BY SUSAN MILIUS

Forget honking Vs of geese or gathering herds of wildebeests. The biggest yearly mass movements of land animals may be the largely overlooked flights of aphids, moths, beetles, flies, spiders and their kin.

About 3.5 trillion arthropods fly or windsurf over the southern United Kingdom annually, researchers say after analyzing a decade of data from special entomological radar and net sweeps. The larger species in the study tended to flow in a consistent direction, suggesting that more species may have specialized biology for seasonal migrations than scientists realized, says study coauthor Jason Chapman, now at the University of Exeter in Penryn, England.

The creatures detected in the study may be little, but they add up to roughly 3,200 metric tons of animal weight, Chapman and colleagues report in the Dec. 23 *Science*. That's 7.7 times the tonnage of U.K. songbirds migrating to Africa and equivalent to about 20,000 (flying) reindeer.

These are "huge flows of biomass and nutrients," Chapman says. "One of the things we hope to achieve in this work is to convince people who are studying terrestrial ecosystems that they cannot ignore what's happening in the skies above them."

Biologist Martin Wikelski of the Max Planck Institute for Ornithology in Radolfzell, Germany, who wasn't part of the study, calls these migrants "aerial plankton." It's a reference to the much-studied tiny sea creatures whose movements and blooms power oceanic food webs. Understanding insect migrations and abundances is crucial for figuring out food webs on land, including those that link insects and birds. That's "particularly important nowadays as we are starting to lose many of our songbirds," Wikelski says.

The word migration applied to arthropod movements doesn't necessarily mean one animal's round trip, Chapman says. Instead, the term describes leaving the home range and undertaking a sustained journey, maybe cued by seasons changing or food dwindling. A return trip, if there is one, could be the job of a future generation.

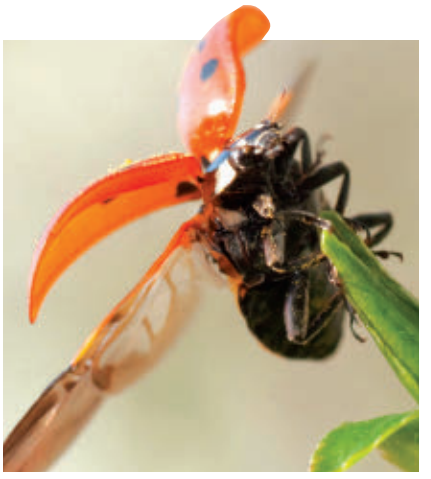
The migrants Chapman studied, traveling at least 150 meters above ground, aren't just accidentally blowing in the wind, he says. Many of the tiniest — aphids and such that weigh less than 10 milligrams — take specific measures to start their journey, such as trekking to the top of a plant to catch a gust. Juvenile spiders stand on tiptoe reeling out silk until a breeze tugs a strand, and them, into the air. "They only do this when wind conditions will enable them to be caught and taken up; otherwise, it's a terrible waste of silk," Chapman says. Some caterpillars also spin silk to travel, and mites, with neither wings nor silk, can surf themselves into a good breeze.

The basic idea that a lot of arthropods migrate overhead is "absolutely not" a surprise to behavioral and evolutionary biologist Hugh Dingle of the University of California, Davis. He says so not dismissively but joyously: "Now we have really good data."

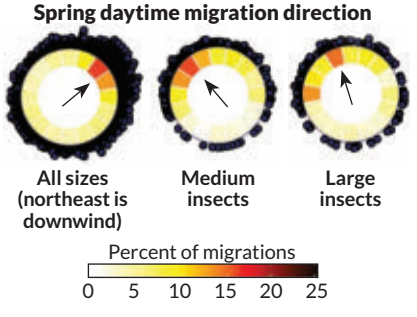
The smallest class of migrants, sampled with nets suspended from a big balloon, makes up more than 99 percent of the individual arthropods and about 80 percent of the total mass. These migrants didn't show an overall trend in flight direction. But radar techniques refined at Rothamsted Research in Harpenden, England, showed distinct seasonal patterns in direction for medium-sized and larger insects.

"That's the big surprise for us," Chapman says. "We assumed that those flows would just be determined by the wind." But medium-sized and large insects such as lacewings and moths overall tended to head northward from May through June regardless of typical wind direction. And in August and September, they tended southward. "Lots of insects we didn't think capable of this are clearly doing it," Chapman says.

Managing such a feat takes specialized biology for directed, seasonal migrations. Many of these arthropods must have some form of built-in compass plus a preferred direction and the genetics that change that preference as they or their offspring make the return migration. Entomologists have known some migratory details of monarch butterflies in North America and a handful of other such insects, many of them pest moths. But speculating about specialized migrants, Chapman says, "there must be thousands of these." ■



Adding up ladybugs (seven-spotted species shown) and other insects and their kin that travel overhead in the southern United Kingdom each year reveals what could be the biggest migration of land animals on the planet.



Not just windblown In a study of arthropods migrating over the United Kingdom, most were tiny and traveled with the wind, as represented by the bulge in dark dots to the northeast on the left compass rim (each dot represents a migrating group). Yet insects of medium size or larger bucked the trend, flying northwest in spring (middle and right circles). Arrows indicate average migration direction.

FROM TOP: LEVIATHAN1983/WIKIMEDIA COMMONS (CC BY-SA 3.0); G. HU *ET AL*/*SCIENCE* 2016

LIFE & EVOLUTION

Unusually loose skin protects hagfish

Floppy outer covering aids in shark attacks, Houdini escapes

BY SUSAN MILIUS

Skin that mostly hangs loose around hagfishes proves handy for living through a shark attack or wriggling through a crevice.

The skin on a hagfish's long, sausage-style body is attached in a line down the center of the back and in flexible connections where glands release slime, said Douglas Fudge of Chapman University in Orange, Calif. This skin easily slip-slides in various directions. A shark tooth can puncture the skin without stabbing into muscle below, Fudge reported January 5.

Loose-fitting skin may help hagfish (*Eptatretus stoutii* shown) survive a shark bite.

Hagfishes fend off attacking sharks by releasing a cloud of slime. Yet video of such events shows that a shark can land a bite before getting slimed. To see how hagfishes survive such wounds, Fudge and colleagues used an indoor guillotine to drop a shark tooth into hagfish carcasses. With the skin in its natural, loose state, the tooth punched through but slipped away from stabbing into the body of either the Atlantic (*Myxine glutinosa*) or Pacific (*Eptatretus stoutii*) hagfish species.

But when the researchers glued the skin to the hagfish muscle so the skin couldn't slip, the tooth typically plunged into inner tissue. When the guillotine dropped on lampreys, which are similarly tube-shaped but with skin well-fastened to their innards, the tooth often stabbed directly into flesh.

The finding makes sense to Theodore Uyeno of Valdosta State University in Georgia. He and colleagues have tested how hard it is to puncture swatches of hagfish skin. Punching through a skin held taut didn't take as long as punching through skin patches allowed to go slack, Uyeno reported January 5. Even a slight delay when a sharp point bears down on baggy skin might allow the hagfish to start dodging and sliming.

But Michelle Graham of Virginia Tech, who studies locomotion in flying snakes, wondered if puncture wounds would be a drawback to such a defense. A hagfish could lose blood from the skin puncture. That's true, said Fudge, but the loss doesn't seem to be great. Hagfish have very low blood pressure, and video of real attacks doesn't show great gushes.

Blood plays a part in another benefit of loose skin — wriggling through cracks, Fudge reported. One of his students built an adjustable crevice and found that hagfishes can contort themselves through slits only half as wide as their original body diameter. Videos show skin bulging out to the rear as the pinch of the opening forces blood backward.

The cavity just under a hagfish's skin can hold about a third of its blood. Forcing that reservoir backward can help shrink the body diameter. The inner body tapers at the end, Fudge said. As blood builds up, "they don't explode." ■

LIFE & EVOLUTION

Sea spider guts act like heart, gills

Unusual digestive system located in legs pumps blood

BY SUSAN MILIUS

A newfound way of delivering oxygen in animal circulatory systems relies on food sloshing back and forth in the guts.

This discovery came in sea spiders. Their spookily long legs hold stretches of digestive tract, which wouldn't fit inside the creatures' scrap of an abdomen. Contractions sweeping up and down the leggy guts cause blood outside the guts to move too, physiologist Art Woods of the University of Montana in Missoula said January 8. As surges of food rise and fall, blood that has picked up oxygen by diffusion whooshes to the rest of the body, Woods proposed.

"Essentially they use their legs like gills," said Jon Harrison, an evolutionary physiologist at Arizona State University in Tempe. "To my knowledge, no one had thought of this before — certainly no one has demonstrated this before."

Sea spiders aren't spiders but a closely related lineage of arthropods. Woods and colleagues began thinking about oxygen consumption while studying sea spiders that grow to have a leg span wider than a dinner plate. A sea spider's outer layer is porous enough for oxygen to diffuse through. But diffusion without an inner pump couldn't meet oxygen needs.

Most sea spider species have a heart that shoots blood out of open-ended vessels where it washes over tissues and then returns. Yet the researchers did not see big regular pulses throughout the body.

Instead, the team found that there's more oxygen in the tips of the legs. Gut activity drives newly oxygenated blood up toward the rest of the body. A video showed a bit of gut bulging inside the leg as a dollop of food washed through, shrinking as the wake died away and then swelling again as a food wave arrived from the opposite direction. These motions let the oxygen-enriched blood circulate, Woods said.

To test the idea, his team lowered the oxygen content of sea spiders' water. The digestive tract's movements increased, as expected if the guts had to work harder to supply oxygen. And when the researchers raised the temperature, which revs up metabolism and increases oxygen demand, gut activity increased, too. ■

TOM MCHUGH/SCIENCE SOURCE

Watch a hagfish slime a shark at **bit.ly/SN_hagfish**

MATTER & ENERGY

Fast-freezing hot water spurs debate

Properties of hydrogen bonds may explain the Mpemba effect

BY EMILY CONOVER

It seems logical to expect cold water to freeze faster than hot, but some experiments have suggested the opposite. There's now a new explanation for why hot water might freeze faster than cold under certain conditions. The phenomenon — the Mpemba effect — may be due to the properties of the bonds that link up neighboring water molecules, chemists report. Yet other researchers contend the effect doesn't exist at all.

References to quick-freezing hot water date back to the time of the ancient Greeks. In the 1960s, a Tanzanian student named Erasto Mpemba noticed that ice cream solidified faster when put into the freezer steaming hot. Scientists have proposed a variety of explanations for the phenomenon — now named for the student — including the effects of evaporation, convection currents and dissolved gases or other impurities in the water. But none have been fully accepted.

In the Jan. 10 *Journal of Chemical Theory and Computation*, chemists propose that hydrogen bonds, the links between hydrogen atoms and the oxygen atoms of neighboring water molecules, could be part of the puzzle. Dieter Cremer of Southern Methodist University in Dallas and colleagues studied the strengths of hydrogen bonds in water molecule simulations. "We see that hydrogen bonds change when warming up water," he says.

The strength of hydrogen bonds depends on the arrangements of nearby water molecules. In simulations of cold water, both weak and strong hydrogen bonds were observed, but in higher temperature simulations, a larger percentage of the hydrogen bonds were strong, because "the weaker ones are broken to a large extent," Cremer says.

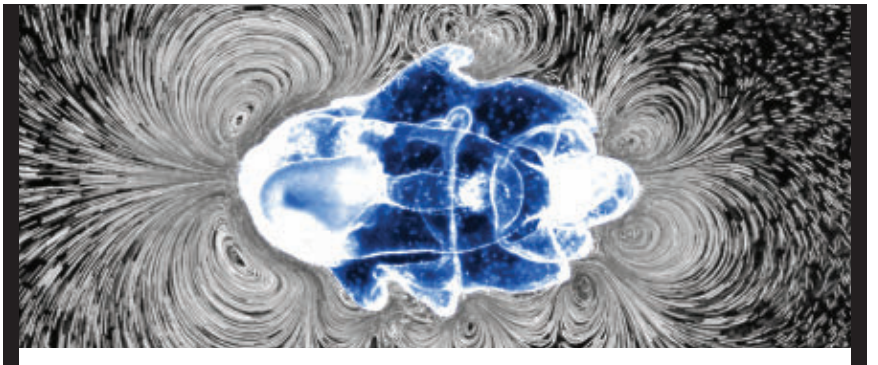
Cremer and colleagues realized their new understanding of hydrogen bonds could explain the Mpemba effect. As water is heated, weaker bonds break, and groups of molecules form into fragments that can realign to form the crystalline structure of ice, serving as a starting point for the freezing process. For cold water to rearrange in this way, weak hydrogen bonds first have to be broken.

"The analysis in the paper is very well done," says Caltech chemist William Goddard. "The big question is, does it actually relate directly to the Mpemba effect?" The study didn't simulate the freezing process to show it proceeds faster when the new hydrogen bonding insights are included. "It doesn't actually make the final connection," Goddard says.

But physicist Jonathan Katz of Washington University in St. Louis says the idea "just makes absolutely no sense." In Mpemba experiments, water freezes over minutes or hours. As the temperature drops over that period of time, weak hydrogen bonds would reform and molecules would rearrange, Katz argues.

Meanwhile, scientists are still debating whether the Mpemba effect is even real. Attempts to observe it have been inconsistent. In experiments published November 24 in *Scientific Reports*, scientists measured the time for hot and cold samples of water to cool to zero degrees Celsius. "No matter what we did, we could not observe anything akin to the Mpemba effect," says Henry Burridge of Imperial College London.

However, that study "excluded a very important aspect of the phenomenon," says chemist Nikola Bregović of the University of Zagreb in Croatia. Burridge's study observed only the time to reach the temperature at which water freezes, not the initiation of freezing itself — a complex process that is difficult to control and one of the reasons the effect is so hard to verify. "I am still convinced that hot water can freeze more quickly than cold water," Bregović says. ■



LIFE & EVOLUTION

Baby starfish on the hunt whip up whirlpools

A baby starfish scoops up snacks by spinning miniature whirlpools. These vortices draw in tasty algae so the larva can slurp them up, scientists from Stanford University report December 19 in *Nature Physics*.

Before starfish take on their familiar shape, they swim the ocean as millimeter-sized larvae. They use hairlike appendages called cilia to paddle. The larvae also adjust the orientation of these cilia, the scientists found, to fine-tune their food-grabbing vortices.

Scientists studied larvae of the bat star (*Patiria miniata*), a starfish found on the U.S. Pacific coast, in seawater suffused with tiny beads that traced the flow of liquid (time-lapse image of a larva shown above). Too many swirls can slow a larva down, the scientists found, so the baby starfish adapts to the task at hand, creating fewer vortices while swimming and whipping up more of them when stopping to feed. — *Emily Conover*

W. GILPIN, V.N. PRAKASH AND M. PRAKASH/*NATURE PHYSICS* 2016

ATOM & COSMOS

Dark matter still missing

Chalk up one more loss for physicists searching for dark matter. Scientists with the XENON100 experiment have largely ruled out another experiment's controversial claim of a detection.

XENON100, located in Italy's Gran Sasso National Laboratory, aims to directly detect particles of dark matter — the unknown substance that scientists believe makes up the bulk of matter in the cosmos (*SN: 11/12/16, p. 14*).

In the new analysis, published online January 3 at arXiv.org, XENON100 scientists looked for an annual variation in the rate of blips in the detector, a tank filled with 161 kilograms of liquid xenon. Such a signal could be a hallmark of Earth's motion through a prevailing wind of dark matter particles as the planet makes its yearly jaunt around the sun. Another dark matter experiment at Gran Sasso, DAMA/LIBRA, claims to have found strong evidence of a yearly modulation, but others have failed to replicate the result.

Scientists combed data collected over four years for events that could be caused by dark matter interacting with electrons in XENON100. The researchers found no evidence of an annual cycle.

Dark matter optimists can still cling to hope, though: DAMA uses a different detection material, composed of sodium iodide crystals rather than xenon. That might explain the difference between the two experiments. Future detectors will attempt to replicate DAMA's result using sodium iodide. — *Emily Conover*

BODY & BRAIN

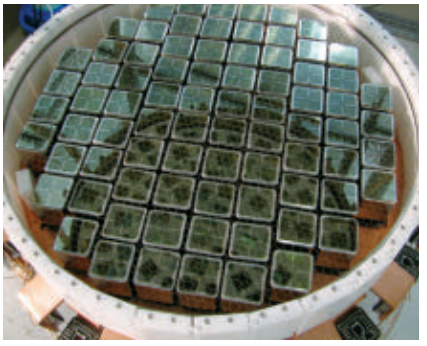
Ebola vaccine proves effective

An experimental Ebola vaccine has triumphed in West Africa.

Of 5,837 people in Guinea and Sierra Leone who received a single shot of the vaccine, rVSV-ZEBOV, none became infected with the virus 10 to 84 days after vaccination. That's 100 percent protection, researchers report online December 22 in the *Lancet*.

World Health Organization researcher Ana Maria Henao-Restrepo and colleagues tested a "ring vaccination" approach, immediately vaccinating family members and other contacts of people infected with Ebola. This strategy seemed to staunch the virus' spread. Among 4,507 people never vaccinated or who got a delayed vaccine, 23 contracted Ebola.

The findings echo preliminary results (*SN: 9/5/15, p. 6*) and offer a promising line of defense for future outbreaks. But scientists do not know how long the vaccine's protection lasts. — *Meghan Rosen*



A search for dark matter by the XENON100 experiment has found nothing. Photomultiplier tubes within the detector (shown) spot light produced in interactions possibly caused by dark matter particles.

BODY & BRAIN

New test screens for prions in blood

A new blood test can detect even tiny amounts of infectious proteins called prions, two new studies report.

Incurable prion diseases — such as mad cow disease, or BSE, in cattle and variant Creutzfeldt-Jakob disease, or vCJD, in people — result from a normal brain protein called PrP twisting into a disease-causing "prion" shape that kills nerve cells in the brain. As many as 30,000 people in the United Kingdom may be carriers of prions that cause vCJD, presumably picked up by eating BSE-tainted beef. Health officials worry that infected people could unwittingly pass prions to others through blood transfusions. But until now, there has been no way to screen blood for the proteins.

In the test, described in the Dec. 21 *Science Translational Medicine*, magnetic nanobeads coated with plasminogen — a protein that prions grab onto — trap prions. Washing the beads gets rid of the rest of the substances in the blood. Researchers then add normal PrP to the beads. If any prions are stuck to the beads, the infectious proteins will convert PrP to the prion form, which will also stick to the beads. After many rounds, the researchers amplified the signal enough to detect vCJD prions in all of the people in the studies known to have the disease. — *Tina Hesman Saey*

MATH & TECHNOLOGY

Retracted result on network equivalence reinstated

A computer scientist has taken his colleagues on a roller coaster ride.

In the span of several days, László Babai of the University of Chicago walked back his earlier claim of making a major advance on a classic puzzle of computer science, only to reinstate it after fixing an error in his work.

At issue is the problem of "graph isomorphism," which demands that a computer quickly determine if two networks of interconnected points, or "graphs," are equivalent. For complex graphs, this task could be time-consuming.

In 2015, Babai reported at a meeting that he had created an algorithm that solved this problem much faster than previously possible (*SN: 12/12/15, p. 6*). Using previous algorithms, the time the task takes balloons almost exponentially as the graphs increase in complexity. But Babai's method operates in what's called "quasi-polynomial time," which means graphs can be compared within a time period that grows more slowly with complexity.

On January 4, Babai announced that mathematician Harald Helfgott of the University of Göttingen in Germany found an error in the result. Babai downgraded his claim to a smaller speedup. That demotion didn't last long: On January 9, Babai announced on his website that he had fixed the problem.

Despite the flip-flopping, Helfgott's independent review has increased some researchers' confidence in the result. "I'm more convinced that it's correct," says MIT computer scientist Ryan Williams. But, he says, as Babai has yet to publish the new result, "there's not a whole lot to go on right now." — *Emily Conover*

DEVASTATION DETECTIVES

New rocky evidence about the dinosaurs' final days

By Thomas Sumner

Below the shimmering turquoise waters of Mexico's Yucatán Peninsula lies the scene of a prehistoric mass murder. In a geologic instant, most animal and plant species perished. Drilling through hundreds of meters of rock, investigators have finally reached the footprint left by the accused: Earth's most notorious space rock impact, Chicxulub. The dinosaur killer.

Sleuthing scientists are assembling the most detailed timeline yet of the dinosaur apocalypse by giving fresh scrutiny to telltale fingerprints left by the fateful event 66 million years ago. At the impact site, mountains formed in mere minutes where an asteroid (or maybe a comet) crashed onto Earth's surface, the new work reveals. In North America, a towering tsunami buried plants and animals alike under thick piles of rubble. Around the world, skies darkened by the resulting debris chilled the planet for years.

But the asteroid may not have acted alone. Life may have already been in trouble. Growing evidence points to a supervolcanic accomplice (*SN: 1/10/15, p. 12*). Outpourings of molten rock and caustic gases in what is now India may have acidified the oceans and destabilized ecosystems long before and after the Chicxulub impactor hit. The jolt of the impact may have even boosted the eruptions, some researchers argue.

As more clues have been uncovered, many of them conflicting, the identity of the dinosaurs' true killer — impact, volcanism or both — has become less clear, says Paul Renne, a geoscientist at the Berkeley Geochronology Center in California.

DOUGLAS HENDERSON

"As we've improved our understanding of the timing, we haven't resolved the details," Renne says. "The last decade of work has only made it harder to distinguish between the two potential causes."

The smoking gun

What is clear is that a massive die-off took place around this time. It is visible in the layers of rock. One of the starkest changeovers in that planetary record marks the boundary between the Cretaceous and Paleogene periods some 66 million years ago (previously known as the Cretaceous-Tertiary or K-T). Studies of fossils found (or not found) across that K-Pg boundary reveal that about three-quarters of plant and animal species went extinct — from the ferocious *Tyrannosaurus rex* to microscopic plankton. Everything living on Earth today traces its ancestry to the few lucky survivors (see Pages 22 and 26).

Over the years, scientists have blamed many suspects, from global plagues to a planet-frying supernova, for this catastrophic die out. In 1980, a team of researchers including father-son duo Luis and Walter Alvarez reported discovering abundant iridium in places worldwide along the K-Pg boundary. Iridium is rare in Earth's crust, but the metal is abundant in asteroids and other space rocks. The finding was the first hard evidence of a killer asteroid impact. But without a crater, the hypothesis couldn't be confirmed.

Piles of impact debris led crater hunters to the Caribbean. Eleven years after the Alvarez paper, scientists at last identified the smoking gun — a hidden crater circling the coastal Mexican town of Chicxulub Puerto. (The crater actually had been discovered in the late 1970s by oil company scientists, who used variations in Earth's gravitational tug to visualize its 180-kilometer-wide outline. Word of that find, however, didn't reach crater hunters for years.) Based in part on the gaping size of the depression, scientists estimate that the impact released 10 billion times as much energy as the nuclear bomb dropped on Hiroshima.

That's big, but questions have remained about how the impact might have caused so much death and destruction worldwide. To find answers, scientists recently returned to the scene of the crime.

Instant mountains

Reaching the Chicxulub crater itself takes effort. Tens of millions of years of sediment deposits now entomb the crater hundreds of meters underground, much of it below the seafloor. The solution, the *Myrtle* drilling vessel, looks a bit awkward cruising the ocean. Three colossal black cylinders rise from the deck like sailless masts, giving the ship a top-heavy look. Once in position, the ship transforms. The hulking cylinders drop to the seafloor and the ship jacks itself out of the water, standing tall on three legs like an oil rig.

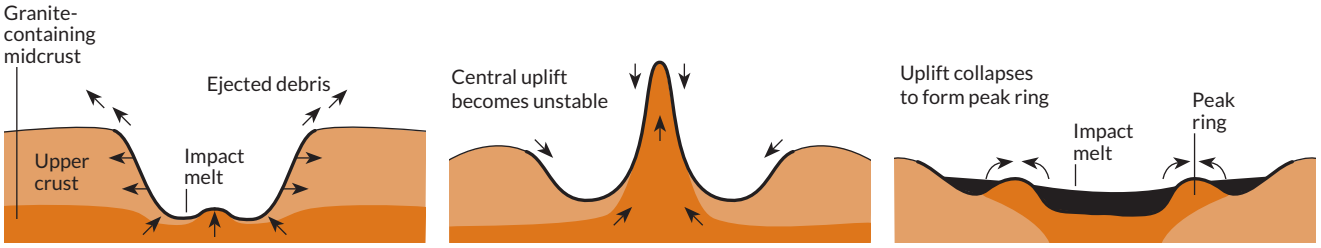
From this platform above the waves, scientists probed deep underground last April and May, to a halo of hills that tower hundreds of meters above the crater floor, about 30 kilometers off the Yucatán Peninsula. This peak ring formed in the aftermath of the impact and is the only one of its kind left on Earth. Getting hold of the rocky evidence locked inside the peak ring is key to understanding just how powerful the impact was.

It's also helped to resolve a mystery about how such large peak rings form. Simulations suggest that an impact churns deep rocks to the surface, leaving the circle of peaks. Some scientists, though, argued that the ring had a less violent origin, forming from near-surface materials as the ground rebounded after impact. Confirming whether the computer simulations reflect reality required some seriously deep drilling, says Sean Gulick, a geophysicist at the University of Texas at Austin who co-led the expedition.

The team drilled 1,334.7 meters down from the seafloor over nearly two months at a cost of about $75 per centimeter. The effort proved worth it once the first impact-forged rocks from the crater itself were in hand, says Joanna Morgan, a geophysicist at Imperial College London and the project's co-leader. The rocks are "dramatic," she says, a kaleidoscope of black, green, red and white

Rocks collected from a ring inside the Chicxulub crater (intact core, left, and core fragment, right, with mineral deposits) contain granite usually found at much greater depths, showing that the impact brought deep rocks to the surface.

FROM LEFT: ARAE@ECORD_IODP; WUELBERS@ECORD_IODP



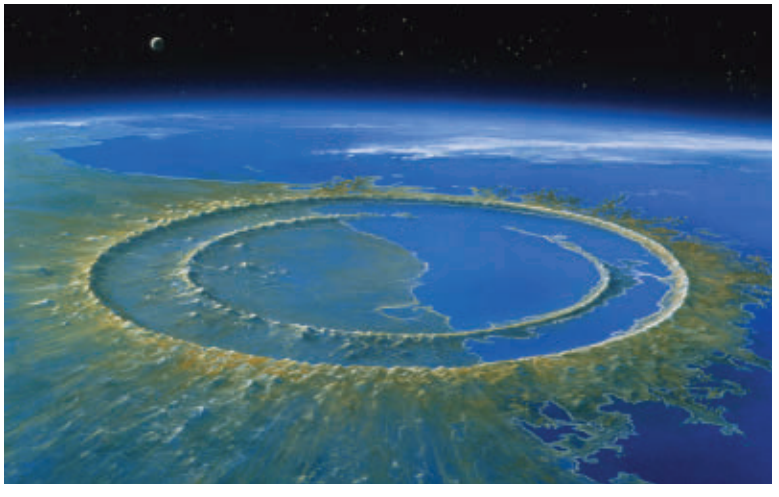
Ringing true The elevated ring inside large impact craters forms from deep rocks churned to the surface by the blast. In minutes, these rocks flow into the newly opened void, meeting in the crater's center as a single column (center) before collapsing outward and forming the peak ring structure. SOURCE: J.V. MORGAN *ET AL*/*SCIENCE* 2016

minerals including granite. "It looks like a fake kitchen countertop," Gulick says. "No other rock looks like this."

That granite solved the peak ring formation mystery even before the ship returned to shore. In the region, minerals such as granite are buried many kilometers below the surface in the midcrust. Finding abundant granite in the relatively shallow peak ring means the models were right: The force of the impact churned deep material to the surface, the researchers reported in the Nov. 18 *Science* (*SN Online: 11/17/16*). That lifted material flowed into the newly opened wound in Earth's surface, meeting in a giant column at the crater's center before collapsing outward and forming the roughly 550-meter-tall peak ring — less than 10 minutes after impact.

Scientists will use the data collected by the Chicxulub drilling team to improve simulations to better estimate how much energy and debris the impact unleashed, says Ross Potter, a planetary scientist at Brown University in Providence, R.I. Getting those numbers right is important because the blast itself wasn't the big killer in the impact scenario. It was the darkness that followed.

A drilling expedition into the ring of hills (inner circle) inside the Chicxulub crater (illustrated) suggests that simulations of the impact event are correct.



Inescapable night

The ground shook. Powerful gusts roiled the atmosphere. Debris rained from the sky. Soot and dust, spewed by the impact and resulting wildfires, filled the sky and began to spread like a giant sunlight-blocking shade over the entire planet. A new simulation gives researchers a better sense of just how long the darkness lasted; earlier estimates ranged broadly from just months to years.

The length and severity of the global cooldown was dramatic, says paleoclimatologist Clay Tabor of the National Center for Atmospheric Research in Boulder, Colo. He and colleagues assembled one of the most detailed computer simulation ever made of the impact's climate consequences, a sort of digital crime scene reconstruction.

The simulation begins with the preimpact climate, based on geologic evidence of ancient vegetation and levels of atmospheric carbon dioxide. Then comes the soot. A high-end estimate of released soot, based on the size and global fallout of the impact, is 70 billion metric tons, the weight of about 211,000 Empire State Buildings.

For two years, no light reached Earth's surface — any part of it, the simulation shows. Global temperatures plummeted by 16 degrees Celsius and Arctic ice spread southward, Tabor reported in September in Denver at the Geological Society of America's annual meeting.

Some areas would have been hit particularly hard, Tabor's work suggests. The equatorial Pacific saw dramatic drops in temperature while coastal Antarctica barely cooled. Inland areas generally fared worse than coastal areas. Those divides could help explain why some species and ecosystems weathered the impact while others didn't, Tabor says. Six years after the impact, sunshine returned to preimpact levels. Two years after that, land temperatures rose above preimpact conditions and the climate ultimately warmed several more degrees due to the insulating blanket of carbon sent airborne by the impact.

FROM TOP: J. HIRSHFELD; DETLEV VAN RAVENSWAAY/SCIENCE SOURCE

Evidence of the chilling darkness is in the rock record. Local sea surface temperatures modified the lipid molecules in the membranes of ancient microbes. The fossilized remains of those lipids provide a temperature record, says geologist Johan Vellekoop of the University of Leuven in Belgium. Fossilized lipids in what is now New Jersey suggest that temperatures there plummeted 3 degrees following the impact, he and colleagues reported in *Geology* in June.

Similar abrupt temperature drops plus darkened skies killed plants and other species that nourish the rest of the food web, Vellekoop says. "Dim the lights and the entire ecosystem collapses."

The cold darkness was the impact's deadliest weapon, but some unfortunate critters died too soon to witness it.

Buried alive

An ancient graveyard covers swaths of Montana, Wyoming and the Dakotas. Called the Hell Creek Formation, it's hundreds of square kilometers of paleontologist paradise. Erosion has left dinosaur bones jutting out of the ground, ready to be plucked up and studied. Here, in the dry badlands, thousands of kilometers away from the Chicxulub crater, paleontologist Robert DePalma of the Palm Beach Museum of Natural History in Florida found something surprising: signs of a tsunami.

Evidence of the supersized tsunami generated by the Chicxulub impact had previously been found only around the Gulf of Mexico — never this far north or so far inland. But the symptoms of tsunami devastation were clear, DePalma says. The rushing water dumped sediment onto the landscape. The debris originated from the nearby Western Interior Seaway that once cut across North America from Texas to the Arctic Ocean.

The sediment contained iridium and glassy debris formed from rock vaporized by the impact as well as fossilized marine species such as snail-like ammonites carried from the seaway. The macabre evidence didn't stop there.

"These are the dead bodies," DePalma said at the geological society meeting, pulling up slides of fish fossils found inside the tsunami deposits. "If a CSI team walks over to a burnt-out building, how do they know if the guy died before or during the fire? You look for carbon and soot in the lungs. In this case, fish have gills, so we checked those out."

The gills were packed with glass from the impact, which means the fish were alive and swimming when the asteroid hit. The fish remained alive, DePalma says, up until the moment the tsunami pummeled the landscape and crushed the fish under debris. Those unfortunate fish are the first known direct victims of the Chicxulub impact, he says. The ensuing climate change and deforestation took longer to do their damage.

The *Myrtle* drilling ship and its three towering legs offered a stable platform for scientists to drill into the crater left behind by the Chicxulub impact.

Just under the fish-filled tsunami deposits was another amazing find: dinosaur tracks from two species, says Jan Smit, a sedimentologist at VU University Amsterdam. "These dinosaurs were running and alive before they were hit by the tsunami," he says. "The entire ecosystem in Hell Creek was alive and kicking until the last moment. In no way was it on the decline."

The new evidence from the Hell Creek Formation confirms that most of the deaths at the time were caused by the Chicxulub impact, Smit argues. "I was 99 percent sure that it was the impact, and now that we've found this evidence, I'm 99.5 percent sure." While many other scientists share Smit's certainty, a growing faction doesn't. Emerging evidence supports an alternative hypothesis that the dinosaurs' demise came at least partly from deep within the Earth.

Death from below

Long before the Chicxulub impact, a different disaster was mounting on the opposite end of the globe. The Deccan volcanic eruptions in India

(at the time, a separate landmass near Madagascar) would ultimately belch about 1.3 million cubic kilometers of molten rock and debris. That's more than enough material to bury Alaska to the height of the world's tallest skyscraper. Gases spewed by similar volcanic outpourings have been linked to other major extinction events (*SN: 9/19/15, p. 10*).

After determining the ages of crystals embedded in the Deccan lava flows, researchers reported in 2015 that the bulk of the eruptions began roughly 250,000 years before the Chicxulub impact and continued for about 500,000 years after. The eruptions were raging at the height of the extinctions (*SN: 1/10/15, p. 12*).

These 65-million-year-old shells, *Cucullaea antarctica*, hold chemical clues of temperature change during the extinction event.

This new timeline lends credence to those who doubt that the Chicxulub impact was the chief perpetrator of the extinction event. "Deccan volcanism is vastly more dangerous to life on Earth than an impact," says Princeton University paleontologist Gerta Keller. Recent research is showing just how detrimental. In the same way that iridium marks the fallout from the Chicxulub impact, the Deccan volcanism has a calling card of its own: mercury.

Most mercury in the environment originated from volcanoes. Large eruptions cough up tons of the element, and Deccan was no exception. The bulk of the Deccan eruptions released between 99 million and 178 million metric tons of mercury in total. Chicxulub released just a fraction of that.

All that mercury left a mark. In southwestern France and elsewhere, a research team discovered copious mercury in sediment laid down before the impact. Those same sediments held another clue as well: the fossilized shells of plankton from the dinosaur days. Unlike healthy shells, these specimens are thin and cracked, the researchers reported in *Geology* in February 2016.

The fragmented shells suggest that CO_2 released by the Deccan eruptions made the oceans too acidic for some creatures, says Thierry Adatte, a geoscientist at the University of Lausanne in Switzerland who coauthored the study with Keller.

"Survival was getting very difficult for these critters," Keller says. Plankton form the marine ecosystem's foundation and their decline reverberated up the food web, she proposes. A similar trend is happening today as seawater soaks up CO_2 from fossil fuel burning. As waters become more acidic, the shell-making process requires more energy (*SN: 8/6/16, p. 8*).

Partners in crime

The Deccan eruptions wreaked havoc in at least part of Antarctica. Analyzing the temperature-dependent chemical makeup of the shells of 29 clamlike bivalves from the continent's Seymour Island, researchers assembled a roughly 3.5-million-year record of how Antarctic temperatures changed around the time of the dinosaur extinction. Following the start of the Deccan eruptions and the resulting rise in atmospheric CO_2, local temperatures warmed about 7.8 degrees, scientists from the University of Michigan and University of Florida reported in July in *Nature Communications*. About 150,000 years later, a

Deccan volcanic eruptions spewed more than a million cubic kilometers of molten rock and debris in what is now India. The outpourings, starting before and running after the Chicxulub impact, may have contributed to the mass extinction that ended the reign of the dinosaurs.

FROM TOP: S.V. PETERSEN; MARK RICHARDS

second, smaller warming phase coincided with the Chicxulub impact. Both of these warming phases corresponded with high extinction rates on the island.

"Everyone wasn't just living happily, and then boom, this impact came out of nowhere," says study coauthor Sierra Petersen, a geochemist at the University of Michigan. Plants and animals "were already under stress and not having a great day, and this impact happens and pushes them over the top." Both catastrophic events were major contributors to the extinction event, Petersen argues. "Either one would have caused some extinction, but such a mass extinction is due to a combination of both events."

Noting that some parts of the world were affected by the Deccan eruptions before the impact is not enough to demonstrate that life overall was stressed at the time, says Imperial College's Morgan. Fossil evidence in many regions suggests that marine life flourished until the impact, she says.

But maybe bad luck wasn't the reason the dinosaurs encountered two devastating disasters at once. Maybe the impact and the volcanism were in cahoots, some researchers propose. The idea isn't a scheme to get impact purists and the volcano devotees to play nice. Volcanic eruptions often follow major earthquakes, such as the 1960 Cordón-Caulle eruption in Chile that started two days after a nearby magnitude 9.5 quake. The seismic shock waves from the Chicxulub impact potentially reached magnitude 10 or above, Paul Renne says.

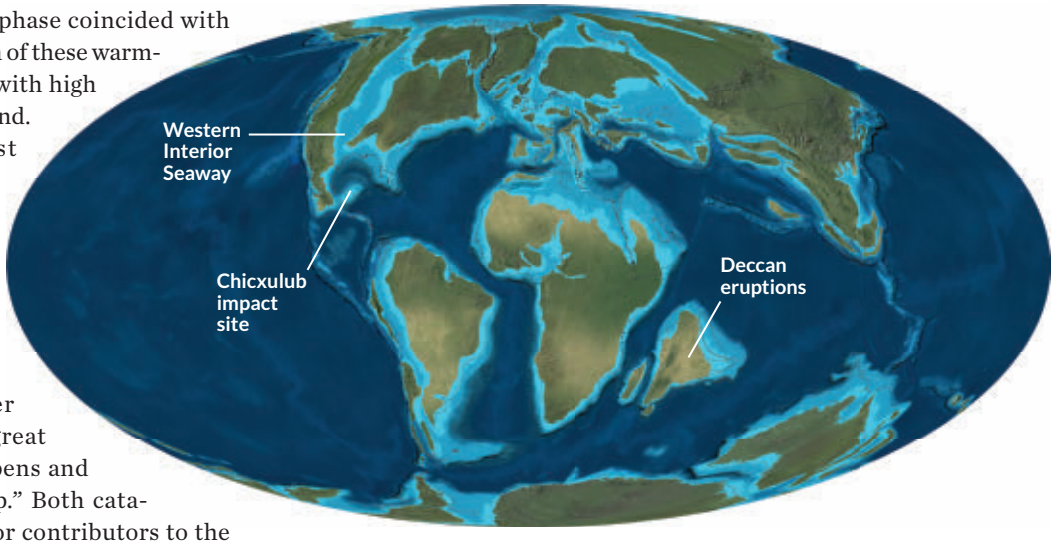
Dating the Deccan lava flows, Renne and colleagues traced the intensity of the volcanism during the time of the impact. Eruptions continued uninterrupted for 91,000 years around the extinction event, Renne reported last April in Vienna at a meeting of the European Geosciences Union. The nature of the eruptions, however, changed within 50,000 years before or after the impact: Erupted material jumped from 0.2 to 0.6 cubic kilometers annually. Something altered the volcanic plumbing, he speculates.

In 2015, Renne and colleagues formally outlined their one-two punch extinction hypothesis in *Science* (*SN: 10/31/15, p. 12*). The shock of the impact fractured the rock enclosing the Deccan magma, the team proposed, allowing the molten rock to expand and possibly enlarging or combining magma chambers. Dissolved gases in the magma formed bubbles, which propelled material upward like in a shaken soda can.

> "Everyone wasn't just living happily, and then boom, this impact came out of nowhere."
>
> SIERRA PETERSEN

The physics behind this impact-volcano team-up is tenuous, scientists on both sides of the debate say, especially because Deccan and the impact site were so distant from each other. "This is all guesswork and perhaps wishful thinking," Princeton's Keller says. Gulick in Texas says the evidence isn't there. "They're hunting for another explanation when there's already an obvious one — the impact did it alone."

Over the coming months and years, improved simulations of the dinosaur doomsday and ongoing investigations of Chicxulub and Deccan rocks will add fuel to the deliberations. Ruling a definitive guilty verdict on either accused killer will be difficult, Renne predicts. Both events devastated the planet in similar ways at around the same time. "It's no longer easy to distinguish between the two," he says. For now, at least, the case of the dinosaur killer will remain an unsolved mystery. ■



Double doomsday
Disasters unfolded across the world around 66 million years ago, from the Chicxulub impact in the Yucatán Peninsula, which sent a tsunami into the Western Interior Seaway, to the ongoing Deccan volcanic eruptions in India. These devastating events, imprinted in the rock record, altered the history of life on Earth.

Explore more

- Penny Barton. "Revealing the dynamics of a large impact." *Science*. November 18, 2016.
- Paul R. Renne *et al*. "State shift in Deccan volcanism at the Cretaceous-Paleogene boundary, possibly induced by impact." *Science*. October 2, 2015.

The Survivors

DOUGLAS HENDERSON

After mass extinction, a new crowd of animals had room to explore a reshaped world

By Meghan Rosen

For dinosaurs, the end of the world began in fire.

The space rock that stamped a Vermont-sized crater into the Earth 66 million years ago packed a powerful punch. Any animal living within about a thousand miles of the impact zone was probably vaporized, says paleontologist Stephen Brusatte of the University of Edinburgh in Scotland.

"Everything would have been toast."

But outside of the impact zone, amid the smoking ruins of the battered planet, some survivors emerged.

Life there was no picnic. Wave after wave of life-threatening disasters pummeled the animals that remained, says paleontologist Nicholas Longrich of the University of Bath in England. Earthquakes. Wildfires. Volcanoes. Acid rain. Dust and gunk in the air, blotting out the sun. "It's this series of biblical plagues," Longrich says.

With little light, much plant life perished, and entire food webs collapsed. Life would have been like an ancient *Hunger Games*, with all living creatures as contestants. The odds were not in their favor. From sea to land to lake to sky, animals suffered incredible losses.

"You're basically losing all the big herbivores, all the big carnivores, apex predators in the oceans, entire guilds — wiped out overnight," Longrich says. On land, he adds, anything bigger than a beaver went extinct. Just a few places in North America offer a fossil record of the early years after the extinction, he says, but "there's no evidence for anything over 10 kilos surviving."

Tyrannosaurus rex, *Triceratops*, *Ankylosaurus* and all other nonavian dinosaurs gone.

A lucky few animals managed to cope with the dramatic changes reshaping their environment, Brusatte says. But why exactly some animal groups survived and others bit the dust is still one of paleontology's biggest mysteries.

New fossil research is now helping scientists peer back through time, offering glimmers of what might have been: How some animals made it through one of the worst extinction events the planet has ever seen — and how mammals, in particular, came to dominate.

Sussing out animals' survival strategies could offer hints about how animals today might handle a changing climate, Brusatte says. It might even expose the evolutionary drivers that shaped modern life. After the extinction, evolution went wild, he says. The survivors "had a new world to play in — a new world to conquer."

Cretaceous catastrophe

Near the very end of the Late Cretaceous Epoch, right before the world blew up, one of the largest mammals in North America may have been noshing on bones.

Didelphodon vorax, a honey badger–looking creature with oddly bulbous teeth, was petite by today's standards — weighing just about five kilograms. But it was no lightweight. "Pound for pound, it had the greatest bite force of any mammal we've ever measured," says paleontologist Gregory Wilson of the University of Washington in Seattle.

Wilson and colleagues estimated *Didelphodon*'s bite force from the shape of its fossilized skull. The mammal could snap its jaws together with about 50 pounds of force — enough to crush bones and crack shells, the team reported December 8 in *Nature Communications*.

This fearsome skill wasn't enough to save it: After the asteroid hit and global disasters descended, *Didelphodon* went extinct — just like duck-billed dinosaurs and *Pteranodon*.

The colossal wipeout of *Didelphodon* and so many others is plain to see in the fossil record. In Montana's badlands, where Wilson and colleagues hunt for ancient teeth and bones, tributaries of the Missouri River carve steep bluffs into the earth, exposing slabs of sandstone and siltstone rock. Montana is part of the Western Interior, an ancient seaway that once cut a wide aisle through North America from the Gulf of Mexico to the Arctic.

Much of what scientists know about the dino-killing event, called the Cretaceous–Paleogene, or K–Pg, extinction, traces back to this sweeping tract of land. The area has rocks with fossils from before and after the extinction event. "We haven't found many places in the world like it," Wilson says. Spain, France and Romania hold a few dinosaur and mammalian fossils from this time period (and a handful of underexplored spots in India and South America may offer more). But so far, the Western Interior is home to the best land-based record scientists have.

In Montana, the rocks capture a snapshot of time from about 2 million years before the extinction to roughly 1.5 million years after. A thin layer of reddish-brown clay marks the before and after of the asteroid's impact. "It's a line in the sand, almost literally," Brusatte says. Within the clay, here and elsewhere in the world, scientists find elevated levels of iridium, a silvery-white metal carried to Earth via asteroid. Though not visible by eye (scientists need chemical tests to spot it), the metallic dust marks a memory of the impact known as Chicxulub (see Page 16).

MAIN: MISAKI OUCHIDA; INSET: G.P. WILSON *ET AL*/*NATURE COMM*. 2016

In the Late Cretaceous, a badger-sized mammal, *Didelphodon vorax* (illustrated), may have used its incredible bite force to crunch through bones or turtle shells. Inset shows CT scans of fossil skull and teeth.

All around the globe, Brusatte says, scientists see "a knife-edge separation in the rock" before and after Chicxulub hit. "For over 150 million years you have tons and tons of dinosaur bones, and then literally — Bam! There's nothing."

Dinosaurs were among the animal groups hit hardest by the extinction. Others suffered fewer casualties. In what is now northeastern Montana, about half of fish species survived, Wilson reported at an Origins Project workshop at Arizona State University in 2015. Turtles and salamanders seemed to fare the best, losing only roughly a quarter of their species, Wilson and colleagues reported in a series of studies in 2014.

"Most people think that mammals did awesome," Wilson says. But at least 75 percent of mammals were snuffed out, according to his analysis, which compared fossils present before and after the extinction. Longrich and colleagues put the number even higher: Of 59 mammalian species living in North America during the Late Cretaceous Epoch, about 93 percent died out after the asteroid hit. Those calculations appeared in the *Journal of Evolutionary Biology* in August 2016.

Still, some species found a way to endure.

Survival strategies

A small body. An aquatic lifestyle. Night vision. An unfussy palate. Any one of these features could have helped survivors withstand the relentless undoing of their ecosystems.

It makes sense. Small animals would have required less food than large ones and may have had an easier time finding shelter. Animals that lived in water could have been buffered from dramatic temperature swings.

Nocturnal animals would have been able to hunt for food when debris-filled skies wrapped the world in gloom. The right diet, in fact, could have been one of the biggest tickets to survival. Among insects, for instance, the difference between survival and demise depended on dietary diversity.

Some insects are adventurous eaters: They feed on lots of different kinds of plants. Other insects are pickier. Leaf miners, for example, typically dine on just one plant species, or a few closely related ones, which made it hard to survive the cataclysm.

These insects burrow through leaves, leaving behind a distinctive trail. Cataloging the trails and other damage patterns on fossil leaves can give researchers a rough idea of the kinds of insects that went extinct — or survived, says Penn State paleontologist Michael Donovan. It's like a calling card stamped into stone.

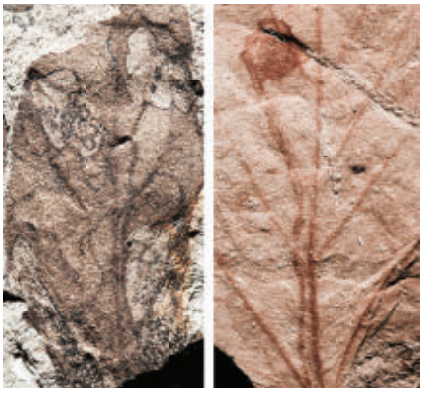
Donovan examined 3,646 fossil leaves found in Patagonia, Argentina, from slices of time bracketing the Chicxulub impact. The leaf-mining patterns seen before the impact vanished after the asteroid hit, he and colleagues reported in *Nature Ecology & Evolution* in 2016.

That suggests a major extinction of leaf-mining insects,

a find echoed in previous results from North Dakota. (Though not all perished. Donovan saw new leaf-mining patterns after the extinction.) Other types of leaf damage did persist through the extinction event — damage made by insects that eat many plant species. Unlike leaf miners, these insects took what they could get in the dark days after the impact. "That's probably a good way to survive," Donovan says.

This type of strategy may have helped some species adapt to their new habitat, Longrich says, which after the K–Pg extinction "happened to be this post-apocalyptic wasteland world." It's like Mad Max of the movies, he says. "A guy who's super versatile — good at many different things," Longrich says, "that's who's likely to live through an apocalypse."

Some animals may have already been plugged into the right food chain. When dinosaurs began dying and leaves fell from trees, the bodies and detritus would have littered the ground and washed into rivers and lakes. That would have been a bonanza for the garbage disposal crew. Decaying matter could feed microbes and fish and insects, which could then feed larger animals, like crocodiles and mammals.



Insect-feeding damage on fossil leaves (winding paths and blotches shown) offer clues about insects during the time of the K-Pg extinction.

Birdlike dinosaurs with beaks could have cracked into another Cretaceous leftover: seeds. The calorie-rich food could have lasted for decades, says paleontologist Derek Larson of the Philip J. Currie Dinosaur Museum in Alberta and the University of Toronto. Other birdlike dinosaurs, with sharp teeth but no beaks, would have had trouble eating seeds. That might explain why they succumbed, while their close relatives — ancestors of modern birds — survived, he and colleagues suggested last year in *Current Biology* (*SN: 5/14/16, p. 11*).

Making it as a mammal

Mammals seemed to capitalize on the detritus-based food chain too, Wilson says. He and University of Washington student Stephanie Smith studied fossils found in northeastern Montana from a 1.2-million-year window after the impact. "Fossil mammals are mostly just teeth," Smith said at the 2016 Society of Vertebrate Paleontology meeting in Salt Lake City. "Luckily, teeth contain a lot of information."

Smith compared the intricate details of fossil teeth with those from living mammals to learn about the ancient animals' diets. In Montana, at least, mammals that lived during the first 200,000 years after the extinction event tended to have teeth that were good for crunching insects — "sharp and pointy," Wilson says. These animals would have had a reliable source of supper. But plant eaters, which have teeth with big basins for grinding and crushing, would have seen their food supplies wither.

Pointy teeth (left) may have helped some mammals eat insects just after the K-Pg extinction. Some later mammals developed broad teeth for grinding plants (right).

For some mammals, a sharp sense of smell could also have offered a competitive edge. *Onychodectes tisonensis*, a bull dog–sized mammal that lived about 350,000 years after the extinction, had one of the largest olfactory bulbs of any mammal (relative to the cerebrum) — bigger than those found in even expert sniffers like modern dogs and pigs. The smell organs look like two almonds sticking out from the front of the brain, says James Napoli of Brown University in Providence, R.I., who reported the results at the paleontology meeting last year. He and colleagues built a digital model based on a CT scan of an *Onychodectes* skull unearthed in New Mexico in 1892.

Having big olfactory bulbs means the animal would have been good at nosing out meals, a valuable skill when food is scarce, Napoli says.

Onychodectes belongs to a weird group of mammals called taeniodonts, says study coauthor Thomas Williamson of the New Mexico Museum of Natural History and Science in Albuquerque. "They have bizarre-looking skulls, enlarged forearms, big claws," he says. The animals may have survived by digging up and eating tough roots and tubers. "We call them the pigs of the Paleocene."

Paleontologists don't know for sure if this group of animals lived through the asteroid crash, or if they arose afterward. There's just one reported taeniodont fossil from the Late Cretaceous — a partial skull from Alberta, Canada.

If taeniodonts did make it through the impact and its aftermath, an aptitude for rooting out hidden food caches would have been useful. If, instead, the animal group emerged later, *Onychodectes* could have been one of the early examples of mammalian experimentation.

For more than 150 million years, mammals had been "kept under the thumb of the dinosaurs," Wilson says. After the extinction, with dinosaurs out of the picture, the "Age of Mammals" could begin.

Boomtime for mammals

In the years after the impact, the world was like a school playground that had banished the big kids.

The animals that survived the early hard years gave rise to a slew of new species able to fill the niches left behind by dinosaurs — and all the other creatures that didn't make it.

FROM TOP: M. P. DONOVAN *ET AL/NATURE ECOLOGY & EVOLUTION* 2016; SMITH AND WILSON 2016 (CC-BY 4.0), SPECIMEN NUMBERS UCMP 117903 AND USNM V9278

The mammal *Periptychus carinidens* lived more than 60 million years ago. Though no good representation exists yet, it may have looked something like *Ectoconus* (illustrated), an extinct member of the same family.

Before the impact, humans' ancestors mostly scurried along the ground. But afterward, with fewer predators and competitors, they were free to try out new lifestyles, like living in trees and gliding.

Placental mammals, a group that includes humans, elephants and most mammals living today, experienced a big evolutionary boom, says Thomas Halliday, a paleobiologist at University College London. "Diversification exploded."

Without dinosaurs breathing down their necks and with fewer competitors, placental mammals had "freedom to evolve in a variety of new directions," Halliday says. It's like they were "exploring almost every aspect of the ways of being a mammal."

When exactly these mammals arose and how much dinosaurs were holding them back remains controversial: Molecular evidence places their origin tens of millions of years before the dinosaurs died. Fossil evidence puts it closer to the K–Pg extinction.

In a series of papers published in 2015 and 2016, Halliday and colleagues analyzed mammalian fossils to sketch out a clearer picture of placental mammals' history. First, the team built a family tree focused on placental mammals that lived in the Paleocene, the 10-million-year epoch immediately following the extinction. That's no easy feat, Halliday says, because these animals tend to lack the kind of standout features that would clearly label them as members of one group or another.

So he and colleagues created an exhaustive catalog of 680 body features (such as skull length, tooth number and molar shape) in 177 genera of extinct and living placental mammals and their close relatives. Presumably, animals that shared features were more closely related than those that didn't. With so many species, the web of potential relationships was astronomical, Halliday says. "There were more possible arrangements ... than there are hydrogen atoms in the universe." The team plugged the data into a computer, which chugged through all the possibilities and came up with the most likely family tree.

Then, the researchers used the tree to calculate rates of evolution. Placental mammals, they found, probably did originate in the Late Cretaceous, but they evolved three times faster after the extinction event than in the 80 million years before it. "We're talking about new anatomical innovations," Halliday says: molars good for grinding leaves, limbs adapted for climbing or swimming.

One of these early innovators was *Periptychus carinidens*, a muscular animal that walked like a bear and had five toes with "weird little hooves," says University of Edinburgh paleontologist Sarah Shelley. "It's not like anything alive today."

Shelley, Williamson and Brusatte described *Periptychus* fossils found in New Mexico's San Juan Basin at the 2016 paleontology meeting. "They have really strange cheek teeth," Williamson says. The teeth are enlarged and conical with big ridges that run from the base to the tip. He thinks *Periptychus* used its weird chompers to eat hard objects — seeds, perhaps, or unripe fruit.

Periptychus was among the first plant-eating placental mammals to emerge after the extinction — and for a few million years it flourished. Fossils of the animal have been found from West Texas to eastern Montana, Williamson says. "It must have been a highly successful mammal." But *Periptychus* couldn't cope with changes that came later — it died out about 60 million years ago. The animals "were early experiments," he says, "but they were ultimately dead ends."

> Placental mammals experienced a big evolutionary boom. Diversification exploded.

That's how it goes with evolution, Halliday says. After the dinosaurs died and mammals tested out different modes of life, some found success and others fizzled. "The most successful strategies are honed and the less successful ones are pared away," he says.

What's left is what we have today: more than 5,400 different mammal species spread across the world. But descending from an evolutionary winner doesn't guarantee a safe future. As species carve out an ever more ideal niche, they become more and more vulnerable to extinction, Halliday says. Animals built for a narrow mode of living tend to have a hard time handling disruptions to their environment. And as the climate changes, some species have already begun to suffer. "In the metaphorical sense, we are in the middle of the asteroid strike right now," he says.

Already, a changing climate has erased pockets of plants and animals across the globe, John Wiens of the University of Arizona in Tucson reported in December 2016 in *PLOS Biology*. Further warming in coming decades could ramp up extinctions, he warns.

That's why studying life and death 66 million years ago is still relevant today, Brusatte says. "It's not just storytelling about the ancient past," he says. "It can help us understand our modern world," and maybe even influence conservation strategies to mitigate some of the changes that are happening now. ■

Explore more

- Stephen L. Brusatte *et al*. "The extinction of the dinosaurs." *Biological Reviews*. May 2015.

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The Lucky Ones

Of all the early birds, only one lineage survived

By Susan Milius

The asteroid strike (or was it the roiling volcanoes?) that triggered dino doomsday 66 million years ago also brought an avian apocalypse. Birds had evolved by then, but only some had what it took to survive.

Biologists now generally accept birds as a kind of dinosaur, just as people are a kind of mammal. Much of what we think of as birdlike traits — bipedal stance, feathers, wishbones and so on — are actually dinosaur traits that popped up here and there in the vast doomed branches of the dino family tree. In the diagram at right, based on one from paleontologist Stephen Brusatte of the University of Edinburgh and colleagues, anatomical icons give a rough idea of when some of these innovations emerged.

One branch of the dinosaur tree gradually turned arguably avian (in the Avialae/Aves group) by about 165 million to 150 million years ago. That left plenty of time for bona fide birds to diversify before the great die-off.

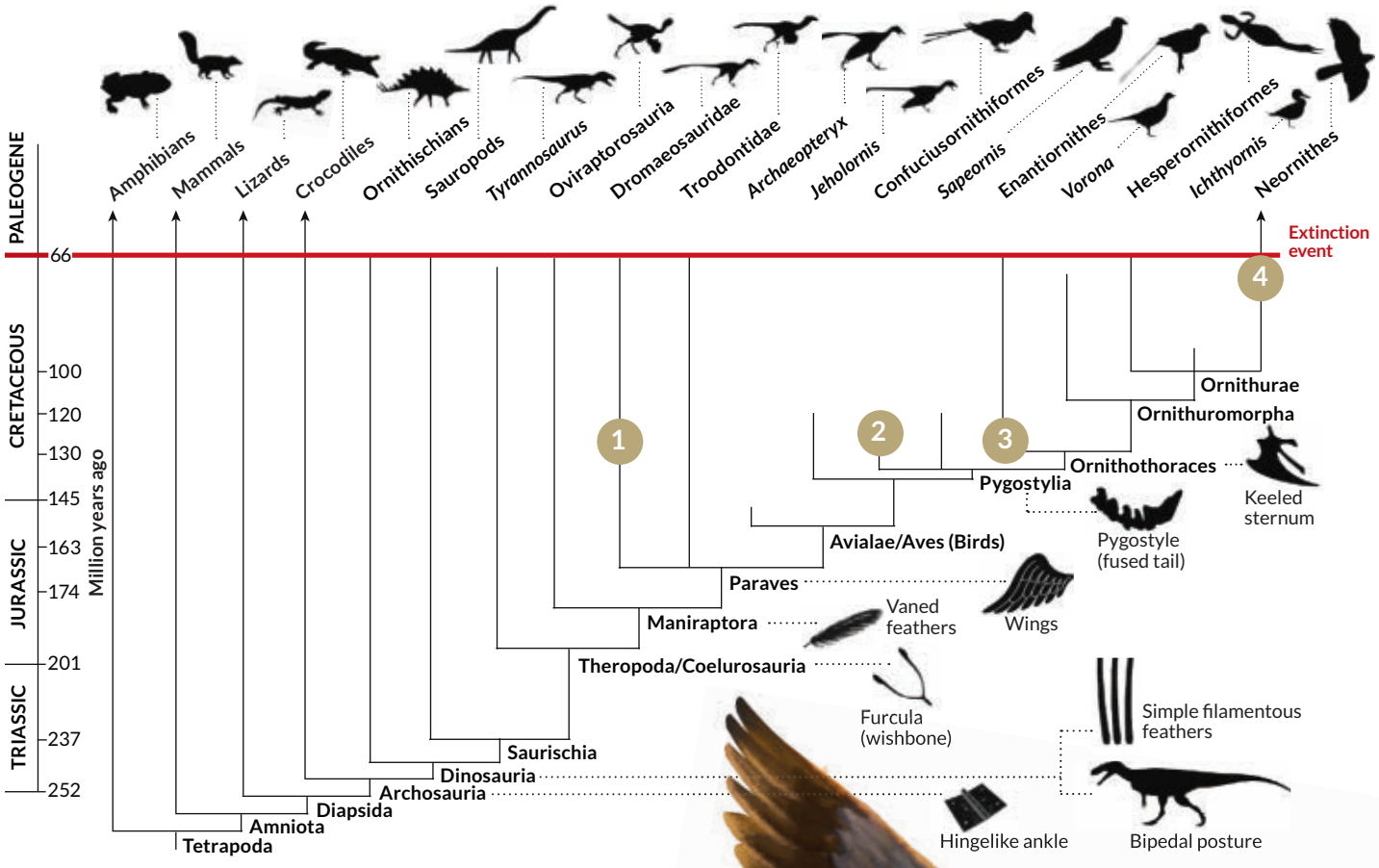
The bird pioneers included the once widespread and abundant Enantiornithes, or "opposite birds." Compared with modern birds, their ball-and-socket shoulder joints were "backwards," with ball rather than socket on the scapula.

These ancient alt birds may have gone down in the big extinction that left only fish, amphibians, mammals and a few reptile lineages (including birds) among vertebrates. There's not a lot of information to go on. "The fossil record of birds is pretty bad," Brusatte says. "But I think those lineages that go up to the red horizontal line of doom in my figure are ones that died in the impact chaos." ■

Microraptor dinosaurs were relatives of the velociraptors that (in ridiculously oversized form) put the screaming gotchas into *Jurassic Park*. *Microraptor*, alive about 126 million to 120 million years ago, perched on a different branch than birds, but it had birdlike qualities. *M. gui* (shown) had the asymmetrical feathers with off-center shafts considered essential for serious flight. It even had feathers fanning off its legs, leading some paleontologists to propose that early flight had a four-winged phase.

Confuciusornis sanctus, an early bird living 125 million to 120 million years ago, was a mash-up. Like modern birds, *C. sanctus* had toothless beaks and a shortened, fused tail called a pygostyle. Yet it didn't have a fully curved, keeled breastbone where powerful flight muscles attach in modern birds. Its wings had claws, which is very rare in birds today.

FROM LEFT: JASON BROUGHAM, JASONBROUGHAM.COM; ALLISON ELAINE JOHNSON

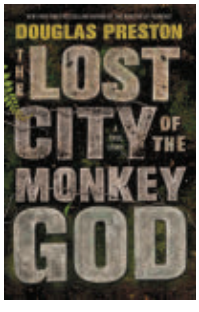


Protopteryx was an early Enantiornithes bird, one of a diverse bunch during the Cretaceous Period. The species illustrated here, *P. fengningensis* (from 130.7 million years ago), was sparrow-sized with big flight-capable wing feathers, soft down and long tail feathers. It also had teeth. Successful as the whole line was, it did not survive.

Ornithurae were the survivors. *Vegavis iaai* was first described based on a 66-million- to 68-million-year-old fossil found in Antarctica. The fossil preserved rings of mineralized collagen from a syrinx, a structure that lets birds sing (*SN: 11/12/16, p. 7*). Classifying *Vegavis* as an early member of today's waterfowl group weakens an old argument that modern birds arose only after other dinos died. The *Vegavis* find suggests that birds had already been branching into ducks, chickens and the ostrich group well before the big extinction.

TIMELINE ADAPTED FROM S.L. BRUSATTE, J.K. O'CONNOR AND E.D. JARVIS/*CURRENT BIOL.* 2015; ILLUSTRATIONS FROM LEFT: UTAKO KIKUTANI; NICOLLE RAGER FULLER

In this Honduran valley, a team found artifacts, including the sculpture below, from a society that may have inspired the "White City" myth.



The Lost City of the Monkey God
Douglas Preston
GRAND CENTRAL PUBLISHING, $28

BOOKSHELF

Fiction meets fact in science adventure tale

Legend has it that hundreds of years ago, a rich, powerful city stood in the jungle of what is now eastern Honduras. Then, suddenly, all of the residents vanished, and the abandoned city became a cursed place — anyone who entered risked death.

In a captivating real-life adventure tale, journalist and novelist Douglas Preston argues that the legend is not complete fiction. *The Lost City of the Monkey God* is his firsthand account of the expedition that uncovered the sites of at least two large cities, along with other settlements, that may form the basis of the "White City" myth. Even the curse might be rooted in reality.

Stories of the White City, so named because it was supposedly built of white stone, trace back to the Spanish conquistadores of the 16th century, Preston explains. These stories enthralled filmmaker Steve Elkins, who set out in the mid-1990s to uncover the truth. Finding the ruins of an ancient culture in one of the most remote parts of Central America would require a combination of high-tech remote sensing, old-fashioned excavation and persistence.

Elkins enlisted the help of experts who used satellite images and lidar to find potential targets to explore. Lidar involves shooting laser pulses from above to sketch out the contours of a surface, even a thickly vegetated one. The resulting maps revealed outlines of human-made structures in several locations. Preston deftly explains the science behind this work and makes it exciting (being crammed into a small, rickety plane for hours on end requires its own kind of bravery).

By 2015, archaeologists, accompanied by a film crew and Preston, hit the ground to investigate. They weren't disappointed. The team uncovered an earthen pyramid, other large mounds, a plaza, terraces, canals, hundreds of ornate sculptures and vessels, and more. These discoveries are providing clues to the identity of the people who lived there and what happened to them. What's clear is that they belonged to a culture distinct from their Maya neighbors.

This culture probably prospered for several hundred years, perhaps longer, before vanishing around 1500. Drawing on historical evidence, Preston argues that disease brought by Europeans was the culture's downfall. A series of epidemics, perhaps smallpox, may have prompted people to desert the area, inspiring the myth's curse.

The expedition did not escape this curse. Preston and others brought back a parasitic infection known as leishmaniasis. Preston devotes the last quarter of the book to detailing his and others' struggle to deal with this potentially fatal disease.

The Lost City of the Monkey God is at its best when Preston recounts his time in the field. He presents an unglorified look at doing fieldwork in a rainforest, contending with poisonous snakes, hordes of biting pests and relentless rain and mud. He also offers a window into the politics of science, offering a frank appraisal of the criticism and skepticism this unconventional expedition (paid for by a filmmaker) faced.

Much of the book is a thrill to read, but by the end, it takes a more somber tone. The "White City" faces threats of looting and logging. And researchers who go there risk contracting disease. Some readers may wonder whether the discovery was worth it. Perhaps some mysteries are better left unsolved. — *Erin Wayman*

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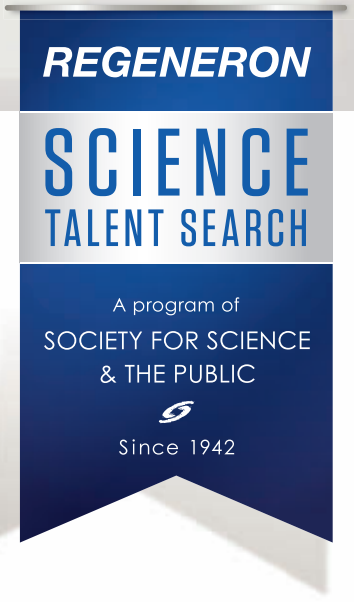

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DECEMBER 10, 2016

Fake out

In the fight against fake news — demonstrably untrue information presented as fact and perpetuated via social media — the human brain is both a great weakness and our only hope, **Erika Engelhaupt** wrote in "You've probably been tricked by fake news and don't know it" (*SN Online: 12/4/16*). Her *Science & the Public* blog post explores how humans form memories and what readers can do to avoid being duped. Read more at bit.ly/SN_fakenews.

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Critter calculations

Savvy for judging quantities is turning up across the animal kingdom — even among spiders and other invertebrates, ***Susan Milius*** *reported in "Animal math"* (SN: 12/10/16, p. 22).

Some astute readers pointed out that designing experiments to test animals' quantitative skills takes great ingenuity, but sometimes human bias may skew the results.

"Articles on animal cognition often presuppose that animals are non-intelligent. Thus, when researchers find that a dog can distinguish between a small and large number of items, it's hailed as significant," **Matthew Fisher** wrote. "If we think of cognition as existing along an evolutionary continuum, then results such as these are not surprising. The same evolutionary forces shape human cognition as in any other animal," he wrote. "We need to move away from the unscientific, Cartesian notion that animals are unthinking automata."

Irene Pepperberg, who studies the language and number-related abilities of African gray parrots and other birds at Harvard University, objected to **Milius'** suggestion that no one seriously argues that nonhuman animals possess symbolic numerical systems. "Several respected scientists, myself included, argue exactly that," **Pepperberg** wrote.

"I certainly didn't intend to dismiss this work," **Milius** says. "I was trying to conjure up the simplistic Dr. Dolittle case of nonhuman animals having a whole symbolic system parallel to humans' — woof for 1, double-woof for 2, for example — that scientists have only to decode."

Raise a glass

Science writer Dava Sobel's book The Glass Universe *tells the story of women "computers" at Harvard Observatory. Beginning in the late 1800s, these women charted the heavens using glass photographic plates,* ***Macon Morehouse****,* Science News' *Deputy Managing Editor, News, wrote in her review "Astronomy's unsung heroines get their due"* (SN: 12/10/16, p. 28).

Online reader **Jan Steinman** asked how black and white lines on the plates provide hints to a star's elemental makeup.

Prisms inside telescopes split light from a star into a spectrum, which appears as a black streak on a plate. Within this streak are patterns of spectral lines — the result of a star's elements or molecules emitting and absorbing photons of light at distinct wavelengths. "It's kind of like taking a black-and-white picture of a rainbow," says astronomy writer **Christopher Crockett**. "The color information is still there, just spread out across the image." Spectral lines can also tell astronomers about a star's temperature and velocity, for example, and are used to study other celestial bodies including galaxies, asteroids and comets.

Belly of the beast

Plant-eating mammals have bigger torsos relative to body size than carnivores, but the same might not have held true for dinosaurs, ***Emily DeMarco*** *reported in "Boning up on belly size"* (SN: 12/10/16, p. 32).

Online reader **Stanton de Riel** wondered if dinosaurs, like their modern avian descendants, had gizzards that may have helped with digestion.

"Yes, there were some dinosaurs that used a gizzard with grinding stones," says **Marcus Clauss**, a physiologist at the University of Zurich. Some dinosaurs even evolved grinding teeth along with gizzards — a "seeming aberration" because there is no known advantage to having both, **Clauss** says. It's possible the creatures ate particularly tough plant food. None of those dinosaurs were included in the recent analysis.

Correction

"Mount St. Helens is a cold-hearted volcano" (*SN: 12/10/16, p. 4*) states that the volcano's magma source originates from the Juan de Fuca plate melting as it descends beneath the North American plate. This is incorrect. As the Juan de Fuca plate descends, it releases fluids that rise and trigger melting in the rock above.

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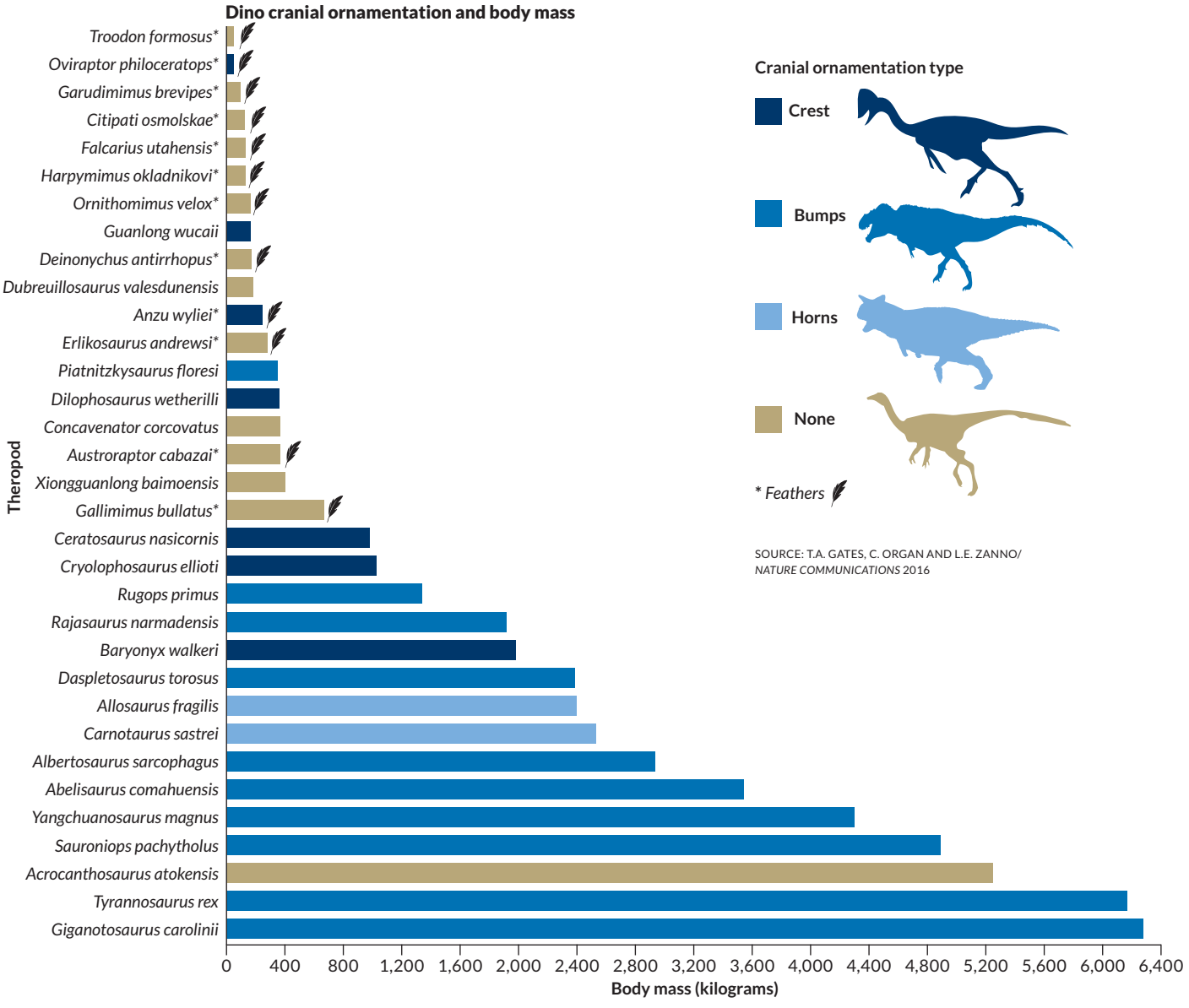

Head decor linked to bigger dinos

Dinosaur fashion, like that of humans, is subject to interpretation. Bony cranial crests, horns or bumps may have served to woo mates or help members of the same species identify one another. While the exact purpose of this skull decor is debated, the standout structures tended to come with an even more conspicuous trait: bigger bodies.

Terry Gates, a paleontologist at North Carolina State University in Raleigh, and colleagues noticed an interesting trend in the fossil record of theropods, a group of dinosaurs that includes *Tyrannosaurus rex* and the ancestors of birds (see Page 26). Bigger beasts often sported skeletal headgear.

Across the family tree, Gates and his team analyzed 111 fossils (selection of species shown above) dating from 65 million to 210 million years ago, and the trend held true. The researchers also calculated that over time, theropod lineages with head ornaments evolved giant bodies (larger than 1,000 kilograms) 20 times faster on average than those without.

Ornaments might have supersized some dinos, but researchers aren't sure. The analysis, which appeared September 27 in *Nature Communications*, suggests theropods had to reach at least 55 kilograms to grow the headgear.

But among big-boned relatives of modern birds, skull toppers weren't in vogue. Many of these dinos grew heavier than 55 kilograms, but they instead sported feathers that resembled those used by modern birds for flight. That might be because bigger, bolder feathers and showy headwear served similar ends. Gates speculates: "Once you have a signaling device in the form of a feather, why grow a bony cranial crest?" For these plumed dinosaurs, feathers were in and bony ornaments were out. — *Helen Thompson*

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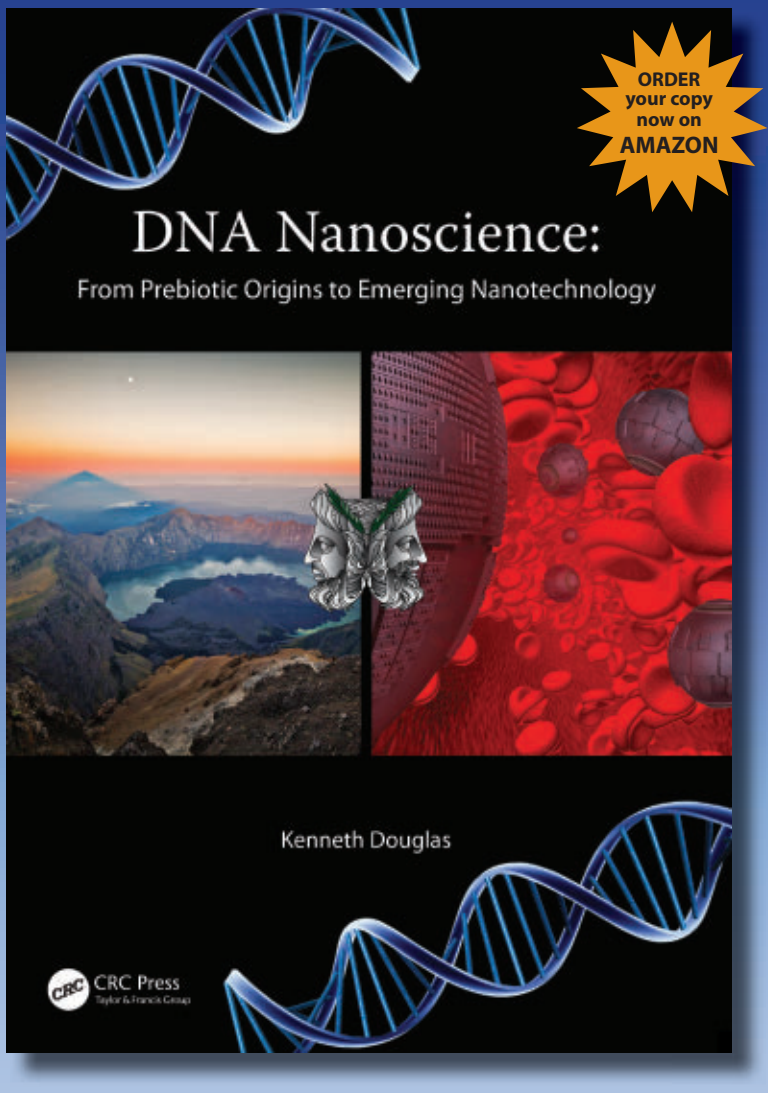

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Author of *At Home in the Universe*

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—Seth Fraden
Professor of Physics; Director, The Bioinspired
Soft Materials Center, Brandeis University

Author: Dr. Kenneth Douglas is a member of the research faculty in the Department of Physics at the University of Colorado–Boulder. His primary research interest is in biomimetic nanofabrication. He is co-inventor of the first-ever U.S. patents for the parallel fabrication of nanoscale multi-device structures.