SPECIAL ISSUE: EVOLUTION AT DARWIN'S BICENTENNIAL

Science News

MAGAZINE OF THE SOCIETY FOR SCIENCE & THE PUBLIC ■ JANUARY 31, 2009

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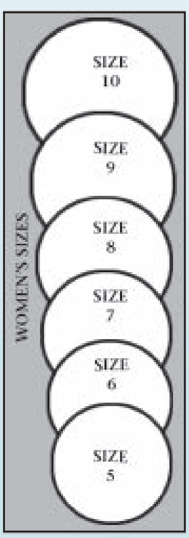

USING THE RING SIZE CHART
Place one of her rings on top of one of the circle diagrams. Her ring size is the circle that matches the inside diameter of the ring diagram. If her ring falls between sizes, order the next larger size.

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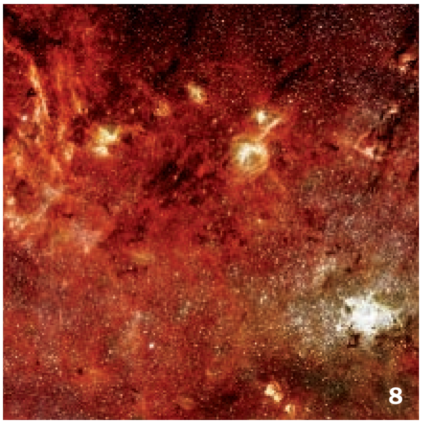
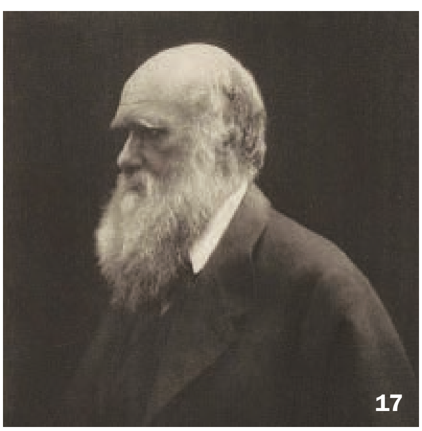
JANUARY 31, 2009 • VOL. 175 • NO. 3





FROM TOP: HUBBLE PORTION OF PANORAMA: Q.D. WANG, NASA, ESA, SPITZER PORTION: S. STOLOVY/SPITZER SCIENCE CENTER/CALTECH, JPL/NASA; NICKOLAY HRISTOV/BROWN UNIV.; CAUDWELL XTREME EVEREST; REPRODUCED WITH PERMISSION FROM JOHN VAN WYHE, ED., THE COMPLETE WORK OF CHARLES DARWIN ONLINE (DARWIN-ONLINE.ORG.UK)

ScienceNews

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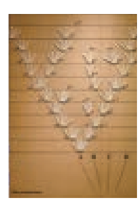

COVER Candles trace the tree of life Charles Darwin sketched in his seminal work, *On the Origin of Species*. *Photo by Cary Wolinksy*

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FROM THE EDITOR

Modern biology owes unpayable debt to Darwin

For any endeavor, identifying the greatest practitioner of all time is almost always contentious. Ask sports fans to select the best baseball player, and you'll get a lot of votes for Babe Ruth, but also some for Ty Cobb, Willie Mays and Ted Williams (surely none for Barry Bonds, though). Football aficionados might name Jim Brown, Sammy Baugh, Red Grange or Jerry Rice.

Within the sciences, you'll get similar disagreements. Physicists would argue over Isaac Newton and Albert Einstein, with perhaps a few votes for Niels Bohr. Mathematicians would divide their votes among Newton, Archimedes and Carl Gauss.

But then there's biology. The greatest biologist of all time? There's only one answer. Any other vote invalidates the voter as unqualified. It's Darwin.

On the occasion of his 200th birthday (on February 12), the world is celebrating the life and work of the man who made modern biology possible. As geneticist Theodosius Dobzhansky once so aptly proclaimed, "Nothing makes sense in biology except in the light of evolution." No scientist's birthday warrants more hullabaloo and hoopla.

No doubt Darwin himself would be a bit uncomfortable with all the fuss. He would have insisted that the facts he chronicled, and the ideas he articulated to explain them, deserved all the attention — not Darwin himself.

And so in this special issue marking Darwin's birthday, our focus is on the science going on today that descended from Darwin's original work. My account of his life (Page 18) serves merely to introduce our staff's reports on the multifaceted aspects of evolutionary science occupying researchers now, as Rachel Ehrenberg puts it, "in labs, on beaches and in bogs."

Her report (Page 21) assesses some of the refinements in Darwin's work that scientists are still actively formulating, on issues ranging from the rate at which evolution proceeds to the definition of *species*. Tina Hesman Saey then explores (Page 26) the evolutionary frontier on the molecular level, describing experiments tracking evolution in bacteria to shed light on its mechanisms and surprises. Sid Perkins (Page 30) recounts some recent tales told by the fossil record, showing how gaps in that record are far from holes in Darwin's theory, but rather are places to look for intriguing new evidence.

All that leaves much unsaid about the vast diversity and depth of evolutionary biology research today. So longer versions of these features, and additional features on other evolutionary arenas, are available now on the *Science News* website, www.sciencenews.org. All of these reports send the message that Darwin's life is worth celebrating — because the science he started has survived and thrives.
— Tom Siegfried, Editor in Chief

Scientific Observations

"Speciation will not be a deliberate, programmed event. Instead it will involve an ever faster accumulation of small, useful improvements that eventually turn *Homo sapiens* into a new hominid. We will likely see glimpses of this long-lived, partly mechanical, partly regrown creature that continues to rapidly drive its own evolution. As the branches of the tree of life, and of hominids, continue to grow and spread, many of our grandchildren will likely engineer themselves into what we would consider a new species, one with extraordinary capabilities, a *Homo evolutis*."

JUAN ENRIQUEZ, FOUNDING DIRECTOR OF THE LIFE SCIENCES PROJECT AT HARVARD BUSINESS SCHOOL, ANSWERING THE WWW.EDGE.ORG 2009 ANNUAL QUESTION, "WHAT WILL CHANGE EVERYTHING?"

Science Past | JANUARY 31, 1959

SEA VOICE MAY WARN REDS OF COMING STORMS – By listening to the sea's voice, Russian scientists say they may be able to detect approaching storms. A Scientific Information Report circulated by the Central Intelligence Agency carries an abstract from an "unevaluated" paper prepared by Ya. Petrov, a Russian scientist. [He] says ... V. V. Shuleykin has studied the vortex air flow behind sea waves which creates an "infrasonic wave" called "sea voice." Mr. Shuleykin suggests detection of these waves could serve as forewarning of approaching storms. The work is being done at Russia's L'vov Polytechnic Institute, which boasts a special magnetic sound recorder for capturing and reproducing sound waves too low in frequency to be heard.

Science Future

February 7–15
Wonders of Physics annual show at the University of Wisconsin–Madison. Visit sprott.physics.wisc.edu/wop.htm

February 12
A global celebration of Charles Darwin's birthday. Visit www.darwinday.org

February 14–15
Take your valentine on a simulated Mars mission at the Chabot Space & Science Center in Oakland, Calif. Visit www.chabotspace.org

SN Online

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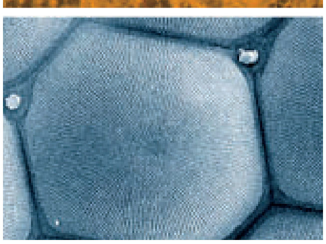
DARWIN TURNS 200

This special issue celebrating Darwin's birthday has even more legs online. Read two additional features, one on using computational biology to understand evolution and another on sexual selection and some of evolution's stranger outcomes. Plus, subscribers can download PDFs of all six features in a special

Darwin package, including longer versions of the stories in the magazine. Visit www.sciencenews.org/darwin

HUMANS

Discoveries from an Armenian cave include what may be the oldest known preserved human brain, along with unexpected artifacts. See "Armenian cave yields ancient human brain."

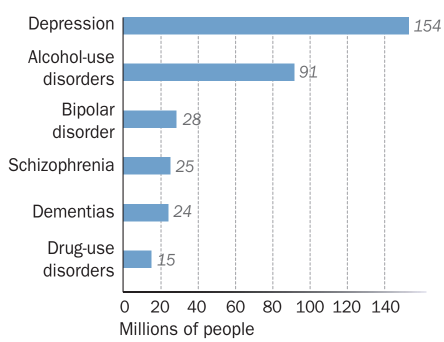


The (-est)

Scientists have uncovered what could be the oldest retinas yet examined. The 45-million-year-old red bulging peepers of two flies stuck in Baltic amber (one shown, top) still had enough soft tissue to confirm predictions that their kind had already evolved a fancy, open array of photoreceptors, according to a paper published online in December in *Proceedings of the Royal Society B*. Andrew Parker of the Natural History Museum in London and his colleagues were able to study fine details of the inner and outer structure (shown, bottom) of the flies' eyes.

Science Stats | GLOBAL MENTAL HEALTH

Estimated number of sufferers of major mental disorders worldwide in 2002



SOURCE: *THE STATE OF HEALTH ATLAS*, UNIV. OF CALIFORNIA, 2008

CLOCKWISE FROM TOP LEFT: GEORGE GENDELMAN; PHILIP DOWELL (C) DORLING KINDERSLEY; GENGO TANAKA (BOTH)

“ Healthy people have a huge range of variation in being able to respond to stress. ” — CYNTHIA BEALL, PAGE 13

In the News

STORY ONE

Migrants settle Americas in tandem

Two groups may have crossed the land bridge independently

By Bruce Bower

Diversity ruled among the first American settlers. Within a relatively short time span, at least two groups of people trekked across a land bridge from Asia to Alaska and then went their separate ways, one down the Pacific Coast and the other into the heart of North America, a new genetic study suggests.

A team led by geneticist Antonio Torroni of the University of Pavia in Italy estimates that these separate migrations into the New World occurred between 17,000 and 15,000 years ago.

Even more populations with distinct genetic signatures and languages may have crossed a now-submerged strip of land, known as Beringia, that connected northeastern Asia to North America within that relatively narrow window of time, the scientists also contend in a paper in the Jan. 13 *Current Biology*.

“Whereas some recent investigators had thought that a single major population expansion explained all mitochondrial DNA variation among Native Americans, this new report revives earlier ideas about multiple expansions into the New World,” comments Theodore Schurr of the University of Pennsylvania in Philadelphia.

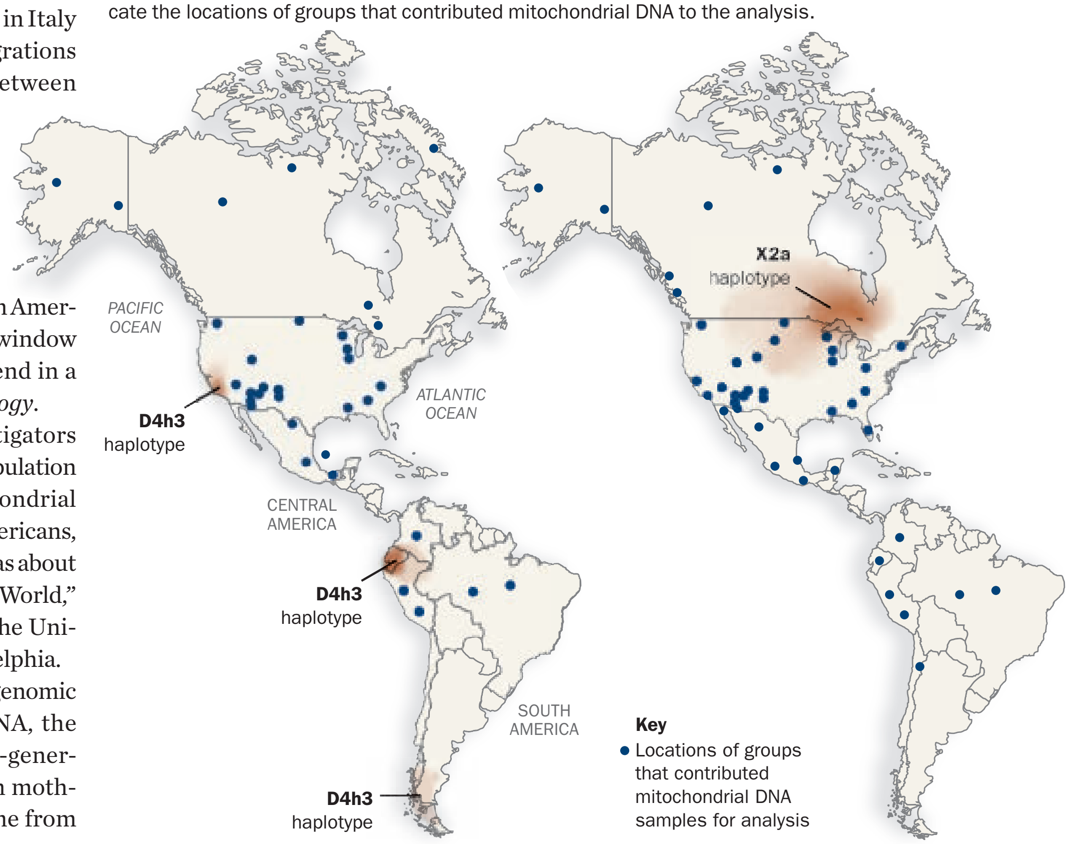
Torroni’s team analyzed entire genomic sequences of mitochondrial DNA, the genetic material in cells’ energy-generating units that gets passed from mothers to children. Genetic data came from Native American groups in North, Central and South America. The researchers focused on the disparate geographic distributions of two rare mitochondrial DNA haplogroups — characterized by a distinctive DNA sequence derived from a common maternal ancestor — that still appear in Native Americans.

“Our study presents a novel scenario of two almost concomitant paths of migration, both from Beringia about 15,000 to 17,000 years ago, that led to the dispersal of the first Americans,” Torroni says.

If that hypothesis holds up, he adds, it suggests that separate groups of New World migrants founded prehistoric Native American tool traditions independently in eastern and western North America. The new findings also raise

Gene study gives new hints about earliest Americans

Maps show the geographic distribution of two rare mitochondrial DNA types in Native American groups, as reported in a new study. One type, called D4h3, clusters along the Pacific Coast, while the other, X2a, appears most frequently around the Great Lakes. The findings suggest distinct populations may have migrated to the Americas as far back as 17,000 years ago. Blue dots indicate the locations of groups that contributed mitochondrial DNA to the analysis.



TORRONI *ET AL.*/*CURRENT BIOLOGY* 2009

the possibility that the first Americans spoke languages from more than one language family, a proposal that has been hotly debated by linguists.

Despite the new evidence, scientific consensus on how and when the New World was settled remains elusive.

"Peopling of the Americas is a hard problem," says Jody Hey of Rutgers University in Piscataway, N.J. "My guess is that it will be a couple more years before we have a good picture of what happened."

Hey takes a skeptical view of the new study. Different present-day Native American populations display signature mitochondrial DNA patterns, so it's not surprising that rare haplogroups would be unique to separate regions, he says. And Torroni's analysis, he adds, doesn't explicitly address whether genetic data more closely reflect a single migration, a pair of simultaneous migrations or some other pattern of population movements.

"Within a rather short period of time, there may have been several entries into the Americas from a dynamically changing Beringian source."
ANTONIO TORRONI

Some climate reconstructions suggest that an ice-free corridor from Alaska into North America wasn't passable until around 12,000 years ago, Schurr says. If so, that creates a roadblock for Torroni's scenario of an earlier inland migration.

Investigators also differ on how best to study ancient population movements using genetic data. Two approaches currently dominate, Hey notes. Some researchers track today's geographic distribution of different haplogroups and generate tree diagrams that portray patterns of ancestry, as Torroni's group did. Other investigators, such as Hey, use statistical methods to test whether genetic data fit simple models of how populations might have been structured.

In 2005, Hey took the model-based approach to examine mitochondrial DNA from northeastern Asians and Native Americans. He concluded that a single group of New World settlers, including perhaps 70 fertile adults, crossed Beringia no more than 14,000 years ago (*SN: 5/28/05, p. 339*).

In the new study, Torroni and his colleagues got different results by searching a large genetic database for mitochondrial DNA. The team found 55 unrelated individuals who displayed either of two rare Native American haplogroups, called D4h3 and X2a, identifying 44 instances of haplogroup D4h3 and 11 instances of haplogroup X2a.

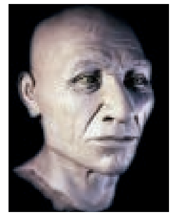
Further analyses indicated that the D4h3 haplogroup spread into the Americas along the Pacific Coast, rapidly reaching the southern tip of South America. Estimated ages of D4h3 sequences from Chile are nearly as old as the estimated time of the Beringia crossing. In contrast, haplogroup X2a crossed Beringia and spread into what's now western Canada, eventually clustering in the Great Lakes area, the new study suggests.

Examination of an additional 276 mitochondrial DNA sequences from unrelated people, representing the six haplogroups common in Native Americans, indicated that those genetic types entered the Americas at about the same time as the two rare haplogroups did.

"Within a rather short period of time, there may have been several entries into the Americas from a dynamically changing Beringian source," Torroni says.

Extensive mitochondrial DNA data have yet to be obtained for many Native American populations, Schurr cautions. Hence, precise age estimates don't exist yet for the major New World haplogroups and sub-branches. Such estimates are needed to check the veracity of competing scenarios of migration to the Americas. ■

Back Story | FOSSILS AND ARTIFACTS PUSH BACK ESTIMATED DATES FOR THE FIRST PEOPLING OF THE AMERICAS

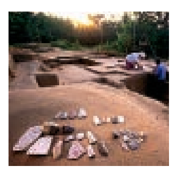


9,300 years ago
A male skeleton, dubbed the Kennewick Man by its discoverers in 1996, became buried and fossilized on the banks of Washington's Columbia River.

13,600 years ago
The Clovis people, for a long time regarded as the first human inhabitants of North America and ancestors of all of its indigenous cultures, hunted mammoths in America with their distinctively fluted stone points.

14,000 years ago
Human excrement fossilized in south-central Oregon; when discovered, it pushed back the date for the first Americans.

By 14,000 years ago
Primitive structures, stone and wood implements, fire pits and chewed plant cuds were left behind by early Americans at Monte Verde, in south-central Chile. This is the most accepted of a number of pre-Clovis sites, but it still has its skeptics.



18,000 years ago
Humans camped many times at a site in Virginia called Cactus Hill, where distinctive stone tools that looked unlike Clovis artifacts were found. Dates are based on nearby coal, though some researchers are still wary of them.

FROM TOP: JAMES CHATTERS/AFP/GETTY IMAGES; A114450_08D, 1971.15498/THE FIELD MUSEUM; GILBERT *ET AL.*, *SCIENCE*; DILLEHAY *ET AL.*; KENNETH GARRETT/NATIONAL GEOGRAPHIC SOCIETY

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Milky Way puts on weight

New estimate makes galaxy comparable to Andromeda

By Ron Cowen

LONG BEACH, CALIF. — Hey Andromeda, you'd better watch out. Your little brother, the Milky Way galaxy, isn't so little after all. In fact, the Milky Way is just as massive, weighing in at about 3 trillion suns, according to a new study.

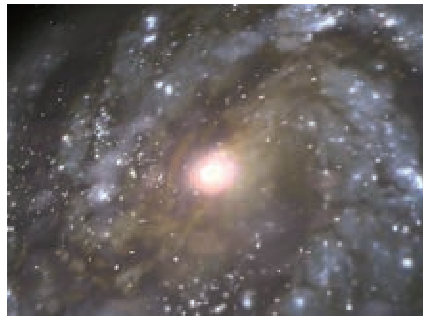
That means that the Milky Way and Andromeda — the largest members of the Local Group of galaxies — might smash into each other earlier than astronomers had predicted.

To map the Milky Way, the study used the Very Long Baseline Array of 10 radio telescopes stretched out over thousands of kilometers. Unlike visible-light observations, which are obscured by interstellar dust, radio studies enable astronomers to penetrate through dusty byways.

Mark Reid of Harvard University and colleagues based their findings on observations of nearly 20 regions of intense star formation across the galaxy — many of them traced by methanol masers, concentrations of methanol that act as amplifiers for radio waves. Reid reported the study's results January 5 at the American Astronomical Society meeting.

Masers require the high temperatures and densities of star-forming regions. By repeatedly observing the masers when Earth is at opposite sides of its orbit around the sun, Reid and collaborators could measure the parallax of these regions — the slight, apparent shift of each maser's position due to Earth's motion.

Those apparent shifts accurately revealed the distances to the masers and their two-dimensional motion across the sky as they orbit the galactic center. Astronomers determined



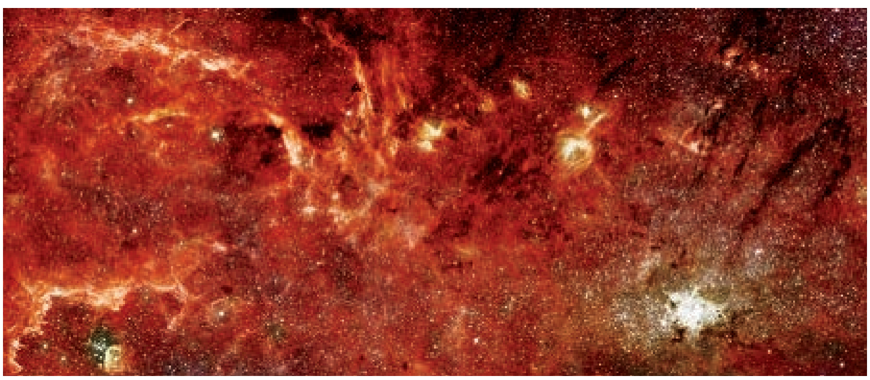
A heftier size puts the Milky Way (shown above) on par with Andromeda, implying a closer collision date.

the full three-dimensional motion of the masers — which includes the velocity along the line of sight to Earth — by measuring tiny shifts in the frequency of the masers' radio emissions.

From these velocities and distances, Reid and collaborators found that the Milky Way spins at about 254 kilometers per second, about 15 percent faster than previously calculated. Applying Newton's law of gravity to the faster spin speed shows that the Milky Way is about 50 percent heavier than had been calculated, putting it on par with Andromeda.

"The more mass in the big galaxies — the Milky Way and Andromeda — ... the sooner they will collide," says Reid. Researchers had previously thought that the two galaxies would merge in about 5 billion years. Reid says he is not certain exactly how much sooner the two giants would collide because the full three-dimensional motion of each galaxy has not yet been determined. A heavier Milky Way might also have a greater retinue of satellite galaxies — tiny galaxies, like the Large and Small Magellanic clouds — that orbit it, he adds.

"Mass is the most fundamental parameter for our galaxy, and there are a lot of important implications if the claimed revisions are correct, including the orbits of satellite galaxies around us," comments Robert Benjamin of the University of Wisconsin–Whitewater, who has studied the Milky Way using NASA's Spitzer Space Telescope.



Core of the galaxy in high-res

Astronomers have produced the sharpest infrared portrait of the central 300 light-year–span of the Milky Way, showing details as small as 20 times the length of the solar system. The false-color composite combines images taken by the Hubble Space Telescope and the Spitzer Space Telescope of this turbulent region, which houses a supermassive black hole and lies 26,000 light-years from Earth. The image shows that most of the massive stars are widely distributed across the galaxy's center rather than confined to the core's three known massive-star clusters, as previously thought. The massive stars could constitute a new stellar class, says Q. Daniel Wang of the University of Massachusetts Amherst, whose team unveiled the portrait January 5 at a meeting of the American Astronomical Society. *— Ron Cowen*

FROM TOP: NASA/CXC/A.HOBART; HUBBLE PORTION OF PANORAMA: Q.D. WANG, NASA, ESA; SPITZER PORTION: S. STOLOVY/SPITZER SCIENCE CENTER/CALTECH, JPL/NASA

“The more mass in the big galaxies — the Milky Way and Andromeda — … the sooner they will collide.” — MARK REID

Tuned in to new noise from the sky

Radio static could be from earliest stars or black holes

By Ron Cowen

LONG BEACH, CALIF. — When astronomers launched a balloon-borne experiment from Palestine, Texas, three summers ago, they expected to find a faint radio signal from the slight warming of interstellar space by an early generation of stars. Instead, the scientists discovered a booming, uniform radio noise six times louder than anyone had predicted.

The team described the mysterious radio static January 7 at a meeting of the American Astronomical Society. Four reports detailing the analyses are available online at arxiv.org/abs/0901.0562, arxiv.org/abs/0901.0559, arxiv.org/abs/0901.0555 and arxiv.org/abs/0901.0546.

Al Kogut of NASA’s Goddard Space Flight Center in Greenbelt, Md., and his colleagues calculate that the radio noise is much too loud to come from the combined emissions of all the galaxies in the universe that emit radio waves. But the static could be signals generated by the first supermassive black holes.

Cosmologist David Spergel of Princeton University, not a member of the discovery team, says the static could also be due to the energy unleashed by the explosive death of the first generation of stars. “And those are the most conservative explanations,” he adds.

Kogut and colleagues base their findings on 2.5 hours of flight data gathered by seven radio receivers called ARCADE (Absolute Radiometer for Cosmology, Astrophysics, and Diffuse Emission).

The radio spectrum seen by ARCADE “is telling us that we’re actually seeing a signature from a period of time that we know very little about and are very interested in,” Spergel says.

ARCADE’s receivers were cooled to just 2.7 degrees above absolute zero for its roughly 36-kilometer–altitude flight on July 22, 2006. The receivers were the first detectors capable of definitively recording the strange radio signals, Kogut says.

Because ARCADE operates at the same low temperature as the cosmic microwave background — the whisper of radiation left over from the Big Bang — heat from the instrument can’t be confused with the radio signals it detects.

Life

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Courting mosquitoes match pitch to signal when they're in the mood

Carriers of dengue fever virus harmonize their love songs

By Laura Sanders

Mosquitoes use their own eHarmony to find a compatible mate. New research shows that male and female mosquitoes sing harmonious duets of matching love songs by vibrating their wings. Annoying recordings of mosquito duets aren't likely to go platinum, but they give researchers some interesting new ways to think about courtship behavior in insects.

The study, published online January 8 in *Science*, finds that male and female *Aedes aegypti* — carriers of dengue and yellow fever — change the pitch of their buzzing to match each other's harmonics. The results go "way beyond the accepted dogma on hearing in mosquitoes and perhaps indeed in other organisms," comments Daniel Robert of the University of Bristol in England.

A female mosquito's come-hither buzz, produced by vibrating her wings at a certain rate, is irresistible to males. Scientists have long thought that male mosquitoes could hear just enough to locate and home in on a female, says study coauthor Ronald Hoy of Cornell University. What's more, until a 2006 study showed that *Toxorhynchites brevipalpis* females match notes with males, females were thought to be deaf.

The importance of female behavior in many animals has been overlooked until the past few decades, Hoy says. "The assumption was that it's all about the guys."

Understanding how mosquitoes woo one another may lead to new ways to stop their reproduction, which in turn could halt the spread of diseases they carry.

A single female mosquito flying through the air produces a complex sound made up of a fundamental tone — which hovers around 400 hertz — and a stack of harmonics. Sometimes called overtones, harmonics are multiples of the fundamental tone. A female mosquito therefore can produce tones around 400, 800 and 1,200 hertz, Hoy says.

A female mosquito's come-hither buzz, made by vibrating her wings, is irresistible to males.

In the new experiments, researchers delicately tethered live mosquitoes to the ends of flexible wires and recorded the tones made by the wings of a male and female mosquito as they came within a few centimeters of each other. Although the fundamental tones for each mosquito didn't change very much during a "fly by" — females still produced a fundamental 400-hertz tone and males a 600-hertz tone — each mosquito produced a faint harmonic note, right around 1,200 hertz, that was closely in sync.

That these songs match means that the female hears and responds to the presence of the male, and vice versa, shattering the notion that female mosquitoes are inactive bystanders in courtship behavior, the team suggests. At the same time, 1,200 hertz far exceeds the accepted range of male mosquito hearing.

"You're not going to hear the harmonic until you're really close," Hoy says. "It's like whispering sweet nothings." Picking out these loving murmurs is an acoustic feat. "I doubt that humans — except for a few musicians with great, and trained, ears — could do that," he says.

Moth jams bat sonar

A bat closes in on its prey, a tethered moth. William Conner and Aaron Corcoran of Wake Forest University in Winston-Salem, N.C., and colleagues used the same setup to study a tiger moth called *Bertholdia trigona. B. trigona* "goes berserk," making a lot of noise above the range of human hearing when a hunting bat approaches, Conner notes. Bats rely on their natural sonar to locate flying moths in the dark, but in the lab, the bats rarely managed to nab one of these loud moths. When researchers disabled the moth's noisemaking organs, though, bats caught the moths in midair with ease and ate them, Conner reported January 5 in Boston at a meeting of the Society for Integrative and Comparative Biology. He says the work is "the first example of any prey item that jams biological sonar," adding that when threatened these moths emit a steady, broadband sound. Insect-hunting bats and their moth prey have become a classic in the study of evolutionary arms races, he says. "This is warfare." —*Susan Milius*

NICKOLAY HRISTOV/BROWN UNIV.

Humans

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Simultaneous Stone Age tool use

Signs of early hand-ax making not limited to eastern Africa

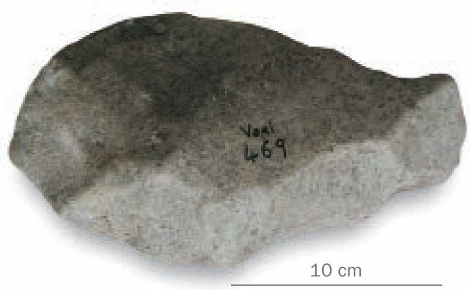
By Bruce Bower

Although separated by several thousand kilometers, southern and eastern Africa were, in a sense, a stone's throw from each other in ancient times. New evidence suggests that human ancestors in southern Africa fashioned teardrop-shaped stone hand axes 1.6 million years ago, nearly twice as long ago as previously thought and about the same time such tools first appeared in eastern Africa.

Ryan Gibbon of the University of Witwatersrand in Johannesburg and his colleagues dated hand axes and related stone implements, collectively known as Acheulean artifacts, using measures of the relative decay of radioactive forms of aluminum and beryllium in quartz from the soil and gravel bearing the artifacts. The team identified 465 tools brought out of a diamond-mining pit bordering South Africa's Vaal River, near the town of Windsorton. Those implements included 10 hand axes, two hand axes with large chopping edges known as cleavers and two elongated, three-sided picks.

The findings at Windsorton, published online December 20 in the *Journal of Human Evolution*, raise the question of whether human ancestors developed Acheulean tools independently in southern and eastern Africa at around the same time or developed the tools in only one area from which the tradition spread rapidly to distant regions.

The team's findings support a preliminary age estimate of 1.6 million years reported by other researchers for Acheulean artifacts from South Africa's Wonderwerk Cave, located about 100 kilometers northwest of Windsorton.



Human ancestors in southern Africa may have made hand axes and cleavers (one "blade" shown) 1.6 million years ago.

R. GIBBON

Body & Brain

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For C-section, wait full term

Babies born before, after 9 months face higher risk

By Nathan Seppa

Babies delivered by cesarean section a week or two before the full 39 weeks of pregnancy face a heightened risk of respiratory problems and other complications, researchers report in the Jan. 8 *New England Journal of Medicine*. Being born too late isn't good either, the study finds.

Obstetric gynecologist Alan Tita of the University of Alabama at Birmingham and his colleagues identified more than 13,000 births in which a woman had delivered by nonemergency cesarean section at 37 weeks or later. All mothers had had a previous C-section at some point.

The researchers found that 15 percent of babies delivered at 37 weeks had a complication, compared with 8 percent of those delivered at 39 weeks. Complications included respiratory problems, low blood sugar and blood infection, or the need to go to the intensive care unit, get resuscitated, put on a ventilator or stay in the hospital more than five days. Of babies born at 38 weeks, 11 percent had complications. Those born at 40 weeks were not more likely to have problems, but babies born after 41 or 42 weeks faced risks similar to those born at 38 and 37 weeks.

A closer look at these women reveals that those delivering earlier were more likely to be married, white and privately insured than those delivering at 39 weeks or later, says Michael Greene of Harvard Medical School and Massachusetts General Hospital in Boston. The early deliverers may have placed a premium on having their own doctors perform the cesarean, requiring planning and scheduling, he says.

The risks of such early deliveries are now clearer, Tita says. "This study brings some of these problems to the fore. Hopefully, with this publication, some of these practices will change," he says.

But there remains at least one major confounding factor in all this: The risk of stillbirth is greatest at 39 weeks or more.

It remains unknown whether avoiding the slight risk of stillbirth outweighs the other risks shown in this study, Greene says. "This is interesting and useful information, but the stillbirth risk is not accounted for," he concludes.

Researchers took blood samples from climbers on Mount Everest.

CAUDWELL XTREME EVEREST

Record low for blood oxygen levels

Challenges in Everest's thin air could inform patient care

By Rachel Ehrenberg

Avalanches, vicious winds and sub-zero temperatures aren't the only extremes endured by those who climb Mount Everest. Hypoxia, a lack of oxygen that can lead to cell death, also threatens.

But a study of people ascending Mount Everest's slopes suggests that some humans are especially tolerant of low-oxygen levels, perhaps because they use oxygen more efficiently. The findings, reported in the Jan. 8 *New England Journal of Medicine,* could inform the treatment of critically ill hospital patients struggling to breathe. The new work also reports the lowest recorded blood oxygen levels in a nonhibernating mammal.

Patients suffering from cystic fibrosis, septic shock and other critical ailments often have severely low levels of blood oxygen, says Michael Grocott of University College London, lead author of the new study. But because the health of such patients is compromised, studying the effect of low oxygen alone isn't easy.

Basic questions still loom, Grocott says. "Why do some people adapt well while others seem to struggle?"

As part of ongoing research, in 2007 more than 200 people trekked to Everest's base camp at 5,300 meters above sea level, making themselves available to doctors and scientists aiming to get at why some people fare better than others in thin air.

The new study focused on 10 individuals. The team sampled blood, analyzing oxygen and carbon dioxide levels, pH and concentrations of lactate and hemoglobin, at altitudes ranging from 75 meters (London) to 8,400 m (near the summit).

At the highest altitudes, subjects showed an impressive adaptability, says Grocott. The blood oxygen levels (measured as pressure in millimeters of mercury) of the four climbers tested near the summit were startlingly low — the lowest a mere 19.1 mm Hg. In patients, levels below 60 mm Hg cause concern, Grocott says.

"This shows that healthy people have a huge range of variation in being able to respond to stress," says Cynthia Beall of Case Western Reserve University in Cleveland.

The findings suggest that the amount of oxygen alone isn't the secret to physiological success. Other factors could be how much oxygen a person's hemoglobin can carry, or the efficiency of the cellular factories known as mitochondria.

NEWS BRIEFS

Surgery soothes muscles

Parkinson's patients randomly assigned to get medication plus surgery show dramatic improvements, whereas patients getting medication alone do not, a team of surgeons and scientists report in the Jan. 7 *Journal of the American Medical Association*. The surgery, called deep-brain stimulation, involves installing two tiny electrodes in the brain. The electrodes send out a mild current that can calm muscle problems by interrupting aberrant messages. The benefits extended to older patients; one-fourth of the trial's participants were age 70 or older. *—Nathan Seppa*

Dopamine's role in thrills

Fictional thrill seeker James Bond may have a deficit of dopamine receptors. Earlier work has suggested that a propensity for risky behaviors, like driving fast and gambling, is influenced by dopamine, one of the brain's reward chemicals. Now, a team of researchers led by David Zald of Vanderbilt University in Nashville reports in the Dec. 31 *Journal of Neuroscience* that volunteers who scored high on a novelty-seeking scale had fewer dopamine receptors in the ventral midbrain region. *—Laura Sanders*

SIRT family's middle child

A formerly underappreciated member of the sirtuin family of proteins may hold the key to youthfulness and is the first shown to specifically govern activity of other genes. Researchers including Katrin Chua and Howard Chang of Stanford University report in the Jan. 9 *Cell* that SIRT6, a sibling of the aging-related protein SIRT1, is an important regulator of gene activity in mice. *—Tina Hesman Saey*

Numbers

For longer versions of these and other Numbers stories, visit **www.sciencenews.org**

Finding where criminals live by the numbers

Mathematician combines calculations with geography

By Patrick Barry

WASHINGTON — Math as a tool to track down criminals has never been as precise as the TV show *NUMB3RS* depicts. But mathematicians are developing better ways to estimate where a person on a crime spree might live.

Using information about the layout of a city, such as the locations of similar crimes there in the past few years, beefed-up mathematical tools could improve estimates of where a criminal lives based on where he or she commits crimes, suggests research presented January 7 at the annual Joint Mathematics Meetings.

"I feel like I'm in a gold mine, and I'm the only one who knows what gold looks like," says Mike O'Leary, an applied mathematician at Towson University in Maryland who performed the new research. "There are so many good mathematical problems in this field" of criminology.

A well-established principle of criminology is that perpetrators will tend to commit more crimes close to their homes simply because of convenience and transportation realities. So older techniques estimate where a criminal lives based on the locations of unsolved crimes attributed to that criminal.

But those techniques ignore the actual layout of a city, instead assuming that the likelihood of a criminal striking near his or her home drops off evenly in all directions regardless of roads, neighborhoods, lakes and other geographical features.

"They don't have any way to incorporate yet data about geography," O'Leary says. "Mathematically they just don't have the tools for it."

> "I feel like I'm in a gold mine, and I'm the only one who knows what gold looks like."
> MIKE O'LEARY

To help find the perpetrator of a type of crime, such as robbing a convenience store, O'Leary's methods would use historical records of incidences of similar crimes to generate a likelihood distribution for that crime for the whole city. This distribution inherently contains information including where major roads and easy targets are located. The analysis also folds in census data about neighborhood demographics, as well as an analysis of how far from home criminals of different ages typically strike.

Other researchers have also developed software that attempts to incorporate this information. Until now, however, much of the research has been done by social scientists, comments Ned Levine, a geographical researcher at Ned Levine & Associates in Houston who developed crime-analysis software called CrimeStat. O'Leary has "added some insights into the mathematics that previously we were struggling with," Levine says. "He's really cleaning up the mathematics."

O'Leary is still working on the computer software that performs his analysis. The code for the software will be freely available, and the complete package will be free for police departments to use.

Math explains survival of beetles

New equations show why competing species can coexist

By Patrick Barry

WASHINGTON — Placing two species of flour beetle in the same jar of flour needn't always result in one species driving the other to extinction, as ecologists have thought. A new mathematical model presented January 5 at the Joint Mathematics Meetings shows how competing species can sometimes coexist.

The new research raises questions about the common assumption that only one species can survive in a specific ecological niche. Like similar species of flour beetles living in and eating the same flour, two species that share a niche ought to compete until one wipes out the other.

But that view assumes that no evolutionary changes occur in the beetles over a few dozen generations. By including equations for subtle evolutionary changes on such short time scales, mathematicians found that evolution can sometimes steer the two species toward coexistence.

"I think it opens some questions about this dogmatic view in ecology," says Jim Cushing, coauthor of the study and an applied mathematician at the University of Arizona in Tucson. "It reopens the issue of what you consider a niche to be."

Cushing and his colleagues were trying to explain classic flour-beetle experiments from the 1960s, in which one of the two species pushed the other to extinction every time — except once. In that case, the species coexisted for more than 30 generations.

Researchers had noted a small change in the traits of those beetles. Flour beetles sometimes eat the eggs of their own species and those of closely related species. The beetles in the oddball case had evolved to become more voracious egg eaters. Cushing's team designed a mathematical model that allowed the egg-eating trait to evolve, affecting the birth and death rates of each species so that neither went extinct after more than 30 generations.

"They're showing how just a tiny bit of evolution might actually explain the discrepancy," says Joel Brown, an ecologist at the University of Illinois at Chicago.

Earth

For more Earth stories, visit **www.sciencenews.org**

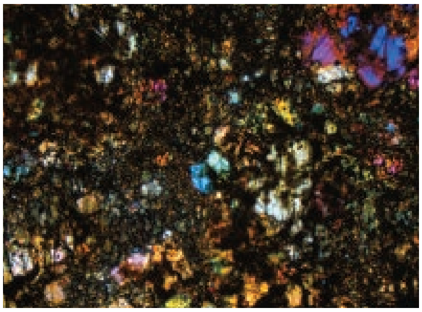
Meteors deliver Earth-like crust

Fragments may have formed early in solar system's history

By Sid Perkins

Two meteorites retrieved from West Antarctica contain a type of rock commonly found in Earth's crust but previously unseen in meteorites. Analyses suggest that the meteorites, the oldest rocks of their type yet found, are fragments of an asteroid that coalesced early in the solar system's history.

When asteroids collide, fragments of their surfaces spray into space and can make their way to Earth, where they fall as meteorites. In the Jan. 8 *Nature*, James Day of the University of Maryland in College Park and his colleagues describe the first meteorites discovered that are composed of a relatively light type of rock similar to those that make up the Earth's continents — rather than the dense basaltic rock that is akin to cooled lava and found in ocean crust.



DAY

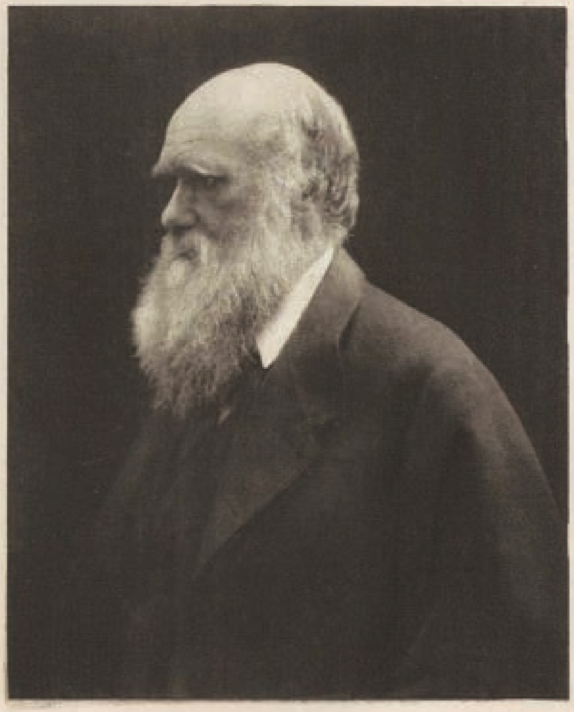
Meteorites found in Antarctica (slice above) have an unexpected composition.

"This is what Earth's earliest crust may have looked like," Day says. While remnants of Earth's earliest crust have been consumed by erosion and tectonic activity, asteroids were small enough to essentially be frozen in time, their makeups still reflecting their early composition.

Minerals rich in volatile elements such as sodium, potassium and sulfur make up more than 75 percent of the two meteorites, meaning their chemical composition is similar to that found in silicate rocks. The ratios of isotopes of lead in the objects hint that their minerals cooled about 4.52 billion years ago, less than 50 million years after the solar system formed.

The team's new report "is a plausible, comprehensive explanation of where these [meteorites] may have come from," says Robert Hazen of the Carnegie Institution for Science in Washington, D.C.

DARWIN *turns* 200



Two centuries ago, modern biology's founding father was born in England. He became the most celebrated scientist of his time, deciphering the records of life's history from creatures extinct and living and thereby explaining the genesis of life's diversity. Today his view of evolution by natural selection forms the core of the scientific study of life, and his mode of thought has earned its own addition to the lexicon of both scientific and popular discourse. Darwinian logic pervades the sciences of life, from the spread of viruses to interactions between and within human cultures, and has infiltrated other arenas as diverse as quantum physics and computer science. Far from a relic in textbooks, Darwinism breathes vitality into biology on a broad spectrum of research frontiers, inviting reflections on the life of, and the science made possible by, Charles Darwin.

In this special section

Web edition **www.sciencenews.org/darwin**

Expanded versions of the articles featured here as well as two additional stories exploring evolutionary science today—**Computing Evolution** and **A Most Private Evolution**—are available on the *Science News* website in a special Darwin anniversary package.

FOR SUBSCRIBERS ONLY: Downloadable PDF files of the complete Darwin Web edition

By Tom Siegfried

Charles Darwin was born into a world that today's scientists wouldn't recognize.

When baby Darwin arrived on February 12, 1809, modern science was also in its infancy. Dalton had just recently articulated the modern theory of the chemical atom, but nobody had any idea what atoms were really like. Physicists had not yet heard of the conservation of energy or any other laws of thermodynamics. Faraday hadn't yet shown how to make electricity from magnetism, and no one had a clue about light's electromagnetic identity. Geology was trapped in an antediluvian paradigm, psychology hadn't been invented yet and biology still seemed, in several key ways, to be infused with religion, resistant to the probes of experiment and reason.

Then came Darwin. By the time he died in 1882, thermodynamics possessed two unbreakable laws, chemistry had been codified in Mendeleyev's periodic table, Maxwell had discovered the math merging electricity and magnetism to explain light. Lyell had established uniformitarianism as the basis for geology, Wundt had created the first experimental psychology laboratory, and science had something substantial to say about how life itself got to be the way it was — thanks to Darwin's perspicacious curiosity, intellectual rigor, personal perseverance and power of persuasion.

Superlatives are commonplace in accounts of Darwin's life. "An intellect which had no superior, and with a character which was even nobler than the intellect," wrote Thomas Henry Huxley, Darwin's champion in the original evolution debates. More recently Stephen Jay Gould called Darwin "the Muhammad Ali of biology." But all Ali did was fight. Darwin was more like Willie Mays — he could hit, hit with power, run, field and throw. Translated to science, Darwin could read, reason, experiment, theorize and write — all as well or better than any of his contemporaries. Several scientists before Darwin had expressed the idea of evolution, some even hinting about the role of selection. But none had the wherewithal to perceive the abundance of evidence for evolution, deduce its many nuances, explain its mechanism, foresee and counter the many objections, and articulate it so convincingly to the world.

And even had Darwin never written a word about evolution, he would be remembered today as one of the 19th century's premier botanists, a superb entomologist and prominent geologist. He was a leading authority on carnivorous plants and coral reefs, pigeons and bees, earthworms and orchids, beetles and barnacles (especially barnacles). And yet he was never educated to be a scientist and held no academic position. All he brought to the scientific table was his brain. What a brain.

Woe unto the beetles

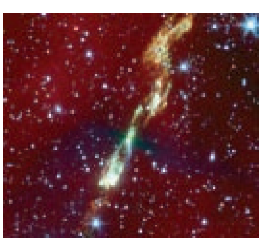
In his youth, Darwin was an average student but an avid reader. He had an early interest in observing and collecting, mainly beetles and butterflies. ("Woe unto the beetles of South America, woe unto all tropical butterflies," a friend wrote in advance of Darwin's famous sea voyage.) When it came time for higher education, Darwin headed to Edinburgh, a few hundred kilometers north of his birthplace in Shrewsbury, England, to study medicine. Soon discovering that he couldn't stand the sight of blood, Darwin headed back south to Cambridge, to prepare for the clergy, a profession in which blood wouldn't be such a problem.

His heart was not in religion, though, and his Cambridge years exposed him to other intellectual pursuits — lectures on botany, for instance, fieldwork with geologist Adam Sedgwick and friendships cultivated with biologists like John Stevens Henslow. Darwin's interest in science was stirred while reading books by the German savant Alexander von Humboldt and the English astronomer John Herschel, which imbued in him "a burning zeal to add even the most humble contribution to the noble structure of Natural Science," Darwin wrote later.

Henslow was perhaps the first to see in Darwin the makings of an uncommon scientist, and recommended him to serve as naturalist on the exploration voyage of the *Beagle*. During that ship's leisurely circumnavigation of the globe, Darwin spent five years observing the planet's diverse life, its sundry geological formations and rich fossil record of life long gone. Darwin's eye saw more than what met it. He remarked on the variations between fossils and living forms, on the similarities of animals separated by vast distances and on the subtle differences and relationships among organisms on the South

From the beginning...

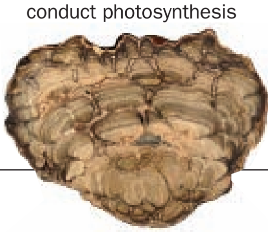
Milestones in the history of life and evolutionary science



4.6 billion years ago (bya)
Origin of solar system and Earth

By 3.9 bya
Meteorite bombardment of Earth ends. Evidence suggests presence of life.

3.5 bya
Evidence for presence of cyanobacteria, which conduct photosynthesis



Stromatolite formed by fossilized cyanobacteria communities

2.7 bya
Disputed evidence for presence of eukaryotes, first cells with DNA encased in a membrane-bound nucleus

NASA/JPL-CALTECH/LES LIE LOONEY (UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN); EDWARD KINSMAN/PHOTO RESEARCHERS

American mainland and the nearby Galápagos Islands.

By the time the voyage ended in October 1836, Darwin had amassed a mental catalog of life's diversities and subtleties never before held in one head. It gave him a lot to think about.

Sick at Down Darwin's dispatches to England during the *Beagle* trip made him a scientific celebrity by the time he returned, and he hobnobbed with London's elite. But soon ill health drove him southeast of London to a rural home (known as Down House) near the town of Downe.

For the rest of his life, Darwin suffered, almost daily, from a mystery illness something akin to repetitive food poisoning. Doctors of his day couldn't help him; modern diagnosticians have speculated on a variety of disorders, ranging from lactose intolerance to Crohn's disease.

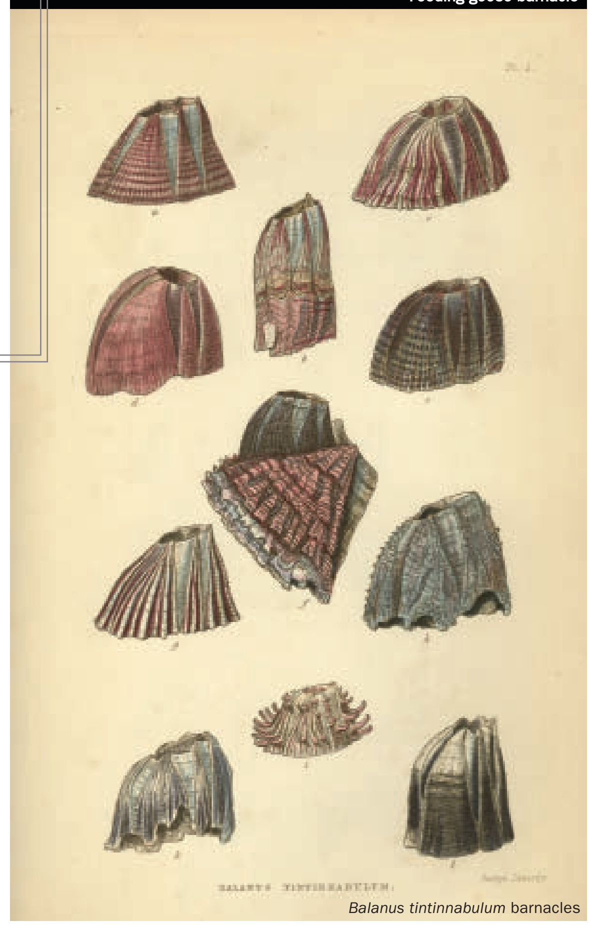
> ... the most earthshaking ideas in the history of biological science remained unpublicized. Darwin was busy classifying barnacles.

Whatever it was, Darwin's illness, a curse to him, perhaps established the circumstances subserving his scientific success. Forced to live in the country, he had no job and few distractions. He could devote his time to investigating nature in his own way. He spent eight years studying every aspect of every species of barnacle, for instance. All that time he also read with a vengeance, compiling and indexing detailed notes from book after book. He read science and philosophy and history and even trashy novels (there should be a law, he said, against unhappy endings). When Darwin opined, he knew what he was talking about, and he knew what everybody else knew, too.

He knew so much that he could often see what others couldn't, and he could also reason about things without wondering whether his suspicions would be supported by observations — he knew what observations had already been made. If they were insufficient, he made his own, growing orchids, breeding pigeons, spying on earthworms.

Of all his reading, the most signal was the 1798 essay on population by Thomas Malthus, which Darwin perused "for amusement" in 1838. About 15 months earlier, Darwin had begun a systematic investigation of "the species question," an issue at biology's foundation. Conventional wisdom held that species had been created individually and were immu-


Feeding goose barnacle


Balanus tintinnabulum barnacles

1.2 bya
First multicellular organisms

Trilobites, common in Cambrian seas

542 to 488 million years ago (mya)
(Cambrian period)
Time of the Cambrian explosion, when diversity of life-forms balloons

488 to 444 mya
(Ordovician period)
Invertebrates — especially arthropods and mollusks — dominate the sea. First land plants appear.

359 to 299 mya
(Carboniferous period)
A time of forests, swamps, seed ferns, mosses, lycopods and the origin of the amniote egg. Insects are abundant.

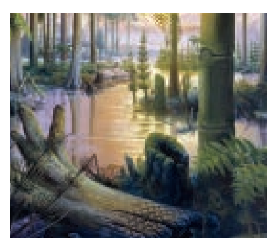


table. Some thinkers, though (including Darwin's grandfather, Erasmus), believed otherwise. While on the *Beagle*, Darwin began to suspect that immutability was not correct (though he was unimpressed by grandpa's book, judging it to have an excessively high ratio of speculation to fact). But the idea of natural selection had not yet entered the grandson's mind.

Malthus helped. Population, unchecked, would grow uncontrollably and run out of resources, he wrote. Scarcity kept populations in check; not all who were born could survive to reproduce. Darwin recognized in this account the "struggle for existence" he had observed in all manner of plants and animals. "It at once struck me that under these circumstances favorable variations would tend to be preserved and unfavorable ones to be destroyed," he wrote in his autobiography. "The result of this would be the formation of new species. Here, then, I had at least got a theory by which to work."

By 1842 he had prepared a rough 35-page outline (in pencil) of his evolutionary ideas, expanded by 1844 to a 230-page manuscript. In a letter to his wife, he allowed that his theory would be "a considerable step in science," if it ever were to be accepted "even by one competent judge." He asked in that letter that she be sure to publish the manuscript if he died before getting around to it himself. He did show it to a couple of colleagues, but otherwise the most earthshaking ideas in the history of biological science remained unpublicized. Darwin was busy classifying barnacles.

By 1854 he had begun spending most of his time on the species question, and in 1856 the geologist Lyell warned him to publish soon, before another naturalist anticipated him. Sure enough, two years later Alfred Russel Wallace, working in Indonesia, arrived at nearly the same notion — that species developed over time as small variations accumulated, with favorable ones enhancing survival. For counsel and comment, Wallace sent his paper to — Darwin.

Dismayed, Darwin sought advice from Lyell. Wallace's idea deserved to be published. Could Darwin now dare publish himself, without appearing to be stealing Wallace's discovery?

Lyell and Henslow brokered a compromise. Wallace's paper would be read to the Linnean Society, and so would an extract of Darwin's 1844 manuscript, at one session, with Lyell and Henslow vouching that they had indeed seen Darwin's work years earlier. Wallace was acknowledged, but Darwin's claim to priority was preserved. That hardly mattered, though. It was Darwin's artful reasoning and marshaling of the evidence that established evolution by natural selection, as presented in his masterwork, *On the Origin of Species*. Published in 1859, it electrified the scientific and intellectual world, evoking the prejudicial condemnation that afflicts most great new insights, but also filling the open-minded with food for centuries' worth of future biological thought.

A simple solution

For so momentous a problem, Darwin's solution seems elegantly simple, although also so subtle that its exposition is often badly mangled. Offspring differ slightly from their parents and each other (descent with modification), making some "fitter" than others in the struggle for existence (survival of the fittest). Over periods of time unimaginably long, the small changes from generation to generation accumulate, mutating one species into others. On smaller scales, over shorter times, such accumulated changes can be seen in various breeds of dogs or pigeons or plants, often induced by the artificial selection of particular traits by human breeders. On evolutionary scales of millions of years, the selection driving the appearance of new species is natural.

Some scientists (such as Huxley) saw the truth in Darwin's views immediately; others came to agree gradually. Many, of course, disagreed bitterly. But most of the "rebuttals" of evolution, even today, merely raise points that Darwin anticipated and countered. Gaps in the fossil record? To be expected, Darwin explained, because the geological record was so imperfect, as if only a few pages remained from only the most recent volume in the entire encyclopedia of the Earth's history.

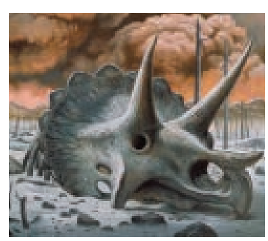
Today Darwin's original idea has been borrowed by investigators in diverse disciplines, from psychology to computer science. Even in physics, the word "Darwinian" appears in papers on thermodynamics, quantum physics and black holes. Within biology, Darwin's ideas have themselves evolved. Speciation isn't always gradual, change isn't always the result of selection, organisms are not the only units of selection, evolutionists now believe. Darwin foresaw some of these views, and he would have embraced them all — as a man of science willing "to give up any hypothesis, however much beloved ... as soon as facts are shown to be opposed to it," in his words. "If I know myself, I work from a sort of instinct to try to make out truth."

And in the battle to wrest truth from nature, none fought better than Darwin. "He found a great truth," Huxley wrote in Darwin's obituary, "trodden under foot, reviled by bigots, and ridiculed by all the world; he lived long enough to see it, chiefly by his own efforts, irrefragably established in science, inseparably incorporated with the common thoughts of men."

251 mya
Earth's largest mass extinction event occurs at the end of the Permian period. Most marine and land vertebrate species are wiped out, along with many plants and insects.

251 to 65 mya
(Mesozoic era)
This era includes the age of gymnosperms (plants with seeds) and the age of reptiles. Its subdivisions are the Triassic (extinction survivors, including dinosaur ancestors, recolonize); the Jurassic (dinosaurs); and the Cretaceous (end of the age of the dinosaurs). First flowering plants appear (130 million to 125 million years ago).

65 mya
Asteroid hits Earth. Mass extinctions of marine life and some terrestrial life, including dinosaurs (ancestors of modern birds). The age of mammals begins.



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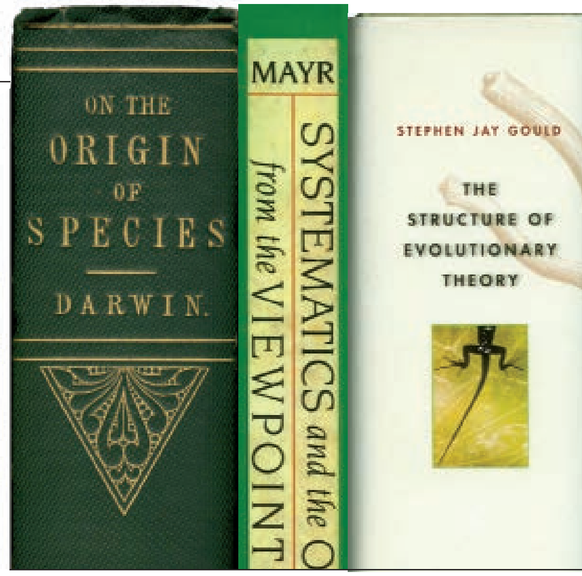
Evolution's Evolution



Darwin's dangerous idea has adapted to modern biology

By Rachel Ehrenberg

Just a decade after he published *On the Origin of Species,* Charles Darwin was already worrying about the evolution of his idea. In an 1869 letter to botanist Joseph Dalton Hooker, Darwin lamented: "If I lived twenty more years and was able to work, how I should have to modify the *Origin,* and how much the views on all points will have to be modified! Well, it is a beginning, and that is something."

Calling the *Origin* a mere "beginning" is like saying the Beatles were just a rock band or that Shakespeare wrote some decent plays. Darwin's gifts to science were radical. He not only proposed that Earth's beings all shared a common ancestry, but also described an elegant mechanism to explain how all that diverse life came to be. Darwin was a master of merging data from different disciplines, painstakingly drawing from zoology, botany, geology and paleontology to build a solid foundation for evolutionary biology. Today, 150 years later, scientists continue to grapple with ideas descended from that foundation. Still, Darwin's central tenets survive, fit enough to frame the questions posed by modern biology.

"He had great intuition," says Yale University's Michael Donoghue. "He's the guy we all envy."

Darwin's powers of observation and reason extended from microflora to megafauna; he could see the whole forest while scrutinizing the branches on the trees. His ideas illuminated life's development in the Earth's deep past and foreshadowed many scientific developments to come, including the refinements to his theory that scientists are still exploring. Yet were Darwin alive today, his head might spin at the complexities entangling the expansion of his original ideas.

Evolutionary theory is not a well-preserved fossil in a dusty museum, but a thriving field of study in labs, on beaches and in bogs. The exploding research program known as "evo-devo," for instance, has wed evolutionary theory to embryology and genetics, helping to unravel the evolution of organisms' structures and forms. Scientists are also reformulating ideas about evolution's pace, showing that Darwin's idea that change happens gradually doesn't always capture the whole story. Researchers are fleshing out Darwin's central idea of natural selection — discovering when it's the driver and when it takes a back seat. And along with investigating how selection operates on organisms — Darwin's unit of choice — scientists are also showing how it acts on groups, genes and behavior. Experts are even still debating the very definition of "species."

If Darwin came back, "in some ways he would be mystified," says evolutionary biologist Douglas Futuyma of Stony Brook University in New York. "Evolutionary biology has been radically changed — and deeply enriched."

Like confessing a murder

Of course, Darwin was familiar with radical change. In his day most biologists (or "naturalists," then) believed that each species was individually created and forever immutable. But during his travels in the 1830s on her majesty's ship the *Beagle,* Darwin saw plants and animals and fossils — and distributions of all three — that just didn't square with the idea that species don't change.

By 1844 Darwin had accepted the unacceptable and wrote to Hooker: "At last gleams of light have come and I am almost convinced (quite contrary to the opinion I started with) that species are not (it is like confessing a murder) immutable."

20 mya
Proconsul, one of the earliest apes, appears around this time.

5.3 to 1.8 mya
(Pliocene epoch)
The likely human ancestor *Australopithecus* lives at various African sites. The famous partial skeleton "Lucy" is thought to be from 3.2 million years ago.

A model of "Lucy"

2.5 to 2 mya
The first species of the genus *Homo* lives in southern and East Africa.

1.8 mya
Homo erectus lives in East Africa and eventually spreads throughout Africa and to Europe and Asia.

Porpoise paddle

Mole

Human hand

> "What can be more curious that the hand of a man, formed for grasping, that of a mole for digging, the leg of a horse, the paddle of the porpoise, and the wing of the bat, should all be constructed on the same pattern, and should include the same bones, in the same relative positions?"
>
> — Darwin, *On the Origin of Species*

Subversive as it was, Darwin's proposal that species can change was not the first. In the late 1700s, French naturalist Georges Cuvier had established that after great environmental change, some organisms got snuffed out, went kaput, extinct. A little later, zoologist Jean Baptiste Lamarck proposed the notion of adaptation, explaining variation among organisms as a response to their environments.

But Darwin (and later Alfred Russel Wallace, independently) saw that life's variation could arise from the struggle to survive among competing organisms. Individuals better equipped for their environment than their siblings or neighbors would live; the features that enabled their survival would be passed on to their kids. Darwin called this process natural selection, and life evolved largely because of it, he argued.

Body building

Evolution via natural selection, Darwin believed, could yield both life's incredible diversity and its striking similarities of form. In recent years evolution and embryology have become integrated into a flourishing field dubbed "evo-devo," for evolutionary development, a research program investigating how bodies — their size, shape, color and different parts — evolve.

An early evo-devo milestone came in the 1980s when scientists learned that genes for the body plan in fruit flies have counterparts in creatures as distantly related as humans, worms and yeast. As opposed to housekeeping genes that code for proteins involved in day-to-day living, these toolkit genes actually govern the construction of the house. Mutations in some fruit fly toolkit genes, for instance, transform a fly's antennae into legs.

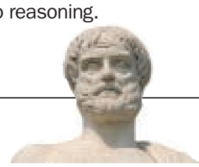
Mining the DNA record has revealed that regulation of gene activity — often by DNA segments previously thought of as junk — is critical in shaping development. These regulatory regions of DNA command genes to roar, keep quiet or merely murmur — making lots, none or a little of the molecules the regions encode. Scientists still debate the role of regulatory DNA in large-scale morphological changes, but evidence is accumulating that the timing and location of gene regulation are as important as changes in good old-fashioned protein-coding genes.

DNA also allows scientists to penetrate the smokescreen often presented by anatomy. Many cave-dwelling fish, for example, who spend their lives in perpetual darkness, have lost their eyes and pigment, which puzzled Darwin (he ascribed the fishes' loss of eyes as "wholly to disuse"). But scientists have recently shown that the loss results from the

150,000 to 100,000 years ago
Appearance of first *Homo sapiens,* who migrate across Africa and Europe

100,000 to 40,000 years ago
Homo neanderthalensis, now extinct, lives in Europe and Asia.

384 to 322 B.C.
Aristotle's lifetime. He defines an unchanging life hierarchy based on life-forms' characteristic bodily activities, from reproduction to reasoning.



1749
Georges-Louis Leclerc, Comte de Buffon begins publishing *Histoire Naturelle*. It notes similarities between humans and apes and that the two may have a common ancestor.

1798
Georges Cuvier publishes studies of mammoth and Indian elephant anatomy. His findings suggest that species can go extinct.

TOP, CLOCKWISE FROM TOP LEFT: PHILIP DOWELL (C) DORLING KINDERSLEY; ROBERT CLARK; ANDREAS FEININGER/ TIME & LIFE PICTURES/GETTY IMAGES; TIMELINE: SNESKA/ISTOCKPHOTO; SHEILA TERRY/PHOTO RESEARCHERS careful coordination of gene activity—the eyes are actively "killed" during development. Why remains unknown.

Exploring the gulf between genes and an organism's observable features (its phenotype) reveals a much more complex picture of selection and inheritance than sketched by Darwin. In his view, natural selection was a grim reaper whose scythe was the external environment. As the late paleontologist Stephen Jay Gould put it, the organism proposes, the environment disposes. But many scientists now view the developing body as an environment in constant conversation with itself. Rather than a one-way street from DNA to organism, scientists now talk about U-turns, crosstown buses and roundabouts.

"It's much more complicated than what we thought," says biologist and philosopher Massimo Pigliucci of Stony Brook University. "Nonlinear interactions, branching, with lots of feedback. That's the new frontier."

For example, scientists are investigating how environmental factors such as pH, diet or nurturing behaviors can change DNA's packaging. This packaging, which involves such features as the presence or absence of a chemical tag, can change gene activity, and these epigenetic patterns can be inherited. Such findings suggest "a bewildering increase in the complexity of the entire inheritance system," Pigliucci wrote recently in *Evolution*.

Other factors influencing the evolution of shapes and forms include the physical properties of cells.

"Take a pool of water — we're familiar with it having a still surface," says Stuart Newman of New York Medical College in Valhalla. "If we agitate it, we can get waves or vortices — but it can't do any old thing. It's hard to get variety — there's only a few things it will do based on its physical properties."

Similarly, the clusters of cells in a rudimentary embryo can do only so much. One kind of perturbation might make them elongate, another might prompt a hollow cavity to form. Newman and his colleagues reported last year in *Developmental Biology* that when wings and legs begin to bud off a developing chicken embryo, a protein spurs the limb cells to become more cohesive than nearby nonlimb cells. This physical property of being differentially sticky can lead to the layers of tissues seen in embryos. Add some feedback loops and you can get the repeating patterns seen in animal body plans, such as the vertebrae of a backbone or a segmented abdomen.

Even if physics dictates form, selection plays a role. "There's still going to be a shakeout — you need selection on what can exist," Newman says. "But you don't have to put waves in the water one-by-one.... You can get rapid transitions with physics."

Not always gradual

Darwin was not a fan of rapid transitions. In his view evolution acted through the relentless accumulation of tiny changes through vast spans of time. These gradual transitions are sometimes found in the fossil record, but often are not. And that record also reveals exuberant bursts of innovation, such as the Cambrian explosion, a period of roughly 20 million years beginning about 520 million years ago. The major body plans found in most modern animal groups, such as arthropods and chordates, were established by the Cambrian.

In 1971 Niles Eldredge proposed an explanation for these moments of great change, an idea he later expanded with Gould. They argued that evolution can happen in fits and starts; organisms remaining unchanged for long periods of geologic time is actually the norm. This general state of equilibrium is then on occasion punctuated by the emergence of new species.

Say a barrier, such as a river, isolates a portion of a snail population. This smaller population might undergo intense selection quickly (in geologic time, where 5,000 to 10,000 years is a blink), becoming a new species. If the river then dries up, the new species is reunited with its sister species. The new species could outcompete its sister, which goes extinct, or both snail species might persist. In the fossil record, it might look like one species was replaced by a related species, or that a new species suddenly appeared.

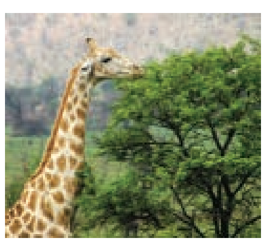
"Punctuated equilibrium" captured biologist Ernst Mayr's idea of speciation — an isolated subpopulation accruing so many changes that it can no longer breed with its former population — and translated it into the language of the geologic record. Mayr's ideas were a core part of the "modern synthesis," the merging of Darwinian selection with Mendelian genetics during the 1920s, '30s and '40s. In the early 1900s, scientists had established that mutations could be passed on to the next generation. In the 1920s, scientists such as Ronald Fisher and Sewall Wright gave evolution a mathematical backbone. The field of population genetics was born; its tenets being that variation arises in populations through both random genetic mutation and recombination (sex), and evolution occurs when the gene frequencies in a population change through time.

Selection and chance

The mathematical musings of Fisher and Wright demonstrated that natural selection wasn't the only guest at evolution's cocktail hour. Chance also plays a role in determining the genes of the next generation.

1809
Charles Darwin is born February 12 in Shrewsbury, England.

1809
Jean Baptiste Lamarck states in the *Philosophie Zoologique* that heritable changes could be forged by the environment during an organism's lifetime.



1831
Darwin departs on the voyage of the *Beagle* on December 27, returning to England in 1836.

The idea of natural selection “was brilliant, original, it was called the ‘dangerous idea’ because it was so powerful,” says Futuyma. “But is that going to explain everything? No.”

Suppose the original snail population divided by a river was a mixture of red-shelled snails and brown-shelled snails. When the river runs through it, the isolated subpopulation — just by chance — might be mostly red snails. In time, the genes for red shells might dominate, or might peter out — the ratio of brown to red snails will “drift” around. This genetic drift happens without selection, yet the gene frequencies for different colors are changing. That genetic drift can be a mechanism of evolution. In the late 1960s geneticist Motoo Kimura and others proposed that most changes at the molecular level were neutral — imparting no benefit or harm — suggesting that genetic drift, not selection, was the prevailing evolutionary force.

> The idea of natural selection was “called the ‘dangerous idea’ because it was so powerful.”
>
> Douglas Futuyma
> Stony Brook University

Today scientists generally accept that the evolution of molecules may differ in some ways from the evolution of organisms. Selection is still a star, but drift certainly has its role, and which dominates is often a matter of circumstance, and which level of the hierarchy is involved. While debate continues over where and how selection acts, many scientists advocate the “Russian nesting doll” approach that allows selection at many levels, including species, groups, individuals, cells and, of course, genes.

A similarly contentious (and productive) area of research focuses on the concept of “species” itself. A dominant approach, first championed by Mayr in animals (and later by botanist Verne Grant in plants), argues that species are real entities defined by their ability to interbreed. Yet some organisms snub this “biological species” concept. Among species with several populations over an extended range, it isn’t unusual that populations near each other can successfully interbreed, while populations at the opposite ends of the range are so divergent that they are incompatible.

While interbreeding is certainly important in the maintenance of species, it leaves something to be desired as a definition (what about asexual species, for example?). Some scientists have proposed phenetic species, which define organisms by their overall similarities. Others call for a phylogenetic species concept that recognizes groups descended from a common ancestor, as evidenced by shared characteristics, such as mammals having fur and mammary glands.

Brent Mishler of the University of California, Berkeley, who with Donoghue was a framer of the phylogenetic species concept, has argued that hierarchical ranking, from subspecies up through families and orders, is of little practical or intellectual use, and that ranks on all levels should be done away with.

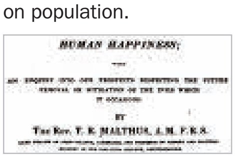
The tree of life has thousands of nested levels, Mishler writes in a chapter to appear in *Contemporary Debates in Philosophy of Biology*. Defining species — or any other rank — is in many ways arbitrary. Given a genus of moths and a genus of spiders, the rank of “genus” tells almost nothing about the two groups, such as their number of species or evolutionary age. It would be better to recognize branches or “clades” on the tree of life — a fork and all the twigs that arise from it, which have evolutionary meaning, Mishler says.

While humans crave discrete definitions, little in biology is tidy, and putting its parts together isn’t necessarily becoming easier. In making the tremendous progress since Darwin, scientists have become more and more specialized, says Pigliucci. But that specialization comes at a cost — there’s a lack of integration at higher levels — even though integration was Darwin’s claim to fame. His insights connected everything in biology, all life becoming related pieces of an integrated whole. Such integrated thinking is needed today as humans grapple with how ecosystems will respond to climate change or invasive species.

“It’s funny that evolutionary biology has not played much of a role in biodiversity — it’s been almost entirely seen as an ecological issue,” says Donoghue. “But evolutionary biology has a lot to say about these issues — oddly enough, evolutionary biology is all about diversity. We’re just starting to connect these dots.”

Darwin was all about connecting dots, says Pigliucci. “Today Darwin would be excited and bewildered by what we know, but would also probably push us to focus on the interdisciplinary aspects,” he says. Darwin was “an inherently interdisciplinary guy. But it took him years! The bulk of *Origin* is painstaking examples from a variety of disciplines — in a sense we aren’t there now. We know a lot about molecular biology and development in model systems and we know a little about ecology and evolution, but we know almost nothing about how they all fit together.”

1838
Darwin reads economist Thomas Malthus’ essay on population.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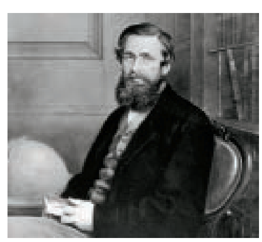
The Rev. T. R. MALTHUS, A.M. F.R.S.

1842
Darwin prepares a rough sketch (a 35-page outline) of his evolutionary ideas. Two years later, Darwin finishes his 230-page manuscript.

1858
Alfred Russel Wallace (right) sends a paper, which mirrors Darwin’s idea, to Darwin. Both of their ideas are presented at the Linnean Society.



1859
On the Origin of Species is published in London on November 24.

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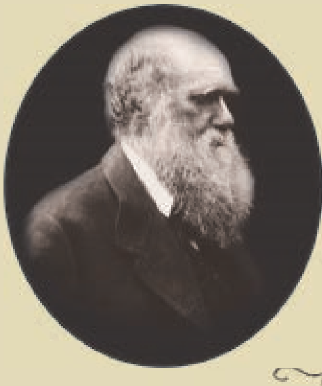

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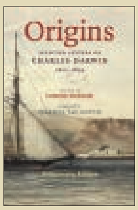

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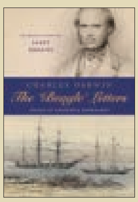

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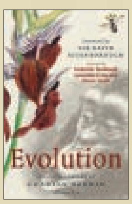

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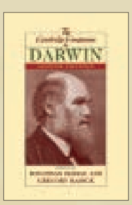

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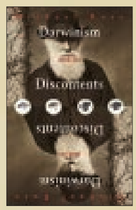

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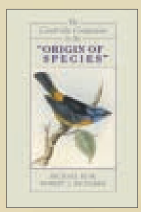

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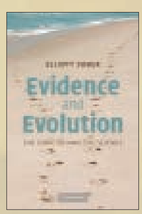

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Molecular Evolution

Investigating the genetic books of life reveals new details of 'descent with modification' and the forces driving it

By Tina Hesman Saey

Zachary Blount sits in front of a tower of petri dishes. Blount used the assembled dishes to test trillions of bacteria to see which had evolved the ability to eat a chemical called citrate.

Charles Darwin didn't know about genes and DNA. In fact, hardly anyone noticed when Gregor Mendel, a monk whose pea experiments eventually led to modern genetics, published his findings in an obscure journal a few years after Darwin's *On the Origin of Species* appeared in 1859. It would take nearly a century more before James Watson and Francis Crick deciphered the structure of DNA, the molecule that contains the manual for building an organism. Yet Darwin was still able to describe a mechanism — natural selection — for how evolution shapes life on Earth. That's like describing how a car works without knowing about the existence of internal combustion engines.

While Darwin achieved his insights without molecular help, biologists today are intimately familiar with the molecules responsible for the diverse array of organisms that populate the planet. The study of genes has revealed evolution as essentially a high-stakes poker game in which organisms draw randomly from a deck of genetic choices. At stake is the chance to pass along genes to the next generation. Sometimes the hand is good enough to get ahead, but some hands are losers, perhaps to the extent of extinction. By studying the winners, scientists are learning how the forces of evolution work on DNA, the biochemical repository of an organism's entire natural history. DNA records the mutations that helped some animals to survive ice ages while others perished, the nips and tucks that make animals more attractive to mates, the big leaps that allowed plants to become domestic crops — they're all there, written out in a simple alphabet of four letters.

Each organism's book of life is contained in its genome, and scientists have been hard at work creating a library of species's books. Comparing the genomes of different creatures will help researchers learn the history of how life on Earth has evolved.

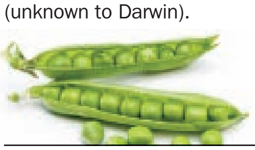
But many questions remain. Scientists still don't know how cells first formed, including how former bacteria came to live inside cells as mitochondria or chloroplasts. Another mystery is how the complex structure of genes in eukaryotes — organisms in which the genetic material is encased in a nucleus — evolved. One of the biggest issues is whether life on Earth was destined to evolve the way it has.

Limits on evolution

Play a poker game, rewind it to the beginning, start again and see what happens. Would the game play out the same every time? Stephen Jay Gould, the late paleontologist, didn't think so. If you restart the game, the shuffled cards will turn up a little different each time, and the exact order in which the cards are drawn can have profound consequences for the outcome. Replaying the "tape of life" from some point in the past would produce very different lifeforms than the ones we have today, Gould thought.

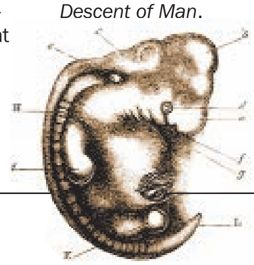
Other scientists disagree. Organisms are dealt a finite num-

1865
Gregor Mendel presents experiments on heredity in hybrid pea plants (unknown to Darwin).



1869
Johann Miescher isolates a molecule rich in phosphorus and nitrogen that he calls nuclein, later revealed to be DNA.

1871
Darwin publishes *Descent of Man*.



Human embryo illustrated in Descent of Man

1882
Darwin dies on April 19 at age 73 and is buried in Westminster Abbey (illustration of funeral at right).

ber of genes and so must choose from a limited menu of evolutionary options, narrowing the directions the organisms can go in a particular environment. “The evolutionary routes are many, but the destinations are limited,” says paleontologist Simon Conway Morris of the University of Cambridge in England. As a result, organisms often end up independently developing the same sorts of structures to solve a particular problem. Although the details of how eyes work vary between species, for example, the basic structures are similar.

While it’s impossible to turn back time (no matter how easy Superman makes it look) and replay all of evolution again, scientists have devised other ways to investigate the issue.

Richard Lenski, an evolutionary biologist at Michigan State University in East Lansing, is among the scientists hitting the rewind button on evolution. Meter-high letters taped to the windows of his lab spell out the lab’s motto: EVOLVE. In the center of the “O,” the face of Charles Darwin peers out toward the football stadium.

Inside the lab, a dozen glass flasks containing clear liquid swirl in a temperature-controlled incubator. Although the naked eye can’t see them, millions of *E. coli* bacteria grow in the flasks, doing what the window exhorts. Lenski started the cultures in 1988, intending to follow the course of natural selection for several hundred generations. Now, two decades later, the cultures are still growing and have produced more than 45,000 generations of bacteria each.

These 12 flasks “represent the stripped-down bare essentials of evolution,” says Zachary Blount, a graduate student in Lenski’s lab. The environment never changes. No new genes enter the system from migrating microorganisms. And the scientists take no action to affect the course of evolution within the flasks. Only the intrinsic, core processes of evolution influence the outcome, Blount says.

Lenski and his colleagues have watched the game play out, occasionally analyzing DNA to peer over the players’ shoulders and find out what cards they hold. On the surface, the populations in the 12 flasks seem to have traveled similar paths — all now grow larger cells and have become more efficient at using glucose than their ancestors. And many of the strains have accumulated mutations in the same genes. Notably, though, none of the strains developed exactly the same genetic changes.

Randomness is an important part of the evolutionary equation, as the experiment illustrates. During the first 2,000 generations, all of the 12 populations rapidly increased in size and fitness. But then these changes began to slow down, hitting the evolutionary equivalent of a dieter’s plateau.

After 10,000 generations, it became apparent that not all the flasks were on the same trajectory. Though cells in all the flasks became larger, each population differed in the maximum size the cells reached. The populations also differed in how much fitter they were than their ancestors, when grown in direct competition. The “experiment demonstrates the crucial role of chance events (historical accidents) in adaptive evolution,” Lenski and colleague Michael Travisano wrote in a 1994 paper. The experiment has progressed, and several of the flasks now contain mutator strains, bacteria that have defects in their DNA replication system. Such defects make mistakes more likely to happen every time those bacterial strains copy their DNA to divide. Sometimes a mistake can have lethal consequences, damaging a gene crucial for survival. But other times coloring a bit outside the lines creates opportunity for advancement.

Even within a given flask, some bacteria take slightly different paths. One flask now contains two separate strains — one that makes large colonies when grown on petri dishes, and one that makes small colonies. The large- and small-colony strains have coexisted for more than 12,000 generations. The large-colony producers are much better at using glucose so they grow quickly, but they make by-products that the small-colony producers can eat. Both strains have increased in fitness over the generations. By at least one measure, the two

These 12 flasks contain separate populations of *E. coli*, all evolved from a single ancestor. Only the bacteria in flask A-3 evolved the ability to eat citrate.

1900
Working independently, Hugo de Vries, Carl Correns and Erich von Tschermak rediscover and confirm Mendel’s work on heritable traits.

1903
Walter Sutton publishes a paper making the first clear case for the chromosome theory of heredity.

1908
Godfrey Harold Hardy and Wilhelm Weinberg independently derive a formula for gene allele frequency in populations.

1910
Thomas Hunt Morgan discovers *Drosophila* mutant with white eyes, a sex-linked trait he relates to Mendel’s recessive traits.

1913
Alfred Sturtevant, a student of Morgan’s, publishes the first rudimentary map of a fruit fly chromosome, establishing that genes are real.

TOP: NEERJA HAJELA AND BRIAN BAER/MICHIGAN STATE UNIVERSITY;
TIMELINE: PETROVICH9/ISTOCKPHOTO

could constitute separate species, Lenski and his colleagues proposed in 2005 in the *Journal of Molecular Evolution*.

Still, it seems that Conway Morris was basically right: Though the details were different, replaying evolution in a dozen flasks produced very similar outcomes in each.

But then something completely unexpected happened. After about 31,500 generations, glucose-eating bacteria in one flask suddenly developed the ability to eat a chemical called citrate, something no other *E. coli* do, the researchers reported last June in the *Proceedings of the National Academy of Sciences* (*SN Online: 6/2/08*).

"They've been eating the main course for thousands of generations," Lenski says. "They didn't realize that there was a dessert tray around the corner."

The switch was clearly a radical change of destination for the bacteria. The inability to eat citrate is a biochemical hallmark of the *E. coli* species, so by some definitions, the citrate eaters in that flask are no longer *E. coli*.

But a single change did not a citrate eater make. The researchers found that the bacteria went through a series of steps before evolving the ability to use citrate. One initial mutation happened at least 11,000 generations before the citrate eaters appeared. Lenski doesn't yet know which specific DNA changes led to citrate use, but it's clear that the ability to use citrate is contingent upon those earlier changes. And even bacteria that have undergone those initial changes are still not guaranteed to find the dessert cart. Blount tested 40 trillion bacteria from earlier generations to see if any could evolve the ability to eat citrate. Fewer than one in a trillion could.

The profound difference between the citrate eaters and the other 11 strains, as well as the dependence of the citrate change on earlier mutations, seems to suggest that Gould was also right: Replaying evolution will result in some surprise endings. "The long-term evolution experiment with *E. coli* provides some of the best evidence for both Conway Morris and Gould that one could ever hope to see," Lenski says. "Conway Morris 'wins' based on the number of changes that fit his pattern, but Gould might prevail if weighted by the profundity of change. Both perspectives are important contributions, and they are not mutually exclusive."

> "They've been eating the main course for thousands of generations. [The *E. coli*] didn't realize there was a dessert tray around the corner."
>
> Richard Lenski
> Michigan State University

Now the researchers are watching to see if citrate-eating bacteria will evolve in other flasks, and if citrate eaters will eventually reject glucose and feast only on citrate. Such a transformation would probably herald the birth of a new species. "It would be amazing," says Blount. "It would be like teenagers who no longer like to eat pizza — they prefer broccoli."

When the game changes

While Lenski's experiment takes place in a constant environment, natural evolution must cope with a messier reality. In Steven Finkel's lab at the University of Southern California in Los Angeles, a long-term experiment shows how evolution plays out in an ever-changing environment, more like the real world. This allows Finkel to focus on how evolution and environment are interwoven.

Finkel didn't start out to test evolution in changing environments. The experiment was prompted by a graduate student's casual remark that *E. coli* will live a long time.

"How long?" Finkel asked.

"A long time," the student responded.

"So we set up some experiments to see how long they would live, and they just would never die," Finkel says. The immortal bacterial cultures are teaching scientists how organisms change their environments and adapt to changes wrought by outside forces.

Finkel and colleagues placed the bacteria in a rich broth full of sugars and many other nutrients and then just let them grow. After a short initial lag, the bacteria began growing like gangbusters. Once the nutrients start to run out, the bacteria stop growing so quickly and settle into a senescent state. After a few days, millions of bacteria die, spilling their guts into the surrounding media and providing food for survivors.

It's the postapocalyptic survivors that interest Finkel. As 99 percent of their comrades die off, the surviving bacteria feed on the carcasses of the dead and on metabolic by-products of other survivors. Thus the bacteria change the environment in which they live. It doesn't take long for the cultures in each flask to go their own ways. Within a month, the bacteria in the various flasks convert the light honey color of the broth into a spectrum ranging from light amber to dark amber. Microscope examinations reveal that the originally rod-shaped bacteria take on a wide variety of shapes.

1925
Tennessee court convicts teacher John Scopes of violating a state law against teaching that people descended "from a lower order of animals."

Scopes trial

1925
Raymond Dart publishes his discovery of a fossilized skull from a new species, *Australopithecus africanus*, a key member of the human evolutionary tree.

1928
Frederick Griffith's transformation experiments with streptococcus bacteria suggest that the genetic material cannot be a protein.

1930
Ronald Fisher publishes a mathematical analysis of how natural selection can change the distribution of genes in a population.

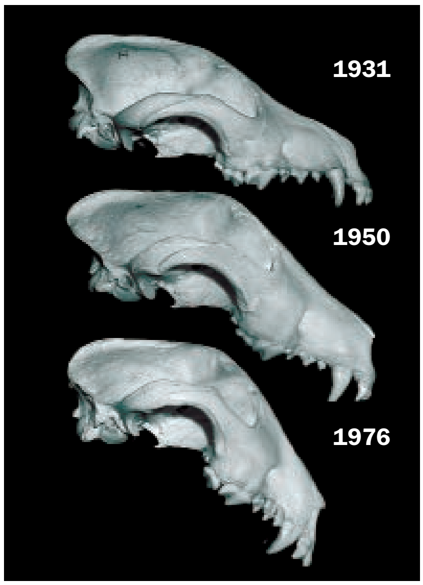
WATSON DAVIS/SCIENCE SERVICE

As different as the bacterial populations appear, they also have something in common. All the cells that have gone through the valley of death are tougher than naive bacteria. And the older the cells get, the more competitive they are, so that 20-day–old cells will drive 10-day–old cells to extinction, and 30-day–old cells beat 20-day–olds. Finkel calls that phenomenon “growth advantage in stationary phase,” or GASP.

On the surface it appears that the number of surviving cells stays constant. But underneath, different mutants rise and fall in number, like waves crashing on the beach, Finkel showed in a 2006 review in *Nature Reviews Microbiology*.

The ability for older cells to compete better has been traced to mutations in four genes, including one that encodes a key protein, RpoS, needed to turn on stress-response genes.

But just because a mutation serves an organism well under some conditions doesn’t mean it’s always beneficial. Thomas Ferenci, a microbiologist at the University of Sydney in Australia, reviewed what happens to *rpoS* mutants under a variety of environmental conditions in the May 2008 *Heredity*. Depending on a cell’s genetic background, an *rpoS* mutation might give the strain a big boost in fitness or make an undetectable difference. Even when the mutations are beneficial, the changes may hold the bacteria back if conditions shift. If salinity rises or the temperature drops, or if bacteria lack oxygen or encounter a toxin, *rpoS* mutants, less able to cope with certain stresses, face a growth disadvantage.



Evidence of recent evolution isn’t limited to microbes. Skulls show the evolution of flatter faces in purebred bull terriers that has been linked to changes in a single protein.

Natural selection works for *rpoS* mutants in some environments and against them in other conditions. “Selection is a deterministic force pushing relentlessly in one direction,” says Michael Lynch, an evolutionary biologist at Indiana University in Bloomington. That direction is toward ever-greater adaptation for the environment in which a population finds itself. But most environments are in a constant state of flux and, as Darwin was careful to point out in his introduction to the *Origin of Species*, selection isn’t the only evolutionary force at work.

Sex, chance and genes

Random genetic drift is an evolutionary force to be reckoned with too. The number of individuals that carry a specific genetic variation within a population — what scientists call the frequency of a gene variant — can change at random, bobbing along like driftwood on the ocean. The indiscriminate nature of drift doesn’t always work to organisms’ betterment. “Drift doesn’t care about fitness,” Lynch says. Drift can haphazardly make a detrimental gene prominent in a population, or accidentally eliminate beneficial mutations.

But there is yet another force that mixes things up — genetic recombination. Recombination is an essential element of sexual reproduction. In general, each parent contributes a single copy of each chromosome to its offspring. Before mom and dad divvy up the genetic goodies to hand down to the children, the two copies of each chromosome are lined up and matched like pairs of socks. When the two chromosomes are zipped together, they swap chunks of DNA, giving each egg or sperm a different combination of the parents’ genes — new raw material for natural selection.

Researchers are still debating the details of how selection works together with mutation, recombination and drift to shape genes and help organisms adapt to their environments, producing the abundance of species around today.

“We’re peeling back the onion of the evolutionary process,” says Sean Carroll, a developmental and evolutionary biologist at the University of Wisconsin–Madison. “The question is no longer ‘does adaptation happen?’ but ‘how does it happen?’ ”

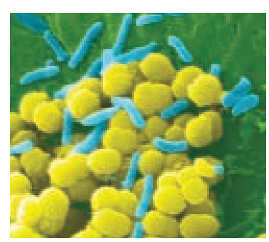
Scientists have begun to learn how molecular tweaks and changes enable animals, plants, bacteria, archaea, fungi and all organisms on Earth to adapt to their environments. The picture is painted in DNA, but it’s far from a completed masterpiece. Changing environments coupled with the forces of natural selection, mutation, recombination and drift are continually reworking the painting. Only time will tell how the landscape will morph — and its inhabitants with it.

1931
Harriet B. Creighton and Barbara McClintock, working with maize, and Curt Stern, working with *Drosophila*, provide the first visual confirmation of genetic crossing-over.

1931
Sewall Wright begins to publish work showing that “random drift,” or chance fluctuations in a population’s gene frequencies, could be a significant factor in evolution.

1941
George Beadle and Edward Lawrie Tatum propose the one gene/one enzyme hypothesis.

1943
Salvador Luria and Max Delbrück report that random mutations, not just selection, can confer resistance in bacteria, shown right.



TOP: JOHN FONDON III/UNIVERSITY OF TEXAS AT ARLINGTON; TIMELINE: NIH/NATIONAL INSTITUTE OF GENERAL MEDICAL SCIENCES

Step-by-step Evolution

Mining the Gaps: Transitional fossils are the hardest to find, but sometimes tell the best stories

By Sid Perkins

Gerobatrachus hottoni lived about 290 million years ago. The species fits into a 50-million–year gap in the amphibian fossil record between primitive amphibians and the frogs and salamanders that subsequently evolved. Paleontologists have unearthed just one example of the species (shown above).

When Charles Darwin proposed the idea of evolution in *On the Origin of Species*, he wrote "if my theory be true, numberless intermediate varieties, linking most closely all the species of the same group together, must assuredly have existed." At the same time, he bemoaned the dearth of such transitional fossils as perhaps "the most obvious and gravest objection which can be urged against my theory."

Surely it was serendipity when, just two years later, quarriers unearthed fossils of *Archaeopteryx*. This creature, now recognized by many scientists as the first known bird, has a mosaic of features that links it with the disparate groups of species on either side of it in the fossil record: While its teeth, tail and overall body shape are distinctly reptilian, its feathers have the same complex structure as the lift-generating feathers of modern birds.

In other words, it is just one of the "numberless intermediate varieties" Darwin predicted must have existed. "It was the right discovery at the right time," says Richard Fortey, a paleontologist at the Natural History Museum in London.

Darwin blamed the lack of transitional fossils in part on the poorness of the paleontological record. It's a rare accumulation of fortuitous events when a creature is fossilized, its remains are preserved over millions of years and then those remains are discovered.

In many cases, that critique still holds true: Researchers have yet to discover fossils of a creature that fits in the gap between bats — which seem to appear suddenly in the fossil record about 54 million years ago — and their mammalian predecessors (*SN: 5/14/2005, p. 314*). The gap in the fossil record between *Archaeopteryx* and its reptilian ancestors also remains unoccupied, although several discoveries of feathered dinosaurs in China have given researchers clues about what these intermediate creatures may have looked like.

Many of the gaps in the fossil record that remained unfilled in Darwin's time now throng with creatures, such as the ones used to chronicle the 48-million–year series of evolutionary changes between whales and their predecessors (*SN: 9/22/01, p. 180*; *SN: 1/5/08, p. 5*). And particular biomarkers — chemical fossils, if you will — in rocks more than 240 million years old have provided clues about the evolution of flowering plants (*SN: 4/21/01, p. 253*).

Paleontologists still randomly stumble across transitional fossils, such as a creature found in Texas that falls in a 50-million–year gap in amphibian evolution and helps pin down when the groups that include salamanders and frogs arose.

As often as not, however, transitional fossils are found when researchers head into the field with a specific target in mind: By focusing on rocks deposited during an interval where gaps in the fossil record exist, scientists can boost the chances of making a critical discovery. That's how researchers unearthed *Tiktaalik*, a 2.7-meter–long beast that plopped into a 9-million–year gap in the chronicle of vertebrates' transition from water to land (*SN: 6/17/06, p. 379*).

1944
Oswald Avery, Colin MacLeod and Maclyn McCarty suggest that nucleic acids are the material of heredity.

1952
Blender experiment by Alfred Hershey and Martha Chase demonstrates that DNA, not protein, is the genetic material.

1953
James Watson (left) and Francis Crick (right) determine the double-helix structure of DNA. They use Rosalind Franklin's X-ray diffraction images.

1958
Crick enunciates the legendary "Central Dogma," that the transfer of information flows from nucleic acid to protein but not vice versa.

CT scanning, used to reinvestigate fossils collected decades ago, has revealed new insights about the anatomy of semiaquatic creatures that preceded *Tiktaalik*. Even genetic analyses of living creatures can provide insight into the fossil record: The evolutionary changes observed in fossil fish deposited over 20,000 years in an ancient lake can be linked to a particular gene often studied in that species' modern-day kin.

Amphibian enigma

About 290 million years ago, a diverse assemblage of primitive amphibians walked the land. But in rocks documenting the 50 million years or so that followed, amphibian fossils are scarce, says Jason Anderson, a paleontologist at the University of Calgary in Canada. Only in rocks deposited after 240 million years ago do such fossils — including those of frogs and salamanders — appear. These creatures apparently evolved during an interval in which few fossils had been discovered.

Recently, however, Anderson and his colleagues unearthed *Gerobatrachus hottoni*, a species whose genus name means "elder frog." About 11 centimeters long, the size of most modern salamanders, the specimen was found in 290-million-year-old, fine-grained siltstone in north-central Texas. Even though it was found in rocks deposited just before the start of the lengthy gap in the fossil record, the fossil has features characteristic of the frogs and salamanders that presumably descended from it or others like it, Anderson says.

Some of the bones in the first and second innermost toes on each of *Gerobatrachus*' feet are fused together, a trait found in salamanders but rarely in other creatures. Because some of the other bones aren't fully developed, Anderson and colleagues suggest that the creature was a juvenile, indicating the fusion of the toe bones occurred before adulthood — a sign that it betrays an evolutionary link to salamanders.

But like frogs, *Gerobatrachus* has a broad skull and a shortened tail, the researchers reported last May in *Nature*. The shape and configuration of bones in the creature's skull, and particularly those in its palate, are very froglike. Therefore, "this fossil seals the gap" between primitive amphibians and the frogs and salamanders that evolved later, Anderson says.

Getting a foot on land

The series of gradual anatomical changes that enabled semiaquatic creatures to completely leave the water and conquer dry land is one of the most important chapters in the tale of evolution. Among other changes, creatures had to develop limbs to support their weight and develop a way to extract oxygen from the air.

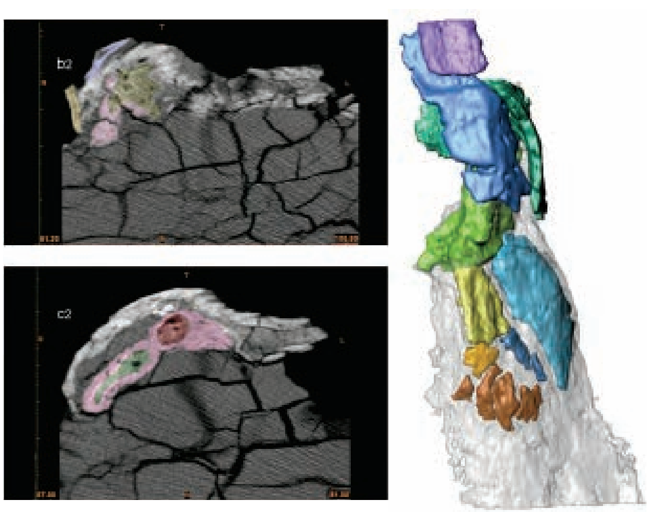
"This whole transition is known from quite a few [species]," says Neil Shubin, a paleontologist at the University of Chicago. Nevertheless, new discoveries are still fleshing out the details of these evolutionary developments.

Members of one species considered to be an important part of the water-to-land transition, a lobe-finned fish called *Panderichthys*, lived in what are now Latvia and Scotland about 385 million years ago. Until recently, the next known member of the evolutionary sequence was a land-adapted creature called *Ventastega*, which lived on land that is now in the Northern Hemisphere about 365 million years ago. Earlier this decade, Shubin and his colleagues braved the cold of northeastern Canada's Ellesmere Island to search for fossils to fill that 9-million–year gap.

His team struck paleontological pay dirt with *Tiktaalik*, which lived about 382 million years ago. Like some fish of the day, it had fleshy limbs that ended in fins. But like land-adapted tetrapods, it had sturdy ribs and a neck. Its fossils also suggest that *Tiktaalik* had both gills and lungs. This blend of features spurred the researchers to dub the creature a "fishapod."

Another way to view a fossil

Previous analyses of fragmentary fossils of *Panderichthys*, a lobe-finned fish that lived about 385 million years ago, hinted that the creature didn't have bones analogous to those in human wrists and digits. But CT scans of a lump of rock containing a nearly complete specimen (two individual CT slices shown below) indicate that the creature indeed had those bones (dark blue, gold and bronze in the reconstruction at right). The presence of these bones makes the fish-to-land transition "a little less dramatic than we thought it was," one researcher notes.



1958
Matthew Meselson and Franklin Stahl show that when DNA replicates, the new helix comprises one old strand of DNA and one new strand.

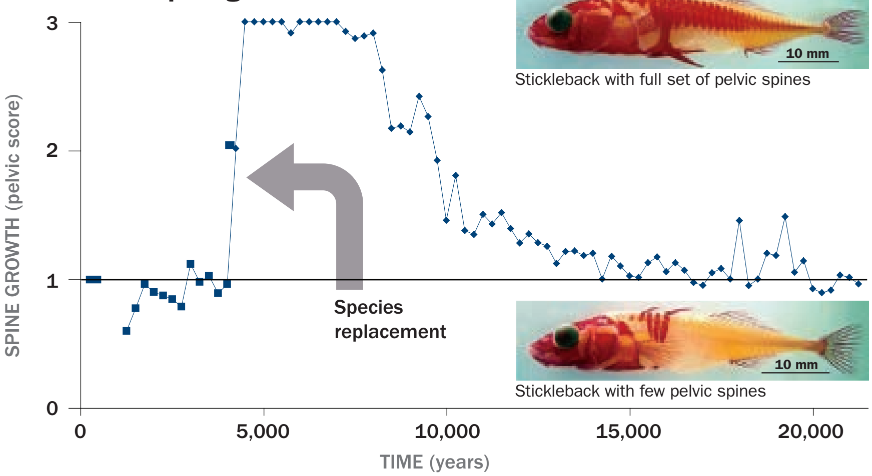
1964
Louis Leakey identifies fossils of and names *Homo habilis* (skull at right), debated to be the first *Homo* species.

By 1966
Francis Crick, Sydney Brenner and Alan Garen succeed in working out the genetic code, in which DNA triplets encode amino acids.

1971/1972
Niles Eldredge proposes "punctuated equilibrium," later developed further with Stephen Jay Gould.

TOP: CT SLICES: BOISVERT *ET AL.*; RECONSTRUCTION: C. BOISVERT, P. AHLBERG; TIMELINE: PASCAL GOETGHELUCK/PHOTO RESEARCHERS

Stickleback spine growth over time



Stickleback with full set of pelvic spines

Stickleback with few pelvic spines

About 10 million years ago, stickleback fish living in a lake void of their usual predators in what is now west-central Nevada sported few if any pelvic spines (modern example at bottom; researchers assign these spineless fish a "pelvic score" of 1 or less). Then, the fossil record suggests that something, possibly a significant change in environmental conditions, led to a sudden shift. After less than 500 years, sticklebacks with a full set of pelvic spines (top) dominated deep waters in the lake for about 3,000 years. Then, a gradually increasing proportion of fish in the lake lost their pelvic spines. After 8,500 years or so, most of the sticklebacks had lost their spined defenses, returning the species' average pelvic score to around 1. One change agent may have been *PITX1*, a recessive gene that influences the size of pelvic armor in modern sticklebacks.

Hidden genes, big changes

Modern genetic tests are also shedding light on evolutionary changes chronicled in the fossil record of stickleback fish that lived about 10 million years ago in a Nevada lake. During a 21,500-year interval, one stickleback species — with a full set of pelvic spines — suddenly replaced a species that lacked such protection, only to gradually lose its spines a few millennia later.

Michael Bell, an evolutionary biologist at Stony Brook University in New York, and biologist Matthew Travis of Rowan University in Glassboro, N.J., tracked changes in stickleback anatomy using fossils from a site at the Nevada lake. The researchers grouped fossils into 250-year–long periods and categorized the fish based on the presence or absence of the components that make up the pelvic spine assembly. Bell and Travis reported their findings in October in Cleveland at the annual meeting of the Society of Vertebrate Paleontology.

At the beginning of the interval, most of the sticklebacks living in this part of the lake had no pelvic spines, but they did have the bony plate on which the spines are attached. Only a few stickleback fossils had a full complement of pelvic spines.

Then, about 4,000 years later, a relatively sudden change came to the lake — possibly because of some as-yet-unidentified environmental catastrophe — and the sticklebacks that lacked pelvic spines were supplanted by those that did have pelvic protection. For about 3,000 years, these spine-sporting fish dominated the ecosystem, but then individuals that lacked pelvic spines began to account for an ever-increasing portion of the stickleback population. Eventually, after another 8,500 years or so, most of the sticklebacks in this part of the lake again lacked pelvic spines.

A stickleback's pelvic spines, like other body parts, require energy to grow and maintain. If not in danger from predators, an individual benefits if its genetic makeup allows it to forgo those spines, Bell says. That could explain the eventual loss of pelvic spines, but it doesn't explain why it took 3,000 years for that phaseout to begin.

Modern genetic studies provide a clue, however. At least six genes influence the presence and length of a stickleback's pelvic spines, Bell says. Most of those genes have little effect, but one — a recessive gene known as *PITX1* — has a large influence. And in modern-day sticklebacks, as the expression of the *PITX1* gene declines, the spines on the creature's left side shorten more slowly than those on the right side.

That same pattern of asymmetry shows up in this lake's fossil record, says Bell. During the 8,500-year period when the sticklebacks were losing their pelvic girdles, about 75 percent of the fish fossils with pelvic spines — precisely the percentage expected in a population with such a recessive gene — had larger remnants on the left sides of their bodies.

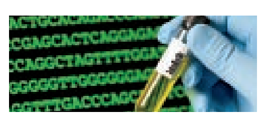
Even before the decline in growth of pelvic spines for the sticklebacks kicked in, however, subtle evolutionary changes were taking place. Measurements of the spines indicate that during the 3,000 years when all the sticklebacks retained all of their pelvic spines despite danger from major predators, the spines were becoming shorter as generations passed. That trend suggests that anatomical changes were happening via

1977
Carl Woese and George Fox publish a paper in *PNAS* identifying the third domain of life, the archaebacteria (now commonly called Archaea).

1983
Homeobox genes are discovered. The homeobox proteins turn on other genes in precise patterns at certain times during development to determine an animal's body plan.

1996
Dolly the Sheep is the first mammal ever cloned from an adult cell.

1999
Human Genome Project completes first sequence of a human chromosome.



2006
Benjamin Voight and colleagues publish data showing that, within human history, a large portion of the human genome has changed in response to "selective pressures."

one of the other genes that affect pelvic spines — or possibly via a different gene yet to be discovered in modern relatives.

Genetic studies help explain the changes seen in the fossil record but also offer a cautionary tale for interpreting that record, says Bell. The delayed decline in growth of pelvic spines for the Nevada sticklebacks can be explained by an initially low frequency of the recessive *PITX1* gene in that population, Bell and Travis propose. For example, if only 1 percent of fish in a group have two copies of such a gene, then the chances of two of them mating and having offspring that also have two copies of the recessive gene are only one in 10,000.

The Nevada sticklebacks illustrate the difficulty in selecting for an extremely rare recessive gene, the researchers say. "For thousands of years, genetic diversity of a population can be hidden," Bell notes. For creatures that take much longer to mature and breed, the physical manifestation of recessive genes could go undetected in the fossil record for even longer.

Plugging holes Critics of evolution delight in a simple irony: When paleontologists discover a creature that fills one gap in the fossil record, they create yet another — one that precedes the newly found intermediate species, and one that follows it. Much to evolutionists' delight, however, paleontologists have remained busy "creating gaps in the fossil record" in recent years. Before the 1970s, scientists discovered an average of 12 new dinosaur genera per decade; since 1990, the rate of discovery has been 10 times higher (*SN: 11/20/04, p. 334*).

But post-Darwin discoveries haven't been limited to large, lumbering land creatures: Scientists have assembled several well-documented lineages of foraminifera, single-celled organisms whose distinctive and intricate shells help pin down the era when sediments containing them were deposited. "This is on-the-ground evidence that Darwin wouldn't have had," says Fortey of the Natural History Museum in London.

And many stretches of the fossil record poorly represented in Darwin's day — specifically the era before the Cambrian period (which began about 542 million years ago and is when much of life's diversity apparently evolved) — are now more thoroughly populated. As Fortey notes: "For Darwin, the Precambrian was a complete mystery, whereas now we have a tremendously detailed narrative" for that era, much of it gathered in the past few decades.

As such discoveries pour in, evolutionary trends almost invariably become clearer. "As you find more and more fossils, you close the gaps with more new species," Fortey adds. In essence, the ever-increasing number of paleontological discoveries is converting a crude connect-the-dots sketch of evolution into a richly detailed pointillist painting.

Charles Darwin: The 'Beagle' Letters

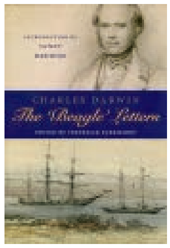
Frederick Burkhardt, editor

Charles Darwin was a prolific letter writer — not unusual in his day, of course, before telephones, e-mail and Facebook. A little less usual is the degree to which his correspondence has been preserved, and so widely read.

Darwin died in 1882, and collecting and assessing Darwinabilia has been a passion for historians of both science and culture ever since. The bicentennial of Darwin's birth has inspired renewed attention and new collections — in this case, a thorough catalog of the letters written by and to Darwin shortly before and during his famous voyage on the HMS *Beagle*, a ship that circumnavigated the globe during the period 1831–1836.

These pages offer much science, from descriptions of South American geology to accounts of Galápagos fauna. "Geology is a capital science to begin," Darwin wrote to a cousin, "as it requires nothing but a little reading, thinking, and hammering." His letters offer personal insights as well: "If it was not for seasickness, the whole world would be sailors."

Depending on your interests (the history of biology, primitive cultures or relationships between 19th century siblings), some of these letters will be more engaging than others. But all are enriched by the late Frederick Burkhardt's copious



footnotes, which offer context and further identifications for the ideas and people that Darwin describes.

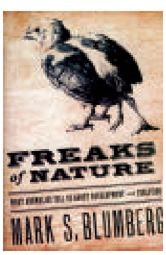
Darwin scholar Janet Browne provides an enjoyable and perceptive introduction that surveys Darwin's life and work and the importance of the *Beagle* voyage to both. These letters "are truly unique for the glimpse they allow into Darwin's thoughts," she writes. "We can accompany Darwin on his voyage of the mind." — *Tom Siegfried*

Cambridge Univ., 2008, 500 p., $32.

Freaks of Nature: What Anomalies Tell Us About Development and Evolution

Mark S. Blumberg

Onlookers gape at freaks. Despite a person's best efforts, it is hard to turn away from conjoined twins, one-eyed infants and legless anythings. But Blumberg, a professor of psychology and editor in chief of *Behavioral Neuroscience*, argues that scientists haven't given nature's oddities enough attention.



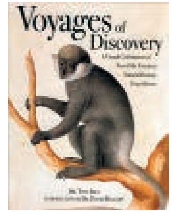
While Blumberg writes in a tone respectful of Charles Darwin's accomplishments, he faults both Darwin and Darwin's 20th century followers for dismissing monstrosities as "abrupt accidents" and "evolutionary dead ends." Rather than sideshow curiosities, Blumberg writes, these evolutionary anomalies are proof that development is just as important as genetics, and small developmental tweaks can lead to very different bodily forms.

"We can continue to carve animals up into discrete chunks and tell stories about the origins of each trait," he writes. "Alternatively, we can move beyond storytelling to take development seriously. When we do, creatures that once seemed so distinctively odd and incomprehensible suddenly become integrated into the large community of organisms."

With well-picked examples, Blumberg constructs his at first peculiar, but ultimately profound, argument. He illustrates how developmental processes can lead to a duplicated face, alternative locomotion and ambiguous genitalia.

Though otherwise startlingly convincing, this read falls short in one respect. Blumberg fails to clearly explain how successful developmental alterations can be passed on to offspring — or fails to acknowledge outright that scientists are still in search of such answers. — *Elizabeth Quill*

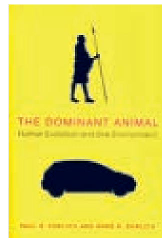
Oxford Univ., 2009, 326 p., $22.95.



Voyages of Discovery: A Visual Celebration of Ten of the Greatest Natural History Expeditions

Dr. Tony Rice

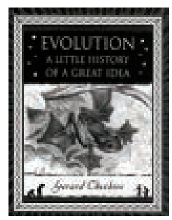
Artwork and photographs from the collection of the Natural History Museum in London document three centuries of exploration. *Firefly Books, 2008, 335 p., $39.95.*



The Dominant Animal: Human Evolution and the Environment

Paul R. Ehrlich and Anne H. Ehrlich

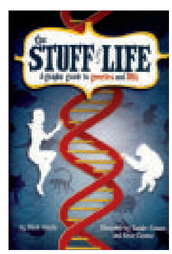
How human culture has shaped the environment, and how the environment has, in turn, shaped evolution. *Island Press, 2008, 428 p., $35.*



Evolution: A Little History of a Great Idea

Gerard Cheshire

A compact guide with one-page chapters covering natural selection, epigenetics, the anthropic principle and everything in between. *Walker & Company, 2008, 58 p., $12.*



The Stuff of Life: A Graphic Guide to Genetics and DNA

Mark Schultz

A scientist from an asexual alien race provides a primer on genetics in this graphic novel for teenagers. *Hill and Wang, 2009, 150 p., $14.95.*

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Right-left preference

In the article "Body in mind" (*SN: 10/25/08, p. 24*), Dr. Casasanto speaks of results with people who are left-handed or right-handed. But no mention is made of people who are innately ambidextrous, as in my family. Has he worked with any of these people? What about people who are almost ambidextrous but not totally? I notice the quality runs in families, but since it is stronger or weaker depending on the individual, I would conclude several genes play a role.
Tana Hemingway, Mesquite, N.M.

"Everyone falls somewhere along a continuum from right- to left-handed," says Daniel Casasanto of the Max Planck Institute for Psycholinguistics in Nijmegen, the Netherlands, whose research suggests people with different kinds of bodies think differently about abstract concepts. "Someone's degree of handedness should influence how strongly they show a preference for their dominant side: Strongly handed people (whether left or right) should show a stronger preference, and weakly handed people, close to ambidextrous, should show a weaker preference. In principle, a perfectly ambidextrous person should show no body-specific preference for things on the left or right — but lots of other factors, in addition to handedness, also influence our judgments." — Bruce Bower

Vitamin D and peanuts

At first glance the study described in "Food advice could be peanuts" (*SN: 12/6/08, p. 8*) seems to control for a single variable. Two equal groups have one difference — exposure to peanuts at an early age and at a later age. Let me suggest that there is another difference. The children of Israel received a great deal more sunlight and therefore more vitamin D than the children in England. Vitamin D improves immune function, and higher levels would mean fewer problems dealing with peanuts.
Bruce Bennett, Watertown, N.Y.

The researchers accounted for several differences between the British and Israeli groups, including age, the existence of other food allergies and any propensity to develop asthma or skin rashes. After adjusting for these factors, the greater incidence of peanut allergy in the British children still stood out. The British children were also clearly more apt to be allergic to tree nuts, but not to sesame, milk or eggs. The researchers didn't account for sun exposure or vitamin D levels. — Nathan Seppa

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Charles Darwin

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Darwin's natural selection redefined the idea of design

Charles Darwin is not around today to explain his views to critics who decry evolution on religious grounds. But among his voluminous writings and correspondence are occasional passages that indicate how he might have answered if questions on such matters were posed to him today. Science News *Editor in Chief Tom Siegfried composed the following questions about Darwin's religious beliefs and views; the answers are all in Darwin's own words, drawn largely from* Charles Darwin: His Life Told in an Autobiographical Chapter, and in a Selected Series of his Published Letters *(1902), edited by his son Francis Darwin.*

Are you an atheist?

What my own views may be is a question of no consequence to any one but myself. But, as you ask, I may state that my judgment often fluctuates.... In my most extreme fluctuations I have never been an Atheist in the sense of denying the existence of God. I think that generally (and more and more as I grow older), but not always, that an Agnostic would be the more correct description of my state of mind.

Before you left for your voyage on the *Beagle*, you studied at Cambridge to prepare for the ministry. Were your views changed on your voyage?

Whilst on board the *Beagle* I was quite orthodox, and I remember being heartily laughed at by several of the officers (though themselves orthodox) for quoting the Bible as an unanswerable authority on some point of morality.... But I had gradually come by this time, i.e., 1836 to 1839, to see that the Old Testament was no more to be trusted than the sacred book of the Hindoos....

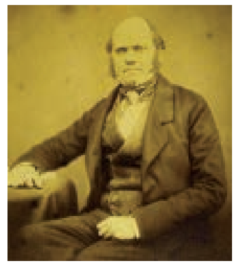
By further reflecting that the clearest evidence would be requisite to make any sane man believe in the miracles by which Christianity is supported, — and that the more we know of the fixed laws of nature the more incredible do miracles become ... I gradually came to disbelieve in Christianity as a divine revelation. The fact that many false religions have spread over large portions of the earth like wildfire had some weight with me.

Today some people cite the arguments of William Paley that the design exhibited in the living world proves the existence of an intelligent designer. You read Paley while at Cambridge and expressed admiration for his work. What do you think about it now?

The old argument from design in Nature, as given by Paley, which formerly seemed to me so conclusive, fails, now that the law of natural selection has been discovered. We can no longer argue that, for instance, the beautiful hinge of a bivalve shell must have been made by an intelligent being, like the hinge of a door by man. There seems to be no more design in the variability of organic beings, and in the action of natural selection, than in the course which the wind blows. But I have discussed this subject at the end of my book on the *Variation of Domesticated Animals and Plants*, and the argument there given has never, as far as I can see, been answered....

I cannot see as plainly as others do, and as I should wish to do, evidence of design and beneficence on all sides of us. There seems to me too much misery in the world. I cannot persuade myself that a beneficent and omnipotent God would have designedly created the Ichneumonidæ with the express intention of their feeding within the living bodies of caterpillars, or that a cat should play with mice....

On the other hand, I cannot anyhow be contented to view this wonderful universe, and especially the nature of man, and to conclude that everything is the result of brute force. I am inclined to look at everything as resulting from designed laws, with the details, whether good or bad, left to the working out of what we may call chance. Not that this notion at *all* satisfies me. I feel most deeply that the whole subject is too profound for the human intellect. A dog might as well speculate on the mind of Newton. Let each man hope and believe what he can.



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How would you describe your feelings about religion generally?

It is impossible to answer your question briefly.... But I may say that the impossibility of conceiving that this grand and wondrous universe, with our conscious selves, arose through chance, seems to me the chief argument for the existence of God; but whether this is an argument of real value, I have never been able to decide....

Nor can I overlook the difficulty of the immense amount of suffering through the world. I am, also, induced to defer to a certain extent to the judgment of the many able men who have fully believed in God; but here again I see how poor an argument this is. The safest conclusion seems to me that the whole subject is beyond the scope of man's intellect. ■

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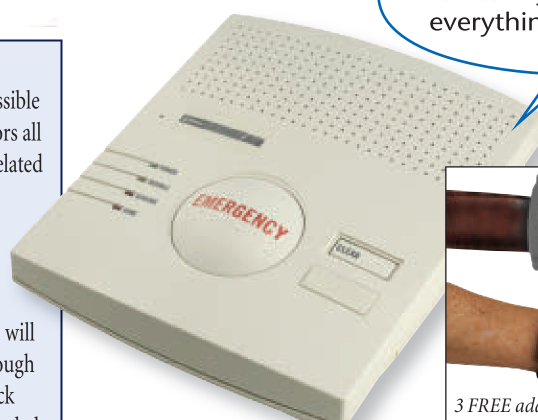

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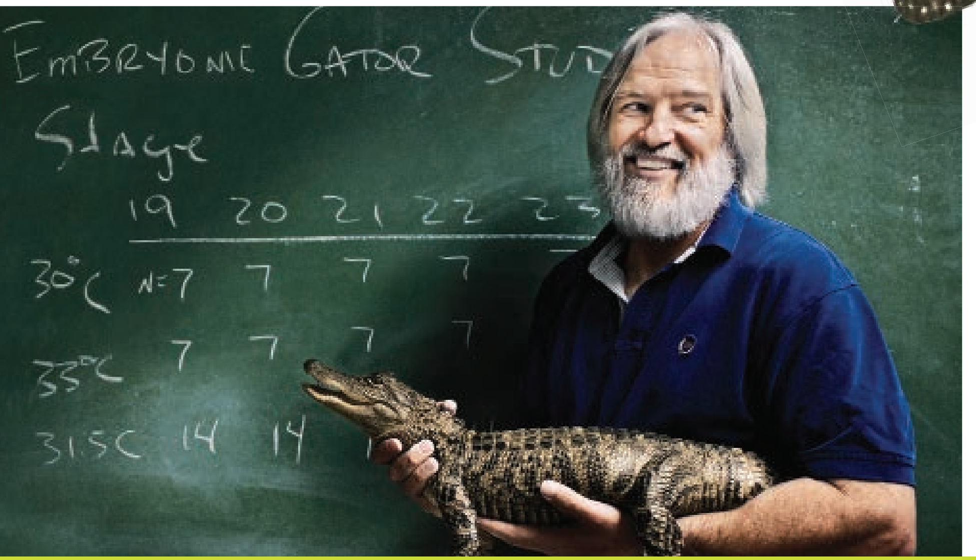

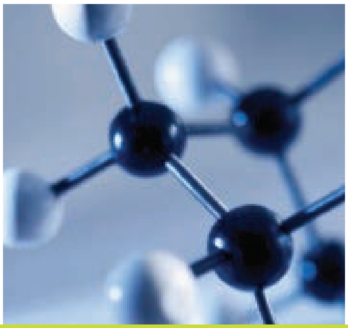

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