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ScienceNews

MAGAZINE OF THE SOCIETY FOR SCIENCE & THE PUBLIC ■ SEPTEMBER 8, 2012

Gas Boom

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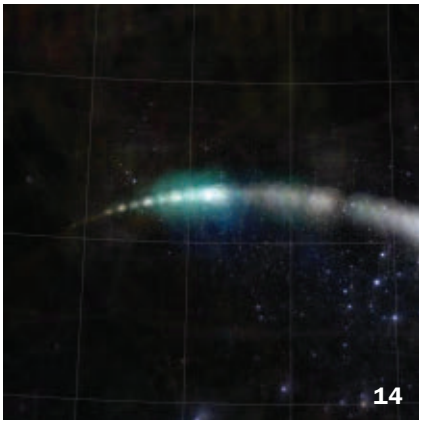

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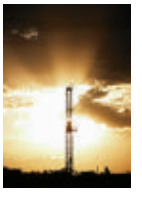

COVER A well tower marks a site for hydraulic fracturing, in which pressurized fluids injected into shale produce cracks that allow natural gas to flow out. *Ed Darack/Science Faction/Getty Images*

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FROM THE EDITOR

Drilling into the fracas over natural gas fracking

It's easy to get lost in the cause célèbre over fracking for natural gas. In television ads, news stories and discussions of energy policy, hydraulic fracturing proponents tout the benefits of using the technology to extract the plentiful gas found in underground shale deposits. Anti-fracking activists have an Academy Award–nominated documentary film, political protests and disturbing tales of what happens when fracking goes wrong: explosive methane leaks, polluted waterways and an uptick in earthquakes.

What has been missing from much of the discourse is the science. How risky is fracking? What are the potential hazards? Are there ways to reduce their likelihood?

A lack of trustworthy information has made matters worse: Recently, a report intended as an evenhanded scientific look at the issues lost credibility after one of its authors was revealed to serve on the board of a company involved in fracking.

On Page 20 of this issue, *Science News* reporter Rachel Ehrenberg provides a scientific primer on fracking, offering neither an indictment nor an endorsement of the technology. As she reports, many scientists believe that fracking's many environmental impacts can be minimized with more regulation, greater transparency and independent monitoring. Deployed without such safeguards, fracking can indeed threaten the health of the environment and humans.

Spills of chemical-laden fracking fluid have contaminated groundwater in a few cases. Fracking in shallow shale deposits, which lie closer to groundwater supplies, may not be a good idea: That may explain why the Environmental Protection Agency found a signal of what looks like fracking chemicals in the water supplies of Pavillion, Wyo. Injecting fracking wastewater into underground wells appears to boost earthquakes near unstable faults. And, yes, in some cases, drilling can trigger leaks of methane, the highly flammable greenhouse gas. But understanding local geology and fixing vulnerabilities in the drilling setup itself could help limit such leaks.

Many questions remain unanswered as scientists scramble to catch up with the boom in drilling for natural gas. All energy sources bring environmental impacts, and whether fracking's risks outweigh its benefits isn't clear. Ultimately, that's as much a question of economics, politics and philosophy as it is of science. But it's crucial that science has a place in that discussion. —*Eva Emerson, Acting Editor in Chief*

PHILIP CHANNING

Enjoy A Bath Again… Safely and Affordably

The Jacuzzi® Walk-In tub is luxurious, feature-packed and affordable

There is nothing like the simple pleasure of taking a warm bath. The cares of the day seem to fade away, along with the aches and pains of everyday life. Unfortunately for many aging Americans with mobility issues, slipping into a bath can result in slipping onto the floor. The fear of falling has made the simple act of bathing and its therapeutic benefits a thing of the past… until now. *first*STREET, the leader in products *Designed for Seniors*® has partnered with Jacuzzi®, the company that perfected hydrotherapy. Together, they've created a walk-in tub that offers more than just safe bathing, peace-of-mind and independence, it can actually help you feel better.

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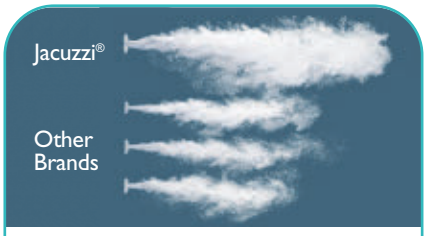

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- **Warranty** - Ask for a lifetime "no leak guarantee." The best tubs offer a lifetime warranty on both the tub and the operating system.
- **Pain Relieving Therapy** - Find a tub that has both water and air jet therapy to soak away your aches and pains preferably with a perfectly balanced water to air mix.
- **Comfort** - Insist on ergonomic design, easy-to-reach controls.
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Say What?

Questing ***\KWEST-ing\ v.*** A host-seeking behavior used by hungry ticks hankering for blood. The tick climbs to the tip of a blade of grass or a leaf and waits with its forelimbs outstretched. When an animal brushes past, the tick climbs aboard. Depending on the tick species, various cues can trigger questing behavior, including body heat, vibrations or a passing host's exhaled carbon dioxide. Researchers in Poland found that one species, the meadow tick (shown), syncs its questing with certain times of day, particularly early afternoon. This coincides with a time when the tick's mammal hosts, deer and elk, are most likely to be out feeding, the researchers note in the July *Journal of Medical Entomology*. —*Allison Bohac*

Science Past | FROM THE ISSUE OF SEPTEMBER 8, 1962

NEW METHOD USES CRYSTAL TO DETECT COSMIC RAYS — A new method for detecting the cosmic rays that continuously bombard the earth from outer space has been developed. The technique of using a crystal to catch the tracks of cosmic rays, already showing its worth on earth, will be tried from an earth satellite this fall.... The method devised under the direction of Dr. Lawrence M. Slifkin of the University of North Carolina, Chapel Hill, N.C., uses a large crystal of silver chloride, which is chemically similar to the silver bromide of usual photographic emulsions. The silver chloride darkens when hit by a cosmic ray.

Science Future

September 26
The Houston Museum of Natural Science celebrates Oktoberfest with the History and Science of Beer. Learn more at bit.ly/SFhoustOkt

September 27–30
The first Wisconsin Science Festival in Madison has hands-on activities and exhibits on the physics of football, the chemistry of urine, Midwest archaeology and more. See bit.ly/SFwiscfest

SN Online

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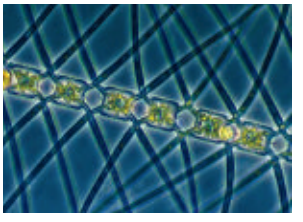
LIFE
Insects practice their own form of suicide bombing. See "Terminator termites have unique technique."

ENVIRONMENT
Iron fertilizer passes a test as a climate aid in "Field test stashes climate-warming carbon in deep ocean."

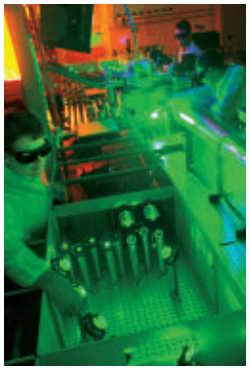


SCIENCE & THE PUBLIC BLOG
Dental resins may be linked to some behavioral shifts in kids. Read "Putting BPA-based dental fillings in perspective."

BODY & BRAIN
Some allergic kids' immune systems can be retrained to handle egg proteins. Read "Egg in tiny doses curbs allergy."

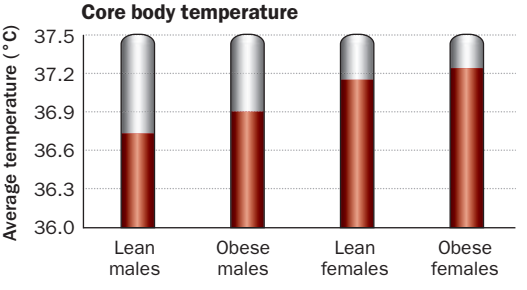
The –est | MIGHTIEST LASER

Twice in a month, physicists broke the record for the world's most powerful laser. On July 5 the National Ignition Facility at Lawrence Livermore National Laboratory in California focused its 192 laser beams and slammed a target with a peak power of more than 500 trillion watts. Fifteen days later, the BELLA laser (left) at Lawrence Berkeley National Laboratory doubled that record, briefly producing a quadrillion watts of power. The NIF laser packs more energy overall, but since peak power is a function of both average power and pulse length, BELLA took the crown with shorter pulses lasting just 40 quadrillionths of a second. Each "shot" briefly concentrates thousands of times the instantaneous power usage of the United States into a single burst. —*Alexandra Witze*



Science Stats | WOMEN RUN HOT

Women's core body temperature runs about 0.4 degrees Celsius warmer than men's, a new study finds, and obesity bumps up temps a bit too. To clear up previously conflicting data, researchers had volunteers swallow pill-sized sensors that radioed core temperature data for 24 hours. The insulating effects of higher body fat percentages in women and the obese compared with lean men may be responsible for the differences, the researchers say. M.E. HOFFMANN *ET AL/OBESITY* 2012



CLOCKWISE FROM TOP LEFT: FTURMOG/FLICKR; MARINA MONTRESOR, SZN, ALFRED WEGENER INSTITUTE; STEPHEN EGTS; ROY KALTSCHMIDT/LAWRENCE BERKELEY NATIONAL LAB

“My concern is that people may look at this study and say being overweight or obese is OK.” —HERMES FLOREZ, PAGE 13

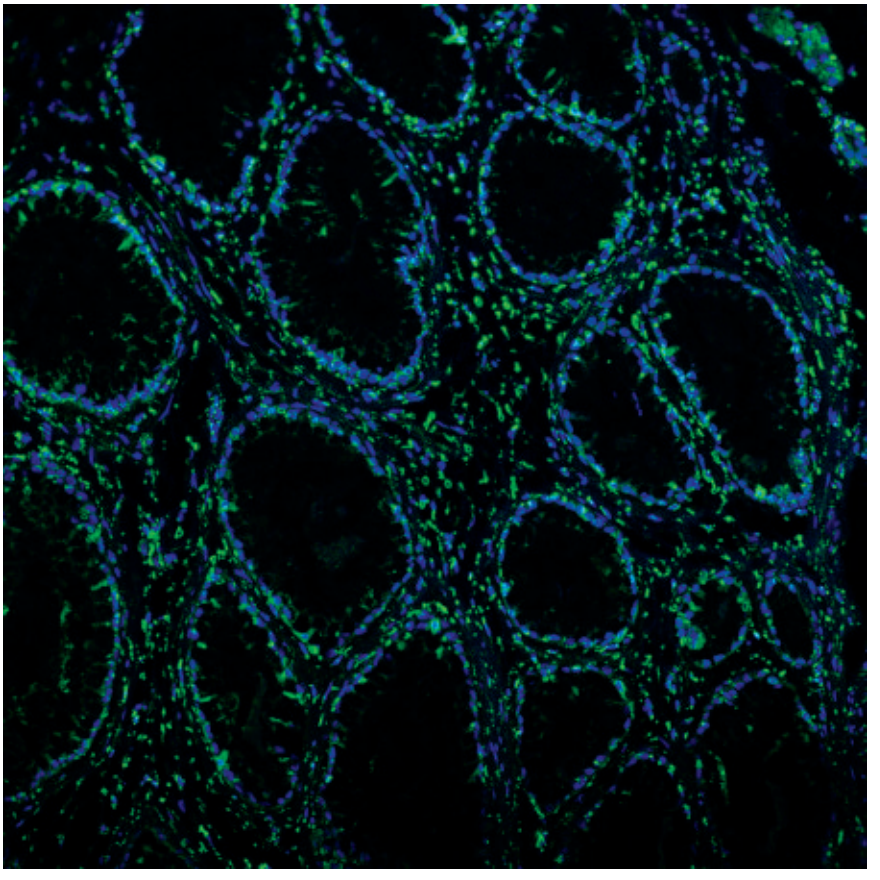
In the News

STORY ONE

RNA research may solve sick snake mystery

Previously unknown viruses could date to dinosaur days

By Tina Hesman Saey



Clumps of proteins (green) in a boa constrictor’s kidney, made visible with fluorescent microscopy, are a hallmark of inclusion body disease. Researchers have pinpointed three unusual viruses that may be linked to the fatal illness.

M. STENGLEIN

Newly discovered viruses may be at fault in a disease that causes snakes to regurgitate their food, behave strangely and even twist themselves into knots.

Researchers at the University of California, San Francisco found three new viruses in captive snakes with inclusion body disease, a fatal illness that strikes boa constrictors and pythons and causes clumps of proteins to build up in the snakes’ cells. Scientists hope to glean clues to virus evolution stretching back to the age of the dinosaurs by examining the trio’s unusual genetic makeup.

“It is so different from anything out there, it’s almost unrecognizable. It’s way out there,” says Joseph DeRisi, a Howard Hughes Medical Institute investigator at UCSF who led the work, which appears online August 14 in *mBio*.

DeRisi’s lab tracks down elusive infectious organisms by sequencing RNA in the cells of a sick animal. RNA, or ribonucleic acid, is a genetic molecule that is a chemical cousin to DNA. Cells store instructions for building proteins in DNA, then make RNA copies of those instructions to send to cellular protein-building machinery.

Many viruses don’t bother with DNA at all, instead storing their genetic information in RNA. So examining RNA gives researchers a better shot at finding viruses than deciphering DNA would. The method could also identify hitchhiking parasites or bacteria.

An outbreak of inclusion body disease at the California Academy of Sciences in San Francisco allowed DeRisi’s group to assemble a collection of RNA from both sick and well snakes. The trick was to isolate odd bits of viral RNA in the samples from the vastly more abundant snake RNA. It was a bit like trying to work a billion-piece jigsaw puzzle with no picture to use as a guide, DeRisi says.

A red-tailed boa named Balthazar provided just the picture the scientists needed. Balthazar is an 11-year-old, 8-foot-long snake who lives at the academy and is used in education programs. The snake is completely healthy and has never had contact with snakes infected with inclusion body disease, says

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Researchers deciphered the complete genetic makeup of a healthy boa constrictor named Balthazar (shown) and used the information to identify viruses that may cause a deadly snake disease.

Freeland Dunker, a veterinarian at the academy.

Assembling Balthazar's complete genetic blueprint let the researchers eliminate snake RNA from their sample of sick and well snakes. What was left behind yielded three previously unknown viruses. The California Academy of Sciences virus, CASV, came from an annulated tree boa at the academy. The Golden Gate virus, GGV, was found in a boa constrictor also from the academy. The Collierville virus, CVV, came from a boa constrictor in Tennessee.

The newly identified viruses are similar to arenaviruses, a class previously found predominantly in rodents. Sometimes an arenavirus, such as the one that causes Lassa hemorrhagic fever, will infect a human. But the viruses have never been found in reptiles before.

The snake viruses also have a feature never before seen in any arenavirus — a gene found in the Ebola virus, which is in a completely different class called filoviruses. Virologists didn't think it possible for those two classes to swap genes, says William Gallaher, a virologist at Louisiana State University Health Sciences Center in New Orleans.

Ebola could have mixed with arenaviruses long ago, resulting in the combination snake virus. But Gallaher thinks the possibility is slim. The two virus types have different biology, so for both to be active in the same cell at the same time and able to mix their genetic material seems unlikely, he says.

DeRisi is excited about another possibility: Perhaps the snake viruses are an ancient ancestor to the arenaviruses and filoviruses. "Maybe what you're looking at is a dinosaur virus eons old," he says. The ancient reptile viruses may then have given rise to arenaviruses that infect rodents.

Or it could be the other way around: The newly discovered viruses may have originally infected rodents, as arenaviruses do today. Sometime in the murky past, a rodent may have passed its virus on to the snake that ate it, says coauthor Mark Stenglein, a virologist working in DeRisi's lab. "We call that the rodent revenge hypothesis."

There is no evidence that modern mice are passing the disease to pet snakes, Stenglein says. And although the viruses were found in snakes with inclusion body disease, that doesn't necessarily mean the virus causes the illness. The next step will be to infect healthy snakes with the viruses to see if they develop the disease.

The snake viruses are so different from other known types that they are probably in a class by themselves, DeRisi says. An international board of experts on viral taxonomy will have the final say over whether the viruses are really a new class, but DeRisi is confident they are distinct. "It's kind of a no-brainer," he says. ■

Back Story | THE SNAKE LADY'S LETTER

Joseph DeRisi wasn't sure at first what to make of the letter he got a few years ago from Taryn Hook of San Jose, Calif., not to mention the photo she enclosed of herself with a boa constrictor draped around her neck. It wasn't the sort of thing the UCSF virologist is accustomed to finding in his mail.

Hook's letter explained that she was worried her beloved 15-year-old boa constrictor, Larry, had contracted inclusion body disease, a mystery illness that had already claimed the lives of her two other pet snakes.

Hook's letter noted that inclusion body disease can cause bizarre behavior and digestive problems — Larry once refused to eat for six months — and that the virus causing the condition was unknown. Since DeRisi had previously identified viruses that cause a mysterious disease in parrots called proventricular dilatation disease, Hook suggested, perhaps he could help.

DeRisi confesses that the letter and photo sat on his desk for a while. He was about to toss them, but something stopped him. "It was the veterinarian's phone number at the bottom of the letter that clued me in that this thing might be real." He called Larry's vet, Chris Sanders of Wildwood Veterinary Hospital in Portola Valley, Calif., and was soon convinced that inclusion body disease was worth going after. Several years of research have now led to the discovery of three previously unknown viruses that may be linked to the disease.

Taryn Hook of San Jose, Calif., holds her pet boa constrictor, Larry.

Larry, the snake who started it all, has tested negative for all three of the viruses. What's ailing him remains a mystery. —*Tina Hesman Saey*

FROM TOP: J. DERISI; COURTESY OF T. HOOK

At first and even second blush, you will think this is the famous brand "X" watch that sells for over $1,000. But this is the Rodell-7 Argonaut™ Watch, the last watch you will ever need to buy. And, incredibly, it can be yours for only ~~$129~~ $69 (or even less) – read on!*

Fairy Tales

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Humans

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New fossils hint at ancestral split

African jawbone suggests two early species in human genus

By Bruce Bower

Newly discovered face and jaw fossils show that at least two species of the human genus *Homo* lived alongside each other in East Africa nearly 2 million years ago.

These new finds are a good match for a roughly 2-million-year-old *Homo* brain case and face excavated in 1972 in the same part of East Africa, reports a team led by anthropologist Meave Leakey of the Turkana Basin Institute in Nairobi, Kenya. Long considered a puzzling exception among early *Homo* finds, the 1972 discovery features big bones and a flat, upright face. That fossil, together with the new finds, represents a new *Homo* species, Leakey and her colleagues conclude in the Aug. 9 *Nature*.

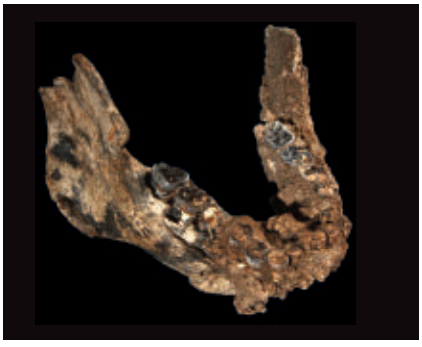
Until now, researchers have found it difficult to exclude the possibility that the flat-faced fossil — known as KNM-ER 1470 — came from a male of the same species as smaller, early *Homo* finds in East Africa.

"After so many years of questions about the identity of the enigmatic 1470 fossil, the chances that it's from a separate species have greatly improved with our new discoveries," says anthropologist and study coauthor Fred Spoor of the Max Planck Institute for Evolutionary Anthropology in Leipzig, Germany.

Members of Leakey's field team unearthed the new fossils from 2007 to 2009 along the shore of Kenya's Lake Turkana. Previously dated volcanic ash layers at the site place the finds at between 1.78 million and 1.95 million years old. Further study is needed before assigning the early *Homo* fossils to particular species, Spoor says, and it's unclear whether either species led to *Homo erectus*, which appeared about 1.7 million years ago, or to people living today. For now, he proposes only that at least two *Homo* species inhabited East Africa nearly 2 million years ago.

Anthropologist Bernard Wood of George Washington University in Washington, D.C., suspects that Leakey's team has found fossil evidence for a new, early *Homo* species distinct from both the 1470 specimen, which he classes as *H. rudolfensis*, and other *Homo* fossils from that time, which he groups under *H. habilis*. The newly found face fossil, which belonged to a child about 8 years old, mirrors the shape of the adult 1470 face, Wood says. But the nearly complete lower jaw and partial lower jaw that Leakey's team found fit neither in *H. rudolfensis* nor in *H. habilis*, he says.

Spoor's proposal that at least two species inhabited East Africa 2 million years ago goes too far, contends anthropologist Tim White of the University of California, Berkeley. Too few early *Homo* fossils exist to rule out whether the new finds, and the 1470 specimen, fall within a single species that included substantial skeletal differences across individuals and between sexes, White says.



A nearly 2-million-year-old lower jaw discovered recently in East Africa, along with other new finds, differs substantially from smaller, earlier discoveries of *Homo* fossils in the region.

Jewish Diaspora written in DNA

Genetic analysis supports history of ancient migrations

By Tina Hesman Saey

Historical Jewish migrations out of the Middle East about 2,000 years ago can be traced through the DNA of people living in Africa today.

These distinctive genetic signatures bolster historical accounts, human geneticist Harry Ostrer of Albert Einstein College of Medicine in New York City and colleagues report online August 6 in the *Proceedings of the National Academy of Sciences*. Their analysis included 509 people from 15 Jewish populations.

Jews settled in Tunisia more than 2,000 years ago, and DNA signatures carried from the Middle East are still evident in Tunisian Jews today, the researchers found. Together with Libyan Jews, the Tunisian Jews form a separate branch from Moroccan and Algerian Jews.

Jews in Morocco and Algeria bear signatures characteristic of Sephardic Jews, who once lived in Spain and Portugal. After being expelled from the Iberian Peninsula in the late 15th century, some Sephardic Jews went to North Africa, carrying their genetic heritage with them.

DNA signatures in Ethiopian Jews distinguish them from Middle Eastern Jews and from other people living in Ethiopia. The findings are consistent with historical accounts that local people were converted to Judaism, then spent more than 2,000 years in cultural and genetic isolation.

Though the new study is the most in-depth of its kind, it certainly doesn't determine who is a Jew. "Genetics is only a facet of identity," says Francesc Calafell, a population geneticist at the Institute of Evolutionary Biology in Barcelona.

"Genetics is only a facet of identity." —FRANCESC CALAFELL

DNA hints at African cousin

Profiles suggest existence of now-extinct human relative

By Tina Hesman Saey

Researchers have found the genetic signature of a sister species to *Homo sapiens* buried in the genetic blueprints of 15 African hunter-gatherers. Its DNA apparently jumped into the *Homo sapiens* gene pool through interbreeding with modern humans about 30,000 to 70,000 years ago, when other modern humans and Neandertals were mixing in the Middle East. Researchers report the genetic findings in the Aug. 3 *Cell*.

The evidence for past interbreeding is convincing, says Richard "Ed" Green, a genome biologist at the University of California, Santa Cruz. "There is a signal that demands explanation, and archaic admixture seems to be the most reasonable one at this point," he says.

Scientists have discovered that some people with ancestry outside Africa have DNA inherited from Neandertals or from Denisovans, a mysterious group known only through DNA derived from a fossil finger bone found in a Siberian cave (*SN: 6/5/10, p. 5; SN: 1/15/11, p. 10*).

Those researchers had DNA from fossils to guide them. This time, researchers led by Sarah Tishkoff at the University of Pennsylvania in Philadelphia didn't have fossil DNA, or even fossils.

Tishkoff's group took DNA donated by 15 African hunter-gatherers — five Pygmies from Cameroon and five Hadza and five Sandawe from Tanzania — and compiled complete genetic blueprints for each person. Population geneticist Joshua Akey of the University of Washington and his colleagues helped analyze the data. Using a statistical analysis, the team determined that about 2 percent of the DNA from the hunter-gatherers came from an unknown species of hominid that split from modern human ancestors about 1.1 million years ago. These long-lost human cousins must have then interbred with modern humans sometime before the common ancestral lineage of the three hunter-gatherer groups separated about 30,000 to 70,000 years ago, Akey says.

Other researchers aren't convinced that the DNA remnants identified are the genetic remains of a new species of human cousin. The DNA could have come from a genetically distinct group of modern humans that has since died out due to changes in the environment, diseases or confrontations with rival groups of people, says Jean-Jacques Hublin, a paleoanthropologist at the Max Planck Institute for Evolutionary Anthropology in Leipzig, Germany.

Relatively recent interbreeding isn't the only explanation for the presence of this newly discovered DNA, says anthropological geneticist Paul Verdu of Stanford University. He thinks the DNA may be the genetic stamp left by a common ancestor of modern humans and another species. The DNA may have morphed so much in non-African groups, just by chance, that it is now unrecognizable.

Maiden died with TB-like illness

Analysis captures data on Incan mummy's immune system

By Tina Hesman Saey

As she climbed to her death 500 years ago, a 15-year-old Incan girl known as the Maiden was combating a bacterial infection similar to tuberculosis, an analysis indicates. Angelique Corthals, a forensic anthropologist at the City University of New York, and colleagues report the findings online July 25 in *PLOS ONE*.

The Maiden was one of three children whose mummified remains were found near the summit of an Argentine volcano in 1999. Corthals wanted to know whether the children were given a fermented corn drink called chicha, which was used to numb sacrifice victims. Researchers swabbed blood and saliva from the lips of the Maiden and another mummy, a boy. The face of the third mummy, a younger girl, was damaged by a lightning strike after burial, so the researchers couldn't include her in the study.

There was no sign of corn liquor, Corthals says, but the protein profiles indicated that the Maiden's immune system had been more active than the boy's. Her swabs contained immune system proteins indicating chronic lung infection. DNA evidence showed that the girl was carrying some type of *Mycobacterium*, although the researchers can't yet nail down whether the species is the same one that causes tuberculosis.

"It is going to be the first paper among probably a lot to come looking at infectious diseases among dead people," says Robert DeSalle of the American Museum of Natural History in New York City.

This now-mummified Incan girl, known as the Maiden, was sacrificed on top of a South American volcano 500 years ago. New data suggest the girl had an active infection with a bacterium similar to the one that causes tuberculosis.

JOHAN REINHARD

Environment

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Extreme heat rising worldwide

Temperature records reveal increased odds of swelter

By Janet Raloff

It's not your imagination. Not only are extremely hot temperatures occurring more frequently across the globe, but those heat waves are getting more severe.

Back in the 1950s, temperatures on any given summer day were just as likely to be near average as they were to be unseasonably high or low. Climatologist James Hansen of NASA's Goddard Institute for Space Studies in New York City likens that scenario to rolling a die with two sides each corresponding to low, average and above-normal temperature.

Since the 1980s, that metaphorical die has increasingly become weighted toward delivering a warm day, Hansen and his coworkers report online August 6 in the *Proceedings of the National Academy of Sciences*. In fact, Hansen says, since 2000 it's as though on any roll four sides will draw hotter than average summer heat.

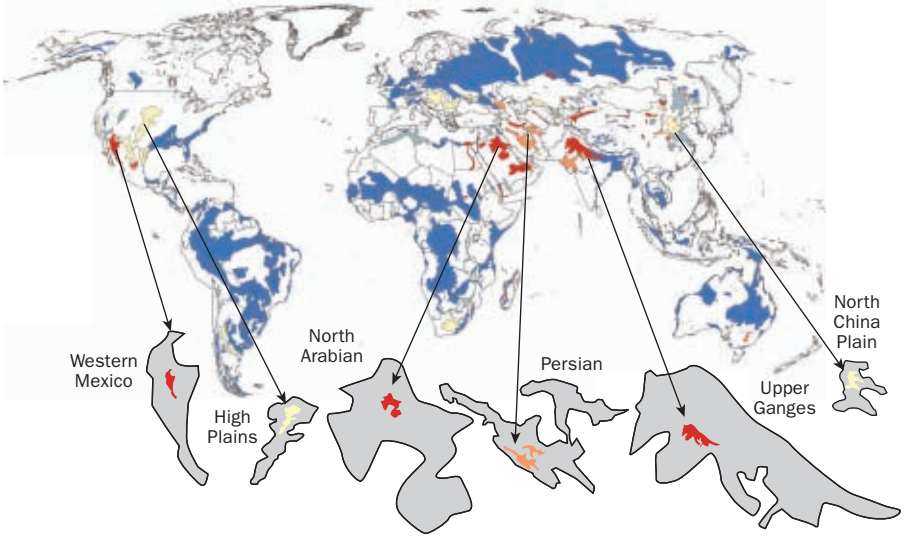
Hansen says the study also suggests that a new level of extreme heat is emerging "that almost never occurred 50 years ago." Formerly striking about 0.2 percent of the Northern Hemisphere's land in any given summer, this degree of anomalous warmth now strikes about 10 percent of that area. Within a decade, his data suggest, these hot spells could reach 16.7 percent of the hemisphere's land mass.

"We're not showing that this is a consequence of an increase in carbon dioxide and other greenhouse gases," Hansen says. In fact, his team's analysis makes no attempt to attribute the underlying source of warming to any particular cause. He does volunteer, however, that there is "a strong consensus within the scientific community that the warming we're seeing is primarily a response to an increase in greenhouse gases."

John M. Wallace of the University of Washington in Seattle says he is not surprised to see this shift toward more extremely warm days — and hotter extremes within those periods. "Just as a rising tide lifts all ships," he says, there is good reason to believe that growing global warming should elevate extremes. Computer projections of Earth's changing climate call for such a pattern. "If a trend in that direction is detectable already," Wallace says, "that would constitute an important finding."

The focus on temperature changes in recent decades — as opposed to all types of weather extremes, including floods, storms, droughts and more — constitutes "picking a relatively easy target," says Thomas Knutson of the National Oceanic and Atmospheric Administration's Geophysical Fluid Dynamics Laboratory in Princeton, N.J. Still, he says, the new data are interesting and "underscore the substantial changes already underway in terms of surface temperatures and their extremes."

Groundwater use outpaces supply



T. GLEESON *ET AL./NATURE* 2012

A handful of thirsty countries are guzzling their groundwater reserves much faster than those resources can be renewed.

India, Pakistan, China, Saudi Arabia, Iran, Mexico and the United States lead the global pack of water-thirsty nations, researchers report August 9 in *Nature*. Irrigation for agriculture drives much of the demand, says hydrogeologist and study coauthor Tom Gleeson of McGill University in Montreal.

He and colleagues devised a new "groundwater footprint" measure to evaluate the sustainability of withdrawals from the world's aquifers. A footprint larger than its aquifer means people are using water faster than it can be replenished, Gleeson says.

Though 80 percent of the world's aquifers (blue on map) have sustainable footprints, people drawing on others (red, orange and yellow) are draining the world's water supply. For these overtapped reservoirs, groundwater footprints (in gray below map) vastly exceed aquifer area (in color). For the Upper Ganges the footprint is 54 times the size of the aquifer. "It's not sustainable," Gleeson says. "We don't know how long the aquifers will last." —*Meghan Rosen*

Life

20 hertz — The highest frequency of infrasound

200 hertz — The average frequency of a woman's voice

10 kilometers — The distance an elephant's call can travel in air

How elephants call long-distance

Air rushing through larynx produces infrasonic tones

By Susan Milius

Elephants don't purr so much as sing when they unleash low-frequency rumblings at friends and foes kilometers away.

Too low for humans to hear, the infrasonic components of elephants' calls have at times been attributed to a process similar to a cat's contented thrum. But new measurements made by blowing air through the voice box, or larynx, of a deceased zoo elephant suggest that the mechanism is actually a (much bigger) analog to a person speaking or singing.

Cascades of fast, active muscle contractions give cats their purr. Biologists have speculated that similar muscle twitching creates the deep throbbing of elephant infrasound. But elephants can get their rumbles going just by exhaling air through their vocal tracts, says Christian Herbst of the University of Vienna. With the new demonstration of air power, Herbst says, "there's no need to go into the purring hypothesis." He and his colleagues make their case for superlow elephant song in the Aug. 3 *Science*.

As air passed through the disembodied larynx in the lab, flapping vocal cords re-created sounds similar to an elephant's infrasonic blast in the lowest-pitched vibration, called the fundamental frequency. These infrasonic tones can reach up to 10 kilometers under ideal conditions in air and vibrate via the ground too, theoretically going much farther.

An elephant's larynx (CT scan reconstruction of basic bone and cartilage scaffolding shown) functions much the same way as do larynxes in smaller, squeakier mammals, including people.

Vocal folds flapping in the wind might be only the beginning of the story, says Caitlin O'Connell-Rodwell of the Stanford School of Medicine's otolaryngology department. The test didn't capture all of the complexities of a real call from a living animal with an intact head.

"Elephants have these really interesting anomalies," O'Connell-Rodwell says. A large cavity opens in the front of an elephant skull, with deposits of dense fat a bit like the acoustic structures found in marine mammals.

Body & Brain

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Brain takes note when others err

Some neurons light up only upon seeing a peer's mistake

By Laura Sanders

When one monkey sees another monkey messing up, the event ignites a small cluster of nerve cells in the brain that are sensitively tuned to others' failures. The results may help explain why members of another primate species are such exquisite connoisseurs of blame.

"We humans are very sensitive to others' mistakes," says Masaki Isoda of the Okinawa Institute of Science and Technology in Japan. He and his colleagues describe macaques' blunder detectors online August 5 in *Nature Neuroscience*.

Catching other people's slipups isn't just schadenfreude. Noting another's lapse, be it a gymnast's step out of bounds or another animal's regurgitation of a poisonous berry, is a good way to learn about the world. "Everybody's life is a bit of a trial-and-error game," says neuroscientist Matthew Shane of the Mind Research Network in Albuquerque, who was not involved in the new study. An ability to sense others' errors helps people see what doesn't work without suffering the consequences firsthand.

Past studies have suggested that certain nerve cells in a brain region called the medial frontal cortex are general error catchers: The cells were thought to fire when a person makes a mistake and also when witnessing someone else err. But by listening in on single nerve cells in macaques, Isoda and his team found that some of these neurons don't seem to care about a personal mistake. Instead, these neurons are exclusively trained on other animals' errors.

> "Everybody's life is a bit of a trial-and-error game."
> MATTHEW SHANE

Isoda and colleagues taught macaque monkeys to press either a yellow or a green button for a liquid reward. After every two rounds, the two monkeys switched between pushing the button and watching. If the button pusher got the right answer, both monkeys got a treat. But if the answer was wrong, both monkeys were denied.

Electrodes monitoring neuron behavior during the game found a small group of cells that fired away when a monkey watched its partner commit a treat-costing error, but not when the monkey itself messed up. (The researchers knew the observing monkey caught the error because it would not lick its lips in anticipation of a reward.)

People so readily pin the blame on a sister, neighbor or boss when things go wrong that it would make sense for people to also have nerve cells that can make these distinctions, Shane says.

Creating a full sense of another person's error involves other brain systems as well, says neuroscientist Ellen de Bruijn of Leiden University in the Netherlands. "You start to think about this other person and take the perspective of this other person," she says. That kind of sophisticated social reasoning probably involves brain areas outside the medial frontal cortex, she says. ■

DANIEL STREICKER

Rabies resistance arises

Some people living in a vampire bat–ridden part of the Peruvian Amazon seem to have developed natural resistance to the rabies virus. The discovery of antirabies antibodies in the blood of 14 percent of healthy individuals tested in two communities suggests that people had been exposed to the virus and survived, researchers from the U.S. Centers for Disease Control and Prevention and the Peruvian Ministry of Health write in the August *American Journal of Tropical Medicine and Hygiene*. Those testing positive for antibodies reported bites, scratches or skin contact from a vampire bat (shown). Only one person sampled reported having been vaccinated against rabies. "Why these individuals don't die is very intriguing," says disease ecologist Amy Gilbert of the CDC. Many factors may determine whether a bite leads to full-blown infection. The vampire bat's relatively gentle bite may deliver a lower viral dose than a dog's or raccoon's. The proximity of the bite to the victim's head can also play a role. Even the victim's genetics may be important. —*Rachel Ehrenberg*

5.3 percent | U.S. 12th graders who used ecstasy, 2011

36.4 percent | U.S 12th graders who used marijuana, 2011

63.5 percent | U.S. 12th graders who used alcohol, 2011

Ecstasy causes memory loss

New drug users do worse than nonusers on recall test

By Laura Sanders

Light use of the club drug Ecstasy may cause subtle memory deficits. People who popped an average of three Ecstasy tablets a month over a year saw their memory slip on a laboratory test, scientists report online July 26 in *Addiction*.

The new results offer some of the best evidence yet that the drug can change the brain, says neuroscientist Ronald Cowan of Vanderbilt University Medical Center in Nashville. "It's been very, very difficult to convince people that there's a causative effect of the drug," he says. "This adds strong evidence to that."

Scientists debate whether Ecstasy, a drug that brings euphoria, boundless energy and heightened sensory experiences, can actually harm the brain in part by messing with cells that produce the chemical messenger serotonin. Past studies have been notoriously hard to interpret because brain differences seen between Ecstasy users and nonusers could have existed long before the drug use began. And people who use Ecstasy frequently tend to use other drugs too, making it hard to tease out Ecstasy's effect.

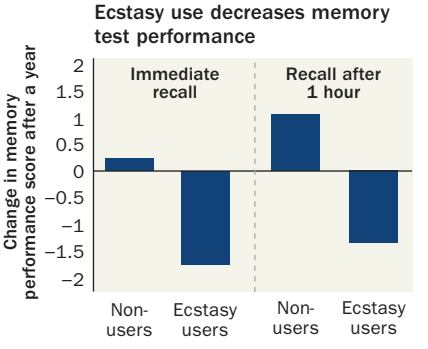
For the study, Daniel Wagner of the University of Cologne in Germany and his colleagues wanted to catch people as they started using Ecstasy. The team recruited 149 people who had used the drug five or fewer times and ran the subjects through a battery of brain tests looking for signs of mental deficits. One year later, the team retested 43 people who had not used Ecstasy since being recruited, and 23 who had used 10 or more Ecstasy pills in that time. These people reported using an average of 33.6 tablets.

On most laboratory tests, the two groups performed similarly. But on one memory test, participants who had used Ecstasy scored worse. Ecstasy users had trouble remembering which distinctive border had framed a particular picture, both immediately after they saw a set of images and one hour later. The results show that a moderate amount of Ecstasy use over just a year can cause memory problems, says Wagner. "We were really surprised by that."

It's not clear whether this deficit seen in the laboratory would be noticeable in everyday life, says neuroscientist Jerrold Meyer of the University of Massachusetts Amherst. Perhaps some populations, such as students, would suffer more consequences from this particular memory problem, he says.

"I'm reasonably convinced by their data, but obviously as with any study, there are always unanswered questions," Meyer says. Scientists don't know if memory skills would bounce back when Ecstasy use stopped, for instance, or whether the severity of the memory problem scales with the amount of Ecstasy used.

Memory slip People who took an average of three Ecstasy pills per month in the previous year did worse on a memory test compared with subjects who didn't use the drug. Immediate recall and retention after one hour were tested.
SOURCE: D. WAGNER *ET AL/ADDICTION* 2012



Thin isn't always better in diabetes

Obese have lower mortality rate than normal-weight people

By Meghan Rosen

People who are normal weight when diagnosed with type 2 diabetes may have a higher risk of death than those who are overweight or obese.

While counterintuitive, the findings may suggest that normal-weight people with type 2 diabetes are more likely to have other illnesses, frail bones or wasting muscles, researchers report in the Aug. 8 *Journal of the American Medical Association*.

"This study raises a lot more questions than answers," says epidemiologist Lynne Wagenknecht of Wake Forest Baptist Medical Center in Winston-Salem, N.C. But the authors have done "a really nice job examining every which way, upside down and right side up of what might be going on here," she says.

Led by epidemiologist Mercedes Carnethon of Northwestern University Feinberg School of Medicine in Chicago, researchers combined data from five long-term studies that tracked healthy people for a maximum of 28 years. The team recorded the body mass index, or BMI, and waist circumference of the 2,625 participants diagnosed with type 2 diabetes during the study periods. Compared with overweight and obese people who developed diabetes, normal-weight participants were twice as likely to die during the studies' follow-up periods.

"My concern is that people may look at this study and say being overweight or obese is OK," says endocrinologist Hermes Florez of the University of Miami. "The reality is that height and weight don't tell you the whole story." Factors such as fitness level and body fat are important too, he says.

Atom & Cosmos

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Crowdsourcing looks to heavens

Collected online snaps of Comet Holmes determine orbit

By Nadia Drake

Some people scour the Internet for pictures of celebrities and cats.

Others search for comets.

After performing a Yahoo! image search for photos of Comet Holmes, which whizzed by Earth in 2007, a team of astronomers used the images they found to reconstruct the comet's orbit in three dimensions — proving that astronomers can take advantage of data provided by unwitting participants.

Comet Holmes flew by Earth in 2007. This composite image of the comet was created by astronomers who reconstructed the object's orbit using photos from the Internet.

"I think it's the beginning of something really, really important," Harvard University's Alyssa Goodman says of the study, which appears in the August *Astronomical Journal*. "The biggest deal is the availability of all this data that isn't being collected for the purpose it was used."

Though the Internet is crammed with freely available information — trends on Twitter, for example, can point toward breaking news — organizing it into something useful for science takes skill.

When Dustin Lang, a computer scientist at Princeton University, decided to harness the power of picture-posting astro-observers, he asked an online computer program called Astrometry.net to filter the images. Astrometry.net uses the objects in each photo — stars, for example — to determine where in the sky the image is located.

Initially, the Yahoo! search returned more than 2,400 images. Those included the comet, as well as pictures of completely different things.

"There were two cats in the original search results," Lang says.

Lang and David Hogg of New York University used Astrometry.net to narrow the results to 1,299 usable images — a motley collection of photos snapped from different locations with different cameras and exposures. Then the team reconstructed the comet's orbit in 3-D — and came close to the orbit determined by NASA's Jet Propulsion Laboratory in Pasadena, Calif.

"This is a look at what we could do with really, really heterogeneous data that we don't really know anything about," Lang says. "It was more work than we expected."

And it's not just astronomy that could benefit from such crowdsourcing. "There are many other fields where it will apply later," Goodman says, suggesting that medical images and weather data could be similarly mined.

Lithium mystery could get deeper

Black holes may make a tough problem even tougher

By Nadia Drake

The universe is lacking lithium — and instead of solving what's known as the "lithium problem," a new study makes it even more complicated.

The work, published in the July 13 *Physical Review Letters*, suggests that some small black holes could be acting as lithium factories. The problem is, observed lithium levels are too low to accommodate such production and are also much lower than predicted by otherwise robust theories describing how the first chemical elements were created just after the Big Bang.

"This makes the lithium problem worse," says astrophysicist Brian Fields of the University of Illinois at Urbana-Champaign. "But it could point to more exotic goings-on in the Big Bang."

Lithium, along with hydrogen and helium, was one of the few elements produced in the hot, energetic moments after the Big Bang. Unlike hydrogen and helium, observed lithium levels are three or four times lower than Big Bang physics predicts.

So scientists have been on the hunt for potential sources of lithium destruction.

But Fabio Iocco, a physicist at Sweden's Stockholm University, has proposed the opposite: a potential lithium factory, in the form of relatively small black holes weighing in at an average of five solar masses. As some of these black holes drain material from a companion star, the sucked-in material forms a swirling, doughnut-shaped ring. Iocco calculated that the swirling mass ends up being hot enough — more than 10 billion degrees Celsius — to ignite nuclear fusion and synthesize lithium.

According to Iocco's calculations, even if a tiny fraction of the Milky Way's black holes munched matter in this fashion, the process would generate the same amount of lithium as the Big Bang.

Though tantalizing, the study isn't the final word, says Andreas Korn of Sweden's Uppsala University. "We're still at a loss for a consistent theory," he says.

D. LANG AND D.W. HOGG

Genes & Cells

"The tumor is really a caricature of the normal situation." —HUGO SNIPPERT

Select cell types spawn tumors

Studies support theory that cancers arise from stem cells

By Tina Hesman Saey

New evidence from three independent studies supports the idea that solid tumors in the brain, colon and skin can arise from a few bad cells known as cancer stem cells.

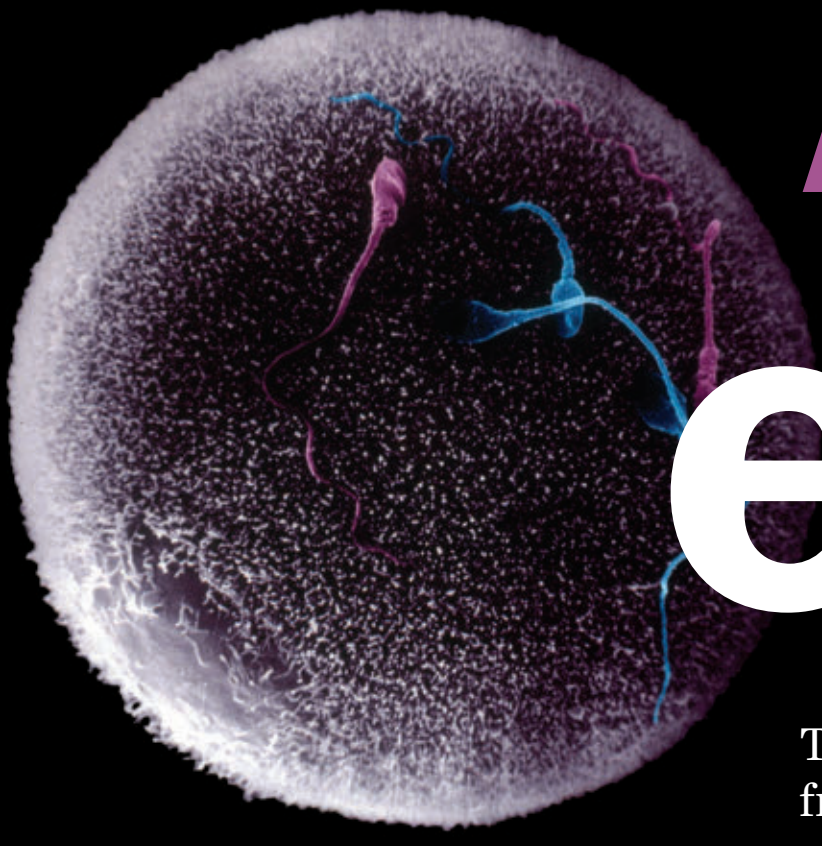
Cancer stem cells are thought to be able to re-create tumors the way that normal stem cells replenish tissues. In one study, researchers found that about 20 percent of cells in benign skin tumors called papillomas are cancer stem cells. But skin cancers called squamous cell carcinomas have a much higher proportion of these rapidly growing cells, Gregory Driessens of the Université Libre de Bruxelles in Belgium and colleagues report online August 1 in *Nature*. The finding could mean that for tumors containing large numbers of cancer stem cells, any cell in the tumor could cause a recurrence of the cancer, Driessens says.

In contrast to squamous cell skin cancers, a deadly type of brain tumor called glioblastoma multiforme relies on only a small pool of such cells to generate the tumor, researchers led by Luis Parada, a molecular geneticist at the University of Texas Southwestern Medical Center in Dallas, report online August 1 in *Nature*.

Parada's team genetically engineered mice to make green fluorescent protein in all stem cells in their brains. After the mice developed glioblastomas, a chemotherapy drug called temozolomide killed dividing cells in the tumor but didn't eliminate the cancer stem cells, which are mostly dormant but have bursts of growth. When chemotherapy stopped, the stem cells began to divide and caused the tumor to grow again. The finding suggests that the only way to cure this type of cancer is to kill the stem cells, Parada says.

A third study, published in the Aug. 10 *Science*, shows that a benign colon tumor called an adenoma grows from stem cells normally responsible for replacing intestinal cells. "The tumor is really a caricature of the normal situation," says study coauthor Hugo Snippert, a molecular geneticist at the University Medical Center Utrecht in the Netherlands.

While the studies don't definitively demonstrate that only cancer stem cells can re-create tumors, they indicate that future research should investigate these cancer types in their native environments, says Phil Jones, a stem cell biologist at the Hutchison/MRC Research Centre in Cambridge, England.



As told by the egg

The story of fertilization, from the female point of view

By Susan Gaidos

Whether the chicken or the egg came first doesn't occupy biologist Luca Jovine's thoughts too much. Animals have been laying eggs for millions of years, after all. Over time, evolution has reshaped both the eggs and the creatures hatched from them.

Instead, Jovine spends his time unscrambling another egg-related conundrum: How does the egg orchestrate the molecular mating dance that creates all these new individuals?

For a fuller understanding of the ways that egg and sperm tango during the lead-up to fertilization, Jovine is seeking help from the chicken.

Eggs come in all shapes and sizes. A lot of animals living on land — chickens and other bird relatives, as well as reptiles — produce oval or round eggs with hard outer shells. Water-dwelling creatures such as frogs lay tiny unshelled eggs in jellylike masses. Most mammals, including humans, reproduce through eggs that are fertilized and develop inside the body.

While evolutionary changes in egg shape and size are easy to detect, some scientists are interested in parts of the egg's exterior undergoing rapid but less obvious changes: The proteins that recognize and bind to sperm. Research is now beginning to reveal how these proteins, found on the outside of the egg, help the female exert her power over the reproductive act.

Biologists have long been puzzled by the molecular events that take place during that momentous embrace between sperm and egg. Researchers using scanning electron microscopes have been able to collect fuzzy images of the occasion, but the details have remained obscure.

Protein studies that do exist have focused mostly on the male's side of the story, emphasizing sperm-on-sperm competition. That's partly because sperm can be easier to study, and are much easier to come by, says Willie Swanson, a biologist at the University of Washington in Seattle. Unlike males, who churn out a lot of sperm, females produce a limited number of hard-to-collect eggs.

Studies are suggesting that sperm aren't completely in control when it comes to fertilization.

"In some sense, the egg has been long ignored," Swanson says.

But now it's the egg's turn to tell her side of the story. With the help of a chicken, Jovine's group at the Karolinska Institute in Sweden has determined the structure of an egg protein that binds to sperm at conception, giving scientists a glimpse of life's initiation from the egg's point of view. In the two years since that advance, researchers have begun hatching even more experiments to better understand how an egg attracts and unites with a sperm that suits her.

Last year, scientists identified a sugary compound on the egg's outer shell that helps sperm bind to egg. Early this

DAVID M. PHILLIPS/PHOTO RESEARCHERS, INC.

year, scientists showed that mammalian eggs secrete a certain enzyme to avoid being fertilized by more than one sperm (which could bring death to egg and embryo). And a recent study suggests that sea urchin eggs devise ways to slow the fertilization process so a female can find the right match.

The findings go beyond understanding the egg's role in establishing new life. Recent work could provide insights into how new species come about. Studies might also aid in developing new contraceptives and explain some cases of infertility.

Shell games

Sex-based reproduction — a primary path to procreation in multicellular organisms — requires two parents. It also requires special reproductive cells, or gametes: an egg and a sperm. The human egg and sperm are opposite in many ways. Eggs are plump and sizable. Sperm cells look like puny arrows, with long tails for motility.

But it wasn't always this way. Once upon a time, long before humans came about, male and female sex cells looked about the same. Florida State University biologist Don Levitan says that the distinguishing features of sperm and egg probably started as an amplification of small natural variations. Cells are not perfectly uniform. Heftier female cells may have produced healthier progeny because they had more substance to create a viable offspring. Smaller male cells may have flourished because they were easier to make. Over time, natural selection drove the big to get bigger and the small to get smaller.

The first organism to develop from a fertilized egg may have been a sponge-like creature, Levitan says. Such animals, among the earliest to have specialized cell types, predate the dramatic burst in life's diversity that occurred during the Cambrian, taking the egg back more than 540 million years.

Today, creatures as simple as sponges and complex as humans still rely on some form of egg for reproduction. But most mammals have given up their egg-laying ways, replacing shell-bound eggs with the ability to nurture the fetus in the womb. Only a handful of mammals, including the platypus, lay eggs.

Curious about the genetic changes that made this transition possible, biologist Henrik Kaessmann of the University of Lausanne in Switzerland and colleagues looked at genes linked with egg-laying and milk production in humans, dogs, opossums and platypuses. The researchers reported in 2008 that mammals could produce milk long before they stopped laying eggs. The results fit with previous thinking that the development of mammary glands — and the ability to nurse babies — may have prompted the transition.

Still, the eggs of humans and other mammals retain a tough, protective casing. In humans, the egg floats in a jelly-like envelope and is surrounded by a hard outer coat called the zona pellucida. Studies of the human zona barrier show that it is made of four major protein chains — called ZP1, ZP2, ZP3 and ZP4.

While hundreds of sperm may latch onto the egg's outer structure, typically only one gets through to fertilize the egg. In 1980, a team of scientists led by Paul Wassarman, now at Mount Sinai School of Medicine in New York City, discovered that ZP3 serves as the docking station to help a mammalian sperm achieve this task. Only after binding to the ZP3 receptor can a sperm go through a process called the acrosome reaction to release the enzymes needed to penetrate the egg. To figure out which part of the ZP3 molecule is crucial for binding in humans, scientists needed its three-dimensional structure. Studies were stymied for decades because human eggs are hard to come by and hard to work with.

That's why Jovine enlisted help from the chicken. His group converted the chicken version of ZP3 into a solid crystal form, then deduced its structure by analyzing patterns of X-ray beams reflected off it. With the help of several different computer programs, the scientists were able to use this structure as a base to build a 3-D model of the mammalian version of ZP3.

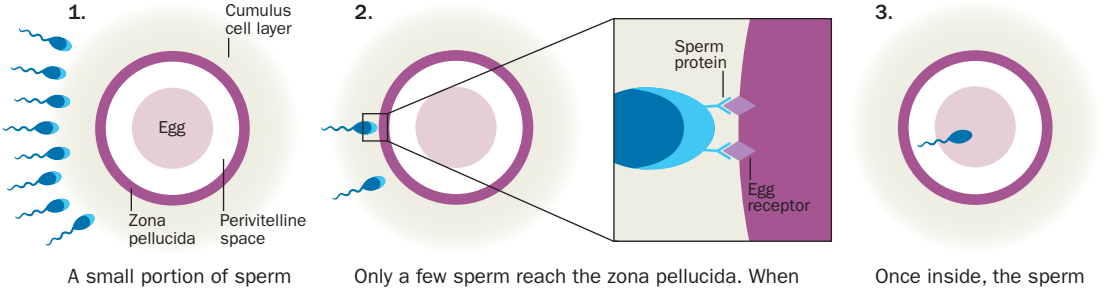
The results, published in 2010 in *Cell*, showed that the receptor is made up of a single protein and is divided into two major sections. Working out the shape of the surface involved in sperm binding raises the possibility of designing small molecules to disrupt the process to prevent conception, Jovine says.

Wassarman says the findings provide information about fertilization not just in mammals, but in other animals as well. That's because one of the two major regions of the ZP3 protein, called ZP-N, contains a structural unit found in the egg-coat proteins of animals ranging from fish to frogs to birds and mammals.

"These findings strongly suggest that features of ZP3 have been conserved

Intimate encounter

In mammals, millions of sperm race through the female reproductive tract vying to be the first to access the egg. But the sperm have to get through a protective membrane called the zona pellucida.



A small portion of sperm make it through a layer of cells around the egg.

Only a few sperm reach the zona pellucida. When a sperm binds, a reaction releases substances allowing the sperm to break through.

Once inside, the sperm fuses with the egg, fertilizing it.

SOURCE: K.G. CLAW AND W. SWANSON/*ANN. REV. GENOMICS HUM. GENET.* 2012

E. FELICIANO

during evolution for more than 600 million years," Wassarman says.

Jovine's team is using this structure as a starting point to build a 3-D model of the zona pellucida, to see how proteins are assembled in this egg-enveloping membrane. "We would like to get a grasp of what sperm sees," Jovine says.

A complete model would help scientists better understand how various proteins work to help, or hinder, sperm attempting to access the egg. ZP2, for example, has long been implicated as another important receptor for fertilization. Early this year, researchers discovered that eggs may secrete an enzyme called ovastacin that slashes away at the ZP2 proteins in the egg's outer shell once fertilization has occurred. That activity, reported April 2 in the *Journal of Cell Biology*, would make it clear that the egg is no longer open for business.

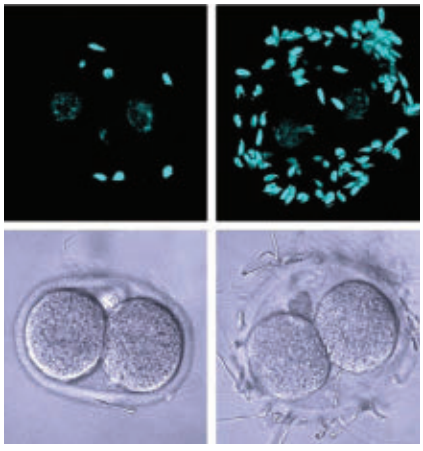
Other efforts are revealing additional insights into the egg's influence. The egg's zona barrier, for example, is adorned in a sugary compound that makes the egg sticky, allowing sperm to latch onto receptors easily. Last year, an international team of researchers identified the sugary compound as Sialyl-Lewis-x.

While such findings are turning up more intimate details on the events surrounding fertilization, scientists still have only part of the story. To fully understand the egg's role in the reproductive process, researchers are looking at how it acts in concert — or even at odds — with sperm.

Choosing Mr. Right

Swanson is working to figure out "who binds to whom" by studying the interactions between individual sperm and egg proteins in red abalone, an ocean-dwelling snail. He makes his predictions by looking at how quickly individual proteins change over time.

Because of the constant struggle to find a mate and multiply, genes governing reproduction are under pressure to evolve. And they do. Over the last 15 years, studies in animals ranging from flies to mice to orangutans to humans show that genes for traits involved in sexual reproduction accumulate changes with unusual speed. When scientists compared more than 1,880 proteins encoded by genes from humans and rodents, a number of proteins involved in reproduction ranked among those with the greatest number of changes. Three of them — ZP2 and ZP3, along with a sperm protein essential for the acrosome reaction — are directly involved in the sperm–egg interaction.



Sperm shutoff After a mouse egg is fertilized, an enzyme called ovastacin breaks apart a key binding protein, preventing sperm from attaching (left, two different views). Without ovastacin, sperm continue to attach (right) even after cell division.

Swanson says that the mere rapidity of change in a particular protein may help scientists find its partner. "If you get a burst of rapid evolution in a particular egg-coat protein, you might suspect that the male protein that recognizes it would also show a burst on the lineage," he says.

Scientists seeking to explain why reproductive proteins evolve so quickly have spun a variety of hypotheses, ranging from sexual selection — where males develop traits to make them more attractive to females — to the avoidance of pathogens. One pet theory is that evolutionary change is driven by sexual conflict. While visions of males and females working together to perpetuate the species work well in the classroom, studies suggest that reproduction is a selfishly motivated exercise.

Take, for example, the conflicting needs of the egg and sperm during fertilization. Sperm are in a contest to win the race to the egg. Because they're competing with each other, they need to get there and power their way in as quickly as possible. Eggs, on the other hand, don't want to be rushed. Bombarded with tiny, lashing sperm, the female would like time to choose the optimal sperm, allowing it to enter while blocking off all others.

"The males are constantly trying to speed up the process, and females are trying to slow it down," Swanson says.

One way to accomplish this feat, over evolutionary time, would be to make subtle changes in the structure of the sperm-receptor proteins on the egg coat.

Levitan, who studies red sea urchins (*Strongylocentrotus franciscanus*), is looking to see how such changes may play out in real life. Like most marine invertebrates, sea urchins dump their eggs into the open sea to be fertilized, which means that different eggs may be fertilized by different fathers. Such situations create intense pressure for sperm to develop even faster ways to penetrate the egg coat, bringing a greater risk that two will make their way in simultaneously.

Urchin eggs work to prevent this by employing molecular blocking mechanisms, which are triggered after a sperm fuses with the egg. A female carrying a novel receptor protein that slightly mismatches the sperm protein might introduce a delay that would allow her time to get the blocks erected before a second sperm enters.

"It can't totally mismatch, or fertilization won't occur," Levitan says. "But it works if you have only a slight mismatch, like a poorly fitting lock and a key, so you have to jiggle a bit until it matches."

Over time, as the locks change shape on the female receptor, the males will evolve a new key in the form of a matching protein on the sperm's egg-recognition molecule, called bindin.

Studies with populations of sea urchins suggest that this scenario may play out in the wild. Levitan's group found that male urchins living in densely populated waters are more likely to carry novel proteins in their bindin, suggesting that females are

A. D. BURKART *ET AL./J. OF CELL BIOLOGY* 2012

taking control by changing their locks.

In one particular study reported in June in *Evolution*, Levitan's team used DNA evidence to show that still-living urchins conceived 100 to 200 years ago, when urchin-eating sea otters flourished, had a smooth-fitting form of bindin. Urchins born during a population boom, coinciding with dwindling otter population, were more likely to carry ill-fitting bindin proteins.

The smooth form allowed for easy fertilization when sperm were scarcer. But as sperm became common, eggs replaced their complementary receptor with a version that reduced the risk of multiple sperm entering.

Such findings may have important implications for human reproductive medicine, as they may explain the egg's role in some cases of infertility. Over time, humans, too, have likely acquired numerous variations in egg and sperm proteins. Swanson and his colleagues are beginning to explore how a mismatch in these proteins could lead to reproductive failure. The work could also lead to new ways to help infertile couples conceive.

"We're trying to look at the whole approach — how the sperm-egg recognition system works together — rather than isolating a gamete and asking what's wrong with the sperm or what's wrong with the egg," Swanson says. "In fact, both of those may be normal, but it's just the interaction that's mismatched."

From egg to species

That's not to say that all mismatches are bad eggs. In some cases, the incompatibility prevents eggs from being fertilized by male members of a different species, an event that may lead to a genetic imbalance or defect. In this way, the egg's self-protective system may give birth to whole new species.

Tiny variations, arising randomly, could occur in the sperm-egg recognition proteins of individuals in populations that live even a short distance apart. In a few cases, females from one population may develop a change in their sperm-binding receptor that prevents reproduction with males outside the group. Over time, the population with that change becomes sexually isolated. Over a very long time, it may become a new species, distinct from its ancestors, Levitan says.

"Even if the two populations came back together at some later time, they may be less compatible or not compatible at all," he says.

While such scenarios remain only a theory, supporting evidence may soon emerge as scientists continue to investigate the egg. If so, the studies may reveal not only the egg's role in reproduction, but also the egg's role in creating new species.

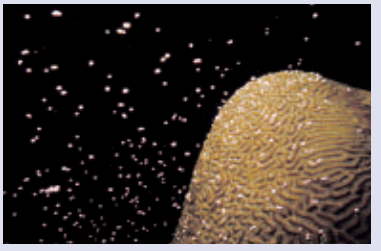
In an unexpected twist, the egg may help explain how that first chicken came about. ■

Explore more

- K.G. Claw and W. Swanson. "Evolution of the egg: New findings and challenges." *Annual Review of Genomics and Human Genetics.* 2012.

Wild eggs

When people hear the word egg, they tend to think of white or brown ellipsoids bought in cartons at the grocery store. But eggs in nature come in a variety of wacky and wonderful forms.



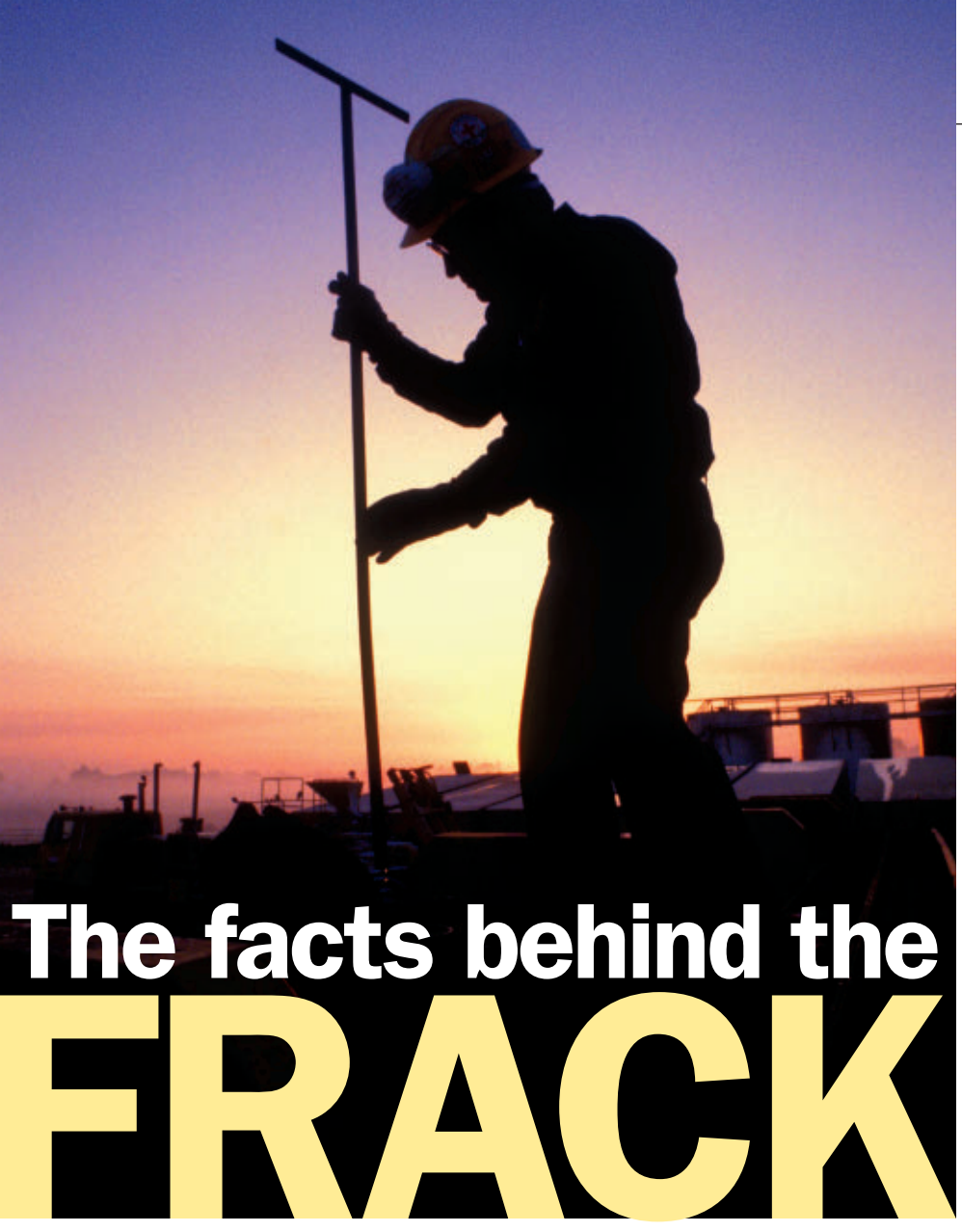
Coral eggs In a burst of brightly colored bulbs, corals release their eggs in synchrony. The eggs are full of waxy fat that fuels development, and makes the eggs float upward toward the water's surface. When eggs meet up with sperm, the youngsters are carried by ocean currents to new homes.

Butterfly eggs These eggs can be things of beauty, with ribbing and fluting pointing the eye toward a little opening called the micropyle. Through the micropyle, sperm enter and fertilize a typically oval or round egg as it is being deposited on a leaf. (Common green birdwing egg shown.)

Shark eggs A lot of sharks give birth to live young, but some lay satchel-like eggs with stringy substances attached. Often these eggs are transparent, allowing full view of a growing shark feeding on the yolk. When empty egg cases wash up on the beach, they are referred to as "mermaid's purses."

Elephant bird eggs An extinct species of bird that once roamed Madagascar laid eggs much larger than anything known today. The largest of these flightless birds was 3 or 4 meters tall, and its eggs could hold as much fluid as 15 dozen chickens' eggs. (Great elephant bird egg shown with a modern egg.) — *Elizabeth Quill*

FROM TOP: EMMA HICKERSON/NOAA; ALEXANDER VYSOKIKH/SHUTTERSTOCK; JUNIPERCREEK/ISTOCKPHOTO; DOMINIC LIPINSKI/PA WIRE



The facts behind the FRACK

Scientists weigh in on the hydraulic fracturing debate

By Rachel Ehrenberg

Residents fear that hydraulic fracturing operations lead to home explosions, pollution and earthquakes. Science can speak to some of these concerns.

To call it a fractious debate is an understatement.

Hydraulic fracturing, or fracking, wrenches open rock deep beneath the Earth's surface, freeing the natural gas that's trapped inside. Proponents argue that fracking-related gas recovery is a game changer, a bridge to the renewable energy landscape of the future. The gas, primarily methane, is cheap and relatively clean. Because America is brimful of the stuff, harvesting the fuel via fracking could provide the country jobs and reduce its dependence on foreign sources of energy.

But along with these promises have come alarming local incidents and national reports of blowouts, contamination and earthquakes. Fracking opponents contend that the process poisons air and drinking water and may make people sick. What's more, they argue, fracking leaks methane, a potent greenhouse gas that can blow up homes, worries highlighted in the controversial 2010 documentary *Gasland*.

Fears that fracking companies are operating in a Wild West environment with little regulation have prompted political action. In June, the group Don't Frack Ohio led thousands of protesters on a march to the statehouse, where they declared their commitment to halting hydraulic fracturing in the state. Legislation banning the process has been considered but is now on hold in California. New York — which sits atop a giant natural gas reserve — has a statewide fracking moratorium; pending policies would allow the process only where local officials support it.

Despite all this activity, not much of the fracking debate has brought scientific evidence into the fold. Yet scientists have been studying the risks posed by fracking operations. Research suggests methane leaks do happen. The millions of gallons of chemical-laden water used to fracture shale deep in the ground has spoiled land and waterways. There's also evidence linking natural gas recovery to earthquakes, but this problem seems to stem primarily from wastewater disposal rather than the fracturing process itself.

While the dangers are real, most problems linked to fracking so far are not specific to the technology but come with many large-scale energy operations employing poor practices with little oversight, scientists contend. Whether the energy payoff can come with an acceptable level of risk remains an open question.

"People want it to be simple on both sides of the ledger, and it's not simple," says environmental scientist Robert Jackson of Duke University. "Our goal is to highlight the problems, so we can understand the problems and do what we can to help."

What is hydraulic fracturing?

Hydraulic fracturing has been cranking up output from gas and other wells for more than 50 years. But not until fracking joined up with another existing technology, horizontal drilling, was the approach used to unlock vast stores of

previously inaccessible natural gas. The real fracking boom has kicked off in just the last decade.

Conventionally drilled wells tap easy-to-get-at pockets of natural gas. Such gas heats homes and offices, fuels vehicles and generates electricity. But as easily accessible reserves have been used up, countries seeking a steady supply of domestic energy have turned to natural gas buried in difficult-to-reach places, such as deep layers of shale.

Gas doesn't flow easily through shale or other impermeable rock. Drilling a conventional well into such formations would gather gas only from a small area right around the well. And, for shale in particular, many formations in the United States extend hundreds of kilometers across but are less than 100 meters thick, hardly worth sending a vertical well into.

Combining hydraulic fracturing with horizontal drilling offers a way to wrest gas from these untapped reserves. By drilling sideways into a rock formation and then sending cracks sprawling though the rock, methane can burble into a well from a much larger area.

The drill-frack punch goes something like this: After constructing a drill pad, engineers drill a well straight down, typically for thousands of meters, toward the target bed of rock. Operators then begin "kicking off," turning the drill so it bores into the formation horizontally, forming an L-shape.

After small explosive charges perforate the far end of the well's horizontal portion, called the toe, hydraulic fracturing can begin. Millions of gallons of fracking fluid — a mixture of water, sand and chemicals — are pumped into the well at pressures high enough to fracture the shale. Methane within the shale diffuses into these fissures and flows up the well. Along with the gas comes flowback water, which contains fracking fluid and additional water found naturally in the rock.

After the well's toe is fracked, engineers repeat the procedure, moving back along the horizontal portion of the well until its heel is reached. Compared with conventional wells, which may steadily pump out fuel for more than a decade, shale gas extraction is like blasting open a faucet. There's a huge surge in gas, but it may become merely a dribble after a few years. At the end of its life, the well gets plugged.

Today hydraulic fracturing is used in about nine out of 10 onshore oil and gas wells in the United States, with an estimated 11,400 new wells fractured each year. In 2010, about 23 percent of the natural gas consumed in the United States came from shale beds.

While the immediate output is gas, the uptick in this type of extraction has also fueled fears over fracking's potential dangers — such as drinking water contamination.

Does methane leak into water?

One of the most explosive issues, literally, is whether fracking introduces methane into drinking water wells at levels that can make tap water flammable or can build up in confined spaces and cause home explosions.

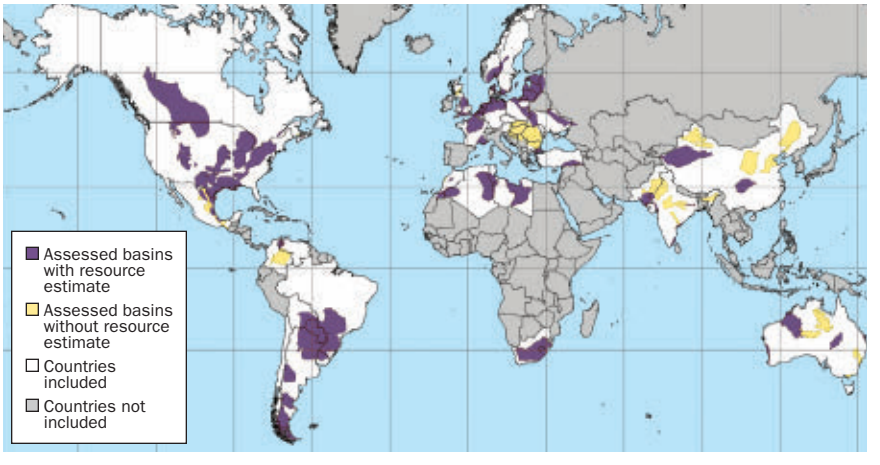
Studies are few, but a recent analysis suggests a link. Scientists who sampled groundwater from 60 private water wells in northeastern Pennsylvania and upstate New York found that average methane concentrations in wells near active fracturing operations were 17 times as high as in wells in inactive areas. Methane naturally exists in groundwater — in fact, the study found methane in 51 of the 60 water wells — but the higher levels near extracting sites raised eyebrows.

To get at where the methane was coming from, the researchers looked at the gas's carbon, which has different forms depending on where it has been. The carbon's isotopic signature, and the ratio of methane to other hydrocarbons, suggested that methane in water wells near drilling sites did not originate in surface waters but came from deeper down.

But how far down and how the methane traveled aren't clear, says Duke's Jackson, a coauthor of the study, published last year in the *Proceedings of the National Academy of Sciences*. He proposes four possibilities. The first, most contentious — and, says Jackson, the least likely — is that the extraction process opens up fissures that allow methane and other chemicals to migrate to the surface. A second possibility is that the steel tubing lining the gas well, the well casing, weakens in some way. Both scenarios would also allow briny water from the shale and fracking fluid to migrate upward. The well water analysis found no evidence of either.

Newly fracked gas wells could also be intersecting with old, abandoned gas or oil wells, allowing methane from those sites to migrate. "We've punched holes in the ground in Pennsylvania for 150 years," Jackson says. Many old wells have not been shut down properly, he says. "You find ones that people plugged with a tree

Untapped resource With the help of hydraulic fracturing, drillers can access natural gas that was previously locked in shale beds. A recent report from the U.S. Energy Information Administration analyzed major shale basins (shown) in 32 countries around the world.



U.S. ENERGY INFORMATION ADMINISTRATION

Fracking footprint

A typical shale gas drilling site is abuzz with activity. After a well pad is constructed, engineers drill straight down, typically thousands of meters, toward the target shale. Then the well is drilled horizontally. Explosives set off in the horizontal portion create holes in the well's sides through which millions of gallons of fracking fluid are pumped. The fluid fractures the shale, releasing the trapped gas for recovery. Beyond the rig itself, there are holding tanks and pits, and trucks for pumping in water and carrying away wastewater and gas. Such a big operation leaves a lot of room for error.

Potential hazards

1. Blowout When blowout prevention equipment is absent or fails, pressurized fluid and gas can explode out the wellhead, injuring people and spewing pollutants.

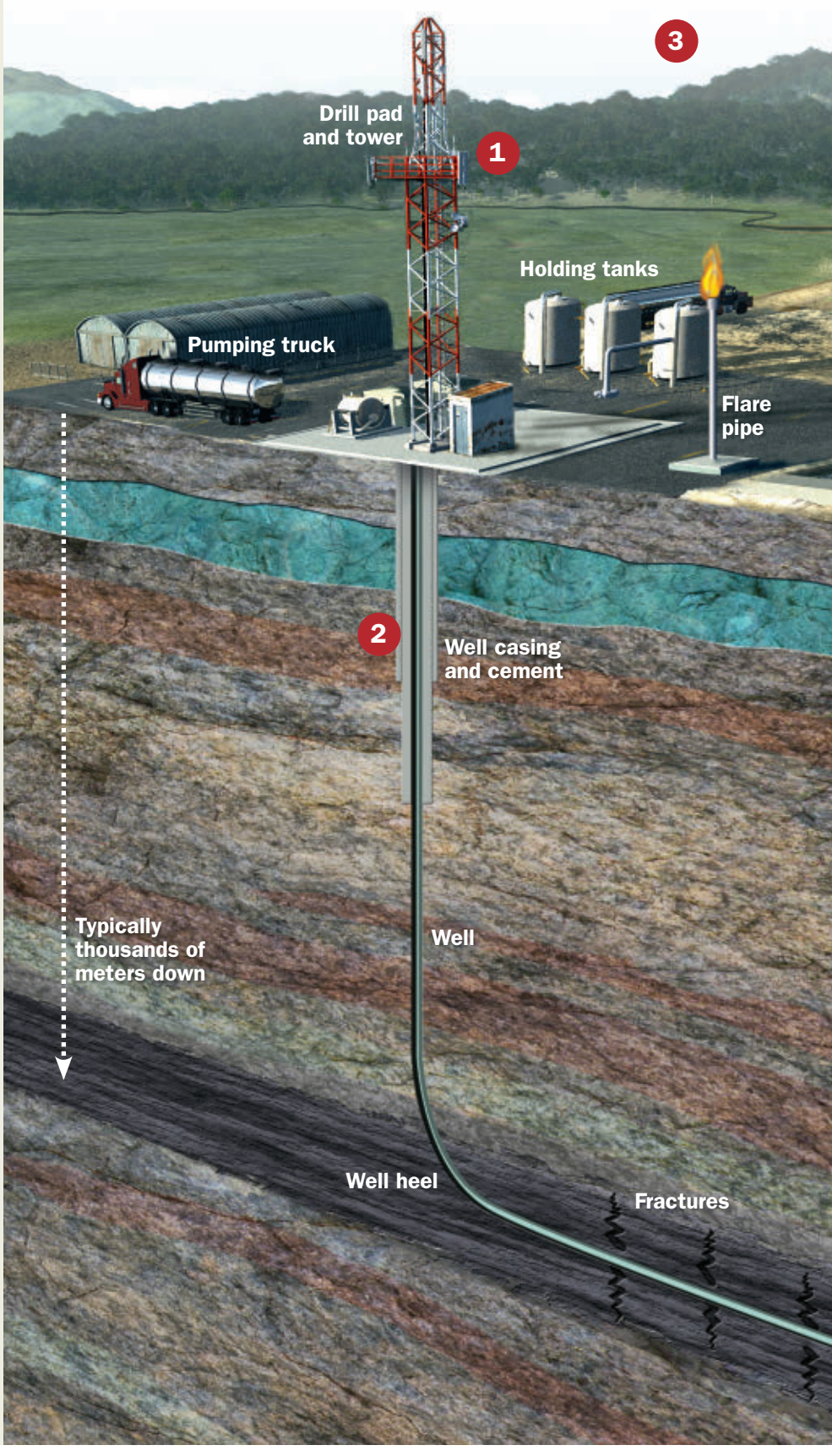
2. Gas leak Methane, the primary gas in natural gas, may be present in layers of rock above the target layer. Cracks in the cement that seal the well to the surrounding rock can provide a path for this methane to travel into the water table.

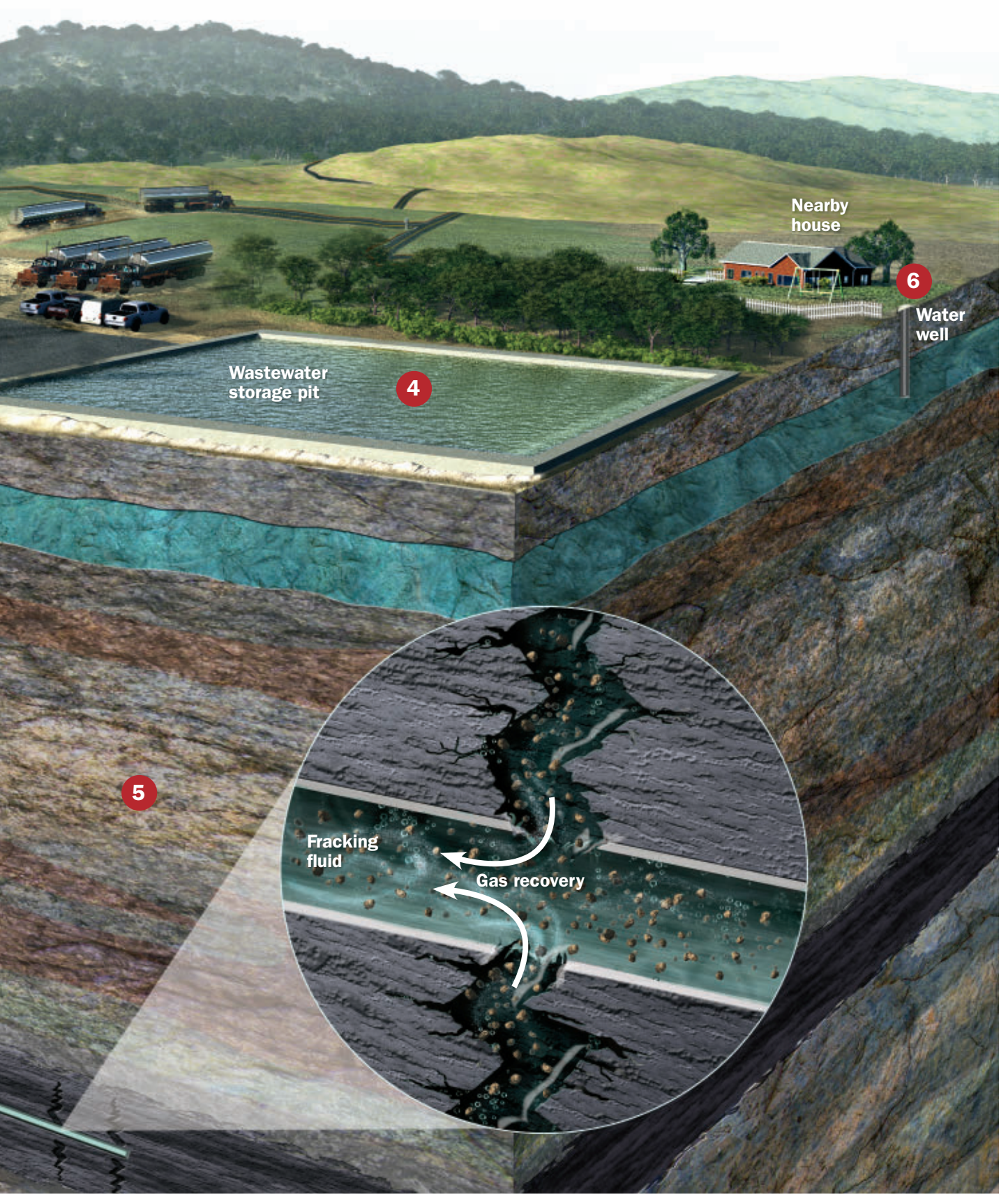
3. Air pollution Flare pipes that burn methane so it doesn't build up, diesel truck exhaust and emissions from wastewater evaporation can dirty the air near a drill site. When methane is released without being burned, it acts as a potent greenhouse gas, trapping 20 times as much heat as carbon dioxide.

4. Wastewater overflow Fracking fluid, about 1 percent of which is made up of chemicals (sometimes including carcinogens), is increasingly recycled for use in other wells. But sometimes it is stored in open pits that emit noxious fumes and can overflow with rain.

5. Other leaks There are some worries that local geology in particular areas would allow fracking-produced fluid and methane to travel upward. But most evidence of exposure stems from surface problems such as spills or illicit dumping.

6. Home explosions If methane does get into the water table—because of cracked cement, local geology or the effects of old wells—it can build up in homes and lead to explosions.





NICOLLE RAGER FULLER

stump." In some places in Pennsylvania, West Virginia and elsewhere (especially those with existing coal beds), methane turned up in well water long before hydraulic fracturing became widespread.

A fourth possibility, which Jackson thinks is most probable, is that the cement between the well casing and the surrounding rock is not forming a proper seal. Cracking or too little cement could create a passageway allowing methane from an intermediate layer of rock to drift into water sources near the surface. Such cases have been documented. In 2007, for example, the faulty cement seal of a fracked well in Bainbridge, Ohio, allowed gas from a shale layer above the target layer to travel into an underground drinking water source. The methane built up enough to cause an explosion in a homeowner's basement.

Other types of gas and oil wells have similar problems, Jackson says, but fracking's high pressures and the shaking that results may make cement cracks more likely. "Maybe the process itself makes it harder to get good seals," he says. "We need better information."

Accompanying these concerns are worries that methane leaking into the air will have consequences for the climate and human health. Burning methane creates fewer greenhouse gas emissions and smog ingredients than other fossil fuels, so natural gas is considered relatively clean. But evidence suggests that methane frequently escapes into the air during drilling and shipping, where it acts as a greenhouse gas and traps heat. Such leaking undermines the gas's "clean" status.

Methane leaking into the air can also cause ozone to build up locally, leading to worries about headaches, inflammation and other ills among people who live nearby. Scientists in Pennsylvania have proposed a long-term study examining possible links between air pollution from the shale gas boom and human health. A more immediate concern for human health, Jackson and others argue, is exposure to fracking wastewater.

Is fracking fluid hazardous?

A typical fracked well uses between 2 million and 8 million gallons of water. At the high end, that's enough to fill 12 Olympic swimming pools. Companies have their own specific mixes, but generally water makes up about 90 percent of the fracking fluid. About 9 percent is "proppants," stuff such as sand or glass beads that prop open the fissures. The other 1 percent consists of additives, which include chemical compounds and other materials (such as walnut hulls) that prevent bacterial growth, slow corrosion and act as lubricants to make it easier for proppants to get into cracks.

As the gas comes out of a fracked well, a lot of this fluid comes back as waste. Until recently, many companies wouldn't reveal the exact chemical recipes of their fluids, citing trade secrets. A report released in April 2011 by the House Energy and Commerce Committee did provide some chemical data: From 2005 to 2009, 14 major gas and oil companies used 750 different chemicals in their fracking fluids. Twenty-five of these chemicals are listed as hazardous pollutants under the Clean Air Act, nine are regulated under the Safe Drinking Water Act and 14 are known or possible human carcinogens, including naphthalene and benzene.

In addition to the fracking fluid, the flowback contains water from the bowels of the Earth. This "produced" water typically has a lot of salt, along with naturally occurring radioactive material, mercury, arsenic and other heavy metals.

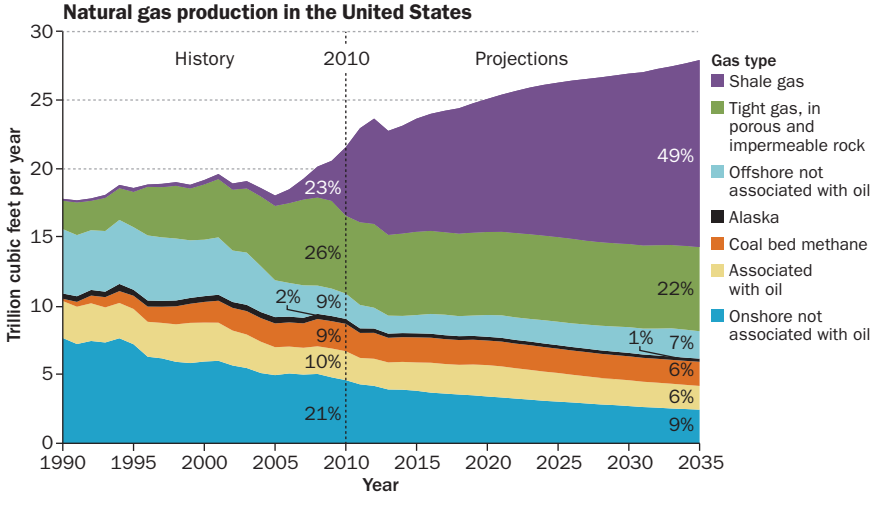
"It's not just what you put into the well. The shale itself has chemicals, some of which are quite nasty," says Raymond Orbach, director of the University of Texas at Austin's Energy Institute. A report analyzing the risks associated with fracking was released by the Energy Institute in February in Vancouver at the meeting of the American Association for the Advancement of Science. (The report is under independent review because one of its authors didn't disclose that he is on the board of a gas-drilling company, but Orbach stands behind the study.)

Wastewater is dealt with in different ways. Sometimes it is stored on-site in lined pits until it is trucked off. When these pits are open to the air, they can release fumes or overflow, with possibly hazardous consequences.

The Energy Institute report cites one case in West Virginia in which about 300,000 gallons of flowback water was intentionally released into a mixed hardwood forest. Trees prematurely shed their leaves, many died over a two-year study period, and ground vegetation suffered. A briefing paper coauthored by geophysicist Mark Zoback of Stanford University points to spills: In 2009, leaky joints in a pipeline carrying

Shale's big role The United States will produce more natural gas in the future, and much of it from shale, a recent report suggests. By 2035, total U.S. gas production is expected to increase to 27.9 trillion cubic feet, up from 21.6 trillion cubic feet in 2010.

SOURCE: U.S. ENERGY INFORMATION ADMINISTRATION'S *ANNUAL ENERGY OUTLOOK* 2012



wastewater to a disposal site allowed more than 4,000 gallons to spill into Pennsylvania's Cross Creek, killing fish and invertebrates.

For obvious ethical reasons, controlled studies exposing people to fracking fluid don't exist. And long-term population studies comparing pre- and post-fracking health haven't yet been done. But these incidents — and the known dangers of some of the chemicals used — raise alarms about the possible consequences of human exposure.

Local geology in some areas may also allow fracking chemicals and produced water to seep up from deep below into water sources. A study published in July in the *Proceedings of the National Academy of Sciences* found a geochemical fingerprint of briny shale water in some aquifers and wells in Pennsylvania. Local geology probably also played a role in fracking fluid getting into drinking water in Pavillion, Wyo., a site that has been at the heart of the fracking controversy.

Still, several reviews of where fracking chemicals and wastewater have done harm find that the primary exposure risks relate to activities at the surface, including accidents, poor management and illicit dumping.

An accepted disposal route is injecting the water into designated wastewater wells. But that strategy can cause an additional problem: earthquakes.

Does fracking cause earthquakes?

Hydraulic fracturing operations have been linked to some small earthquakes, including a magnitude 2.3 quake near Blackpool, England, last year.

But scientists agree such earthquakes are extremely rare, occurring when a well hits a seismic sweet spot, and are avoidable with monitoring.

Of greater concern are earthquakes associated with the disposal of fracking fluid into wastewater wells. Injected fluid essentially greases the fault, a long-known effect. In the 1960s, a series of Denver earthquakes were linked to wastewater disposal at the Rocky Mountain arsenal, an Army site nearby. Wastewater disposal was also blamed for a magnitude 4.0 quake in Youngstown, Ohio, last New Year's Eve.

A study headed by William Ellsworth of the U.S. Geological Survey in Menlo Park, Calif., documents a dramatic increase in earthquakes in the Midwest coinciding with the start of the fracking boom. From 1970 to 2000, the region experienced about 20 quakes per year measuring at or above magnitude 3.0. Between 2001 and 2008, there were 29 such quakes per year. Then there were 50 in 2009, 87 in 2010 and 134 in 2011.

2.8
Greatest magnitude U.S. earthquake linked to fracking

5.3
Greatest magnitude U.S. earthquake linked to wastewater disposal

"The change was really quite pronounced," says Ellsworth. "We do not think it's a purely natural phenomenon." But the earthquakes weren't happening near active drilling — they seemed to be clustered around wastewater wells.

It's hard to look back without pre-quake data and figure out what triggers a single earthquake, notes Ellsworth. There are several pieces of the geology equation that, if toggled, can tip a fault from stable to unstable.

A recent study examining seismic activity at wastewater injection wells in Texas linked earthquakes with injections of more than 150,000 barrels of water per month. But not every case fit the pattern, suggesting the orientation of deep faults is important.

Ellsworth advises that injection at active faults be avoided. Drill sites should be considered for their geological stability, and seismic information should be collected. Only about 3 percent of the 75,000-odd hydraulic fracturing setups in the United States in 2009 were seismically monitored.

"There are many things we don't understand," says Ellsworth. "We're in ambulance-chasing mode where we're coming in after the fact."

Is it worth it?

That ambulance-chasing mode is what makes current shale gas operations so worrisome to many. If scientists had the data needed to identify problems and find ways to ameliorate or eliminate them, then the current fracas over fracking may have been preempted.

"Transparency has been missing," says Stanford's Zoback. "Then the public gets suspicious and alarmed, and you get misplaced hysteria."

Zoback and other scientists surveying existing data generally have concluded that there are dangers associated with fracking but that existing technologies, regulation and serious enforcement could resolve them. Such regulations would include minimizing the local environmental footprint of setting up the well site and trucking in water and sand, monitoring the integrity of steel casings and cement, swapping out toxic chemicals from the fracking fluid, and collecting seismic and other geologic data.

Like many technologies, fracking comes with promise and with risk, says Zoback. Rules tailored depending on local geology and other factors can mitigate those risks. Consider all the regulations surrounding automobiles. There are seat belts and air bags, emission tests and proper and improper ways to dispose of oil and brake fluid.

Ultimately, unless people are willing to cut way back on their energy use, the risks associated with natural gas recovery have to be weighed against the risks that come with coal, nuclear power and other energy sources.

"It's clear that it's a remarkable resource," Zoback says. "It's abundant, and as a transition fuel between today and the green-energy future, natural gas really is the answer, I'm convinced. But that's not a get-out-of-jail-free card." ■

Explore more

- S.G. Osborn *et al*. "Methane contamination of drinking water accompanying gas-well drilling and hydraulic fracturing." *Proceedings of the National Academy of Sciences*. May 17, 2011.

Making DATA

Researchers pursue analogy between statistical evidence and thermodynamics

By Tom Siegfried

A fundamental problem for almost all science is how to tell a fluke from a fact.

It's usually very hard to know whether an experiment's result reflects a truth of nature or a random accident. So scientists use elaborate math to gauge the odds that a finding is bogus. But those odds rarely offer definitive evidence — or even much evidence at all. In fact, evidence in science is a slippery concept. It's kind of like the U.S. Supreme Court's idea of pornography: Scientists supposedly know evidence when they see it.

But they don't know precisely how much evidence they've got; standard mathematical tricks for drawing inferences do not translate statistical data into a quantitative measure of evidential weight. Whether assessing the cancer risk from a food additive, the curative power of a new medicine or the results of an athlete's drug test, evidence pro and con cannot be easily quantified, compared or objectively added up. For today's scientists, weighing evidence is like measuring temperature before the invention of the thermometer.

For that matter, primitive thermometers didn't do such a hot job either. Not until the mid-19th century, when British physicist Lord Kelvin invented the absolute temperature scale, could scientists speak accurately about how much hotter one object was than another. Kelvin derived his temperature definition using the nascent science of thermodynamics — the laws of nature governing the flow of heat. With a firm theory relating heat flow, volume, pressure and temperature, he could define a temperature scale where zero meant the absence of heat and each degree represented the same amount of temperature difference. Modern scientists trying to "take the temperature" of their evidence desperately need a similarly rigorous scale.

So contends Veronica Vieland, a statistical geneticist at the Battelle Center for Mathematical Medicine at Nationwide Children's Hospital and Ohio State University in Columbus. In several articles published during recent years, she has trumpeted the need for a better measure of evidence — a way to gauge the reliability of data linking genes to disease, for instance. With Susan Hodge, also of the Battelle Center, and other collaborators, Vieland has proposed that something like Kelvin's temperature scale could serve as the model for calibrating the strength of evidence in biomedical research.

"The more I pursued the analogy," says Vieland, "the more I started to think that our problem wasn't just like Kelvin's problem, it actually *is* Kelvin's problem."

Now she and her colleagues have produced a paper, recently posted online (arxiv.org/abs/1206.3543), that outlines the temperature-evidence analogy in detail. Equations transliterated from thermodynamics to statistical data show how the weight of evidence can be assessed on an absolute scale, at least for a simple standard example: whether a coin is balanced fairly for flipping.

If you flip a penny 10 times and get four heads, it's not obvious whether the coin was doctored to favor tails. Insights from probability math show that four heads out of 10 makes for very weak evidence (if any at all) that a coin is biased. But nobody has ever devised a very clear way to quantify that evidence. A standard statistical measure, called the P value, supposedly tells you how likely you are to get four heads (or fewer) out of 10 flips if the coin is fair. But that's not the same as evidence that the coin is or isn't fair — a P value is merely the probability that data are consistent with the hypothesis being tested. P values alone cannot quantify the probability of the hypothesis itself.

All sorts of problems afflict P values (*SN: 3/27/10, p. 26*); they are not a calibrated unit of measurement — that is, they mean different things in different contexts — and in general they don't behave like evidence is supposed to behave, as Hodge emphasized at a recent workshop in Columbus. "P values depend on decisions made by investigators," she said. Precisely the same data can be assigned different P values, for instance, depending on seemingly irrelevant considerations,

such as whether the experimenter had planned to flip the coin 10 times, or to flip it until four heads showed up.

And as Vieland notes, it wouldn't make sense to add strong evidence to weak evidence and conclude that the total evidence is lukewarm. But that's what P values typically do. So P values do not measure evidence in any standard way. Before Kelvin, the same was true for temperature measurements.

Warming up to statistics

At first glance, temperature and heat don't seem to have much to do with statistics and evidence. But after a bit of reflection, Vieland's idea makes some sense. Temperature, after all, is itself a statistical concept. In a gas of a given temperature, the molecules fly around at a wide range of speeds; the measured temperature is related to the average velocity of the molecules.

Scientific evidence, like temperature, is also usually statistical. Evidence is typically presented as a statistical analysis of data gathered in an experiment, often expressed as a P value. But unlike P values, temperature measures the same thing regardless of substance or circumstance.

Producing the evidence version of the Kelvin temperature scale requires translating thermodynamics math into analogous equations for evidence. Doing so draws on earlier work relating thermodynamics to information theory. Information theory measures a quantity of information, designated entropy, with precisely the same math used in computing the entropy described by the second law of thermodynamics.

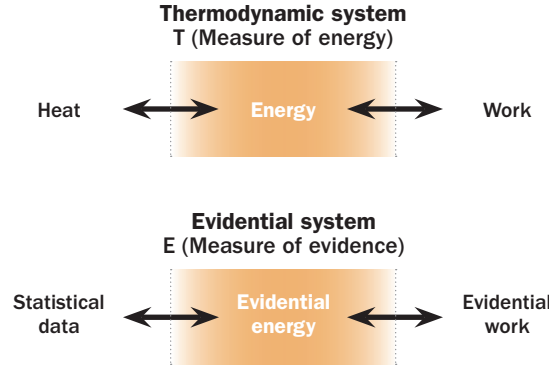
Using this mathematical connection between thermodynamic entropy and information entropy, Vieland and colleagues show how to treat statistical data as a gas governed by the laws of thermodynamics. In thermodynamics, an "equation of state" describes how the pressure and volume of a gas relate to its temperature. Vieland and colleagues rewrite the equation to describe statistical data that test whether a coin is fair. Results from sets of coin tosses (number of heads per number of flips) are the units of data, corresponding to molecules in a gas. In the new equation, temperature (T) of a gas is replaced by E, a measure of strength of evidence or "evidential energy." Volume becomes the quantity of statistical data; pressure becomes a measure of how much changing the amount of statistical data affects the evidential energy.

With this analogy, statisticians could plot data in a way that shows how the strength of the evidence varies for competing hypotheses (the coin is fair, or the coin is biased). A key point is that the new evidence measure can be calibrated on an absolute scale (like Kelvin's temperature), so that new data (from more coin flipping) can adjust the evidence plot in a consistent way.

Vieland describes that process as the flow of "evidential information," analogous to the flow of heat in a steam engine (as governed by the laws of thermodynamics).

Math for describing such heat flow was worked out in the early 19th century by the French savant Sadi Carnot. His goal was figuring out how to make steam engines efficient — maximizing the work that could be done with a given amount of heat. In a typical engine, heat expands a gas (say, in a piston). As the gas expands, the pressure in the piston gets lower. And after the heat input stops, the gas cools but continues to expand, doing work. To start the cycle over, work is needed to push the piston downward, compressing the gas and raising its pressure. Engines are useful because more work comes out in the first part of the cycle than is needed to restore the piston to its starting position. And thermodynamics is useful for describing such engines because the

Evidence analog Heat flowing into a thermodynamic system (top) provides energy that can be converted to work. Temperature offers an absolute measure of the system's energy. An analogous system (bottom) might provide a consistent way to measure strength of evidence provided by statistical data. E, a measure of "evidential energy," would quantify the amount of evidential work that statistical data supply.



B. RAKOUSKAS

ratio of work output to input depends solely on temperature and not on the substance being heated (the insight that allowed Kelvin to develop the absolute temperature scale).

Vieland and friends work out the coin analogy in terms of the Carnot cycle; her informational steam engine shows how the flow of information (in a set of statistical data) relates to E, the evidence equivalent of temperature. "A given change in evidential energy will always correspond to the same amount of change in E," Vieland and colleagues write.

Pursuing the analogy a little further, Vieland suggests a "first law" of evidence: "conservation of total evidential information," in parallel with the conservation of energy. In this case, the information law states that evidence cannot be expanded without additional input of data. Evidence's analog to thermodynamics' second law would be something like "evidence flows in only one direction" — that is, data used once cannot be reused, just as waste heat from an engine cannot create order but merely contributes to rising entropy, or disorder.

Beyond fair coin flipping

While this work demonstrates a way of measuring evidence in principle, much more work needs to be done, Vieland emphasizes.

"We have not so much solved the evidence measurement problem, as reformulated it in a way that makes it amenable to solution for the first time," Vieland writes in her paper with Hodge, Jayajit Das and Sang-Cheol Seok. "Our formalism would not replace other statistical investigations, but it would ideally provide a basis for reporting results of statistical analyses on a unified scale for purposes of meaningful comparison ... across disparate applications."

At the Columbus workshop, convened to discuss issues of measurement theory in biology, other experts expressed interest in the Vieland proposal. They agreed that the problem of measuring evidence in biology is deep; biological data analysis commonly lacks the theoretical underpinnings needed to guarantee validity. A whole field of theoretical study known as measurement theory, designed to address such issues, goes largely ignored.

"There is very little discussion of measurement theory in biology," said Thomas Hansen of the University of Oslo. "That has unfortunate consequences."

Hansen and others wondered, though, whether the thermodynamics analogy is necessary to address the problem. If a measurement system inspired by thermodynamics turns out to work, fine, but the motivating analogy does not need to be included in justifying a new system of measuring evidence, they suggested.

But Vieland thinks something more fundamental is going on than a dispensable analogy. "This is more than an analogy — there really is reason to think that we have a system that works like a thermodynamic system at least to some extent," she says. "I actually think we are underestimating the connection between the mathematics of thermodynamics and the mathematics of information flow and dynamical information systems. I think there is a deep mathematical connection."

In the past, efforts to connect information to thermodynamics have often been casually dismissed. Although entropy in information theory and entropy in thermodynamics are described by the same math, traditionally most physicists have treated that curiosity as a mere coincidence. But more recently, some physical findings have suggested that the link between information and thermodynamic entropy is deep. Black hole physics, for instance, profited enormously from work by Stephen Hawking and others linking the physical entropy of black holes with the amount of information they have swallowed. Further work has merged physics with information more generally in the study of quantum information theory (*SN: 4/7/12, p. 26*).

It may well be that the reach of thermodynamics really does extend from steam engines, black holes and information theory to the quantification of the weight of evidence in all sorts of realms.

As physics Nobel laureate Frank Wilczek writes in a recent paper (arxiv.org/abs/1204.4683), analogies comparing thermodynamics to information have been around for decades. At first, such analogies seemed limited, "because on the information side there did not appear to be richness of structure comparable to what we need on the physical side. Recent developments in quantum information theory have, however, unveiled a wealth of beautiful structure," with "profound, natural connections to just that structure."

So it may well be that the reach of thermodynamics really does extend from steam engines, black holes and information theory to the quantification of the weight of evidence in all sorts of realms. If so, biology and other sciences would surely benefit.

"I have to think that there are just major errors going on out there," Vieland says. "We're just misinterpreting data in a way that's completely obscure to biologists. Biologists have no way of seeing what these errors might be or when they might be happening." It would be nice if curing that problem could be a simple as taking a temperature. ■

Explore more

■ V.J. Vieland *et al*. "Measurement of statistical evidence on an absolute scale following thermodynamic principles." Online at arxiv.org/abs/1206.3543

Tom Siegfried is the former Editor in Chief of Science News.

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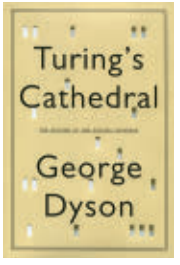
Turing's Cathedral: The Origins of the Digital Universe

George Dyson

Computers are mathematically pretty powerful, considering the only numbers they use are 0 and 1. That power, of course, stems from binary digital logic, dimly foreseen by Francis Bacon four centuries ago and articulated more clearly by Leibniz several decades later. But the modern computer's ability to exploit that power grew from the mathematical imagination of Alan Turing (*SN: 6/30/12, p. 26*) in work appearing a few years before World War II.

Dyson's book dives deeply into the postwar development of Turing's ideas under the direction of John von Neumann at the Institute for Advanced Study in Princeton, N.J. The institute's computer, MANIAC, was not the first all-purpose digital electronic computer (that was ENIAC, at the University of Pennsylvania), but in Dyson's telling it was the most influential. MANIAC combined binary numbers representing memory with those representing codes (programming) in a way that persists to the present day. "The entire digital universe, from an iPhone to the Internet, can be viewed as an attempt to maintain everything, from the point of view of the order codes, exactly as it was when they first came into existence, in 1951," in Princeton, Dyson writes.



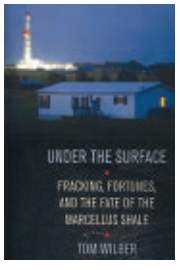
His book is full of insights into the evolution of computing in the modern era, as well as historical detail that sometimes seems excessive (it's hard to say why you'd need to know the starting salaries of all the engineers who worked on the project, for instance). But for those interested in the history of technology placed in broader social context — from the use of the new computers to design hydrogen bombs to the computer's implications for understanding the nature of life — Dyson's book provides ample helpings of substance as well. — *Tom Siegfried*

Pantheon, 2012, 401 p., $29.95

Under the Surface: Fracking, Fortunes and the Fate of the Marcellus Shale

Tom Wilber

Deep in the earth, from eastern Ohio through West Virginia, Pennsylvania and upstate New York, lies the Marcellus Shale, a nearly 400-million-year-old geologic formation harboring vast quantities of natural gas. That statement isn't up for debate, which makes it rare in the divisive discussions about the rush for gas — and particularly about hydraulic fracturing, the process used to extract it (see Page 20).



Wilber covered natural gas exploration as a reporter for the Binghamton, N.Y., *Press & Sun-Bulletin* and saw the Marcellus story unfold firsthand. From the first town meetings and land leases (some for $25 an acre: "I feel like we traded Manhattan for blankets and beads," says one landowner), Wilber evenhandedly reports the human side of drilling. Against the backdrop of the nation's energy future, global warming and economic woes, he tells stories of people's efforts to make sense of the boom happening around them. The residents are often land-rich and money-poor, and seeing the consequences of their decisions to work with or against gas companies is gripping.

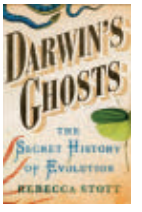
Wilber includes voices from industry, local and state governments, activists and academics. He presents reams of information — and highlights where data are lacking or hard to find. For anyone who wants to learn some backstory on the fuel that keeps the lights on for an increasing number of U.S. homes, this book clearly presents the messy story. — *Rachel Ehrenberg*

Cornell Univ., 2012, 256 p., $27.95

Born Together—Reared Apart

Nancy L. Segal

The story of the Minnesota Twin Study, ongoing since the 1970s, shows the work's role in untangling the genetics of personality, intelligence and health. *Harvard Univ., 2012, 410 p., $49.95*



Darwin's Ghosts

Rebecca Stott

This history of evolutionary science sheds light on Darwin's many predecessors who saw evidence for natural selection. *Spiegel & Grau, 2012, 380 p., $27*

The Good, the True, and the Beautiful

Jean-Pierre Changeux

A neurobiologist ponders Plato's idea of three fundamental "essences" in the context of the human brain. *Yale Univ., 2012, 386 p., $35*

Secret Chambers

Martin Brasier

A paleontologist takes a deep look at the early days of complex cells, more than a billion years ago. *Oxford Univ., 2012, 298 p., $29.95*

Mathematical Excursions to the World's Great Buildings

Alexander J. Hahn

Explore math principles behind the designs of structures from the Parthenon to the Sydney Opera House. *Princeton Univ., 2012, 317 p., $49.50*

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Sun's speed unclear

In "Sun's shock wave goes missing" (*SN: 6/16/12, p. 17*), Nadia Drake reports the speed of the sun through space at 83,500 kilometers per hour, or roughly 11,000 km/h slower than previously thought. Yet in the same issue ("At home in the universe," p. 22), Alexandra Witze reports the speed of the sun relative to galactic rotation as 220 kilometers per second. My first move was to convert Drake's speed to 23.2 kilometers per second. What is going on here?
Tom Knost, Mills River, N.C.

The apparent conflict in the sun's speed arises from the fact that different frames of reference are involved. My story about galactic rotation reports on new measurements of how quickly the sun orbits the galactic center, like a dot on a phonograph record circling around and around as the record plays. Nadia Drake's story covers new measurements of the sun's motion relative to interstellar space — a much larger frame of reference, more like how the dot and the record are moving together in the space between galaxies. — Alexandra Witze

Anthropomor-phobic scientists

"Mystery neurons found in monkey" (*SN: 6/16/12, p. 13*) is an example of the preconceived notion that humans are the only animals that ... you fill in the blank. Did the researchers miss seeing von Economo cells in macaques because they wanted to believe that the cells are related to empathy, self-awareness and consciousness but did not want to believe that macaques might have some of these characteristics? Why were they surprised to find the cells in zebras, which are social animals like us? We are told not to anthropomorphize, but these researchers appear to go to the opposite extreme. Are they anthropomor-phobic?
Leah O'Connor, Chicago, Ill.

More to learn from *Science News*

I first subscribed to *Science News Letter* some 50 years ago, as a budding computer programmer using FORTRAN on early "IBM machines" (as we called them), running on vacuum tubes, punch cards and reel-to-reel tapes. As professional demands outpaced my ability to keep up with periodicals, I reluctantly let my subscription lapse. Now retired, I'm once again a subscriber and look forward to reading every article in every issue. You are all to be commended for distilling the current news in so many technical fields into eminently informative and thoroughly enjoyable reading adventures for the layman. Each new issue in the mailbox is greeted with the enthusiasm of the small boy still within me.
Ed Fisher, Pasadena, Calif.

Send communications to: Editor, Science News, 1719 N Street, NW, Washington, D.C. 20036 or **editors@sciencenews.org**. Letters subject to editing.

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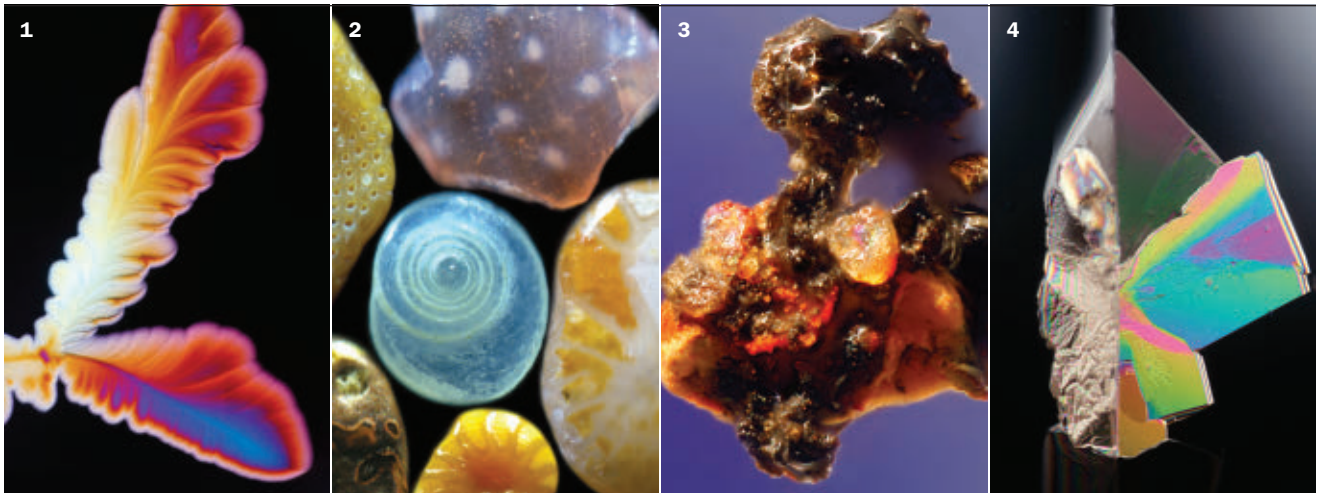
The Science Life

To see more of Gary Greenberg's photos, visit **www.sandgrains.com**



Creating small wonders

Cell biologist and inventor Gary Greenberg's career took a turn about 10 years ago when his brother sent him a canister of beach sand. Greenberg placed a pinch under a light microscope. Magnified hundreds of times, the colorful, intricate sand grains resembled beads from a necklace.

"I was just blown away. I couldn't believe that was what sand looked like," he says. "I got hooked on the idea that there was this entire world people didn't know existed."

He started photographing the magnified sand, as well as flowers, fruit, wine, clothes, paper — whatever he could stick under a microscope. His photos have been displayed in museums and have formed the basis of four books.

Greenberg (left) has always thought art and science should be intertwined. Before earning a Ph.D. in biology at University College London in 1981, he worked for several years as a photographer and filmmaker. He first combined his two passions to create special effects for the 1978 film *Superman*, turning magnified human pancreatic cancer cells into a distant view of the planet Krypton. (The cells' nuclei made great craters, he says.)

Greenberg's own inventions have made his current style of photography possible. A traditional light microscope has a shallow depth of field; only a sliver of an object can be in focus at one time. Over the last 20 years, with his company Edge-3D, Greenberg has designed new high-definition, three-dimensional light microscopes with an improved focal range.

This expertise led Greenberg to one of his latest projects. Researchers from Lehigh University in Bethlehem, Pa., wanted to study the surface of sand grains from the moon in microscopic detail — and in color. Greenberg's photos, taken with one of his special microscopes, helped reveal differences between sand on Earth and on the moon.

"Each grain of sand has a story to tell about the geology from whence it came," Greenberg says. On Earth, wind and water erode sand. On the moon, sand is altered by micrometeorite bombardments. The heat of these impacts vaporizes the surface, leaving behind tiny glass droplets.

The moon sand photos illustrate how Greenberg's work can be both exciting and educational, especially for children, he says. "It's a great way to get them interested in art and science." — *Erin Wayman*

Even familiar objects can look foreign under a microscope. Above is a sampling of photos by biologist Gary Greenberg:

1. Crossed polarizing filters create the rainbow colors seen in these crystals from Beaujolais wine.
2. A magnified view of the beach sand on Maui reveals tiny bits of coral, shells and volcanic material. Repeated tumbling by the ocean's surf leaves the sand grains smooth and shiny.
3. Perhaps the most unusual subject of Greenberg's photography is moon sand. This grain was collected during the Apollo 11 mission from the Sea of Tranquillity, the site of an ancient volcanic eruption.
4. A high-definition, three-dimensional light microscope captured this unusual view of sugar crystallizing out of a solution.

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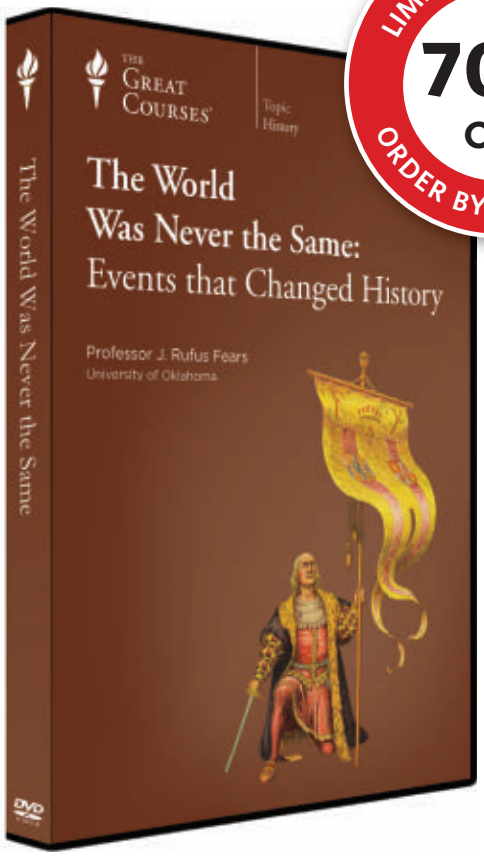

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Taught by Professor J. Rufus Fears
UNIVERSITY OF OKLAHOMA

LECTURE TITLES

1. Hammurabi Issues a Code of Law (1750 B.C.)
2. Moses and Monotheism (1220 B.C.)
3. The Enlightenment of the Buddha (526 B.C.)
4. Confucius Instructs a Nation (553–479 B.C.)
5. Solon—Democracy Begins (594 B.C.)
6. Marathon—Democracy Triumphant (490 B.C.)
7. Hippocrates Takes an Oath (430 B.C.)
8. Caesar Crosses the Rubicon (49 B.C.)
9. Jesus—The Trial of a Teacher (A.D. 36)
10. Constantine I Wins a Battle (A.D. 312)
11. Muhammad Moves to Medina—The Hegira (A.D. 622)
12. Bologna Gets a University (1088)
13. Dante Sees Beatrice (1283)
14. Black Death—Pandemics and History (1348)
15. Columbus Finds a New World (1492)
16. Michelangelo Accepts a Commission (1508)
17. Erasmus—A Book Sets Europe Ablaze (1516)
18. Luther's New Course Changes History (1517)
19. The Defeat of the Spanish Armada (1588)
20. The Battle of Vienna (1683)
21. The Battle of Lexington (1775)
22. General Pickett Leads a Charge (1863)
23. Adam Smith (1776) versus Karl Marx (1867)
24. Charles Darwin Takes an Ocean Voyage (1831)
25. Louis Pasteur Cures a Child (1885)
26. Two Brothers Take a Flight (1903)
27. The Archduke Makes a State Visit (1914)
28. One Night in Petrograd (1917)
29. The Day the Stock Market Crashed (1929)
30. Hitler Becomes Chancellor of Germany (1933)
31. Franklin Roosevelt Becomes President (1933)
32. The Atomic Bomb Is Dropped (1945)
33. Mao Zedong Begins His Long March (1934)
34. John F. Kennedy Is Assassinated (1963)
35. Dr. King Leads a March (1963)
36. September 11, 2001

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