THE DISCOVER INTERVIEW

WALTER ALVAREZ

The geologist who figured out what killed the dinosaurs talks about the stories hidden within rocks and what they add to the grand narrative of "big history."

BY **PAMELA WEINTRAUB** PHOTOGRAPHY **BY MISHA GRAVENOR**

Geologist Walter Alvarez was on an expedition in Italy during the early 1970s when he noticed something fascinating in the limestone mountains outside Gubbio: two dark layers of rock sandwiching a lighter, half-inch-thick seam. The darker sections were filled with fossils of microorganisms known as forams, while the center swath was virtually devoid of fossil life. Alvarez and colleagues from Columbia University's Lamont-Doherty Earth Observatory later determined that the middle layer was laid down at the exact time of the extinction of the dinosaurs. More exciting, he and his father, Nobel Prize–winning physicist Luis W. Alvarez, found that the fossil-free layer was rich in iridium, an element that is rare on the earth but relatively abundant in rocks from space. Piecing those clues together, the two Alvarezes proposed a radical idea: The mass extinction that wiped out the dinosaurs 65 million years ago was caused by the impact of a giant asteroid, which unleashed a globe-spanning cloud of debris and plunged the planet into darkness for months. In 1990, geologists found the crater from this disaster off the north coast of the Yucatan peninsula, validating the impact theory for most of the scientific world.

After that triumph, Walter Alvarez, now at the University of California at Berkeley, began seeking other ways of using science to illuminate history—not just remote geological epochs, but also the events of the human era. "Naturally, a geologist thinks historically, and human history entangled itself with the work I was doing," he says. That thinking began to take concrete form one day when he received an e-mail from Fred Spier, a sociologist at the University of Amsterdam. Spier was working in the field of "big history," a unified, multidisciplinary narrative of everything from the Big Bang to the present. He asked Alvarez if he would be interested in teaching a course on this topic, and Alvarez agreed. "It was a seed that fell on fertile ground," he says.

Before long Alvarez was writing *The Mountains of Saint Francis,* a book that traces Italy's physical and cultural past going back 250 million years. He developed a wildly popular course at Berkeley that integrates cosmology and geology with world wars, sports, and Barack Obama. And he expanded the scope of big history by adding to it his concept of the contingency—the rare, unexpected event (like an asteroid collision) that changes the world in a blink.

DISCOVER senior editor Pamela Weintraub interviewed Alvarez in his Berkeley office, a comfortable space decorated with his own homages to the past: a black-and-white photo of his wife, Milly, taken in her youth, and a piece of the Apennines that dates to the demise of the dinosaurs. Soft-spoken and reflexively sunny, Alvarez turns intense when it comes to the big message behind big history. "Geology is the most important science of the 21st century because there is only one earth, and it's becoming clear that we could damage it beyond the point where it could support us," he says. "Geologists are studying the historical record to understand the controls before we tip into an unstable state."

You seem to elevate geology above other sciences. Why?
Geology is a lot more complicated than astronomy and physics. If you were an early astronomer, you looked at points of light in the sky. The stars stayed in a fixed arrangement and the planets moved against that pattern. It didn't make any difference what happened a billion years before; all that mattered was what you saw now. It took the genius of Tycho Brahe and Johannes Kepler to figure out the movement of heavenly bodies and the genius of Isaac Newton to give us the laws of motion, but these were tractable problems. If you look at a mountain range like the Alps or the

Apennines, on the other hand, you see an extremely complicated pattern of rocks that have the configuration they do because of hundreds of millions of years of history.

How did your predecessors put geology on the map?
The pioneering geologist Nicolaus Steno had a great insight that seems trivial today but wasn't in the 17th century: If you have a pile of stuff, the older stuff is on the bottom. And it's not only the papers on your desk; it's also the rocks in the field. The older ones were laid down first and the younger ones were placed on top. Steno was a great genius because nobody ever previously had the notion that history is written in the rocks.

How did you decide to study that geological history?
I like being out in the mountains, up in the fresh air and the sunshine with the breeze blowing, and you can see all the way across from one side of Italy to the other, so geology appealed to me.

The time you spent in Italy helped you explain the extinction of the dinosaurs 65 million years ago. How did that come about?
In 1970 I received a fellowship and spent a year and a half in Rome as the geologist on an archeological project. Another geologist there invited me on a field research project up in the Apennines, about halfway to Florence. I fell in love with those mountains. When I was invited to go to Columbia to be a researcher at Lamont, I kept wanting to get back to Italy and to those mountains that I found so fascinating.

And fortunately you were able to return to the Apennines with a very helpful colleague.
Yes, Bill Lowrie, a paleomagnetist who could record the direction of the magnetic field at the time a given rock or fossil was formed. This was 1972, '73, and plate tectonics [the theory, now verified, that sections of the earth's crust shift around over millions of years] was just coming along. We became friends, and we thought, hey, it would be really fun to go to Italy to see whether the land had rotated because of plate movement. The local limestone was red, indicating the presence of iron and thus fossil compasses. If we found the compasses tilted around, it would show that Italy and the rest of the continent had rotated. It turned out the idea didn't work very well because there were thousands of layers of bedrock and the layers could slip. But we discovered something else by accident—that these limestones recorded reversals in the earth's magnetic field.

What did these magnetic reversals signify?
Every now and then the earth's magnetic field, which here points north and down, would reverse and point south and up, all due to the convection of the liquid outer core of the earth. Scientists first found evidence that this magnetic field had reversed many times over the history of the earth by measuring the magnetization of rocks that filled in between two diverging tectonic plates under the ocean at the Mid-Atlantic Ridge. If you tow a magnetometer behind a ship or an airplane above the ocean floor, you will find that there are these magnetic stripes and each stripe represents a reversal in the magnetic field. It's literally a magnetic tape recorder.

In this case, you were looking at the magnetic reversals recorded not under the sea but in the layers of rock in a mountain.
The concept was similar. The mountains moved and pushed the earth up, just the way the ocean floor spread out. We also saw black and white stripes, but here's the cool thing. Look at these distances: It requires almost a thousand kilometers of seafloor spreading to record the same amount of time that you find in 150 meters of mountain sediment, so the earth is running two magnetic tape recorders. The one in the seafloor runs 6,000 times faster, and so it captures more detail, but it is less useful than the one in the mountains because we can date the mountain rocks to specific periods of time.

How did you date the rocks in the mountain?
The limestone around the medieval city of Gubbio in Italy contains single-celled organisms called *Foraminifera*, or forams. These are microfossils of little, single-celled organisms that floated in surface water. Whenever a new foram species evolved, it would instantaneously spread all over the oceans and be captured in the sediment before it turned into rock.

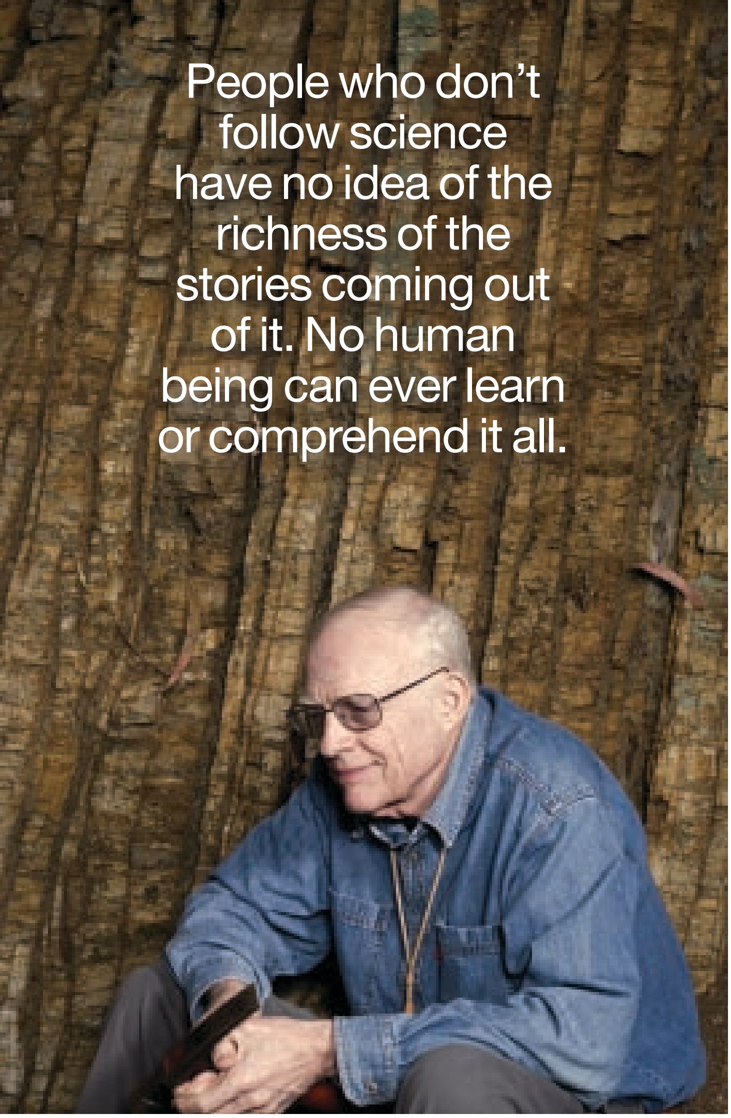
When you say "instantaneously," you are talking about long stretches of time compared with the human life span, right?
Yes. If it took a thousand years to spread, in geologic time that is an instant. For the second half of the Cretaceous [the heyday of the dinosaurs] and all of the Cenozoic [the current epoch]—basically for the last 100 million years—forams have been the best thing we have for dating rocks. By the beginning of the 20th century, micropaleontologists were naming the genera and species of forams. They worked out their evolutionary family tree and linked different species to different parts of the standard geologic timescale.

You have a rock sample here in your office—what can it tell us?
Down here you can see some specks with your naked eye—those are foram fossils. Up here you can't see them unless you have a microscope. The forams are almost gone, and that clear part of the rock represents the near mass extinction of forams and other species. Then farther up you can see the forams again.

That part, where the forams disappear, now seems to represent the time just after an asteroid hit the earth. Do you ever marvel at how much that single, chance event changed things?
The impact of a large object is something that could much more easily not have happened. Its chance of hitting the earth was just vanishingly small.

What if that asteroid had not hit the earth?
The descendants of those forams would have kept right on going, and with them the dinosaurs. The dinosaurs had been around for 150 million years, and they were the dominant large animals on the earth. The mammals were never going to displace them—until that impact took place and the dinosaurs became extinct. And you can see in the paleontological record that from that point on, the mammals burst forth, getting big, getting varied, taking over. We didn't do it because we were superior organisms. We did it because the contingency—the unlikely event of the asteroid hit—got rid of the competition. One of the most profound things that I've learned about history is the importance of the contingency. That's fundamental at the level of every one of us: What are the chances that a man from a little village in Kenya would meet a woman from Kansas and that they would have a child? The chance of Obama ever being born was vanishingly small.

You've been influenced by Yale historian John Lewis Gaddis. How does his work relate to yours—especially to your notion



of contingencies and continuities?

Gaddis uses analogies from geology to explain history, and he's written the most profound thing I've ever seen written about the present, past, and future. He says, "I prefer to think of the present as a singularity...through which the future has got to pass in order to become the past. The present achieves this by locking into place relationships between continuities and contingencies. On the future side of the singularity, these are fluid, decoupled, and therefore indeterminate. However, as they pass through it they fuse and cannot then be separated." The important point is that a continuity is a historical trajectory in which, if you know what happened yesterday, you have a pretty good idea what's going to happen tomorrow. A contingency is an event that was completely unpredictable and utterly changes everything…

…like the asteroid that killed the dinosaurs. It was your interest in the contingency that thrust you into your latest passion, big history. What exactly does big history encompass?

The history of everything that we can possibly observe, starting with the Big Bang. Big history puts the history of the cosmos, the history of the earth, the history of life, and the history of humanity together into a single narrative.

Where did the notion of big history come from?

David Christian invented the concept. He's a Russian historian who trained at Oxford and taught at Macquarie University in Sydney, Australia. He was at a meeting discussing the best curriculum for teaching history. Well, you should definitely start with Greece and the Near East, some people said. But then you would be leaving out Sumeria and ancient Egypt, so we should start there with the Middle East, said others. And somebody said there were all of these little towns in the Neolithic. Somebody else said, yeah, but that develops out of the Stone Age and the Old Stone Age. And then David timidly lifted up his hand and said, you know, if you have this line of reasoning, I can't see any natural time to begin our history course more recently than the Big Bang. There was dead silence, and then one of his colleagues said, well, do you want to teach that? David swallowed hard and said, yeah, I think I do. Being a historian, he didn't know about geology and paleontology and astronomy, so he got colleagues to come in and give guest lectures. Every now and then, one of the guest lecturers would say, I can't do it this year, I am going to be on leave. And David would say, I think I can lecture on that topic, so he gradually turned himself into the first "big historian" and invented the term.

Your colleague Fred Spier has a different take on big history.

He likes to use a vague word, *regime*. One example of a regime is a time interval in history, like the Stone Age or the Renaissance or World War II. A regime can also be related to a place that's a time interval but also unique to a particular part of the world—medieval Christianity would be a case. For me, the four great regimes of big history are cosmos, earth, life, and humanity.

What are the fundamental questions of big history?

What changes when a new regime comes into being? Cosmic history doesn't end when earth history begins. David Christian says we are really talking about the gradual increase of complexity. For instance, you need hydrogen and helium for star formation, but the earth doesn't function on hydrogen and helium. The earth is made primarily of heavier elements: magnesium, iron, silicon, and oxygen. That's why you couldn't get rocky planets in the early cosmos. You needed stars to grow until they exploded as supernovas, processing the material of the cosmos into those heavier elements, leading to more stars and more supernovas and more heavy elements and planets and then, with the emergence of carbon chemistry, life itself.

What are the most extreme contingencies that have altered the course of life on the earth?

One was the evolution of photosynthesis in microbes, the ability to convert sunlight into energy, giving off oxygen. The oxygenation of the earth's atmosphere was the first and surely the greatest of all the episodes of air pollution that have ever been. Microorganisms that previously had free reign over the surface of the earth were forced into restricted environments like the bottoms of swamps and the insides of our stomachs. Another was the evolution by wormlike organisms of the ability to dig around through sediment. Before that, any dead organic matter that fell to the bottom of the sea and got covered by even a little bit of sediment was out of play. We're talking about hundreds of millions or billions of years before that carbon could get back into the life cycle again. Once these organisms could dig, they kept all that carbon in play, speeding the whole biological cycle.

In his book *Maps of Time,* Christian compares the narrative of

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big history to a creation myth. Do you agree?

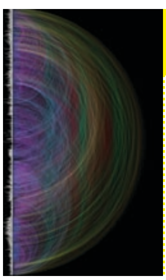
That's a good way of thinking about it. People who don't follow science have no idea of the richness of the stories that are coming out of it. It is so phenomenally complicated that no human being can ever learn or comprehend it all. David has said that the first chronological revolution was when people realized that they could go beyond memory. You can get some of the past by asking your parents what happened. Historians realized you could read and date old documents, finding out things that happened hundreds or thousands of years ago that nobody can remember. But it's only in the last couple of hundred years, since Steno and the first geologists and paleontologists figured out how to read the history of the earth, and only in the last 50 years, since cosmologists figured out how to investigate the history of the cosmos, that we have seen David's second chronological revolution start to unfold.

This is a major problem that standard historians have with big history: How can you take the big view and see the details at the same time?

Hey, we can go deeper and deeper and get more and more inside, but as we do so, it all becomes narrower. Historians have good reasons for being suspicious of big-picture things because early attempts did not work out too well. There wasn't enough information to do it right, and it led to ideological conclusions like social Darwinism. Historians tend to be suspicious of anything that would be called a grand narrative, yet even some of them have recently made an effort in a field called world history, starting with the beginning of writing or agriculture or even anatomically modern humans. For some historians, history means written human history. They feel that scientists may be looking at the past but that whatever they are doing, it is something other than history.

So does big history suggest a grand, unified theory of everything that physicists are searching for?

Physicists like to speak of their goal to discover the theory of everything, but I think they're on the wrong track. At least they've got the wrong name because for them the theory of everything is the theory of all laws and processes. The processes are not nearly as interesting as what unfolds through time as all of those processes operate, and that's history. Big history is the theory of everything. What the physicist is talking about is not the theory of everything but the theory of how everything works. Physicists may put themselves out of a job when they get their theory of everything, but they won't put the rest of us scientists out of work. ◼



SEPTEMBER'S **WHAT IS THIS?**
THE BIBLE

This image renders the 1,200 chapters and 31,000 verses of the King James Bible into visual form. The bars on the left represent the chapters of the holy book; the lengths correspond to the number of verses in each chapter. Each of the 63,779 arcs represents a cross-reference, in which a passage alludes to figures or ideas from an earlier one, while the distance between the two passages determines

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or absence of a single electricity-conducting opant atom on the silicon surface can radically change the behavior of a transistor and lead to errors, even in digital mode. Engineers are working to solve these problems, but the development of newer generations of chips is taking longer. "Transistor speeds are not increasing as quickly as they used to with Moore's law, and everyone in the field knows that," Sarpeshkar says. "The standard digital computing paradigm needs to change—and *is* changing."

As transistors shrink, the reliability of digital calculation will at some point fall off a cliff—a result of the "fundamental laws of physics," says Sarpeshkar. Many people place that statistical precipice at a transistor size of 9 nanometers—about 80 silicon atoms wide. Some engineers say that today's digital computers are already running into reliability problems. In July a man in New Hampshire bought a pack of cigarettes at a gas station, according to news reports, only to discover his bank account had been debited $23,148,855,30 8,184,500.00. (The error was corrected, and the man's $15 overdraft fee was refunded the next day.) We may never know whether this error arose from a single transistor in a bank's computer system accidentally flipping from a 1 to a 0, but that is exactly the kind of error that silicon-chip designers fear.

"Digital systems are prone to catastrophic errors," Sarpeshkar says. "The propensity for error is actually much greater now than it ever was before. People are very worried."

Neurally inspired electronics represent one possible solution to this problem, since they largely circumvent the heat and energy problems and incorporate their own error-correcting algorithms. Corporate titans like Intel are working on plenty of other next-generation technologies, however. One of these, called "spintronics," takes advantage of the fact that electrons spin like planets, allowing a 1 or 0 to be coded as a clockwise versus counterclockwise electron rotation.

The most important achievement of Boahen's Neurogrid may be in recreating not the brain's efficiency but its versatility. Terrence Sejnowski, a computational neuroscientist at the Salk Institute in La Jolla, California, believes that neural noise can contribute to human creativity.

Digital computers are deterministic: Throw the same equation at them a thousand times and they will always spit out the same answer. Throw a question at the brain and it can produce a thousand different answers, canvassed from a chorus of quirky neurons. "The evidence is overwhelming that the brain computes with probability," Sejnowski says. Wishy-washy responses may make life easier in an uncertain world where we do not know which way an errant football will bounce, or whether a growling dog will lunge. Unpredictable neurons might cause us to take a wrong turn while walking home and discover a shortcut; or accidently break our chocolate bar off in a coworker's peanut butter—and discover the peanut butter cup.

Re-creating that potential in an electronic brain will require that engineers overcome a basic impulse that is pounded into their heads from an early age. "Engineers are trained to make everything really precise," Boahen says. "But the answer doesn't have to be right. It just has to be approximate." ◼