Shots from Outer Space

Iconoclast links chaos, cosmic impacts, and Earth's internal workings

By RICHARD MONASTERSKY

Sipping coffee in a San Francisco deli last month, Herbert R. Shaw paused to consider the 6,500 geophysicists convening for their annual meeting across the street. They might as well be across the globe. Though a geophysicist himself and a fellow of the organization sponsoring the meeting, Shaw did not attend a single session this year.

Shaw finds himself separated from most other earth and planetary scientists by a theoretical chasm. His unorthodox views about Earth's cataclysmic past would rankle many, confuse others, and make some absolutely apoplectic.

They will have a chance to discover Shaw's ideas in March, when Stanford University Press publishes *Craters, Cosmos, and Chronicles: A New Theory of Earth.* Shaw, a researcher with the U.S. Geological Survey in Menlo Park, Calif., contends that asteroids and comets hurtling through space have controlled our planet to a far greater extent than scientists had previously recognized. Collisions with such cosmic bombs have shaped almost all aspects of Earth's evolution, he contends, from the beatings of its iron heart to the wrinkling of its rocky skin to the dawning and demise of the dinosaurs.

Shaw argues against the conventional wisdom that asteroids and comets strike Earth at random locations, like scattered spray from a shotgun. Instead, such extraterrestrial missiles have been well aimed — by chaotic interactions with Earth itself — and hit only particular spots on the globe.

"The impacting of objects on Earth and other planets is a highly organized process. Earth is not just being shot at by some random gun out there in space like all the . . . planetologists believe. To me that is just totally absurd," Shaw told SCIENCE NEWS.

The focused barrage of space flotsam, in turn, has dominated Earth's history. The pattern of past impacts, he suggests, determines the positions of the continents, steers the geomagnetic field, creates volcanoes, and occasionally causes mass extinctions. In constructing this theory, called the Celestial Reference Frame Hypothesis, Shaw has taken a sledgehammer to the foundations of geophysics, ensuring no shortage of opponents.

Shaw traces the genesis of his book to an observation he and USGS colleague William Glen made in 1991 while discussing the crisis that afflicted Earth at the end of the Cretaceous period, 65 million years ago. That time, called the Cretaceous-Tertiary (K-T) boundary, is marked by a mass extinction that snuffed out the last remaining dinosaurs, other land animals, and three-quarters of all ocean species. The leading suspect in this murder mystery is a large impact or series of impacts by comets or asteroids, collectively called bolides.

Shaw and Glen noticed that several craters gouged in this general time frame (between 50 million and 100 million years ago) form a surprising pattern — a circular swath connecting the large Chicxulub crater on the Yucatán Peninsula, the Manson crater in Iowa, the Avak crater in Alaska, and three craters (Popigai, Kara, and Kamensk) in Russia. The pattern, which Shaw calls the K-T swath, resembles a tilted halo over the Northern Hemisphere.

After that observation, Shaw began exploring impact craters of various ages in the Phanerozoic period, the last 600 million years. Instead of seeing craters spread randomly among all continents, he discerned three distinct clusters in North America, Eurasia, and Australia.

The arrangement suggested that bolides have been striking a limited set of targets, or "cratering nodes," which have remained the same for at least the last half billion years. Shaw surmised that the three nodes and any other missing ones actually represent the intersection points of cratering rings that, like the K-T swath, encircle the globe.

"That was the trigger that started me thinking about what principles could organize impacts," Shaw says. Though his research career originally focused on studying the melting of rocks inside Earth, Shaw plunged into the distant realm of celestial mechanics in an effort to explain what might aim objects repeatedly toward the same specific swaths.

Such an intellectual leap does not surprise scientists who know Shaw. Glen, a geophysicist and historian of science, describes him as a modern renaissance man. "Shaw's is perhaps the most remarkable and diversely comprised career I have encountered in the several hundred interviews I have done over the past 20 years of historical documentation of the earth sciences," Glen says.

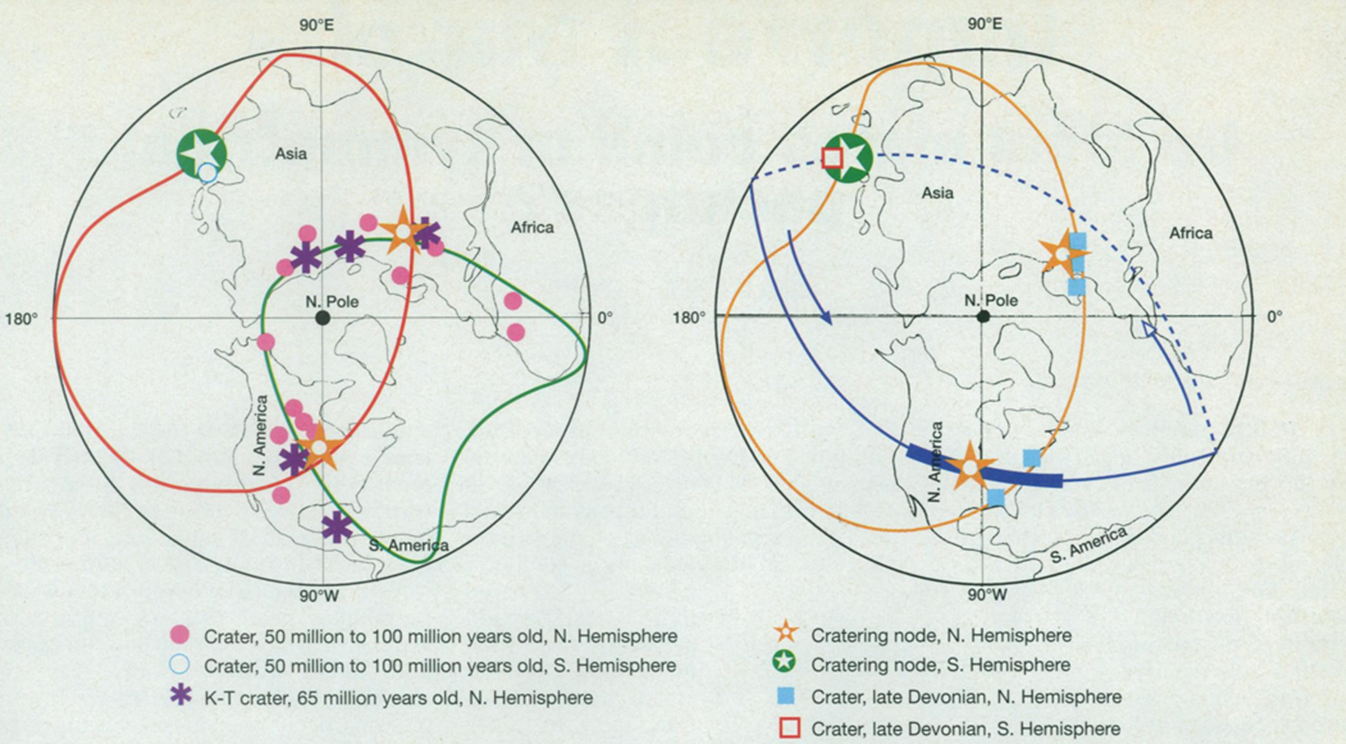
In the 1980s, Shaw pioneered the introduction of nonlinear dynamics, or chaos theory, into geophysics. Starting in 1991, he began applying those powerful tools to the impact problem and arrived at the idea that bolides and Earth interact in a far more orderly way than most scientists believe.

Building on current findings that show chaotic behavior in the solar system (SN: 2/22/92, p.120; 2/27/93, p.132), Shaw hypothesizes that nonlinear gravitational influences create a coordinated mechanism that helps guide the asteroids and comets that reach the inner solar system. Arriving in intermittent bursts, such objects can then be captured as natural satellites orbiting Earth and other planets.

Because of gravitational interactions with Earth, the captured bodies eventually enter only specific orbits, leaving others empty. These so-called orbital resonances develop, suggests Shaw, because Earth contains lumpy arrangements of mass in its interior — perhaps a legacy of a colossal early impact with a Mars-size body that some believe gave birth to the moon. The extradense spots inside Earth repeatedly tug on any satellites, nudging them toward particular orbits, according to Shaw.

Most bolides captured by Earth therefore reach the same limited sets of orbits. When the bodies eventually lose energy and crash to Earth, they repeatedly land along a few swaths because they have been steered by similar orbital trajectories, Shaw says.

Direct evidence in support of Shaw's theory popped up when he stumbled across a 1913 publication by Canadian astronomer C.A. Chant, who documented a string of meteors that shot over North America that year. By collecting eyewitness accounts,



Cratering patterns emerge on map projections of the Northern Hemisphere, with the pole in the center. Left map: Green line represents K-T swath, connecting craters 50 million to 100 million years old. On a globe, this line would form a circle. Asterisks denote cratering nodes, regions frequently hit during the Phanerozoic time, the last 600 million years. Red line is a circle connecting Phanerozoic nodes. Right map shows two special cases that fit Shaw's hypothesis. Blue line represents inferred path of fireballs in 1913, which were observed along shaded course from Canada to Bermuda. Orange curve connects numerous craters of the late Devonian period, roughly 360 million years ago. Both blue and orange circles pass through Phanerozoic cratering nodes.

Chant reconstructed the path of the fireballs from Saskatchewan to Bermuda and mapped the extension of this orbit around the globe.

To Shaw's surprise, the fireball's orbit passed right over two of his cratering nodes. Chant's line also matched almost exactly a great circle around the Earth that Shaw had hypothesized as a potential orbit of objects captured by the planet.

"That could be pure chance, but the fit was so precise that it really was a shock," Shaw says. "Here was an example of a natural phenomenon falling on one of the lines I cooked up out of thin air."

In his all-encompassing model, Shaw sees Earth and its impactors as a feedback system almost as complex as the web of a human conversation. The uneven distribution of mass inside Earth — itself produced by an early crash — influences where later bolides strike. These catastrophes, in turn, repeatedly hammer the same spots on the planet's surface, helping control the flow of material inside Earth. This, then, affects the trajectories of orbiting bolides.

If bolides do pummel the same spots on Earth, then the effects of such an organized beating may ripple from the planet's surface to its very center. According to Shaw, large impacts apparently affect the currents of molten iron within the planet's outer core, helping to orient the geomagnetic field that arises from these currents. In support of that contention, he notes that the three cratering bull's-eyes coincide roughly with well-known concentrations of magnetic forces at the top of the core.

Closer to the surface, the impacts may trigger the largest lava outpourings — known as flood basalt provinces — which form vast plateaus on land and under the sea. As evidence for a connection, Shaw points to the known flood basalts that fall on or near the globe-circling swaths that connect the three cratering nodes he identified. This conflicts with current thinking, which attributes flood basalts to plumes of hot rock rising from deep within the mantle.

Shaw's ideas even challenge aspects of plate tectonics, which holds that Earth's landmasses have migrated across the face of the globe over geologic time. As part of his Celestial Reference Frame Hypothesis, he suggests that the cratering nodes on North America, Eurasia, and Australia have remained fixed for a half billion years. Either the continents must return again and again to characteristic locations, or the basic continental blocks do not drift as much as geophysicists now presume.

According to Shaw's model, the patterning of impacts has also organized the evolution of life by punctuating geologic history with a set of coordinated catastrophes. Although individual impacts may seem random and unrelated, they are governed by the history of feedbacks between Earth and the objects that strike it. In other words, each impact depends on past hits and influences those to come. This linkage allows Shaw to weave the idea of sudden cataclysms into geology's reigning doctrine of uniformitarianism, which holds that regular, repeated processes have slowly shaped the planet's crust in the same fashion they do today.

"It was not simply impacts but rather a uniformitarian and nonlinearly intermittent terrestrial-celestial interaction that killed the dinosaurs," he writes in his characteristic prose.

In style, Shaw's text mirrors his theory of complex interconnections — a case of science imitating life, or vice versa. His book, with its hundreds of pages of footnotes and appendixes, resembles more a tapestry than a linear arrangement of ideas. Similarly, a conversation with Shaw might contain dozens of digressions, swerving from linguistics to satellite construction to the geology of Shiprock, Ariz.

On all topics, Shaw displays scant respect for convention, a trait that extends

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from science to sleep schedules. He prefers to work at night and doze in bursts during the afternoon, sometimes forgoing rest altogether.

Other iconoclastic scientists have raised elements of Shaw's theory in the past — by linking impacts to flood basalts or to the behavior of the geomagnetic field, for instance. Some have noted the concentrations of craters on North America, Eurasia, and Australia. But Shaw is the first to draw all these elements together and view them through the lens of nonlinear dynamics, which can discern patterns in space and time not otherwise apparent.

Shaw's work resembles a "unified field theory" of geophysics, connecting almost every aspect of the planet to the complex ballet between Earth and the swarm of potential impactors in space. "The idea is that everything we've been attempting to develop theories for in Earth makes sense in connection with impact dynamics," he says.

With Shaw's book not yet published, few scientists have had the opportunity to wade through its 600-plus pages. But those who reviewed the manuscript for his publisher say they can predict its reception.

Reviewer Ralph H. Abraham, a mathematician at the University of California, Santa Cruz, says Shaw will surely face the kind of opposition that others encountered when they brought chaos theory to physics, astronomy, and biology. "They were rejected, vilified. It's expensive to be a pioneer, to be a heretic," says Abraham, himself an innovator in the field of nonlinear dynamics.

Judging from progress in other sciences, Abraham says, a decade or more may pass before many geophysicists embrace the tools of nonlinear dynamics that Shaw seeks to introduce into the field.

"Herb will be criticized by everybody," says Glen, who also serves as an editor for Stanford University Press. "This is like Darwin and Wallace; they were pounded by everybody."

Shaw did succeed in winning favorable marks from Abraham, astronomer Archie E. Roy of the University of Glasgow in Scotland, and paleontologist Digby McLaren, former director of the Geological Survey of Canada. "This guy has come along and taken a sort of quantum leap in interpretation," says McLaren. "He's raising some fairly unorthodox ideas, new ideas, which will force us to think about things. I don't think there is any doubt about that. That's the most important part about the book. It's not even whether he is right or wrong but that he can interpret evidence in such a way that the individual building blocks of the theory must be reexamined. It's highly stimulating."

Shaw's book has also received some unanticipated help from nature — namely, the fiery death of comet Shoemaker-Levy 9, whose fragments plunged into Jupiter last July. The comet's demise provides an opportunity to test some of the hypotheses outlined by Shaw, who believes the event bolsters his theory that nonlinear interactions organize impacts on Earth.

Scientific interest in the process of impacting has surged in recent years as researchers accumulate evidence of life-disrupting blows at the K-T boundary and other major turning points in geologic time. But the dust from such events settled millions of years ago. The cosmic spectacle of last July sparked unprecedented interest in impacts by giving scientists their first opportunity to see large objects actually wallop a planet.

Shaw's book could not receive any better advertisement. According to Roy, "This book is being published at a very serendipitous time because it can look to the Jupiter event almost as an excellent example of this process." □

Chemistry

Bearing down on the kilogram standard

Since 1889, a single platinum-iridium bar has lain sealed in an airtight bell jar in the International Bureau of Weights and Measures in Sèvres, France.

Nicknamed "Le Grand K," this bar constitutes the one and only true kilogram.

Of all the standard international units of measure, the kilogram remains the only one whose definition relies on a physical artifact. All other units — of time, length, or electric charge — have their definitions rooted in constants of nature, such as the speed of light or atomic vibrations.

As part of an international effort, researchers at the National Institute of Standards and Technology (NIST) want to redefine the kilogram in a way that will make the standard absolute, unchanging, and accessible to anyone, anywhere — liberating Le Grand K from its heavy burden as standard-bearer.

"One problem is that the current standard tends to drift a little bit," says Barry N. Taylor, a physicist at NIST. "The kilogram has varied by as much as .05 parts per million in the last 100 years." The causes of that variance remain unknown, though Taylor believes that "outgassing, absorption, or just dirt accumulation and cleaning" may be responsible.

The platinum-iridium bar presents other disadvantages. It is inaccessible to researchers, can be reproduced only with difficulty, and could be damaged or destroyed.

To remedy these problems, researchers want to define the kilogram as a function of the Avogadro constant, which measures the number of molecules (6.023×10^{23}) present in a gas occupying 22.41 liters at fixed temperature and pressure. Currently, Avogadro's number is rooted in the exact number of atoms present in 12 grams of the isotope carbon-12.

"By definition, the Avogadro number relates macroscopic masses to atomic measurements," Taylor says. "That makes it appealing as a basis for defining the kilogram."

But creating a reliable, accurate, easily reproducible standard has proved trickier than expected. An apparatus must consistently reproduce a kilogram with an uncertainty approaching one-billionth.

According to Taylor, scientists worldwide are exploring five possible kilogram definitions. Currently, two methods lead in accuracy. The first, called the moving coil watt balance method, relates electrical energy to mechanical power at the quantum level. Invented by B. P. Kibble at England's National Physical Laboratory, this method offers a precise value of the Planck constant, from which one derives Avogadro's number.

A second approach, the X-ray crystal density method, relies on mass and density measurements of silicon atoms in a pure crystal. Researchers in Germany, Japan, Belgium, and the United States are refining the accuracy of this technique, whose uncertainty hovers near one-millionth.

In Japan and Russia, scientists are levitating masses with superconductors; in Germany, experimenters are debugging a vacuum Faraday system, whereby gold atoms beamed onto a collector yield an electric constant, from which an Avogadro number can be derived. A final approach, the volt balance method, has scientists in France, Australia, and Yugoslavia measuring minute differences in electric potential as a way to generate an Avogadro number indirectly.

Still, official adoption of a new standard lingers on the horizon. "With a lot of luck," says Taylor, "we might see a change within the decade."