**SOLAR SYSTEM FORMATION**

# The First Rocks Whisper Of Their Origins

**Researchers were foundering in a sea of meteorite data, but new findings offer a renewed prospect of understanding how the solar system came to be**

John Wood was discouraged. For more than 40 years he had been studying meteorites, in hopes that the first rocks formed in the solar system would reveal when and how they and other planetary bodies came to be. Now a leading figure in his field, Wood was beginning to suspect that the evidence might not be there. And in a plenary lecture at the annual Lunar and Planetary Science Conference, he stunned his colleagues by saying so.

After 200 years of studying meteorites, "we still don't understand what they are trying to tell us," Wood lamented (*Science*, 31 August 2001, p. 1581). "I personally wonder whether we ever will." The problem, he said, is that meteoriticists excel at squeezing information out of rocks but flounder when it comes to piecing together theories. To have any hope of progress, they must think less like geologists and more like astrophysicists.

Two years later, Wood's meteorites are starting to loosen up. New findings reported in recent months hint that they do indeed preserve a record of the solar system's formation—a record that scientists, following Wood's astrophysical prescription, are piecing together more easily.

"When John gave his talk, things did look pretty grim," says astrophysicist Alan Boss of the Carnegie Institution of Washington's Department of Terrestrial Magnetism (DTM) in Washington, D.C. "There was this immense amount of data being created but not much context for understanding what it means; I think the last few years we really have made some progress." Meteoriticist Alan Rubin of the University of California, Los Angeles (UCLA), agrees that progress is being made but cautions that the recent findings are creating new problems even as they reveal new details of the solar system's formation. "We still need a bigger picture," he says.

One area in which theory is proving its mettle is unraveling the detailed timing of events. The grand scheme of solar system formation has been appreciated for centuries: Gas and dust formed a ball that collapsed into a spinning disk, or nebula; the sun grew at the center of the nebula; and orbiting planets agglomerated from the nebula material swirling around the infant sun. But how long did it take? Early computer models estimated that it had taken about 100 million years for Earth and the other terrestrial planets to form. Better-equipped scientists portraying the accretion process in greater detail—dust to pebbles to boulders to planetesimals to planets—have shown that "runaway" planetesimal accretion pares the time down to a few tens of millions of years.

**Halfway there.** A crater-pocked Earth would have swept up more nebular material—some of it reprocessed by the young sun—to reach its final size within 30 million years of the sun's birth.

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Geochronologists can check that timing by choosing a radioactive isotope that steadily sputters out of existence while the planets accrete. Using one such isotopic clock, they found that Earth had accreted by about 60 million years after the solar nebula formed—not a bad match for astrophysics, but hardly perfect.

In a recent flurry of papers, three groups of geochronologists have shown that the modelers may be close to the mark. Each of the three studies—from Qingzhu Yin of Harvard University and colleagues and T. Kleine of the University of Munster, Germany, and colleagues (both in the 29 August *Nature*) and Ronny Schoenberg of the University of Queensland, Brisbane, and colleagues in the 1 September *Geochimica et Cosmochimica Acta*—depends on the radioactive decay of hafnium-182 to stable tungsten-182 with a half-life of 9 million years, a process that provides a clock for timing the birth of terrestrial planets. As a planet accretes, molten iron separates from the rock and falls inward, to form the metallic core. The iron carries hafnium's decay product, tungsten, with it. The hafnium, however, stays behind in the rocky mantle, its "decay clock" effectively reset to zero.

The teams compared elemental and isotopic abundances in rocks from Earth's mantle with those in the most common meteorites, so-called ordinary chondrites. Chondrites are similar to the planetesimals that formed the infant Earth, but because they never yielded their iron to form a core, they retain the full record of hafnium-to-tungsten decay. By checking their isotopic clocks against those in mantle rocks, the researchers found that core formation, and presumably Earth's accretion, were essentially complete by 30 million years after the solar nebula formed, not 60 million years.

"We have new dates and a new time scale that speeds things up by a factor of two," says Alexander Halliday of the Swiss Federal Institute of Technology in Zürich, whose lab produced the 60-million-year figure using hafnium-tungsten. Conceding an as-yet-unexplained error in their earlier work, he said, "We now have much better constraints." The measured time for accretion now neatly matches that of the models.

The new date has its drawbacks, Halliday notes. For one thing, the work also reduces the date of the moon's formation from 60 million years after the solar nebula formed to 30 million years. The later origin had neatly matched the age of the moon's oldest rocks, which were presumed to have quickly frozen out of the ocean of magma covering the new moon. The revised age of the moon creates a 30-million-year gap, forcing scientists to explain either why moon rocks took so long to form or where the first ones went. "That's a bit of a surprise," says Halliday, one to be sorted out with more chemical and isotopic analyses.

The "big picture" approach is also making inroads into the complicated question of how the cosmic dust, ice, and gas in the solar nebula were chemically processed before finally forming planets. Astrophysicist Frank Shu, formerly at the University of California, Berkeley, and now president of National Tsing Hua University in Hsinchu, Taiwan, tackled the problem in 1996, when he proposed his "X-wind" model of nebular processing. Shu was trying to explain the origin of chondrules—millimeter-sized blobs of material that make up the bulk of chondrite meteorites. In his scenario, the young sun blasted the nearest nebular material with heat and radiation and then blew the resulting blobs of molten rock up and out over the nebular disk in the magnetically driven wind typical of newborn stars. Falling back onto the disk, the droplets became chondrules, which formed the building blocks of both chondrites and terrestrial planets.

Other scientists were unimpressed. Recently, though, the astrophysical X-wind model of chondrule formation has been gaining favor as an explanation of at least some nebular processing, thanks to careful studies of another component of chondrites: so-called calcium-aluminum inclusions (CAIs). They are marble-sized inclusions far rarer than chondrules that were melted like their common cousins before being incorporated into chondrites.

Since Wood delivered his lecture, researchers studying CAIs have found signs of short-lived isotopes of beryllium that point to, and perhaps even require, irradiation by the young sun. In conventional thinking, any radioactive isotope that burned out quickly in the early days of the solar system must have come from outside the nebula. Decay products of short-lived isotopes such as aluminum-26 pointed to a supernova blasting a cloud of stellar debris, salting it with short-lived radioactive isotopes, and collapsing it to form the solar nebula.

But in August 2000, Kevin McKeegan of UCLA, Marc Chaussidon of the Petrographic and Geochemical Research Center in Vandoeuvre lès Nancy, France, and François Robert of the National Museum of Natural History in Paris reported finding traces of now-extinct beryllium-10, with a half-life of 1.5 million years. Beryllium-10 isn't made in stars of any sort; it is made by irradiation, suggesting to many researchers that the X-wind had been at work in the solar nebula.

Now, Chaussidon, Robert, and McKeegan are reporting at meetings that they have good evidence of an even shorter-lived isotope—beryllium-7—in a CAI, which would clinch the case for the X-wind model. "This is fantastically exciting," says cosmochemist Donald Burnett of the California Institute of Technology in Pasadena. "If true, it upsets the apple cart." Most researchers are waiting for more details, but after hearing the group's latest presentation at the Goldschmidt Conference in August in Davos, Switzerland, Halliday "suspect[s] the data are good."

If so, scientists will have some explaining to do. Last month in *Science* (6 September, p. 1678), geochronologist Yuri Amelin of the Geological Survey of Canada in Ottawa and colleagues confirmed the aluminum-26 isotopic clock indication that CAIs formed 1 million to 4 million years before chondrules did. Yet both wound up in the same meteorites. "There's a big puzzle how you can possibly store CAIs for millions of years waiting for chondrules to form," says Shu. Marble-sized bits of rock orbiting in the gas of the solar nebula would have been dragged into the sun within tens of thousands of years, he notes, not millions.

Because of such problems, scientists still don't think that X-winds can account for chondrule formation and that a separate mechanism is required. Dozens of possibilities have been proposed, but recent modeling is supporting a longtime favorite: shock waves coursing through the early solar nebula. The theory had languished while it failed to reproduce the entire geologic history extracted from chondrules. Mineralogical and geochemical evidence showed that chondrules had been heated to 1800 to 2100 K for several minutes and then cooled over several hours. A sufficiently powerful shock wave would do the heating, but for years models weren't keeping chondrules hot for long enough after it passed.

This year, two independently developed models—from Steven Desch of DTM and Harold Connolly of Kingsborough College–City University of New York, Brooklyn, in the February *Meteoritics & Planetary Science* and Fred J. Ciesla and Lon L. Hood of the University of Arizona, Tucson, in the August *Icarus*—solved that problem by showing that shocked and heated gas in the solar nebula could have kept the chondrules hot for a few hours before they radiated away all the heat. Shock is now the leading proposed mechanism for chondrule formation. Now theorists are gearing up to explain where the shock waves came from, which is still an open question. The modeling "could have been done before," says Desch. "I think the problem has been, as John Wood said, there haven't been enough astrophysicists working on this."

Wood himself says that he is delighted with "all the marvelous things that have appeared in the last couple of years." He's even getting back into the meteoritics business after several years of chairing committee reports. Perhaps his rocks will tell him more this time.

–RICHARD A. KERR

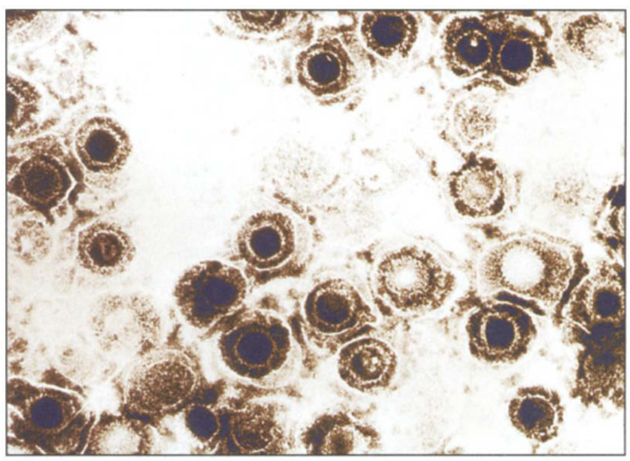
MICROBIOLOGY

# Domino Effects From Battles Against Microbes

**It's not geopolitics, but in the battle of the bugs, strategies of containment and deterrence can tip off unexpected public health consequences**

**SAN DIEGO, CALIFORNIA**—A microbiology megaconference held here last week* made it abundantly clear that invisible dangers lurk everywhere. Antibiotic-resistant bacteria infest hospital catheters, the hands of health care workers, the dirt on supermarket potatoes, and even captive dolphins. Ever more information about how to genetically manipulate microbes could allow terrorists to cause mayhem with bioweapons. And a more mundane threat, nose picking (yes, nose picking), might routinely move dangerous bugs from the skin into the nasal cavity.

But some of the most groundbreaking studies presented at this 4-day meeting—attended by nearly 10,000 researchers and another 2000 exhibitors—emphasized that successes in the eternal battle against microscopic bugs often have far-reaching domino effects. An antiviral medication that eases the symptoms of a sexually transmitted disease might also prevent transmission of the virus that causes it, for instance, as well as transmission of a second, unrelated virus. Another analysis pushed for wider use of the influenza vaccine, arguing that immunizing all infants against the nasty virus could have profound public health benefits. In one negative consequence of widespread vaccinations, however, protecting children against chickenpox might make their grandparents' generation more susceptible to shingles, a painful malady caused by the same virus.



**Daily dose of prevention.** Valacyclovir inhibits the spread of herpes simplex virus type 2 (above) from infected people to their partners.

CREDIT: CDC

* 42nd Interscience Conference on Antimicrobial Agents and Chemotherapy, sponsored by the American Society for Microbiology, 27–30 September.