Tuna especially often follow large driftwood, which may float for 5 years and go thousands of kilometers, says Curtis Ebbesmeyer, an expert on floating objects with the Seattle oceanographic firm Evans-Hamilton. "One piece can develop its own movable ecosystem weighing tons, including birds and sharks," says Ebbesmeyer. The proof is in the catch: Some captains have lately taken to putting radio beacons on driftwood or even hauling in their own artificial logs, made of masses of bamboo, if there are no natural ones to attract fish.

A surprising amount of this drift sinks to the deep-sea floor, where specialized communities lurk as far down as 8000 meters, awaiting the blessed rain. First documented in detail in the early 1980s by the late Harvard marine biologist Ruth Turner, these communities include a subfamily of wood-specialized bivalves, *Xylophaginae*. By dropping wood packets off New York's Long Island, Turner showed that by some unknown method these mollusks home in within weeks on the otherwise barren sea floor, boring quarter-sized holes and soon attracting a huge secondary community.

This discovery was regarded as a curiosity until the past few years, when others began suspecting that deep-sea wood acts as a sort of missing link to animals at deep-sea hydrothermal vents and cold seeps. Marine biologist Craig Smith of the University of Hawaii, Honolulu, has begun studying sunken wood and other scattered organic troves like whale skeletons and kelp, and he has found that some denizens there are related to—or the same as—those on vents. "Wood may act like islands for them to hop from one far-flung vent to another," says Smith.

Some wood-associated organisms appear to use the same metabolic pathways as vent organisms, with bacteria breaking down matter to make hydrogen sulfide, which then is used directly or indirectly by a spectacular complex of fungi, protists, snails, tubeworms, and bivalves. DNA studies of the wood-dwelling mussel *Idas washingtonia* suggest that it may be the ancestor of the major vent mussel subfamily, according to work by Smith and his collaborator Daniel Distel of the University of Maine, Orono. In an article published last February in *Nature*, they suggest that wood that washed down continental slopes may in fact have been an evolutionary steppingstone, providing oases that allowed mussels to eventually colonize vents and seeps.

With humans rapidly razing forests, though, the reign of deadwood may be ending. Giant natural rafts that once clogged most rivers—in 1816 Louisiana's Atchafalaya had one 16 kilometers long, with upright 20-meter trees sprouting on it—have long ago been cleared for navigation. In the United States, the old-growth forests that supplied them are 95% gone; salvage harvesting of stumps, logs, and even driftwood is doing away with the debris.

Since deadwood's significance started becoming clear, managers have made some attempts at repair and preservation. Old longleaf pines are now scarce in the Southeast, so Parks of PNWRS is trying to make young ones rot inside, by injecting fungi. States have started requiring loggers to leave a certain number of snags and logs per acre and preserve a narrow, uncut strip along waterways. And after a century of pulling wood from rivers, the U.S. Army Corps of Engineers is anchoring artificial piles of it in select places in the Pacific Northwest, at great expense. Fish and birds have been shown to colonize some of these habitats, but no one is sure how much is needed for recovery. "Given the growing human population, we can probably never put back enough," says the Forest Service's Sedell. "But we ought to try. So much depends on it." **–KEVIN KRAJICK**

Kevin Krajick is the author of Barren Lands: An Epic Search for Diamonds in the North American Arctic.

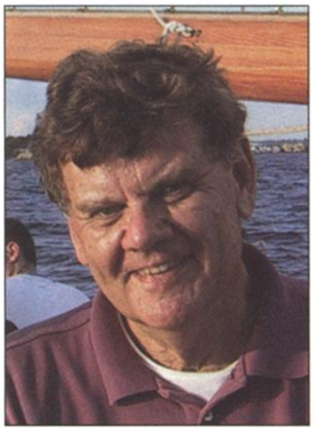
METEORITICS

A Meteoriticist Speaks Out, His Rocks Remain Mute

After 40 years of searching meteorites for the solar system's origins, John Wood believes that his field faces a dead end—but he offers a way out

The prestigious Harold Masursky Lecture should have been an uplifting look at chondrites, the most common type of meteorite, from one of the field's leading practitioners, John A. Wood of the Harvard-Smithsonian Center for Astrophysics (CfA) in Cambridge, Massachusetts. And predictably, Wood began his plenary talk at last year's Lunar and Planetary Science Conference with a review of 19th century studies. They described curious millimeter-sized blobs of rock encased within chondrites and now called chondrules as "drops of a fiery rain" that froze just as the solar system was forming. Wood moved on to what chondrules say about how the solar system formed from a disk of gas and dust 4.6 billion years ago. Then he lowered the boom.

"We still don't understand what the meteorites are trying to tell us," Wood told hundreds of his colleagues assembled in the main gymnasium of NASA's Johnson Space Center south of Houston. "I personally wonder whether we ever will. There's just no convergence."



Chondrite pessimist. John Wood despairs that after 2 centuries of dissecting chondrite meteorites, meteoriticists aren't getting any closer to understanding them.

In the 40-plus years Wood has plied his specialty, geologists and geophysicists have figured out that the continents move, and astronomers have learned how stars are formed, he said. But his field's near-exclusive focus on deciphering chondrites' composition on ever finer scales "has not worked," he declared, "and it won't work." Understanding how the oldest rocks in the solar system formed from the early nebula of dust and gas will require meteoriticists to merge their crabbed analyses of chondrules with a big-picture understanding of how stars form that is being developed by astrophysicists. A grand theory is the only way to make progress, he argued.

"That talk upset a lot of people, especially students," says his first student, Harry McSween of the University of Tennessee, Knoxville, who heard "a senior person saying that what we do is a waste of energy, that this is an unresolvable problem. I thought it was too negative, too." The talk was "an unmitigated disaster," recalls Glenn MacPherson of the National Museum of Natural History in Washington, D.C., who admits to having been discouraged a few years ago, too, but no longer. "We have a way to go, but I think we're making progress."

The birth of blob studies

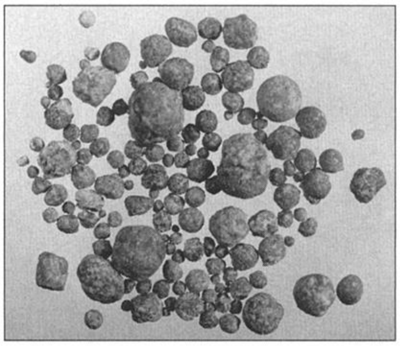
All would agree that progress in the study of chondrites by chemists and geologists has come in fits and starts. Wood reviewed that history in his talk as well as in a profusely illustrated, self-published version of his presentation that he distributed this spring to 150 colleagues. (The editor of the field's leading publication, *Meteoritics and Planetary Science*, had asked Wood to submit a manuscript, but the two of them could not agree on its format.) Wood reminded his listeners that 19th century scientists were dissecting chondrules and divining their basic nature before such prominent figures as Thomas Jefferson had even accepted the idea that meteorites fall from the sky. Two hundred years ago this coming year, English chemist Edward Howard reported to the Royal Society of London that four rocks found as nearby as Wold Cottage, England, and as far away as Benares, India, were all composed of the same four curious components: millimeter-sized spherules, later named chondrules, that constitute 50% to 80% of the mass of chondrites; nickel-containing grains of metal; a mineral now recognized as iron sulfide; and an earthy material or matrix that bound it all together. Faced with the question of how such similar rocks could be found so far part, Howard concluded that they had come from space.

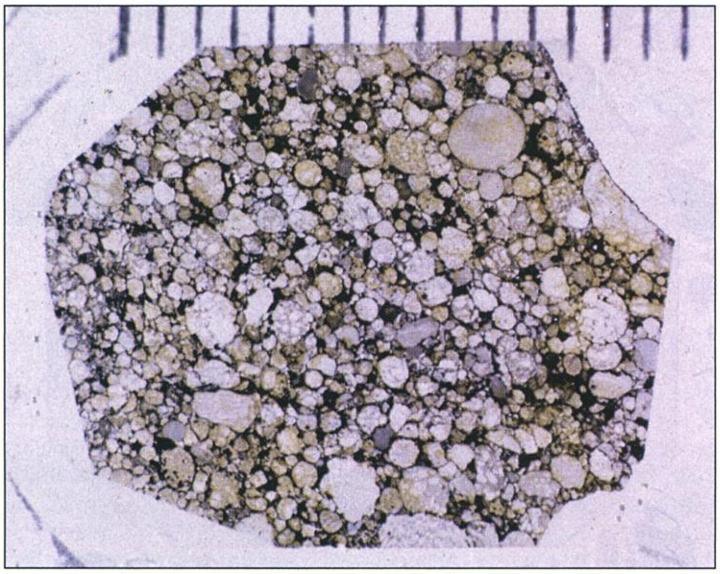
Wood's next "meteorite hero" was English gentleman scientist Henry Clifton Sorby, the first person to study a rock by looking through a wafer of it thinned to the point of transparency. Given his familiarity with steel smelting in Britain, Sorby recognized the high-energy origin of chondrules from their form and crystalline structure. They "were originally detached glassy globules, like drops of a fiery rain," he wrote in 1877. Indeed, research since 1950 would show that some type of material had been heated to 1500° to 1800°C and then cooled rapidly. Sorby had an idea how it happened, too. He suggested that "meteorites are the residual cosmic matter, not collected into planets, formed when the conditions now met with only near the surface of the sun extended much further out from the centre of the solar system." In his manuscript, Wood asked plaintively, "Have we come much farther than this today?"

The field fell into a lull in the first half of the 20th century, but that changed after World War II. Harold Urey moved to the University of Chicago in 1945 after helping build the atomic bomb and single-handedly started the field of cosmochemistry. In 1957, Wood, a graduate student in geology at the Massachusetts Institute of Technology (MIT), stumbled on a collection of 19th century meteorite thin sections across town at Harvard University. He was hooked.

"I was immensely curious to know how the earth formed," he recalls in his manuscript, "and the textbooks and my profs had been no help at all." Wood was joined in meteoritics by people "who were skilled in a whole new galaxy of instruments and techniques that could be used to investigate these objects," he says. Those techniques have since evolved into instruments such as the time-of-flight secondary ion mass spectrometer, the multicollection inductively coupled plasma mass spectrometer, and ion microprobes that allow the precise determination of both chemical and isotopic composition of spots just a few micrometers across.

This high-tech attack on chondrites has yielded a bounty of increasingly detailed information. Chondrites are now divided into four classes and 12 subclasses by mineralogy and chemistry. Chondrites are known to be chemically similar to the sun. Their chondrules remained melted for days, not the millennia that subterranean magma stays fluid, and cooled quickly—over hours to days—but more slowly than if each blob had been alone in empty space. Some were heated repeatedly. Rims enclosed them after formation, some while they were still hot. The rims have a composition similar to that of the matrix. Chondrules have a stunningly narrow size distribution, as if somehow sieved repeatedly.





Mystery rocks. Chondrules (loose and in place) were once millimeter-sized molten droplets, but no one knows what melted them.

CREDITS: J.A. WOOD

The field has also made room for the less abundant, calcium-aluminum-rich inclusions (CAIs) that may have formed a couple of million years before chondrules. These centimeter-sized chunks of rock are loaded with isotopic traces of radioactive elements that burned out before the solar system stopped forming. There are even presolar grains in the matrix that survived without alteration after forming around other stars. This steady stream of chondrite data will keep flowing next month in Rome at the annual meeting of the 1000-member Meteoritical Society, where more than 100 presentations will dissect chondrites and their components.

No grand theories

Wood, for one, is having second thoughts about the data flood. "I'm getting pretty old [69 years], and you tend to take stock of what you've accomplished in your life," he says. Lately, "I've felt there's an intellectual challenge that the community, including myself, hasn't met. I don't think the answer is in the chondrules. They've had the living daylights studied out of them. The ratio of understanding to data has gotten completely out of hand. There's too much taking of data for its own sake. Some people can crank out data and be happy; I guess I have always been a person more interested in understanding things than collecting data."

A number of researchers agree with Wood about chondrite science being swamped by details. "Like other scientists, we spend a lot of time contemplating our navels," says McSween, who took up studying other meteorites, including those from Mars, shortly after completing his dissertation and hasn't missed chondrites. "We lose sight of the context of the samples we're looking at." Carl Agee, who directs the processing of extraterrestrial materials at Johnson Space Center, agrees: "One of the problems with mineralogists and petrologists is we can get bogged down in the details." What's needed, Wood says, is "a unifying paradigm, and there just isn't one."

A simple head count would seem to support Wood's contention. In 1999, Alan Rubin of the University of California, Los Angeles, listed 14 published ways that chondrules could have formed, from condensation of nebular gases (first proposed in 1949) to gamma ray bursts (proposed in 1999). And it's grown since then. One of the latest ideas is that shock waves thought to have spiraled through the nebula might have blasted planetforming planetesimals, melting the material ablated off the planetesimals into chondrules. "There are people who believe chondrules formed by impact" among planetesimals, adds Wood. "I don't believe it for a minute, but that such ideas can be entertained shows how little we understand."

Although Wood is certainly the most outspoken pessimist on the subject, he's not the only one out there. "I would say very little has changed in chondrite research over the past 15 years," says cosmochemist David Kring of the University of Arizona in Tucson, Wood's last student. "A tremendous amount of work has been done. It's just that it doesn't look like they're making progress on fundamental questions." Planetary scientist Michael Drake, also at the University of Arizona, likens the current chondrite dispute to the debate about the moon's origin that ran for 15 years after Apollo astronauts returned pieces of the moon. Then the idea of a giant impact splashing material off the early Earth to form the moon caught hold and is now the consensus among lunar researchers. "We haven't had the equivalent of the giant impact theory in chondrules," says Drake.

The big picture. Understanding the tiny chondrules of meteorites may require a broad perspective on the young sun and its nebula.

Even so, most meteoriticists fiercely defend their contribution to science. Rubin cites better data on the sizes of chondrules, their rate of cooling, and their compositions as evidence of "substantial progress in the last 20 years." Astrophysicist Larry R. Nittler of the Carnegie Institution of Washington's Department of Terrestrial Magnetism (DTM) adds high-precision oxygen isotope measurements on the scale of 10 micrometers and the discovery of traces of the now-extinct radionuclide beryllium-10 as additional achievements. McSween sees "a lot of wonderful discoveries" such as the recognition of relic presolar grains and estimates of the amount of relatively volatile elements lost from chondrules. Such advances have led to "a fairly broad consensus on a number of points," says Rubin, including chondrules' repeated heating and sometimes incomplete melting, their brief time at their highest temperatures and rapid cooling, and their formation in different areas of the nebula.

Rubin would thus whittle down his list of 14 mechanisms to just three: nebular lightning, energy flares from the sudden realignment of the young sun's magnetic field lines, and shock waves of some sort. Lately, though, he's not sure if electrical discharges in the nebula could ever have gotten stronger than they are in a good aurora, much less lightning.

A call for astrophysics

Wood is unimpressed. "They're confusing the means with the end," he says. Making a more precise oxygen isotope measurement on a tinier bit of chondrule is not progress, he says. He likens the collection of such facts to trying to construct a building by throwing together bricks without an overarching plan.

Wood exhorts his meteoritic colleagues to adopt a top-down, inductive approach, starting with astrophysics. Forming chondrules in the solar nebula means "you're now in the astrophysical regime," Wood says. Most "people who talk about models of chondrule formation are not astrophysicists. Most astrophysicists have much bigger fish to fry than what happened in the early solar system." What's needed are astrophysical models that could be tested with the geochemical data, he says, much the way bricks might be fit into the steel framework of a modern building. Wood comes by such astrophysical predilections by way of an early interest in astronomy—he minored in it at MIT—and long exposure to scores of astrophysicists at CfA rather than to the geologists most meteoriticists see in their university settings.

Not everyone is optimistic about Wood's astrophysical approach. He "is one of the few petrologists who have tried to understand chondrules by immersing themselves [in the astrophysics]," says Rubin, "which is laudable. But it isn't realistic to assume many mineralogists and petrologists will be able to do that. Everyone isn't near as bright as John Wood."

How hard it is to bridge the gap between meteoritics and astrophysics became obvious at the 1998 Protostars and Planets meeting held in Santa Barbara, California, says astrophysicist Alan Boss of DTM. Offered the chance to hear the meteoriticists discuss what meteorites had to say about solar system formation, most of the astrophysicists "voted with their feet" that morning and hit the beach. "We're not as ignorant of each other as we were 20 years ago," says Boss, "but there's a long way to go."

One recent theory of chondrule formation suggests that convergence may yet be possible, even incipient. Proposed in 1996 by astrophysicists Frank Shu and Hsien Shang of the University of California, Berkeley, and cosmochemist Typhoon Lee of the Institute of Earth Science in Taipei, the X-wind theory relies on the searing heat close to the violent young sun to melt material on the inner edge of the nebular disk. The powerful "wind" seen to blow away from the poles of young stars would scatter chondrules to the asteroidal belt (*Science*, 20 June 1997, p. 1789). "Shu did a really magnificent job of trying to research the meteoritic literature and the properties of chondrules that needed to be satisfied by a model," says Wood. But there was little response from meteoriticists. "Many meteoriticists are not given to trying to interpret data and [are] suspicious of people who do," says Wood.

That could be changing as more astrophysically inclined researchers like Nittler and Boss take up chondrite origins. Entering a new field "has been a lot of fun," says Shu. "We're getting more attention from the meteoriticists than when we first started, when everybody thought it was crazy." Meteoriticists still aren't convinced that chondrules formed close to the sun, but they are increasingly allowing that CAIs may have formed by the X-wind mechanism. CAIs' isotopic signature, especially their traces of extinct beryllium-10, suggests that heavy solar radiation of the sort close to the sun is the source of short-lived radionuclides, rather than a nearby supernova as once assumed. But perhaps more important than a possible sign of real progress, says Boss, is that Shu—"a big name in star formation"—provides astrophysicists with "a stamp of approval" to work in meteoritics.

Wood plans to follow his own advice to synthesize the data. "I thought I might spend a year or two giving that a try, seeing whether I can break the logjam." He's not optimistic, however: "The answer will probably be no, but I'm going to give it a shot."

—RICHARD A. KERR

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