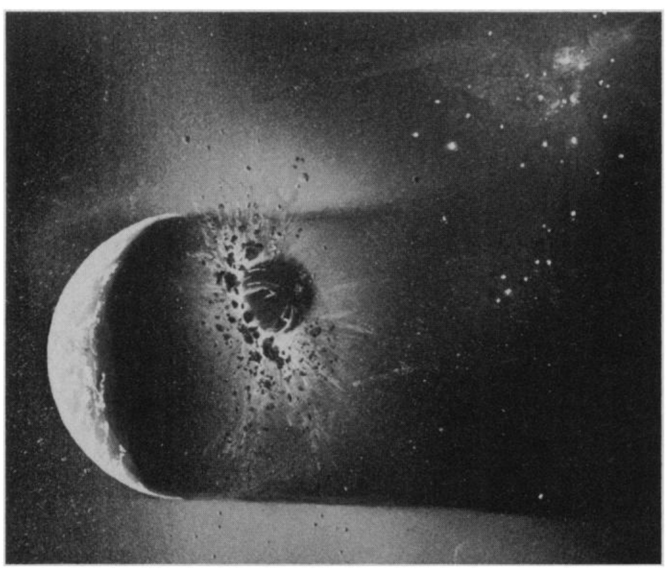
Making the Moon from a Big Splash

The idea that the impact of a Mars-size body on the young earth could have formed the moon has breathed new life into a long-stagnant field

Things were moving so slowly toward understanding the origin of Earth's moon—a major scientific objective of the Apollo landings 15 years ago—that researchers convened the Conference on the Origin of the Moon* in October to see what might be done. The outcome could not have pleased them more. The classic theories of lunar formation—long seen as moribund—were largely dispensed with, and a decade-old suggestion was raised to bandwagon status: what if the moon is the remnant of material blown off the newly formed Earth by the impact of a huge object, a planet in its own right?

Those prompted by the upcoming conference to do additional calculations for the large-impact case encountered no major objections to their preliminary results from geochemists or dynamicists. But all agreed that the current favorite probably owes its popularity as much to its newness as to a strong underpinning of fact. Given its recent emergence from obscurity, the new hypothesis will soon rise or fall on its own merit.

In the large-impact hypothesis, which was first formally proposed by William Hartmann and Donald Davis of the Planetary Science Institute in Tucson in 1975, the moon originated in the most catastrophic event in Earth history. There have been many impacts since. Sixty-five million years ago a 10-kilometer-wide asteroid hit Earth and possibly drove microscopic plankton and the dinosaurs to extinction. But that impactor would be minuscule, a mere mote, beside the moon's suggested progenitor, which might have been as large as Mars—half the size of Earth and one-tenth its mass. George Wetherill of the Carnegie Institution of Washington reassured conference participants that, toward the end of the agglomeration of the solar nebula that formed the inner planets, there would have been at least a few bodies of such size not yet swept up by the present planets, according to his recent calculations. An early, large impact seems quite likely.



A big splash

In this 1978 painting by planetary scientist William Hartmann, a huge planetesimal smashes into the young earth. The material splashed into orbit may have formed the moon. Some current impact theories require a more oblique approach and allow an impactor twice this size.

In mathematical simulations of the catastrophe that were prepared for the conference by A. G. W. Cameron of the Harvard–Smithsonian Center for Astrophysics, a particular kind of large impact appears quite capable of supplying the energy needed to separate the lunar material from Earth. In the most successful simulations, the object falls toward Earth at more than 40,000 kilometers per hour, slides into it at an oblique angle (grazing it actually), vaporizes its own rocky outer mantle and an equal amount of Earth's, and blows that material into orbit. Lifting enough material into orbit had seemed a problem. If it was only the instantaneous force of the impact that shot material outward, like a hammer-blow splintering a rock, all of the debris would either fall back to Earth or shoot off into space, never to return. None would be put into orbit where the moon could form from it.

Cameron and William Ward of the Jet Propulsion Laboratory solved that problem in 1976 when they pointed out that the prolonged acceleration of material by expanding gases produced by the impact might provide the required "second burn," the way the burning of a rocket is able to orbit a satellite. In many of Cameron's simulations, the impact's second burn effect lofted more than twice the moon's mass into orbit, material having more than twice the moon's angular momentum.

There would be a need for excess mass and angular momentum. Much of the material of the disk must be sacrificed—it eventually falls back to Earth—so that its angular momentum can boost the remaining mass high enough to allow formation of the moon. A. C. Thompson and David Stevenson of the California Institute of Technology have calculated that the disk would spread inward and outward so rapidly that within about 100 years some of the material would pass beyond the Roche limit, the distance beyond which the disruptive effects of Earth's gravity cannot prevent accretion of the moon from the remnants of the disk.

The new interest in the large-impact model is admittedly due in part to the consistent failures of all other models. Three classic theories have been lingering for years, championed by a few individuals, but at the lunar origin conference, where as one researcher put it there were "experts on all sides so that no one got away with anything," the classic theories seem to have been finally put to rest. Proponents of rotational fission—the splitting off of the moon from a rapidly spinning, molten proto-Earth—still cannot explain how the proto-Earth came to spin so rapidly, where the resulting excess angular momentum of the earth-moon system went to, and why the moon does not revolve in the plane of Earth's equator, as it should if it had been spun off.

*Conference on the Origin of the Moon, held 13 to 16 October at Kona, Hawaii. Conveners: William Hartmann (Planetary Science Institute), Roger Phillips (Southern Methodist University), and Jeffrey Taylor (University of New Mexico).

Another classic theory—gravitational capture of the moon as it wandered by—was always too improbable to be taken seriously, but the capture of debris ripped from a planetesimal passing inside the Roche limit could not be so easily dismissed. However, Hiroshi Mizuno and Alan Paul Boss of the Carnegie Institution of Washington reported that a solid body is just too strong and stiff to lose more than 1 or 2 percent of its mass during a brief close encounter with Earth. Even a partially molten body would not disrupt, according to their calculations.

The "double-planet" theory of lunar formation, in which Earth and the moon form simultaneously from the same cloud of gas and rock, has always had the problem that the moon and Earth differ in their chemical compositions. A consortium of researchers headed by Richard Greenberg of the Planetary Science Institute pursued a variant of this model in which an existing swarm of debris retained incoming rocky material and allowed large, iron-rich planetesimals to pass into Earth, creating a batch of iron-poor material to form the moon. Unfortunately, they could not find a source of angular momentum to keep this swarm from dissipating long before its work would have been done.

Of course, the large impact hypothesis would not be so popular if, at least at first glance, it did not help explain some of the major mysteries of the moon's origin. Such a heavy glancing blow to the proto-Earth could account for the unusually large amount of angular momentum in the Earth-moon system without producing the embarrassing excess of the fission model. The contribution of rocky material from the mantles of Earth and the impactor—their mantles already having lost much of their iron during the formation of metallic cores—would explain the scarcity of iron in the moon. The heating of the disk could have driven off much of its volatile elements, which are depleted in the moon. And what little iron there was in the disk could have scavenged elements particularly compatible with it and sequestered them in a small lunar core, explaining the depletion of such elements in lunar samples.

A large impact would also meet a more philosophical need. As pointed out by Hartmann and Davis, a single evolutionary process—one that would presumably be part of the formation of every planet—would seem hard-pressed to explain the variety in satellite systems. Neptune's major satellite orbits in "reverse," Uranus's system revolves in a plane perpendicular to all others, the satellites of Earth and Pluto are large enough to be considered sister planets, Mars has two large boulders as its only moons, and Venus and Mercury have no moons at all. The sensitivity of the outcome of a planet's largest impact to everything from the impactor's size to its direction of approach might account for some of this variety.

Testing of the latest favorite theory depends crucially on the poorly understood field of impact cratering. Some work is under way to understand the biological effects of the Cretaceous-Tertiary impact and to determine the means of blasting meteorites off Mars, but this impact would have been in a class by itself.—RICHARD A. KERR

Additional Reading

1. *Abstracts and Program for the Conference on the Origin of the Moon*, LPI Contribution 540, available for $3 ($3.50 outside the United States) from the Library/Information Center, Lunar and Planetary Institute, 3301 NASA Road 1, Houston, Texas 77058.
2. W. K. Hartmann and D. R. Davis, *Icarus* **24**, 504 (1975).
3. A. G. W. Cameron and W. R. Ward, in *Lunar Science VIII* (Lunar Science Institute, Houston, 1976), pp. 120–122.

The Fifth Generation: Taking Stock

The Japanese computer project is approaching its third birthday; meanwhile, the American programs are finally getting organized

In October 1981, at the First International Conference on Fifth Generation Computer Systems, the Japanese Ministry of International Trade and Industry (MITI) announced that it would undertake a 10-year, $850-million effort to develop advanced computers several thousand times faster than the current variety—together with software that will allow those computers to reason, to learn, to understand written and spoken language, and to generally do the things that require intelligence in a human being.

The announcement of the Fifth Generation project was not exactly a surprise—MITI officials had been talking about it since 1979—but the response on this side of the Pacific was dramatic nonetheless. After a decade of Japanese triumphs in automobiles, steel, and consumer electronics, no one was inclined to take a new challenge lightly. In short order there appeared a raft of similar programs, including the Microelectronics and Computer Technology Corporation (MCC) and the Pentagon's "Strategic Computing" program in the United States; the Alvey Program in the United Kingdom; and the multinational ESPRIT program on the Continent.

Recently, two different meetings have offered an opportunity to take stock of all this activity. In October there was the annual convention of the Association for Computing Machinery in San Francisco, subtitled, "The Challenge of the Fifth Generation"(*1*). A month later, the Japanese researchers held their 3-year review meeting in Tokyo (*2*).

It was apparent from both meetings that the activity to date has not been a horse race so much as a jockeying for position at the starting gate. The Japanese have had the planning lead, but as they freely conceded in 1981, they needed the first 3 years simply to catch up with the technologies already developed in the West.

The Americans, by contrast, have an enormous lead in technology. But they have had to spend the last 3 years scrambling to get organized. And the Europeans, caught in the middle, have been operating with a dogged determination that they will not be left behind (*3*).

Only now, in other words, does the race begin in earnest.

In one sense, the push for a "Fifth Generation" follows a long-established pattern. As Gordon Bell of Encore Computer Corporation noted in San Francisco, the history of computing technology resembles a cyclotron: every 10 years or so there comes an injection of new technology, followed by a series of refinements boosting it to higher and higher levels. For the first computers in the 1940's the major technology was the vacuum tube; later generations were based on