The PLANETARY REPORT

Volume XVIII Number 1 January/February 1998

Zooming In on Mars

On the Cover:

Subtle blue-gray clouds hover over the dusty rose Martian surface near Valles Marineris, a series of interconnected east-west canyons spanning roughly 4,000 kilometers (2,500 miles). This is the first color image from the Mars Orbiter Camera aboard *Mars Global Surveyor*, taken last October 3 about 11 minutes after the spacecraft passed close to the planet for the thirteenth time. It was during these initial passes within the Martian atmosphere that *Mars Global Surveyor* team members noticed slight movement in an unlatched solar panel, causing mission officials to change the pace of aerobraking, and delaying the mapping portion of the mission one year.

Image: Courtesy of Malin Space Science Systems and JPL/NASA

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From The Editor

In *The Planetary Report*, we try to balance our reporting on new missions of discovery with the theoretical work that tries to make sense of it all. With the Planetary Society's emphasis on exploration, we sometimes give more weight to the discovery side of the scale. But I think the testing of hypotheses and building of theories can be just as exciting. An old professor of mine used to call this work "geomythology." And in these stories of how we, the world, and the universe came to be, I find great enjoyment and satisfaction.

In this issue, we present a hypothesis-in-process that might help explain one of the great mysteries of science: why the advance of life has followed a jerky course of explosive evolution and massive extinction. Traditionally, scientists have looked for answers on Earth. But as we have learned more about the solar system and galaxy in which we live, as well as our planet, new suspects have presented themselves.

Mike Rampino and his colleagues developed the Shiva hypothesis in one attempt to solve the mystery. I hope you will find the same excitement I did in reading the story of this hypothesis' genesis. It still has obstacles to overcome before reaching the lofty height of scientific consensus. But it's great fun watching its progress.

—*Charlene M. Anderson*

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Members' Dialogue

Go Metric!

In the July/August 1997 issue of *The Planetary Report*, we see numerous references to "degrees Fahrenheit" (for example, page 7, "1,000 degrees Fahrenheit" and "2,250 degrees Fahrenheit"). This is a very unscientific way in which to report the temperature. Furthermore, whether it was in degrees Fahrenheit or degrees Celsius, lay persons would probably not actively relate to it (it would, to them, just be "damned hot"); however, readers with a deeper interest would, almost certainly, prefer the SI version [Systeme International is the system of measures used in science, based on the kilogram, second, meter, ampere, kelvin, mole, and candela]. So, why not just quote degrees Celsius and see what happens?

While still on the subject of units, one frequently sees such references as "10,000 kilometers (6,000 miles)." These double references interrupt the flow of reading the article. Why not just stick with SI (accompanied with footnotes for conversion back to imperial)? This would make for better readability and would accommodate those who might want the information in the old terms.
—D. T. BATH,
Peterborough, Ontario, Canada

Every year or so we wrestle with the issue of metric to English conversions, raising the same points you mention, and we end up keeping the conversions for this one reason: so non-scientific readers will know they are part of our audience, right along with the scientifically aware and the space science professionals who also read The Planetary Report. *Broadening support for SETI and planetary exploration is a fundamental goal of the Society.*

However, your suggestion about using footnotes for conversions is a breath of fresh air. We'll test it in-house to determine whether footnotes create undue problems in magazine layout. If your idea works, look for a change in 1998.
—Karl Stull,
Copy Editor

Take It to the Schools

Mr. Byers' suggestion of bringing the $30.00 educational packages to the schools, instead of waiting for them to come to us, is good (see Members' Dialogue in the September/October 1997 issue). However, I believe I have gone one better and perhaps others can join me. Two years ago, I took my love for space science to school —my children's elementary school. I put together a simple but exciting "lecture" using the beautiful pictures I received when I joined the Planetary Society. Each print of the planets has interesting facts on the back. I include information from *The Planetary Report* that would be understandable for children. When I explain the distance to Andromeda on the chalkboard with all those 0's, the kids gasp! I have also found pictures in *National Geographic* of the moons of Saturn and Jupiter, Venus' valleys and awesome atmosphere, and various galaxies.

My lectures are free and are usually 40-50 minutes long with 10 minutes of question and answer time. I have done about 25 lectures in two years. The teachers enjoy the break, the students love it, and the rewards are tremendous. I am not a teacher but a homemaker with a love of science. I have also given my lectures to several Girl Scout troops.

The schools are in dire need of specialized programs but lack of funds, time, manpower, etcetera make it nearly impossible to enact them. The public *can* and *should* get involved with the education of our children. Contact your local school administrator or district office and tell them that you wish to volunteer your time to share your hobby or career. They will listen.
—NYLA RANKIN,
Brawley, California

The Planetary Society is developing a "planetary exploration slide show" for volunteers to present at school assemblies. This presentation is designed to appeal to students ranging in age from early elementary through high school. For more details, contact me at Society headquarters.
—Linda Hyder,
Manager of Program Development

Humans in Space

I'd like to comment on Norman H. Horowitz's letter in the July/August 1997 column. From a "step further back" point of view, Mr. Horowitz is failing to take into account the effect of good public relations on the flow of money for space exploration from our tax-paying citizens. If a human mission to Mars (expensive, poor science that it is) has enough of a purse-string-loosening effect that twice as many "small, cheap, fast" missions can then be sent out, it would be worth the time, money, and effort.

I'm for it.
—HELEN FREELAND,
Schenectady, New York

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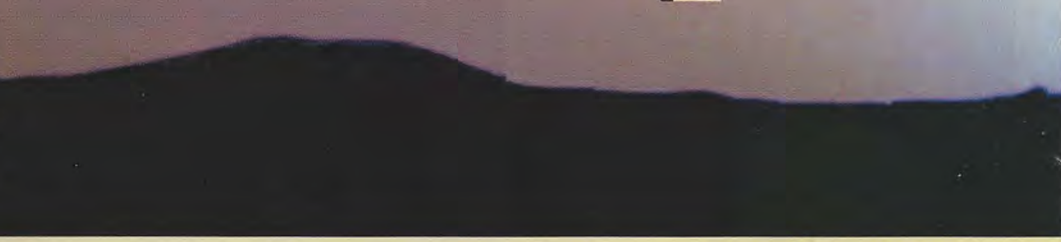
tps.des@mars.planetary.org.

The Sun Sets on *Mars Pathfinder*



As the Sun drops from view behind the horizon, the violet Martian sky evokes a sunset on Earth. While this visual parallel is striking, we can find more subtle and significant similarities between Mars and our planet.

Mars Pathfinder **images reveal signatures of an early water-rich environment in the Ares Vallis region. Light-colored dunes, composed of sand-sized particles, and sand-sculpted rocks, along with possibly water-worn rock conglomerates, suggest liquid water flowed through the valley for as long as a millennium.**

"Water, of course, is the very ingredient that is necessary to support life," said *Mars Pathfinder* Project Scientist Matt Golombek, "and that leads to the $64,000 question: 'Are we alone in the universe? Did life ever develop on Mars? If so, what happened to it?'"

• • • • •

By the time the batteries ran out last September, the *Mars Pathfinder* mission had collected more than 16,000 images from the lander, more than 500 from the rover, and nearly 8.5 million individual measurements of wind, pressure, and temperature. The Alpha Proton X-ray Spectrometer returned 20 studies of rocks and features on the Martian surface.

For a complete archive of *Mars Pathfinder* and *Mars Global Surveyor* images, visit New Views of Mars on the Planetary Society's World Wide Web page at http://planetary.org.

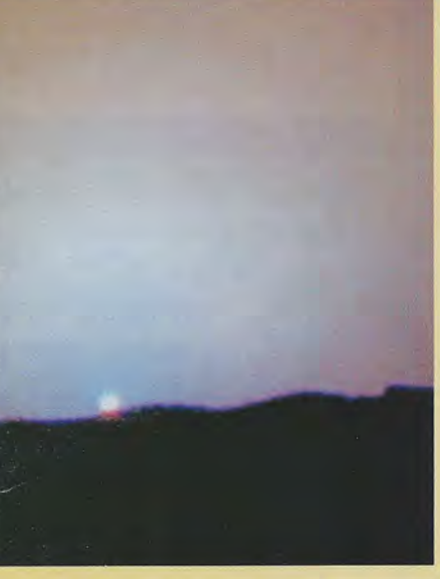
—Jennifer Vaughn, Editorial Assistant

The rover *Sojourner's* camera shows dunes not visible from the *Mars Pathfinder* lander. These dunes, less than a meter high, are several meters wide. Scientists speculate that the dunes were created by winds blowing right to left (northeast to southwest). Sediment such as this on Earth would be made of sand-sized grains, and the presence of sand would point to a history of flowing water. However, scientists are still debating whether these particles can accurately be called sand. On the horizon, the Twin Peaks are about 1 kilometer (0.6 mile) away on the right, and on the left at a distance of 2.2 kilometers (1.4 miles) is Big Crater.

New, more detailed images from the rover show pebble-like structures, rounded surfaces, and possible conglomerate rocks, which on Earth can form through a variety of geologic processes that meld together fragments of varying origins.

But what forces carved the distinctive surfaces of these rocks? Seeking an explanation for how pebbles may have been etched from Martian rocks, geologists consider a number of possible mechanisms. The eroding power of water in waves, floods, or glaciers could have done the job, but similar formations could also be produced by impacts, by lava flows or pyroclastic eruptions, by concretions formed in sedimentary rocks, or by any combination of these processes.

Two close-up images taken by the rover *Sojourner* reveal textures and structures not visible in lander images. Scientists have identified these rocks as conglomerates because their surfaces have rounded protrusions. The rock Cabbage Patch (right, top) clearly shows these protrusions on the surface. The small rock at bottom right shows that weathering has etched out pebbles to produce sockets. Two extracted pebbles (about 0.5 centimeters across, or 0.2 inch) are visible at the lower center of the image.

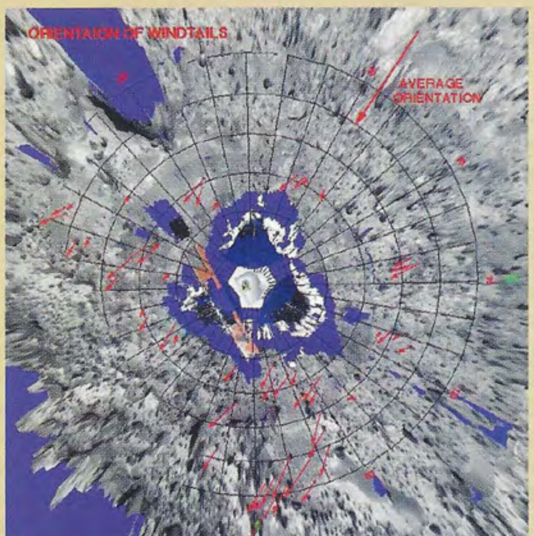


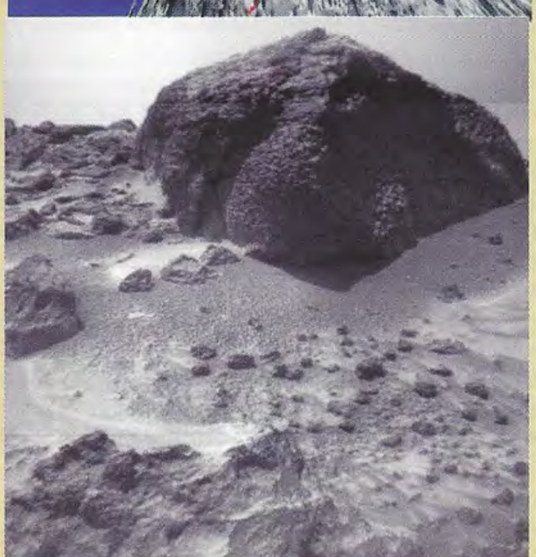
As the search continues for clues to an aqueous past on Mars, team scientists say that today winds have the most significant effect on the planet's surface.

Based on current understanding of how very fine sediment is deposited around rocks, the map below depicts sediment tails at the Sagan Memorial Station. The arrows represent the direction of the wind, blowing from the northeast toward the southwest. The *Viking* orbiters imaged similar patterns of light and dark streaks of sediment in and around Martian craters.

The rover's eye view of the rock Chimp (bottom image) shows fine surface textures as well as wind tails, oriented from lower right to upper left, with small pebbles in the foreground. Streamlined tails, composed of particles deposited by wind on the leeward side, appear around many rocks in the region.

All images: JPL/NASA





Mars Global Surveyor Mapping Mission Delayed One Year

Early last November, as *Mars Global Surveyor* performed a series of aerobraking passes through the Martian atmosphere, a wobble in an unlatched solar panel convinced mission officials to change plans for the spacecraft's route to a low, circular orbit.

The spacecraft's two 11-foot solar panels were designed to remain nearly motionless during aerobraking. One of the panels, which did not properly deploy and latch after launch, showed slight movement as the spacecraft approached the Martian surface, forcing the *Mars Global Surveyor* team to halt aerobraking for nearly two weeks while they assessed the problem. Aerobraking is a technique that allows a spacecraft to lower its orbit by using the drag produced by atmosphere (for more on aerobraking, see the March/April 1994 *Planetary Report*).

After careful study, the team concluded that aerobraking at a slower rate would not jeopardize the vulnerable panel. "This [slower rate of aerobraking] changes *Mars Global Surveyor*'s final mapping orbit," said mission manager Glenn E. Cunningham, "but it should not have a significant impact on the ability of *Global Surveyor* to accomplish the mission science objectives."

Trajectory adjustments will yield an orbit that is an exact mirror image of the original mapping orbit, with data taken along a south to north track rather than north to south.

The new mapping orbit will take an additional year to achieve, with the spacecraft arriving at final position in mid-January 1999 and beginning to map two months later.

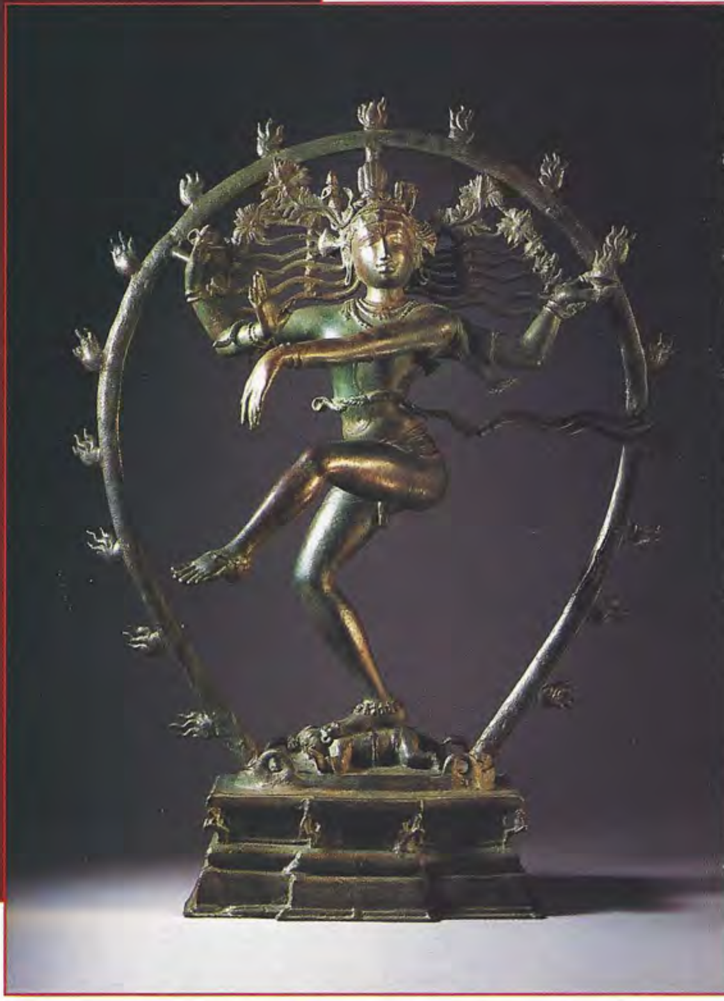
During that extra year, *Mars Global Surveyor* will be in an elliptical orbit that at its periapsis, or closest point to Mars, will skim much closer to the surface than the final mapping orbit. The spacecraft's full suite of instruments will come on during this opportunity to study the planet up-close. "We expect to gain some spectacular new data during this time," said Cunningham. "The spacecraft's orbit will still be elliptical during this period, but at periapsis the surface resolution will be much greater, and the lighting angles will be excellent."

Keep your eye on *The Planetary Report* and check the *Mars Global Surveyor* Web site for updates as new images and data become available: http://mars.jpl.gov/mgs. —*JV*

The SHIVA Hypothesis:

Impacts, Mass Extinctions, and the Galaxy

by Michael R. Rampino



Shiva is the Hindu god of destruction and rebirth. When he stops dancing, this universe will end, and another will be born to start the dance again.

Photograph courtesy of the Norton Simon Foundation, Pasadena, California

Shiva, the world-destroying Hindu deity, symbolizes the rhythm of the universe. When he takes the form of a graceful dancer, the result is cosmic destruction. But the destruction has another side; it is always followed by new creations, and new worlds emerge from the ashes of the old. This Hindu imagery of cyclic destruction and renewal prompted the naming of the Shiva hypothesis, a proposed explanation for a possible 30-million-year cycle of catastrophe and renewal observed in the geologic record.

In the history of life on Earth, mass extinctions are followed by bursts of evolution, as surviving species fill life-niches emptied by global catastrophe. For several extinction events, there is now evidence that the instigating catastrophe was an asteroid or comet impact. Could periodic impacts be responsible for the recurrence of mass extinctions? Some scientists are convinced that impacts have been a driving force in evolution on Earth, and studies indicate that impact-related mass extinctions occur at intervals of about 30 million years. A few researchers suggest that the 30-million-year cycle may result from comet showers, pulled in toward the Sun by the regular motion of the solar system through the plane of our galaxy. Among scientists, the Shiva hypothesis remains controversial, but if it is correct, our world evolves to the rhythm of extraterrestrial bombardment.

From Gubbio to Chicxulub

The discovery of anomalous concentrations of the rare element iridium in a thin clay layer at a rock outcrop near Gubbio, Italy triggered an upheaval in the geological sciences. Walter and Luis Alvarez and their colleagues at the University of California at Berkeley hypothesized that the unusual traces of iridium were from dust created by the collision of a huge asteroid or comet with the Earth 65 million years ago—at the precise time when the dinosaurs and some 75 percent of life on the planet disappeared (see Figure 1). Investigations of this proposal culminated in further remarkable discoveries: a giant, 65-million-year-old, buried impact crater in the Yucatán; widespread evidence in the Gulf of Mexico and Caribbean of a massive tsunami at the same time; and rock deposits from storms of debris blasted out of the crater. The Planetary Society sent two expeditions to Belize in Central America for a first-hand look at these deposits (see the July/August 1995 and July/August 1996 issues of *The Planetary Report*).

The Chicxulub crater on the Yucatán Peninsula, with a diameter of more than 200 kilometers (125 miles) and a precise radiometric date of 65 million years, is the "smoking gun" evidence for the disastrous impact at the K/T boundary. That event brought about the abrupt extinction of all large land animals (most notably the dinosaurs), many plants, and most marine invertebrates, including more than 95 percent of surface-dwelling ocean plankton.

The K/T impact spread a layer of ejecta fallout worldwide. This layer is marked by the anomalous quantities of iridium first seen at Gubbio and also by other trace metals, mineral grains showing evidence of severe shock, glassy tektites and microtektites, the mineral stishovite (an extremely high-pressure form of silicon dioxide), and soot, which seems to have come from the burning of a significant portion of the biosphere.

The catastrophic effects of a Chicxulub-scale impact by an asteroid or comet, with a diameter of 10 kilometers (6 miles), would have included an "impact winter" caused by global dispersal of massive amounts of dust. There would have been six months of darkness and cold, with a sulfuric acid haze that may have lasted years, further cooling the climate. Soon after the blast, reactions in the impact fireball would have formed acid rain, and hot ejecta re-entering the atmosphere would have set the wildfires that left the soot in the telltale layer at the K/T boundary.

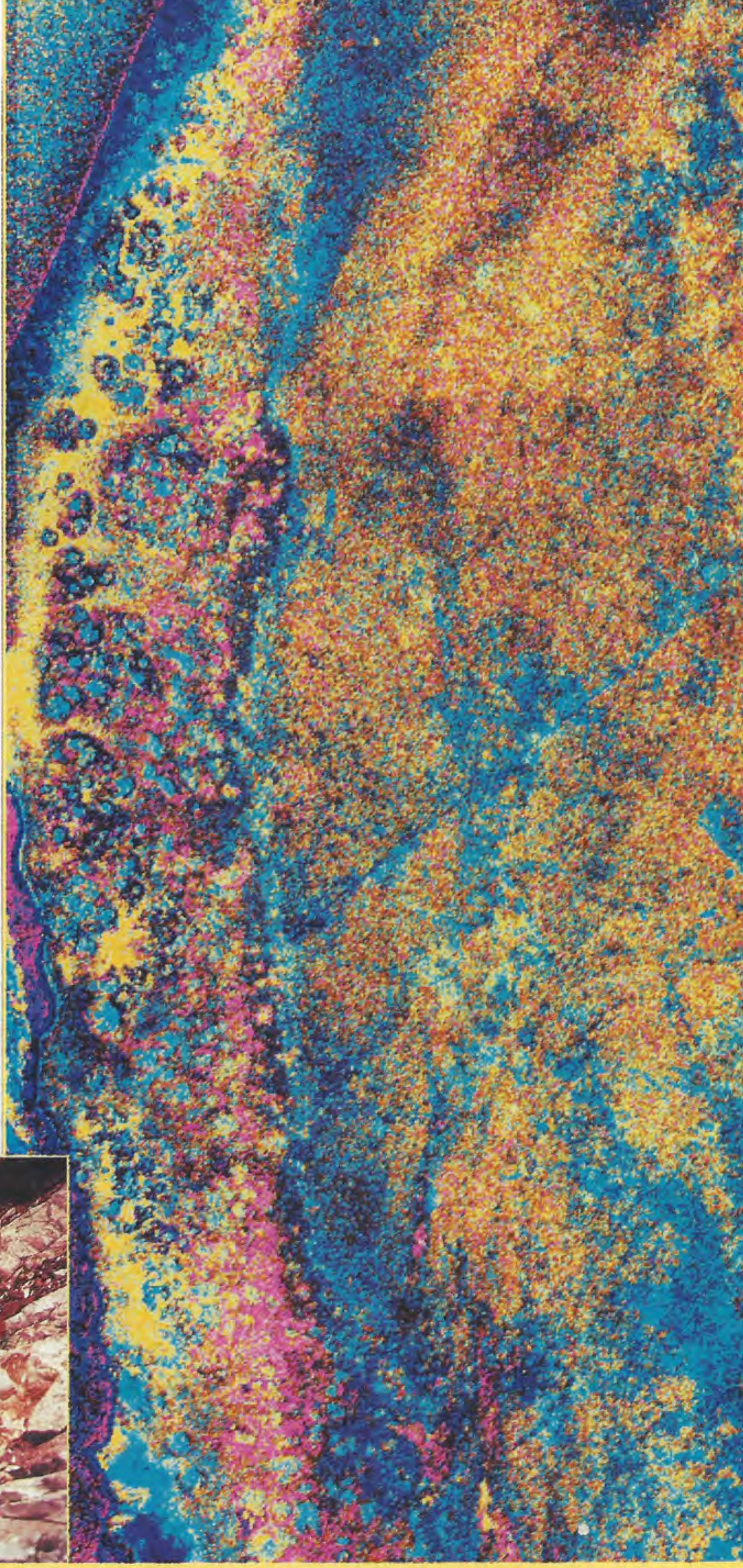
Changes in the world's oceans were important in the transition from the Cretaceous. Jan Smit of the Free University of the Netherlands has studied a very detailed section of the boundary in Spain that has a resolution of a few thousand years, showing that the sudden extinction of calcium carbonate-producing plankton coincides with the iridium-rich fallout layer.

Moreover, an abrupt decrease in the carbon-isotopic composition in sediments at the boundary suggests a drastic reduction in the productivity of the surface oceans, an effect called the "Strangelove Ocean" (after a cult movie from the 1960s that climaxes in global annihilation by nuclear war). The Strangelove Ocean persisted for about 500,000 years. Plant communities on land were decimated, and full recovery took about 1.5 million years.

Although the impact winter may have been too brief to leave its mark in the sedimentary record, the oxygen-

(continued on page 8)

Figure 1: In a gorge near the Italian town of Gubbio, Cretaceous limestones (white) are overlain by darker Tertiary limestones. A thin layer of clay containing anomalous amounts of iridium and shocked minerals marks the infamous K/T boundary, the geologic moment of the extinction of the dinosaurs. Photo: Michael Rampino



The Chicxulub impact crater lies buried under sediments in the Yucatán Peninsula. In this radar image, you can see surface traces that betray the crater beneath. A faint blue "X" in the center right shows where a road crosses the crater floor boundary. The coastline is marked by a ring of cenotes, or fresh water springs, associated with the crater beneath. Image: JPL/NASA

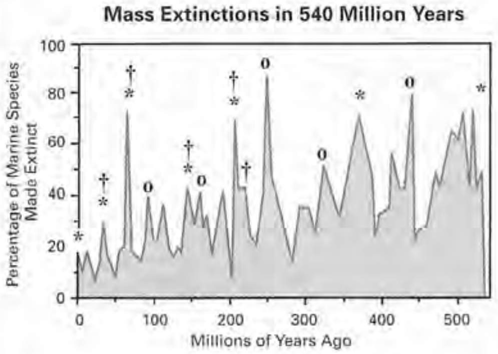


Figure 2: Five major mass extinctions and about 20 minor mass extinctions have occurred over the past 540 million years, as indicated in this chart showing extinctions of marine species (data from Sepkoski). Symbols above extinction peaks indicate associated evidence of large, well-dated impact craters (†), diagnostic evidence of impact (*), or documented but minor iridium spikes (0). Note: Large peaks prior to 450 million years ago most likely reflect incompleteness of the fossil record.

(continued from page 7) isotope ratio of the carbonate shells (providing an estimate of the temperature of the ocean surface) shows a significant change at the boundary, equivalent to a warming of 8 to 10 degrees Celsius (14 to 18 degrees Fahrenheit) for several thousand years. This warming may have been caused by increases in atmospheric carbon dioxide resulting from the great perturbation of the global cycling of carbon, or the warming may have been caused by reduced cloud cover related to the extinction of plankton. The dimethyl sulfide gas normally emitted by plankton is a major source of condensation nuclei for the formation of clouds over the oceans.

Cycles of Catastrophe

Jack Sepkoski of the University of Chicago has compiled data showing extinction rates of marine organisms over the last 540 million years (Figure 2). In this context, the K/T boundary can be seen as one large peak in a record of pulses above a generally low "background" rate of extinction. Major extinctions also occurred at the end of the Ordovician period (about 438 million years ago), in the Late Devonian period (365 million years ago), at the end of the Permian period (250 million years ago), and at the end of the Triassic period (203 million years ago). The greatest extinction in the record, separating the Permian and Triassic periods, involved the disappearance of about 96 percent of marine species, along with most vertebrates (amphibians and reptiles), plants, and insects, according to studies by Dave Raup, also of the University of Chicago. Sepkoski's curve shows about 20 lesser, but still significant, extinction events in which between 20 and 50 percent of then-existing species of marine life disappeared.

The causes of mass extinction have been intensely debated by the geologic community. Geologic thinking has long been biased against catastrophic change, and although many geologists will now admit that the end-Cretaceous mass extinction was probably related to a cosmic impact, the consensus is that mass extinctions are generally caused by a complex interaction of normal terrestrial factors, including changes in sea level, climatic fluctuations, and competition among species. Some geologists would say that the causes of mass extinction are so complex that we will never unravel them. However, if the K/T extinctions resulted from the after-effects of a great impact, as now seems likely, then a powerful hypothesis is available to explain mass extinctions in general—a hypothesis that can be tested in a number of ways.

Correlating Craters and Extinctions

The impact cratering record on the terrestrial planets can be used to test whether there is a general relationship between impacts and extinctions. To start with, work by Gene Shoemaker of the US Geological Survey and colleagues, based on observations of Earth-crossing asteroids and comets and crater counts on the Moon and other planets, has led to the conclusion that bodies large enough to make a Chicxulub-sized crater collide with Earth every 100 million years or so (such an impactor would have a diameter of about 10 kilometers, or 6 miles, the rule of thumb being that the crater diameter is about 20 times that of the impactor). About five or six such impacts should have occurred over the last 600 million years, which agrees with the record of five major mass extinctions in that period of time (Figure 2). Collisions with somewhat smaller bodies—with a diameter of 5 to 6 kilometers (3 to 4 miles) and only one-tenth the power on impact—should have occurred every 20 to 30 million years, and these could account for the roughly 20 minor mass extinctions seen in the fossil record.

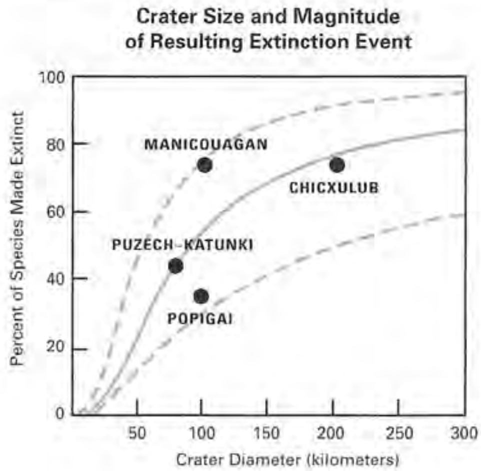


Figure 3: This theoretical "kill curve" relates impact-crater sizes to mass extinctions, assuming a cause-and-effect relationship. Dashed lines indicate upper and lower bounds of error (after Raup). Sizes of the largest well-dated craters (dots) are plotted against the magnitude of concurrent extinctions.

Studies of the atmospheric, climatic, and ecological effects of a large impact have made it clear that such events represent the greatest known perturbations of the biosphere. Thus, we might expect that the record of mass extinctions should mirror the record of large impacts.

Using the average waiting times between mass extinctions and between impacts of various sizes, Raup has produced a quantitative "kill curve" that relates the severity of an extinction to the size of impact craters. To further test this innovative idea, we can plot the largest, well-dated impact craters against the mass-extinction events that seem to coincide with these impacts (Figure 3). The results not only support a general impact-extinction relationship but also suggest a cutoff—that is, craters with a diameter less than about 60 kilometers (40 miles), created by objects 2 to 3 kilometers in diameter (1 to 2 miles), should not produce extinction pulses that would show up in Sepkoski's data. In fact, there are a number of craters with a diameter of 40 to 60 kilometers (25 to 40 miles) that are not associated with mass extinctions, which makes sense according to the curve.

The Biggest Extinction Ever

Another way of testing a general impact theory of mass extinctions is to study in detail the geologic record of other mass extinctions, comparing these with the record at the K/T boundary. Several mass extinctions were accompanied by Strangelove Ocean effects. At the end of the Permian, there were abrupt decreases in carbon-isotope ratios, as shown in work by William T. Holser of the University of Oregon and others, indicating a great mass mortality and lowered productivity in the oceans, similar to that seen at the K/T boundary (Figure 4). Analysis of these data by Andre Adler and me at New York University suggests that

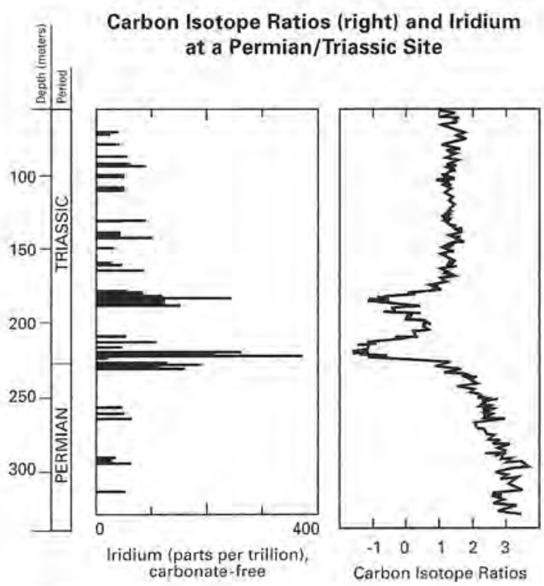


Figure 4: The carbon-isotope graph shown at the right, from a Permian/Triassic site in Austria, represents about 2 million years. The abrupt negative shifts in carbon-isotope composition, indicating drastic decreases in ocean life (the Strangelove Ocean), took place within 50,000 years or less. Note that peaks in iridium, shown at the left, coincide with the shifts in carbon isotopes (chart after Holser).

these major changes took place in less than 50,000 years, and could have been instantaneous. Evidence for sudden warmings and climatic instability at the end of the Permian period is reinforced in the oxygen-isotope record.

Many sections of the geologic record across the Permian/Triassic boundary show an almost total disappearance of typical Permian pollen, indicating a dramatic mass extinction of plant life. A thin layer at the boundary contains only one kind of pollen or spore variety—fungal spores. This represents an ecological disaster in which land plants were devastated and fungi proliferated on the resulting dead organic matter, a situation that might be described as a global "silent spring." Eventually fern-like plants recolonized the environment, and then there was a resurgence to climax-vegetation. However, the recovery of plant diversity took more than 4 million years. This pattern of disturbance is similar to that at the K/T boundary, where the disappearance of plant life is marked by a brief barren interval, followed by a time when only ferns, and in some areas fungi, prevailed.

Is there any evidence of impact at the Permian/Triassic boundary? Two Permian/Triassic layers somewhat enhanced in iridium have been found at several sites (Figure 4). Their iridium values are considerably weaker than those at the K/T boundary, which could indicate impact by icy comets, which are probably less rich in iridium than stony asteroids.

The evidence of impact involvement in the Permian/Triassic extinction, the most drastic die-off in the geologic record, is tantalizing, and geologists continue to search for other signs of impacts. Preliminary evidence of quartz grains with possible shock features has been identified in Australia and Antarctica by Greg Retallack from the University of Oregon and colleagues. These results, if confirmed, could establish a link between impacts and the greatest mass extinction of all time.

Late Devonian Comet Shower?

The Late Devonian mass extinction (about 365 million years ago) is marked by an abrupt negative shift in carbon isotopes, as also observed at the K/T boundary. The Late Devonian extinction of marine invertebrates apparently allowed proliferation of shallow-water algae, which produced widespread algal mats on the sea floor. Such mats do not develop during normal times because snails commonly graze on the algae. The mass extinction of the grazers allowed the algae to grow unimpeded.

A peak in iridium abundance is associated with the algal mats. Some have argued that the iridium increase was caused not by a dust-spraying impact but by the rampant algae absorbing iridium from the environment and thus concentrating it in the algal mats that form the extinction horizon. However, the source of iridium consumed by the

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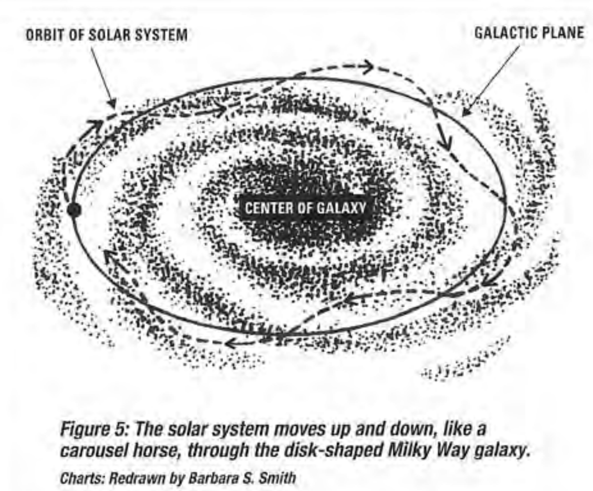


Figure 5: The solar system moves up and down, like a carousel horse, through the disk-shaped Milky Way galaxy.
Charts: Redrawn by Barbara S. Smith

The last Tyrannosaurus *might have looked up to see a comet shower lighting up the sky—and spelling doom for him and his fellow dinosaurs.* Painting: Joe Tucciarone

algae may well have been iridium-enriched, post-impact ocean waters. The case for impact involvement is reinforced by glassy microtektites near the extinction boundary, reported by Philippe Claeys, now with the Humboldt University of Berlin, and others. In addition, the Late Devonian sea floor is marked in a number of localities by chaotic beds that may be tsunami deposits, like those accompanying the K/T extinctions. We know of several impact craters with radiometric ages close to 365 million years, including the Siljan Ring crater in Sweden (55 kilometers, or 34 miles, wide) and the similarly sized Charlevoix crater in Canada. Overall, the evidence accumulates for impacts—perhaps a shower of comets—as a possible cause of the Late Devonian extinctions.

Another instance of multiple impacts associated with mass extinctions may exist at the Jurassic/Cretaceous boundary—meaning that the Cretaceous world, which ended with a huge impact 65 million years ago, may have been ushered in by a series of smaller impacts. Three craters have been dated close to the Jurassic/Cretaceous boundary, about 142 to 144 million years ago: the Gosses Bluff, Australia crater (22 kilometers/14 miles wide, about 143 million years old), the Morokweng impact structure in South Africa (70 kilometers/40 miles or more wide, 145 million years old), and the Mjølnir impact structure in the Barents Sea (40 kilometers/25 miles wide, 142 million years old), which is associated with an ejecta layer rich in iridium and shocked quartz grains that can be traced in strata as far away as 2,500 kilometers (1,600 miles).

Smaller Impacts and Regional Extinctions

The Manson crater in northwest Iowa, attributed to the impact of a 2-kilometer (1-mile) body about 74 million years ago, is a prime example of the regional environmental effects of a relatively small comet or asteroid. The crater has a diameter of 35 kilometers (22 miles). A search for Manson ejecta in similar-age marine rocks to the west led to the discovery of shocked minerals in the widespread Crow Creek bed of the Pierre Shale in southeastern South Dakota, which has been interpreted as a probable tsunami deposit. Calculations suggest that the severe blast and fireball effects of the impact would have killed most creatures on land and in shallow seas within hundreds of, and perhaps a thousand, kilometers of the impact site.

There has been much discussion as to whether dinosaurs in western North America were declining in the 10 million years or so prior to the end-Cretaceous impact. Many paleontologists have argued that the disappearance of many species of dinosaurs well before the K/T boundary was good evidence that the impact was not the cause of the dinosaurs' demise. However, the early die-off of those dinsosaurs may have been a regional event, caused by the Manson impact.

At the time of the Manson impact, nine genera of dinosaurs disappeared in western North America. Soon after, there was a phase of immigration and rapid evolution of other dinosaur species, accompanied by major changes in mammals and marine reptiles, such as the plesiosaurs. The havoc that followed the blast is written plainly in the geologic record. Dinosaur bone beds—some indicating extremely violent conditions and containing entire herds of more than 10,000 Hadrosaurids—occur in 74-million-year-old rocks in Montana, about 1,400 kilometers (900 miles) from the Manson impact site. At a similar distance, the famous "fossil forest" site near Chaco Canyon, New Mexico reveals that trees were killed and buried in place by sudden events, possibly the blast and fire or possibly flash floods triggered by the Manson impact. The overlying sediments contain a profusion of tiny fossil mammals, opportunists, perhaps, that took advantage of the regional kill-off of all large predators.

If this notion of regional extinctions resulting from small impacts is correct, then sub-continental effects of Manson-sized impacts should be relatively common in the geologic record.

Shiva's Galactic Timetable

Analyzing the extinction record over the last 250 million years (the best-dated part of the record), Raup and Sepkoski found an underlying cycle of about 26 million years. My recent work with Bruce Haggerty at NYU on the improved and better-dated extinction data base shows that a cycle of about 30 million years persists through the entire 540 million year record.

Raup and Sepkoski's original findings prompted Richard Stothers of NASA's Goddard Institute for Space Studies and me and, independently, Walter Alvarez and Rich Muller of the University of California at Berkeley to analyze the record of impact craters, and we detected a similar cycle of about 30 million years in the occurrence of large impacts on Earth. Furthermore, it seems that clusters of craters of similar ages are closely correlated with the mass extinction episodes. These results suggest that many impact events, most likely from showers of comets, have led to periodic pulses of mass extinction.

Geological Time Scale

Era	Period	Epoch	Years Ago
Cenozoic	Quaternary	Recent	10,000
		Pleistocene	1,800,000
		Pliocene	5,000,000
		Miocene	22,500,000
	Tertiary	Oligocene	37,500,000
		Eocene	53,500,000
		Paleocene	65,000,000
Mesozoic	Cretaceous		140,000,000
	Jurassic		200,000,000
	Triassic		230,000,000
Paleozoic	Permian		280,000,000
	Carboniferous		345,000,000
	Devonian		390,000,000
	Silurian		430,000,000
	Ordovician		500,000,000
	Cambrian		570,000,000
Pre-Cambrian			

To think in geologic time is to transform your conception of time as marked by minutes, hours, years, and lifetimes. Geologic time begins 4.5 billion years ago, as Earth was forming. It does not proceed in a measured way, with eras and epochs divided into equal parts. Rather, geologists punctuate time by marking changes in the dominant life forms on Earth, as recorded in fossil deposits.

Nearly 4 billion years of Earth-time lie in the shadowy Precambrian era, when simple, single-celled bacteria, plants, and animals dominated the planet. Then, just 570 million years ago, life changed. Suddenly, complex forms emerged and spread in a phenomenon called the Cambrian explosion. From this moment on, time is measured by dramatic shifts in the fossils that characterize each passing age. In other words, geologic time is measured by mass extinctions.

The Paleozoic is the era of invertebrates and simple vertebrates, such as fish, amphibians, and primitive reptiles. The Mesozoic marks the reign of the dinosaurs, an era that ended almost instantaneously only 65 million years ago. Mammals have dominated the Cenozoic, and not even the most scientifically advanced of that group can say how long it will be before another mass extinction punctuates geologic time.

—Charlene M. Anderson,
Director of Publications

If the approximately 30 million year periodicity in mass extinctions and impacts is real, it may be related to a known astronomical cycle—the motion of the solar system up and down through the plane of the Milky Way galaxy. As the solar system revolves around the galaxy, it also bobs up and down, like a horse on a carousel, through the galactic disk. In this cycle, the Sun and planets pass through the dense region of the disk, packed with stars and clouds of interstellar gas and dust, about every 30 million years (Figure 5, page 9). Stothers and I were first to suggest that passage of the solar system through the galactic plane could lead to gravitational disturbance of some of the trillions of comets that orbit the Sun in the Oort Cloud, resulting in periodic showers of comets in the inner solar system. Recent work by astrophysicist John Matese and colleagues at the University of Southwestern Louisiana has confirmed that the pull of the combined mass of the material in the galactic disk is sufficient to induce a hail of comets.

This cycle of doom has relevance to the present-day impact hazard, as the solar system passed through the galaxy's plane in the last few million years. By some accounts a barrage of comets recently dislodged from the Oort Cloud should be approaching the planets now.

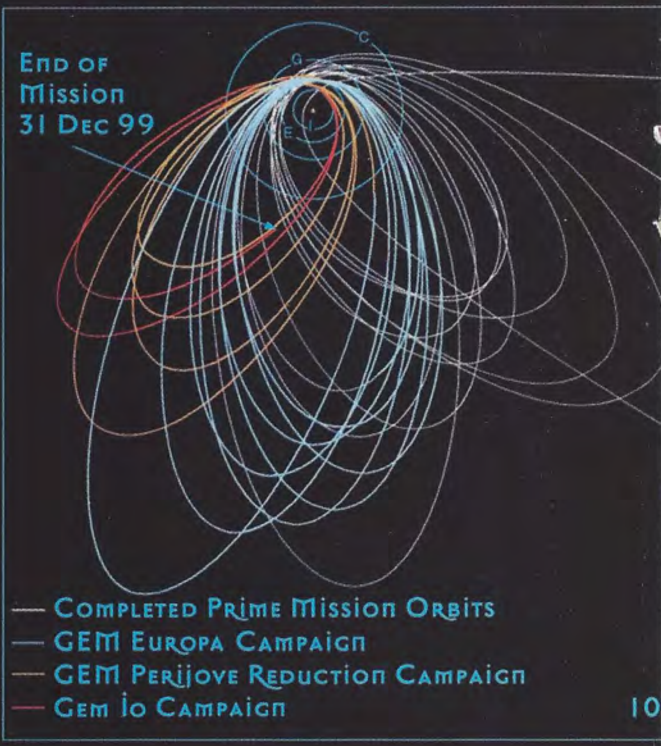
Though we are far from certain in our understanding of catastrophes on a cosmic scale, exciting findings from astronomy, geology, and the history of life seem to be pointing to a general theory relating mass extinctions, and perhaps other geologic events, to the impacts of large comets and asteroids on the Earth. In this view, mass extinctions of life occur as discrete pulses. Major environmental perturbations are shown by changes in carbon isotopes and climatic changes by oxygen-isotope shifts. The mass extinctions are commonly followed by a period of rapid evolution of surviving species, with newcomers filling new niches in the wake of global disaster. Thus with the Chicxulub impact 65 million years ago, the Mesozoic world, populated by giant dinosaurs and flying reptiles, gave way to the modern world of mammals and birds. And thus, like Shiva the Destroyer, cyclic impacts bring an end to one world, allowing a new one to begin.

The impact hypothesis of mass extinctions, which began with study of a thin clay layer at Gubbio, has grown in theoretical and observational support, pointing toward an important unifying concept in the Earth sciences. This new awareness of impacts as a major force in Earth history promises a revolutionary transformation of our view of the cosmos.

Michael R. Rampino is a Research Consultant at NASA's Goddard Institute for Space Studies New York and Professor of Earth and Environmental Science at New York University.

ICE, WATER AND FIRE: THE GALILEO EUROPA MISSION

BY LESLIE L. LOWES

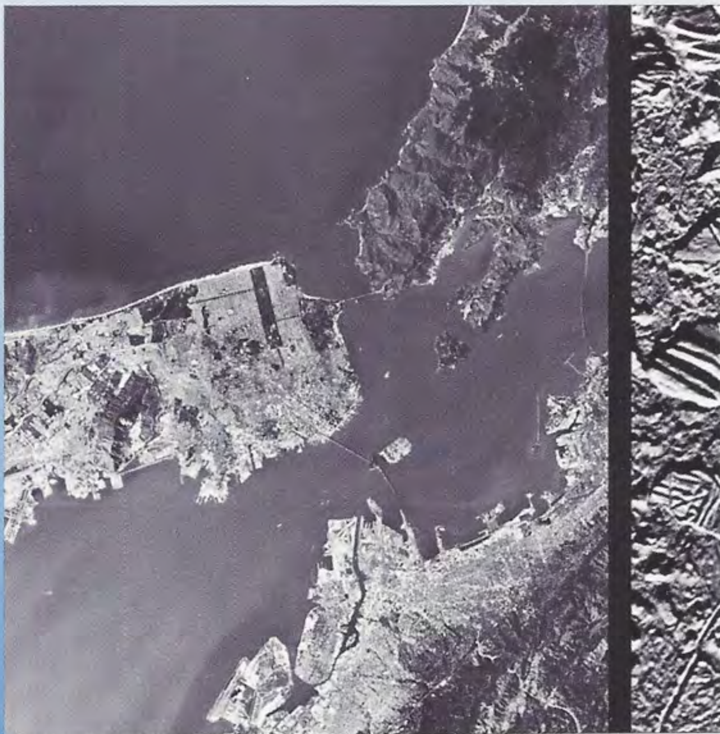


Imagine yourself exploring worlds of extremes, a realm where the deep cold of space freezes water to brittleness while, nearby, molten rock flows under spewing fountains of sulfur. Hung in space behind you is a brilliant globe sporting large, colorful clouds caught in centuries-old storms, with towering thunderclouds that change within hours. *Galileo* has begun the *Galileo* Europa Mission (GEM), spending two more years at Jupiter studying ice, water, and fire there: the icy crust of Europa, the thunderstorms of Jupiter, and the fiery volcanoes of Io.

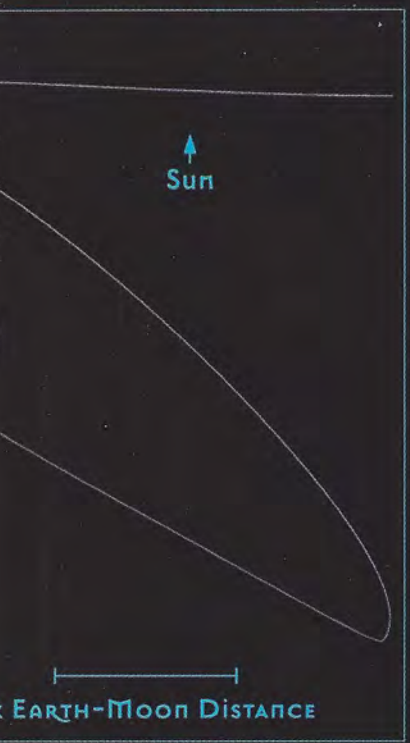
Galileo first arrived at Jupiter on December 7, 1995 after a six-year journey from Earth. The spacecraft swung by the moon Io, then fired its main engine, braking into orbit. *Galileo* collected precious data from a probe it dropped into the Jovian atmosphere, and for the two years of its prime mission—11 orbits around the solar system's biggest planet—*Galileo* revealed fascinating details of Jupiter and its moons.

For example: while Jupiter's composition is mostly the primordial mix of hydrogen and helium, there is also water. Water circulates in the top layers of Jupiter's clouds, causing thunderstorm-like activity in some areas and rendering other areas dramatically dry. *Galileo* showed us a new Ganymede, the first moon in the solar system known to have its own magnetic field. From *Galileo* we learned that intensely cratered Callisto is coated with a layer of fine dust in some places. We've seen that Io's surface has continued changing since the *Voyagers* saw it in 1979. And scientists have found evidence that an ocean existed in recent geologic history—and may still exist—under Europa's crust of ice.

Galileo was originally scheduled to end its exploration on December 7, 1997, but NASA and Congress approved a continuation of the mission through the last day of 1999. GEM has three phases, each with tightly focused objectives: the Europa Campaign ("Ice"), Perijove Reduction/Jupiter Water Study/Io Torus Passages ("Water"), and the Io Campaign ("Fire").



...and Mission Tours

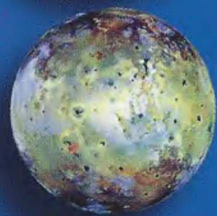


GEM Timetable

Mission start: December 7, 1997

Europa: "Ice"
8 orbits in 13+ months
December 16, 1997 to February 1, 1999
Closest approach: 200 kilometers (120 miles)

Jupiter: "Water"
4 orbits in 4+ months
May 5, 1999 to September 16, 1999
Closest approach: 467,000 kilometers (290,000 miles)



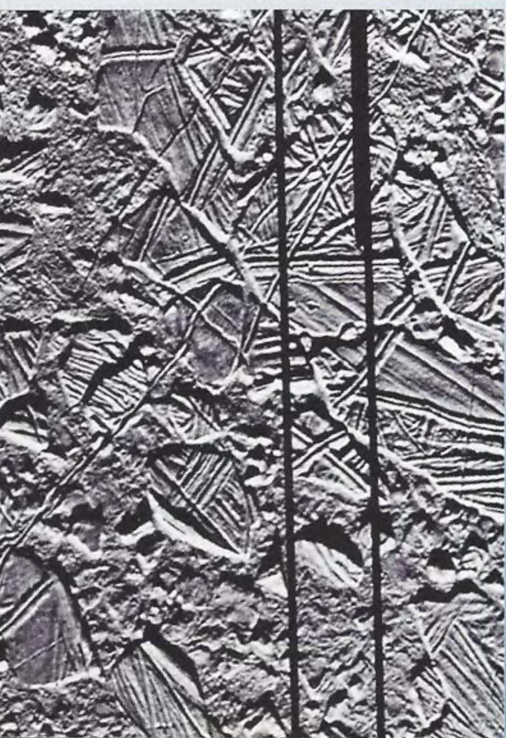
Io: "Fire"
2 orbits
October 11, 1999 to December 31, 1999
Closest approach: 300 kilometers (190 miles)

Mission end: December 31, 1999

Europa Campaign

For the first eight orbits of GEM, spanning more than a year, *Galileo* will search for further evidence of an ocean beneath the icy surface of the intriguing moon Europa and try to determine if that ocean still sloshes today. Scientists will scan the surface for spewing ice volcanoes and other direct evidence of churning water below. They'll count craters, which helps date the youth of the moon's smooth surface (the fewer the craters, the more youthful the surface). *Galileo* will peek at Europa's layered interior by measuring the effects of the moon's gravity, looking for variations in the thickness of its ice shell and possible indications of the depth of the subsurface ocean. A flowing, salty ocean could generate a magnetic field, so scientists will try to determine if the magnetic signals nearest Europa are generated within.

Galileo will get detailed images and atmospheric data from around the Europan globe, including the polar regions, with closest-approach distances ranging from 200 to 3,600 kilometers (120 to 2,240 miles). With resolution three times better than in the prime mission, some planned images will show details as small as 6 meters (the size of a truck!). We'll use stereo imagery to determine heights for Europa's relatively flat surface features. We'll map the distribution and composition of Europa's ice with resolution as fine as 10 kilometers (6 miles), keeping an eye out for contaminants, which scientists believe may result from comet or meteorite bombardment or may come from within Europa itself.

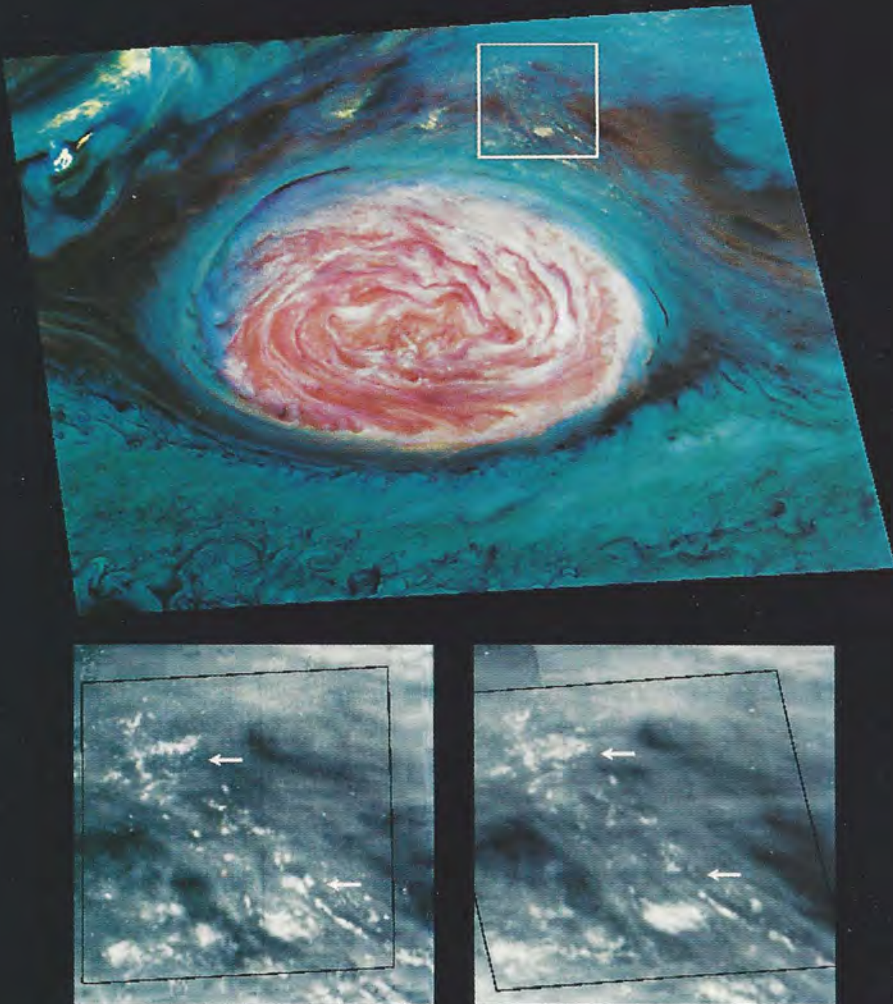


Europa (right half of image) sports raft-like formations of ice the size of cities on Earth. In this image the rafts appear to have broken and floated apart. The San Francisco Bay image shown at the left provides a good comparison for scale and resolution in the Europa image.

Image: JPL/NASA

Peering Down at Jupiter

"Perijove Reduction" isn't some kind of fad diet or a way to shrink the national debt—it's what we need to do to get the spacecraft in an orbit close enough to Jupiter for flybys of Io. For six months in mid-1999, in four successive orbits, *Galileo* will use the gravitational pull of Callisto, along



***Above:* The region around a dark "hot spot" on Jupiter appears in natural color on top and false color below. The atmosphere within a hot spot descends and dries out, then rises nearby to form billowing thunderstorm-like clouds.**

***Left:* Jupiter's Great Red Spot has been a study in sameness for nearly four centuries. But images from Galileo show how gigantic cloud features associated with the ancient storm system evolve in mere hours (insets).**

with thruster burns for fine tuning, to halve the spacecraft's closest distance to Jupiter (called "perijove").

Peering at Jupiter from the closest distances since Arrival Day, *Galileo* will study details of wind and storm patterns, including the billowing thunderstorms that grow to heights several times those we have on Earth. Water circulates vertically in Jupiter's top layers, leaving large areas drier than the Sahara and others drenched like Earth's tropics. Mapping this distribution of water and understanding its role in Jupiter's weather can help us understand Earth's faster-paced weather changes.

Once each orbit, during its passage from "ice" to "fire," *Galileo* will shoot through the Io torus, a donut-shaped cloud of charged particles that ring the orbit of Io. *Galileo* will measure the density of the sulfur that streams from Io's volcanoes and will also measure sodium and potassium, which get "sand-blasted" off the Ionian surface by particles swept along in Jupiter's rotating magnetic field.

Io Campaign

The closest Galilean moon to Jupiter, Io is also the most active body in the solar system, sizzling with dozens of sulfur and silicate volcanoes. The volcanoes are driven by tides that flex the otherwise solid surface of Io as much as 100 meters. But much of Io's forbidding environment remains a mystery, and there will be much to learn from the final two orbits in GEM, which will feature flyovers from 500, then 300 kilometers (310, then 190 miles).

Are scientists trying to keep us all in suspense, waiting until the last part of the mission to glimpse fiery Io with breathtaking detail (resolving features as small as 6 meters)? The suspense will indeed be high as *Galileo* flies right over Pillan Patera's plume of frozen sulfur. But the reason for waiting until the end of the mission to explore Io is that it minimizes changes in perijove, leaving more time and resources for science studies. It also lessens the exposure of the spacecraft to Jupiter's intense radiation, which grows in intensity as you get closer to the gas giant—strong enough in the vicinity of Io to kill a human being.

Galileo has been exposed to varying levels of radiation during its orbits of Jupiter. We expect the spacecraft will continue operating through the intense exposure of the Io campaign. However, radiation will likely pepper the camera's light detector with blinding hits to many pixels and may cause the computer's bits to flip in random ways. In that event, *Galileo* will put itself into "safe" mode until further commands come from Earth. (It's hard to think with your bits flipped!)

Right: The yellow-green glow around Io comes from the scattering of light by a moon-shrouding cloud of sodium atoms. In the near-right inset, Prometheus' volcanic plume casts a reddish shadow across Io's surface. In the far-right inset, Pillan Patera spits gas and dust, which appear blue against the black of space. *Images: JPL/NASA*

Galileo should have ample power from its radioisotope thermoelectric generators for the spacecraft and its instruments, and there should be plenty of propellant for the thrusters. One item of potential concern is *Galileo*'s tape recorder, which has already surpassed its design limit for stops and restarts. If it fails beyond repair, we'll load the onboard computer with a program that allows the instruments to take and transmit data in real time. Using this strategy, *Galileo* will be able to handle only a limited amount of data, significantly reducing the mission's scope. We are keeping our fingers crossed.

Getting More From Less

In keeping with NASA's vision of lower-cost space exploration, GEM's design takes advantage of an already orbiting spacecraft to perform a tightly focused, lower-cost, higher-risk mission. To stay below a cost of $15 million per year, we have trimmed spacecraft and ground operations to a minimum. Engineering and science teams have automated and streamlined wherever possible so that a barebones staff—just 20 percent of the personnel from the prime mission—can operate GEM.

For each orbit's closest-approach to Jupiter or a target moon, *Galileo* will take only two days of data rather than the seven taken during the prime mission. For the remainder of each orbit, we'll gather only minimal data on Jupiter's magnetic environment, using that time for playback of stored data. We are having to do without many mission specialists, who have moved on to other jobs. However, some experts may be brought back as a tiger team should any serious problems arise. After GEM, *Galileo* will no longer return science data but will keep slicing through the intense radiation near Io's orbit, reporting on spacecraft health until it is silenced by radiation damage.

During the GEM mission of ice, water, and fire, *Galileo* will point the way for new investigations of these Jovian worlds of extremes, possibly confirming that an ocean currently exists on Europa and locating areas where the ice is thinnest. This important step will guide future Europa missions—orbiting and potentially ice-boring missions—that will look into a key question for the 21st century: is there life on Europa?

You can follow *Galileo* on the World Wide Web at http://www.jpl.nasa.gov/galileo.

Leslie L. Lowes, Member of the Technical Staff at the Jet Propulsion Laboratory, is Lead Outreach Coordinator for the Galileo *mission.*

Basics of Spaceflight:

Where Are They Now?—Part 2

by Dave Doody

Cassini

Today *Cassini* continues to fall along its intended solar orbit, on target to pass close behind Venus this April in a spiraling path that will deliver the spacecraft to Saturn in July 2004. *Cassini* is keeping its large, high-gain dish antenna facing the Sun to shade the rest of the spacecraft during its tenure in the inner solar system. Heaters controlled by stored settings and commands from Earth are maintaining healthy temperatures on board and are also used to boil off any contaminants that may cling to sensitive science instruments. Trajectory correction maneuvers are scheduled for several points en route, at which times *Cassini* will fire its small rocket thrusters for a few seconds to fine-tune its orbital path.

Pioneers 10 and 11

Like their forerunners in the *Pioneer* series, *Pioneers 10* and *11* were designed primarily to return data about the solar wind and interplanetary medium. The first spacecraft to fly by Jupiter, *Pioneer 10* was launched in March 1972. *Pioneer 11* followed the next year. Today *Pioneer 10* is about 69 AU from the Sun and proceeding outward at about 2.6 AU per year (AU = Astronomical Unit, the mean distance between the Sun and Earth).

Routine tracking and data processing were suspended on March 31, 1997 for budget reasons. Power from the spacecraft's RTGs (radioisotope thermoelectric generators) is low and decreasing.

Because of a similar power decline, *Pioneer 11*'s mission ended in November 1995. *Pioneer 11* could not continue to track Earth, which moves back and forth yearly from the spacecraft's distant viewpoint, today about 50 AU from the Sun and increasing 2.5 AU each year. *Pioneer 11* was the first spacecraft to fly by Saturn and return images from the ringed planet.

These true *Pioneers* proved it was possible to penetrate the asteroid belt, and they paved the way for *Voyagers 1* and *2, Galileo, Ulysses,* and *Cassini*. Flybys of Jupiter gave the *Pioneers* enough energy to escape the solar system, and rather than fall back to the Sun they will silently drift within our Milky Way galaxy forever. *Pioneer 11* will pass one of the stars in the constellation Aquila in about 4 million years.

Magellan

When you see Venus, brilliant in the twilight sky, you're seeing a planet that has been visited many times. The remains of NASA's *Magellan* spacecraft are now mostly gases mixed into Venus' atmosphere. Some of its more massive components, such as the attitude-control reaction wheels, may lie on the planet's surface. Flown intentionally to its destruction, *Magellan* was gathering data about the Venusian atmosphere up to its final moments.

In its primary mission, *Magellan* carried out detailed radar mapping of the planet's surface, and then it went on to perform the first demonstration of aerobraking at a distant world. *Magellan* also mapped most of Venus' gravity field from a low, circular orbit. Many other spacecraft are today part of the evening "star," including probes, landers, and orbiters sent by the US and by the former Soviet Union.

Voyagers 1 and 2

Voyager 1, at just over 69 AU from the Sun, vies with *Pioneer 10* for the title of most distant human artifact. Commands sent to *Voyager 1* at the speed of light routinely take nine and a quarter hours to reach the spacecraft. The return time for signals from the spacecraft is always slightly longer, since the tiny rocket ship is continuously moving away. At its current velocity, *Voyager 1* recedes about one AU every three months. After its historic reconnaissance of the Jovian and Saturnian systems, *Voyager 1*'s path turned northward and out of the ecliptic plane where the planets orbit.

Voyager 2 went on past Jupiter and Saturn to fly by Uranus and Neptune, and then it, too, went out of the ecliptic plane but in a southerly direction. Both *Voyagers* are still healthy today and returning data from interplanetary space en route to interstellar space. They have identified low-frequency radio emissions from the heliopause, the boundary between the Sun's outflowing wind and the sparse interstellar wind coming from other stars in our region of the galaxy. The *Voyagers* may survive to report crossing the heliopause, estimated to be about 50 AU away from the spacecraft.

Probably the first resource to fail for the *Voyagers* will be sunlight, which their sensors use to locate Earth for radio communications. This far from home, the Sun appears as a bright star, but eventually, around the year 2020, it will become too faint for the *Voyagers* to see. Power from the RTGs will diminish about the same time to a level too low to continue essential systems. Today, however, both *Voyagers* continue to watch the Sun and a distant star, and they continually adjust their attitude for Earth tracking, rocking slowly back and forth by firing tiny bursts of hot gas from their rocket thrusters.

Ulysses

Ulysses, a joint project of the European Space Agency (ESA) and NASA to explore the Sun's polar regions, is in excellent health and beginning its second 6.2-year orbit of the Sun. In April 1998 the spacecraft will reach the far point in its orbit, a Jupiter-like 5.4 AU from the Sun. Then it will return to high solar latitudes and continue its primary work.

Four spacecraft are heading out of our solar system and will someday cross the heliopause and enter interstellar space. The other operating spacecraft are locked in orbit about the Sun or planets and will remain artificial satellites within the solar system. *Chart: Dave Doody; redrawn by Barbara S. Smith*

The spacecraft will be working those high solar latitudes during the Sun's next period of maximum activity—a fortunate opportunity. *Ulysses* will execute its south polar pass from September 2000 to January 2001 and its north polar pass from September to December 2001. Before then, however, *Ulysses* will coordinate its observations with ESA's SOHO spacecraft, which carries experiments for studying the Sun's corona and the solar wind.

Discovery

The NASA Discovery program incorporates state-of-the-art technologies into small projects with a fast turnaround. NEAR, the Near-Earth Asteroid Rendezvous, was the first of the Discovery missions to be launched. NEAR encountered the asteroid 253 Mathilde in June 1997 en route to its destination, asteroid 433 Eros, which it will orbit. *Mars Pathfinder*, renamed on Mars as the Carl Sagan Memorial Station, was the second mission in the Discovery series. Each of the Discovery missions costs less than a major Hollywood movie, including everything from design and fabrication through launch and 30 days of operation.

The next mission to be launched under the Discovery program will be *Lunar Prospector*, designed to spend a year in polar orbit around the Moon. *Lunar Prospector* will carry out remote sensing of the Moon from low orbit using five science instruments, including one that will be able to determine for certain whether there is water ice at the Moon's poles.

Stardust, the fourth Discovery mission, launches in February 1999 to gather material from a comet's coma (the "halo" of gas and dust surrounding the comet core) and return it to Earth for analysis.

New Millennium

NASA's New Millennium program is a series of missions designed to test new technologies so they can be confidently used on science missions in the 21st century. The first in this series is *Deep Space One* (DS-1), which launches this July to orbit the Sun, fly by Mars, and then encounter a comet and an asteroid. DS-1 will test a handful of technologies, including a solar-electric propulsion system, known for decades by science-fiction enthusiasts. DS-1's system employs solar panels to generate electricity to power an ion engine.

In addition to missions to visit bodies in the solar system and validate technologies under the Discovery and New Millennium programs, NASA is implementing a number of other scientific investigations in space. Be sure to visit the NASA site on the World Wide Web to find out more: http: //www.nasa.gov.

Basics of Spaceflight

And, finally, where is Basics of Spaceflight headed? This installment concludes its run in *The Planetary Report*. For three years, it's been an honor to touch upon the "how it all works" side of space exploration with you, with readers who share my own excitement in the use of robotic spacecraft to explore our cosmic back yard.

Now the ball is in your court. Let's open a dialog about these subjects on the Web: what's on your mind? If the World Wide Web isn't available from your home or office, you might find a public library nearby that offers connectivity and a little help. I look forward to hearing from you via the Society's Web site: http: //planetary.org.

Dave Doody is a member of the Jet Propulsion Laboratory's Advanced Mission Operations Section and is currently working on the Cassini *mission to Saturn.*

Thanks, Dave, and See You Soon

Dave Doody and his Basics of Spaceflight column are leaving the pages of *The Planetary Report* with this issue. But this is not goodbye—with his knowledge, talents, and generous spirit, Dave has been too valuable to the Planetary Society for us to let him go. He is simply transferring from a formal print medium to an informal electronic forum.

We are developing an interactive page in the Society's home page where Dave will be available to answer questions posed by members. With this feature we will explore new territory, so check our Web site frequently to monitor our progress.

In the next issue of *The Planetary Report*, we will introduce a new column called The Stuff of Life. Noted biologists, chemists, astronomers, and planetary scientists will offer short essays on the elements, compounds, and processes that make life on Earth possible and extend their musings to the possibility of life on other worlds.

So, we thank Dave for his contributions to *The Planetary Report*. And we invite our readers to join us as we branch out with new endeavors.

—Charlene M. Anderson, Director of Publications

News and Reviews

by Clark R. Chapman

American geologists gather annually to share their research, hunt for jobs, scout out new textbooks, and learn what their colleagues have been up to. Meetings of the Geological Society of America (GSA) are far larger than meetings of astronomers. The practicality of geology swells its ranks. But space science, in the guise of "planetology," is also represented.

Last October, the mountains surrounding Salt Lake City glistened with early snow. But down in the Mormon capital, where geologists filled most of the city's hotels, temperatures hovered near 70 degrees. In the many lecture halls and ballrooms of the sprawling Salt Palace convention center, two dozen simultaneous talks proceeded on subjects as diverse as our planet.

At 170 booths on the main floor, entrepreneurs hawked maps, books, computers, and geologists' tools-of-the-trade (even shoes!). Official country maps were offered for sale by foreign geological surveys while the geologists who made the maps circulated on the floor, making professional contacts.

The well-attended planetology sessions presented results about planetary geology, including data from *Galileo* and *Mars Pathfinder*. One session ventured into the more speculative realm of the origin and early evolution of life on Earth and other planets. Unlike astronomers, who usually take a casual approach and scribble on vu-graphs, geologists normally present their work in well-designed, artistic-color slide shows. Papers not scheduled for oral delivery appear in poster displays of equally professional quality, enhanced by the graphics technologies long used by geologists to print large, colorful maps.

Hot Rocks

The GSA treats controversial issues of broad interest at so-called "Hot Lunches." Panelists debate each other, then open the floor to discussion from the audience —at least from those not busily munching fast food before the afternoon sessions begin. One Hot Lunch I attended concerned "dubiofossils" in Mars rocks. The moderator explained that geologists knew about real fossils and pseudofossils (things that look like fossils but definitely aren't). The nano-fossils in Martian meteorite ALH84001 are neither: their nature is uncertain, or "dubious." But they have provided fertile ground for research and controversy since they were announced in *Science* magazine in August 1996.

It appears that the case for real fossils in the meteorite is dissolving—at least in the minds of most researchers. Even the proponents, authors of the original paper, seem to be retreating to open-minded uncertainty about the biological origins of the micro-worms whose portraits have been so widely published. (For a review of Mars meteorite fossil studies, see the November/December 1997 *Planetary Report*.)

If the nano-fossil basis for renewed interest in Mars is faltering, *Pathfinder*'s success this past summer has more than reinvigorated both scientific and public curiosity about the Red Planet. A huge crowd of geologists, eager for the latest *Pathfinder* findings, overflowed the largest auditorium at the Salt Palace one evening, first paying tribute to the memory of Gene Shoemaker; US Geological Survey planetary geologist Mike Carr delivered an enthusiastic, personal eulogy that Gene would have loved.

Mars Mania

Then the personable *Pathfinder* Project Scientist, Matt Golombek, delivered an engaging, lavishly illustrated account of the first months of Mars exploration by *Pathfinder* and the little rover, *Sojourner*. It remained unclear to many in the audience exactly what totally new things we've learned from *Pathfinder* about Mars and about the central question of whether Mars harbors evidence of current or past life. But *Pathfinder* clearly *did* demonstrate the technology of getting onto the Martian surface, and the geologists' Mars mania was palpable as Golombek received a standing ovation.

The planetary sessions, including the Shoemaker/*Pathfinder* evening, were organized by the GSA division of planetology. At its business meeting, officers hawked Mattel's *Sojourner* toy to raise funds for the Dwornik student-paper awards. There was a spread of assorted candies and cookies so planetologists could craft other, sweeter models of *Pathfinder*. Arizona State University planetologist Ron Greeley was honored with the G. K. Gilbert Award, the first of which was given to Gene Shoemaker in 1983.

In a special GSA symposium, deeply relevant to planetary studies, a fellow dressed in the full regalia of Archbishop Ussher opened a session of invited talks dealing with time. The archbishop is famous, or infamous, for dating the origin of the Earth (and universe) at 6,000 years ago (4004 BC, to be exact). Talks treated the history of more recent Earth chronologies, from those of Lord Kelvin to present-day findings, including the latest Moon, Mars, and meteorites results from the new hafnium/tungsten radioactive isotopic chronometer. Other speakers described continuing problems in measuring rock ages precisely enough to resolve raging debates about the rates of catastrophic change in Earth history.

Centuries after Ussher, and even after the revolutionary insights of Gene Shoemaker on the predominance of catastrophism on Earth (whether wrought from the skies or not), geologists are still caught up in philosophical debates on geologic methodologies . . . providing strategic ground for attacks by the rising forces of neo-creationist Luddites.

Clark R. Chapman spoke before the GSA about the chronological implications of the Galileo *spacecraft's pictures of craters on Jupiter's satellites.*

World Watch

by Louis D. Friedman

Cape Canaveral—On October 15, at approximately 5:00 a.m., a mighty Titan 4/Centaur rocket lifted the *Cassini* spacecraft and *Huygens* probe on their way to Saturn. The launch was marked by controversy because the spacecraft carried a nuclear power source. The nuclear power is required because of Saturn's great distance from the Sun, as was the case with *Galileo, Voyager,* and the *Pioneers*.

The Planetary Society has always been sensitive to environmental issues related to planetary exploration. In our support for the *Cassini* launch, we attempted to balance the important concerns of public safety and environmental effects with our philosophical commitment to planetary exploration. In 1990, before the *Galileo* mission began, we looked into the issue of nuclear power aboard spacecraft and, following Carl Sagan's lead, supported that launch while advocating full disclosure of risks and precautions.

Today we advocate smaller and more efficient nuclear power systems for future missions, recognizing that outer-planet and planetary-lander missions will continue to require some sort of nuclear power.

The *Galileo* mission has been a terrific success at Jupiter with repeated flybys of Europa, Ganymede, and Io and the extended mission now underway (for details on *Galileo*'s discoveries and the extended mission, see "Ice, Water, and Fire" on page 12). *Cassini* promises similar rewards at Saturn, and we all await the success of its mission there in 2004 and beyond.

Future outer-planet missions, such as a Europa probe and the Pluto fast flyby, will be smaller and will require less plutonium. Technological advances in power system efficiency promise to reduce the needed amount of nuclear power still further.

Washington, DC—NASA has selected two more missions in the Discovery program of solar system exploration. *Contour*, led by Joseph Ververka of Cornell University, is being built by the Applied Physics Laboratory of Johns Hopkins University. This mission will fly by three comets, deepening our knowledge of these bodies and their origins and perhaps their role in the distribution of water in the solar system.

The other mission, *Genesis*, is being led by Donald Burnett of the California Institute of Technology and built by the Jet Propulsion Laboratory. *Genesis* will collect samples of solar wind particles to bring back to Earth. The collection site will be one of the Lagrangian points of the Earth-Sun system—points in space where gravitational balance will hold an object in position.

These are the fourth and fifth missions of the Discovery series; the first three were the Near-Earth Asteroid Rendezvous (NEAR), *Mars Pathfinder*, and *Stardust* (which, as mentioned in last issue's Society News, will carry a microchip bearing the names of all Planetary Society members as of November 1997).

Cape Canaveral—With its launch re-scheduled from September 1997 to January 1998, *Lunar Prospector* will observe the Moon from polar orbit with a prime goal of determining whether there is water ice in permanently shadowed regions of craters at the lunar south pole. An earlier mission, *Clementine*, detected the radar signature of water ice there.

Paris—The European Space Agency (ESA) has resurrected their interest in Mars exploration by initiating a *Mars Express* for launch in 2003. The mission will fly on a Soyuz rocket, built in Russia and sold by a French-Russian consortium.

When the Europeans dropped their Intermarsnet mission plans, it appeared that they would not be conducting any Mars exploration in the next decade. Intermarsnet was a US-ESA cooperative mission to place several Mars landers in a seismology/meteorology network on the Martian surface.

Mars Express is an orbiter mission that will carry the three main European experiments lost on the ill-fated *Mars '96*. The experiments are HRSC, an imaging system; OMEGA, an infrared spectrometer; and a Fourier Planetary Spectrometer. In addition, a sounding radar and plasma-measuring instrument will complete the science payload.

The mission has about 150 kilograms (330 pounds) of payload mass available for a lander or landers. Several designs and scientific proposals are being studied in England, the Netherlands, France, and Germany. ESA has apparently not made a commitment to funding the landers, so their status remains uncertain at this time.

The successful launch of the Ariane V enables Europe to be a player in other planetary missions. One possibility under study is using the Ariane V for launch of the nascent Mars sample-return mission planned by NASA for 2005. Benefits to the Mars Surveyor program would include increased payload capability and international participation.

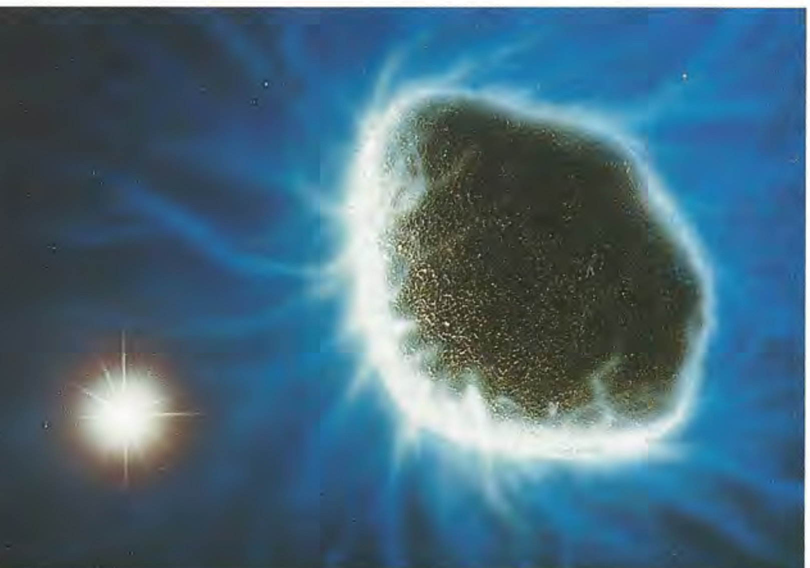
Louis D. Friedman is Executive Director of the Planetary Society.

Questions and Answers

With all the detritus that is constantly streaming away from a comet (in the form of a coma and a tail) and bleeding off into space, why doesn't the comet's nucleus eventually shrink down to nothing?
—James K. Walker, Brasilia, Brazil

Maybe it does. But comets meet their demise in other ways as well. We see evidence of the reduction of comets when they split. In almost all cases, tidal forces produce the splitting. After comet Shoemaker-Levy 9 was captured by Jupiter, its orbit evolved to the point where tidal forces split it into 26 pieces that we could observe with a telescope (there were undoubtedly more).The comet collided with Jupiter in 1994 and became part of the process of planetary accretion.

Certain comets pass behind the Sun and disappear, never to be seen again, as in the case of comet C/1992 N1. This comet was observed three times in July 1992. It then passed behind the Sun and we should have seen it re-emerge on the other side, but we haven't. It seems that this comet may have just fizzled out. Numerous comets belonging to the Sun-grazing Kreutz family meet their demise as the Sun's tremendous heat and gravitational forces consume them.



This close-up of a comet's "dirty iceball" nucleus shows the origin of the gases and dust that will form its bright, fuzzy "head" or coma. These gases and fine particles will then blow off to form the comet's tail. Comets meet their deaths in a variety of ways: breaking apart in the grip of tidal forces from a larger body, getting "eaten up" by the Sun, crashing into a planet or moon, or perhaps just fizzling out.

Painting: John Foster

In another scenario, comets may lose their tails and start looking more like asteroids. In 1948, comet Wilson-Harrington was photographed as part of the Palomar Sky Survey. This object was "discovered" again in 1979 as asteroid 1979 VA. According to measurements that I made with Alan Chamberlin, former graduate student, and colleagues in 1992, there is no evidence of cometary activity in 1979 VA anymore. Another student of mine, Yan Fernandez, analyzed the color and intensity of the tail on the 1948 photographic plate and determined that the tail is not likely to have been dust. These observations are consistent with a theory presented by Fraser Fanale and Jim Salvail, of the University of Hawaii, that heating at the surface results in a fused crust, so low-gas comets may close off their vents. According to this model, the crust would insulate the icy core from the Sun's rays and the comet's nucleus would then look like an asteroid.

Our understanding of comets' behavior and their pathways to extinction is limited. Maybe some comets do waste away to nothing. It is something to watch for.
—LUCY McFADDEN,
University of Maryland

I really enjoyed William Hartmann's article on the Moon's origin (see the September/October 1997 issue of* The Planetary Report*). Why did the Moon seem to stop receding from Earth just at the distance where it exactly covers the Sun during a total solar eclipse? Or is that just a coincidence?
—Steve Ricco, Deerfield Beach, Florida

It's just a coincidence. The receding motion of the Moon, predicted from tidal theory and actually measured by laser signals bounced off reflectors on the lunar surface, is so slow that the Moon has been at about the same distance during all of humanity's brief recorded history. But, on average, it is still receding and its distance from Earth varies slightly during its monthly orbit. Sometimes the Moon is too far away to cover the Sun and if an eclipse occurs, then we get an annular eclipse, with a ring of light remaining visible around the Moon.
—WILLIAM K. HARTMANN,
Planetary Science Institute

The image of a crater on the surface of Europa on the cover of the September/October 1997 issue of **The Planetary Report** *is very interesting, but I don't understand your caption describing it as an impact basin. If it was caused by an impact, where is the rim and where is the debris?*
—Frank Germann, West Saint Paul, Minnesota

Tyre would be better described as an impact structure than a "basin," since it is actually quite flat. Tyre bears a striking resemblance to Callanish, a similar-size structure on Europa's trailing hemisphere whose origin has also been debated (see Figure 1, "Puzzling Rings," on page 12 of the March/April 1997 issue of *The Planetary Report*). *Galileo* imaged Callanish near the morning terminator (the line dividing the light and dark sides of a planet or moon) with enough detail to reveal many smaller, secondary craters radiating from a central smooth patch nearly 50 kilometers (about 30 miles) in diameter. We believe that these small pits and crater chains have been produced by debris ejected during the impact of an object we estimate to have been more than a kilometer (0.6 mile) in diameter. Both Tyre and Callanish are surprisingly different from impact features on the Moon and the other icy Galilean satellites because of their low relief and sets of concentric fractures.

The best current hypothesis is that the impacts penetrated through a thin brittle shell into a ductile interior, such as a subsurface sea. *Galileo* will get a closer look at Tyre in late March 1998—shedding light, we hope, on these mysterious features.
—PAUL GEISSLER,
University of Arizona

What was the first asteroid ever discovered? Who was the discoverer?
—Carla Wilson, Danville, Arkansas

On January 1, 1801 the Italian monk and astronomer Giuseppe Piazzi was checking the stellar positions given in a new star catalog when he noticed that one "star" was not in the catalog. When he observed that the object was moving from night to night and that it lacked the diffuse appearance of a comet, Piazzi correctly concluded that he had found a new solar system body—the first known asteroid.

Originally Piazzi named the object Ceres Ferdinandea, honoring King Ferdinand IV of Sicily, but the name was later shortened to Ceres, the Roman goddess of corn and harvests.
—DONALD K. YEOMANS,
Jet Propulsion Laboratory

Factinos

A recently discovered object, known as 1996 TL66, threatens to disrupt our well ordered vision of the local universe. The Texas-sized body, too big to qualify as a comet but too small to be a proper planet, appears to swing well out of the boundaries of the known solar system. Its highly elliptical orbit carries it to an area of space between the Kuiper Belt and the Oort Cloud that scientists believed to be empty.

Jane Luu and Brian Marsden of the Harvard-Smithsonian Center for Astrophysics and colleagues reported their discovery in the June 5, 1997 issue of *Nature*. While this is the first such object to be found in this "no man's land," Luu estimates that as many as 6,000 others like it may exist. "The point is," says David Jewitt, one of the paper's authors, "we have no idea what is in the outer solar system."
—from the Harvard-Smithsonian Center for Astrophysics and the *Los Angeles Times*

❖

Earth's upper atmosphere harbors unexpected amounts of water vapor, according to data from a pair of satellites. This discovery could bolster a controversial theory that thousands of house-sized comets are hitting the atmosphere every day. "What we have found is astonishing. We really don't have answers," says Robert R. Conway of the Naval Research Laboratory in Washington, DC.

Conway and his colleagues made their discovery last August using an instrument called the Middle Atmosphere High Resolution Spectrograph Investigation (MAHRSI), part of a satellite released and later retrieved by the space shuttle. The instrument measures hydroxyl (OH) ions in the upper stratosphere and overlying mesosphere, from 35 to 100 kilometers (about 20 to 60 miles) above Earth. The amount of hydroxyl is directly related to the atmosphere's humidity.

The MAHRSI data revealed a layer with a surprising abundance of OH in the upper mesosphere over the Arctic. This finding corroborates MAHRSI measurements taken in 1994.

The discovery also backs up observations made by the Halogen Occultation Experiment aboard a satellite in Earth orbit since 1991.
—from R. Monastersky in *Science News*

❖

Earth has a tiny companion that orbits the Sun exactly in tune with our planet, report scientists from York University in Ontario, Canada. Calling the 9.6 kilometer (6.0 mile)-diameter rock the "Mona Lisa of asteroids" for the subtle beauty of its sympathetic vibrations with Earth, Paul Weigert said it was a "thrilling discovery," like "finding a diamond in your own backyard."

Several pairs of bodies within our solar system orbit in harmonic resonances, including several moons of Saturn and Jupiter. But out of hundreds of near-Earth asteroids, only asteroid 3753 is held captive by our planet's gravitational pull in a way that keeps it pulsing in a regular rhythmic dance.

As this asteroid orbits the Sun, it is at times 1,000 times farther away from Earth than is the Moon, Weigert reports in the June 12, 1997 issue of *Nature*. However, it is still considered a "companion" because of the exact one-to-one relationship of its orbit to Earth's.

The asteroid, scientists say, poses no threat to Earth—at least for the next 100 million years, after which it could stray from its present path and careen unpredictably.
—from K. C. Cole in the *Los Angeles Times*

Society News

NASA Takes On the Mars Balloon

The Planetary Society has played a crucial role in developing the Mars Balloon concept since 1987. Over the years, our involvement has broadened to include student projects as well as collaborations with international experts and the French and Soviet space agencies. We have passed the torch on to NASA.

NASA is now developing a small balloon to fly on Mars, possibly by 2003. A Jet Propulsion Laboratory team will work in cooperation with international balloon experts. The Society has donated its spare balloon from last year's member-supported test at Utah State University, and we will continue our support as NASA prepares to make the Mars Balloon fly on the Red Planet.
—Louis D. Friedman,
Executive Director

Track Eros on the Web

Near-Earth Asteroid Rendezvous (NEAR) scientist Clark R. Chapman has posted star charts showing the path of asteroid Eros through the night sky; you can find them on the World Wide Web at: http://boulder.swri.edu/clark/finderos.html.

Before checking the charts, you might want to visit the NEAR mission's home page: http://sd-www.jhuapl.edu/NEAR.

The NEAR spacecraft will reach Eros in January 1999. For a mission overview, see the September/October 1997 issue of *The Planetary Report*.
—Jennifer Vaughn,
Editorial Assistant

More News

Mars Underground News:
Pathfinder mission ends. NASA program for sending humans to Mars.

Bioastronomy News:
Life, the evolution of intelligence, and creating the language of SETI.

The NEO News:
The Society announces grant recipients in a new program to encourage NEO detection.

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—Michael Haggerty,
Electronic Publications Manager

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—Lu Coffing,
Financial Manager

Planetary Society Day at NSTA

The Planetary Society partners with the National Science Teachers Association (NSTA) at their national convention in Las Vegas, April 16 to 19, 1998. Saturday, April 18, will be Planetary Society Day, featuring a great line-up of speakers, including Society President Bruce Murray, Society Executive Director Louis Friedman, Clark Chapman of the Southwest Research Institute, and Linda Hyder, the Society's Education Manager.

Society members can register at the NSTA member rate. For a registration packet, write to Susan Lendroth at Society headquarters, or email your name and address to: tps.sl@mars.planetary.org.
—Susan Lendroth,
Manager of Communications and Events

Sagan Honored with Planet Walk

In November, the Ithaca Sciencenter unveiled the Sagan Planet Walk—an outdoor permanent model of the solar system. The 1,200-meter scale model of the solar system consists of 10 standing stones, which stretch from the Sun, located on Ithaca Commons, to Pluto at the Sciencenter. Each planet location is accurately spaced on a scale of one to five billion. The Planetary Society sponsored the Saturn station, located in front of the Ithaca Public Library. Each station will feature high-resolution color images of its designated planetary body on a porcelain enamel sign. *—SL*

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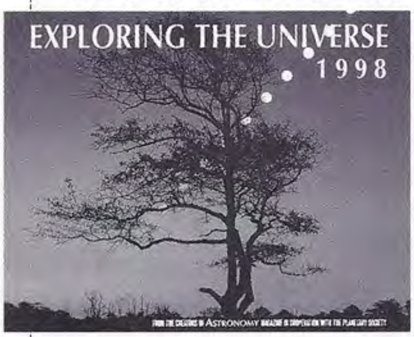

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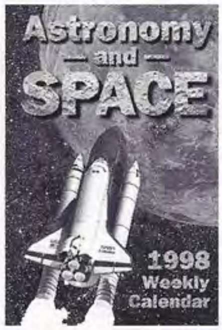

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It's a rare treat when a comet as bright and beautiful as Hale-Bopp pays a visit to Earth's neighborhood. But at times in our planet's history, these celestial callers have come too close—crashing into Earth and destroying vast numbers of plant and animal species. The most famous of these impacts wiped out the dinosaurs 65 million years ago.

On March 29, 1997, Joshua Vaughan captured this view of comet Hale-Bopp over the Wukoki Indian Ruins in the Wapatki National Monument near Flagstaff, Arizona.

Joshua Vaughan lives in Prescott, Arizona. He is a professional photographer whose work has appeared in *Sky & Telescope*, *Popular Photography*, and on the cover of *Astronomy*.

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