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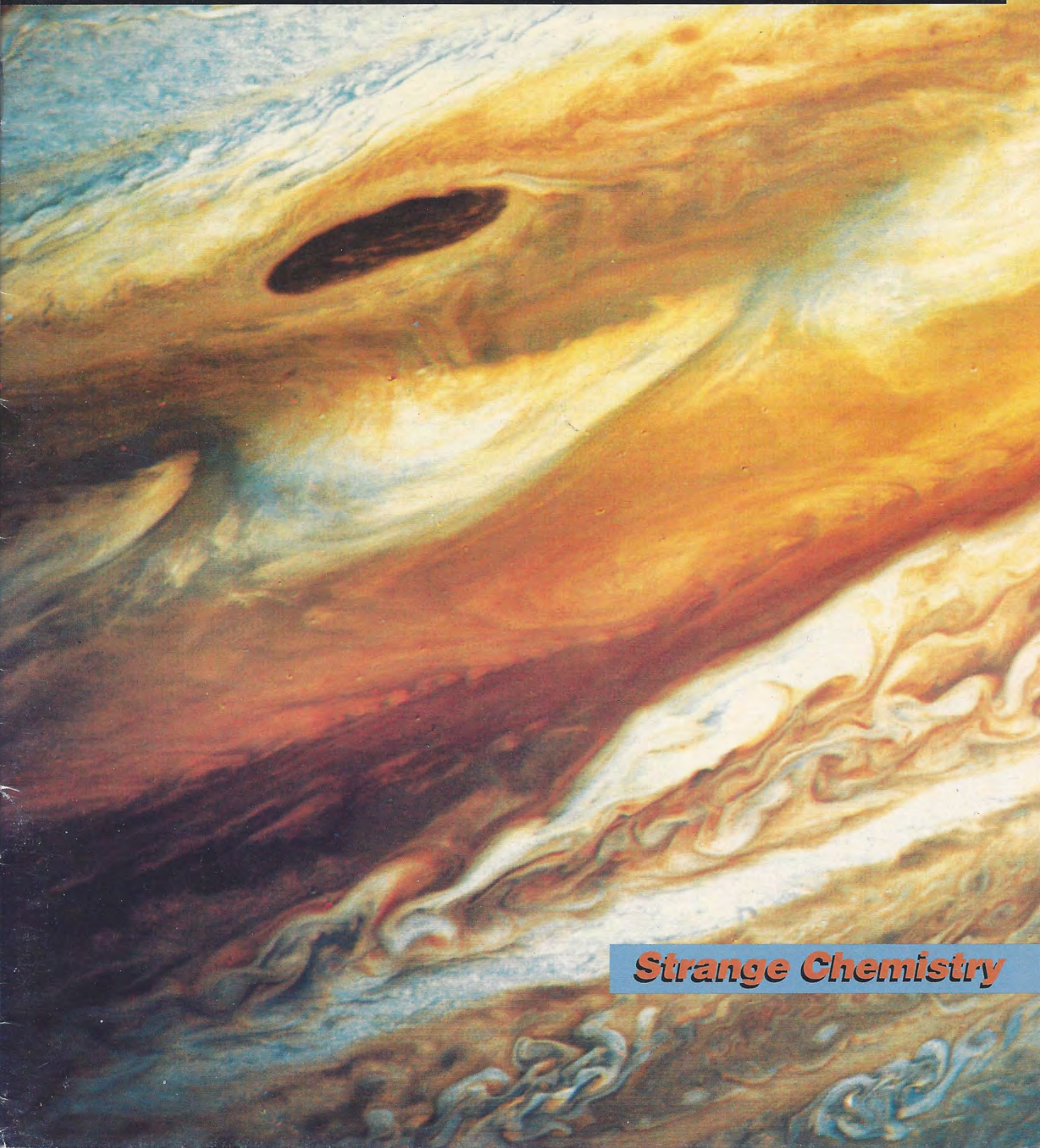

Strange Chemistry

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COVER: The atmospheres of the giant planets possess a chemistry strange to inhabitants of Earth's benign nitrogen-oxygen envelope. Gases that would be powerful toxins to terrestrial lifeforms are routinely generated by chemical reactions within Jupiter and Saturn's swirling clouds. By understanding the processes that create these compounds, we can learn a bit more about how such planets form. This composite image from Voyager 2's cameras exaggerates color differences within Jupiter's atmosphere, which are due to the chemical compositions of the clouds. Image: JPL/NASA

FROM THE EDITOR

Magellan is now well into its mission to map Venus and, despite a few troubling glitches, its radar data are revolutionizing what we know of Earth's sister world. This issue of *The Planetary Report* is devoted primarily to the results of planetary science, to what we've learned about the worlds that share with Earth this small neighborhood in space. After spacecraft complete their missions, investigation and analysis goes on: by compiling years of data into maps, by following up encounter findings with Earth-based observations, and by modeling the environments of these new worlds.

Page 3—Members' Dialogue—Sometimes the good deeds you do are returned with interest, as we learned from our Planetfest '81 essay contest. Our members also seem critical of the current status of planetary exploration in the United States.

Page 4—The Strange Gases of Jupiter and Saturn—Arsenic and germanium, substances you wouldn't want to take with your tea, have been detected in the atmospheres of the giant planets. The presence of even tiny traces of such elements can tell us about a much larger topic—the origin and evolution of our solar system.

Page 12—Planetary Maps: Passports for the Mind—If you're like me, half the fun of a vacation is poring over a road map, planning the trip. Planetary expeditions have made possible maps of other worlds, used by geologists and space mission designers in their work, but available also to those planning excursions to very exotic locales.

Page 20—*Magellan* at Venus: The Mapping Begins—We waited for over a decade between US planetary launches—from *Pioneer Venus*' in 1978 to *Magellan*'s in 1989—but our patience has been rewarded as high-resolution radar images of our closest planetary neighbor have finally started coming in. In this issue we begin our coverage of the *Magellan* results. As the spacecraft continues its mission to map the planet in unprecedented detail, *The Planetary Report* will bring you periodic updates of its progress.

Page 24—World Watch—Equipment failures, management shortcomings and design deficiencies have clouded the bright future we had hoped NASA would see. Continuing budgetary problems plague it still. As *Magellan* orbits Venus and *Giotto* is reawakened, many groups, including The Planetary Society, are searching for solutions to the dilemmas facing the US space program.

Page 25—Hungary: An Able Partner in Exploration—The two spacefaring superpowers, the United States and the Soviet Union, have garnered most of the accolades when it comes to planetary exploration. But many smaller nations have made significant contributions and are capable of making many more. Hungary is a good example, having played a major role in the *Vega* mission to Venus and Halley's Comet. They have great plans for a future exploring the planets.

Page 26—News & Reviews—Our loyal and eloquent columnist, Clark Chapman, ruminates on a topic near and dear to his heart: the role asteroids have played in the evolution of Earth and the life upon it.

Page 27—Society Notes—Testing our Mars Balloon SNAKE design, switching on a new SETI receiver in Argentina, writing to the US Congress, and holding an international contest—things have been busy at The Planetary Society.

Page 28—Q & A—Once in a while a question occurs simultaneously in many minds. Lately, with concerns mounting about the reliability of the space shuttle fleet, many people have been asking: "What ever happened to the *Saturn V*? Why can't we use it now?" We have devoted an entire column to answering this question. *—Charlene M. Anderson*

Members' Dialogue

As administrators of a membership organization, The Planetary Society's Directors and staff care about and are influenced by our members' opinions, suggestions and ideas about the future of the space program and of our Society. We encourage members to write us and create a dialogue on topics such as a space station, a lunar outpost, the exploration of Mars and the search for extraterrestrial life.

Send your letters to: Members' Dialogue, The Planetary Society, 65 N. Catalina Avenue, Pasadena, CA 91106.

My wife and I had the wonderful experience of attending the convocation at Columbia University where our son Richard received his Ph.D. in mathematics. His special interest is in string theory and he has accepted a position at Harvard University as an assistant professor.

I relate this incident in our lives not just because of our happiness in his achievement but because nine years ago Richard was able to take his Dad to Pasadena as a Planetfest '81 essay contest winner. We toured the Jet Propulsion Laboratory and the California Institute of Technology and heard John Williams and the Pasadena Symphony. You made the trip so enjoyable. And sometime during a reflective walk at Caltech, I suspect Richard found the stimulus to pursue an academic career. It was a very impressive experience.

Many thanks for your hospitality, your stimulus and your example. Keep up your good work and best of luck with The Planetary Society.

—ALAN F. WENTWORTH, *Green Bay, Wisconsin*

I was extremely disappointed to read in the July/August 1990 *Planetary Report* that NASA has terminated its portion of a project with the French space agency to develop an infrared mapping spectrometer for the *Mars '94* mission. Not only did NASA renege on a splendid opportunity for international cooperation in an important planetary mission, it undoubtedly generated animosity from the other participating nations and tarnished its credibility.

I agree with the observation about the low priority that NASA's mid-level management places on international cooperation. NASA's administrators are only paying lip service to President Bush's recent pronouncements calling for greater cooperation between the spacefaring nations. If NASA cannot allocate a mere $20 million for such a worthwhile endeavor, how will it ever find funding for a joint human venture to Mars?

I commend The Planetary Society for protesting NASA's decision and wholeheartedly support and encourage further Society involvement in the situation.

—FREDERICK G. GNERLICH, *Highland, Indiana*

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I can't help but be disappointed that, after all the accolades and tributes given to *Voyagers 1* and *2*, [see "The Family Gallery" in the July/August 1990 *Planetary Report*] the visionary spirit of exploration and discovery of uncharted space has fallen out of fashion. People are too quick to forget how difficult it was to gather support for the *Voyager* missions, which had many critics even though they were much less costly than manned expeditions.

Thanks to Robert Farquhar, S. Alan Stern and The Planetary Society, the subject of robotic exploration of Pluto and Charon is finally open for public discussion [see "Pushing Back the Frontier: A Mission to the Pluto-Charon System" in the same issue]. If a mission to Pluto and Charon is to begin in 2001, support and funding must be secured in the early 1990s. Who will have the vision and commitment to take up where Percival Lowell and Clyde Tombaugh left off?

—B. WARREN DAY, *La Verne, California*

NEWS BRIEFS

In September, five scientists from the Jet Propulsion Laboratory and the US Geological Survey joined a team of Soviet scientists to study volcanoes along the Kamchatka Peninsula in the Soviet Union. The joint study marks the first time that western scientists have been allowed in the region since World War II. It also signals the start of a new US/USSR program to improve understanding of volcanoes in the Pacific's "Ring of Fire"—volcanoes and other tectonic features located along the edges of the Pacific Plate.

The Kamchatka Peninsula is not only remote, it is also the home of sensitive Soviet military installations. These two factors have discouraged study of the area's volcanoes by Soviet scientists and, until now, have kept it off limits to western researchers.

As a result, "Kamchatka is sort of a missing link in our knowledge of the Pacific Ring of Fire," said JPL's David Pieri, who leads the American team. These studies will help scientists understand the volcanic forces that help shape the face of our planet, as well as several of its solar system neighbors.

—from the Jet Propulsion Laboratory

More than an orbit's worth of *Magellan*'s mapping data were lost when NASA's Deep Space Network station in Spain ran out of gas. A broken fuel pump in a generator caused a power outage at the station near Madrid and the loss of over three hours of radar images on October 2.

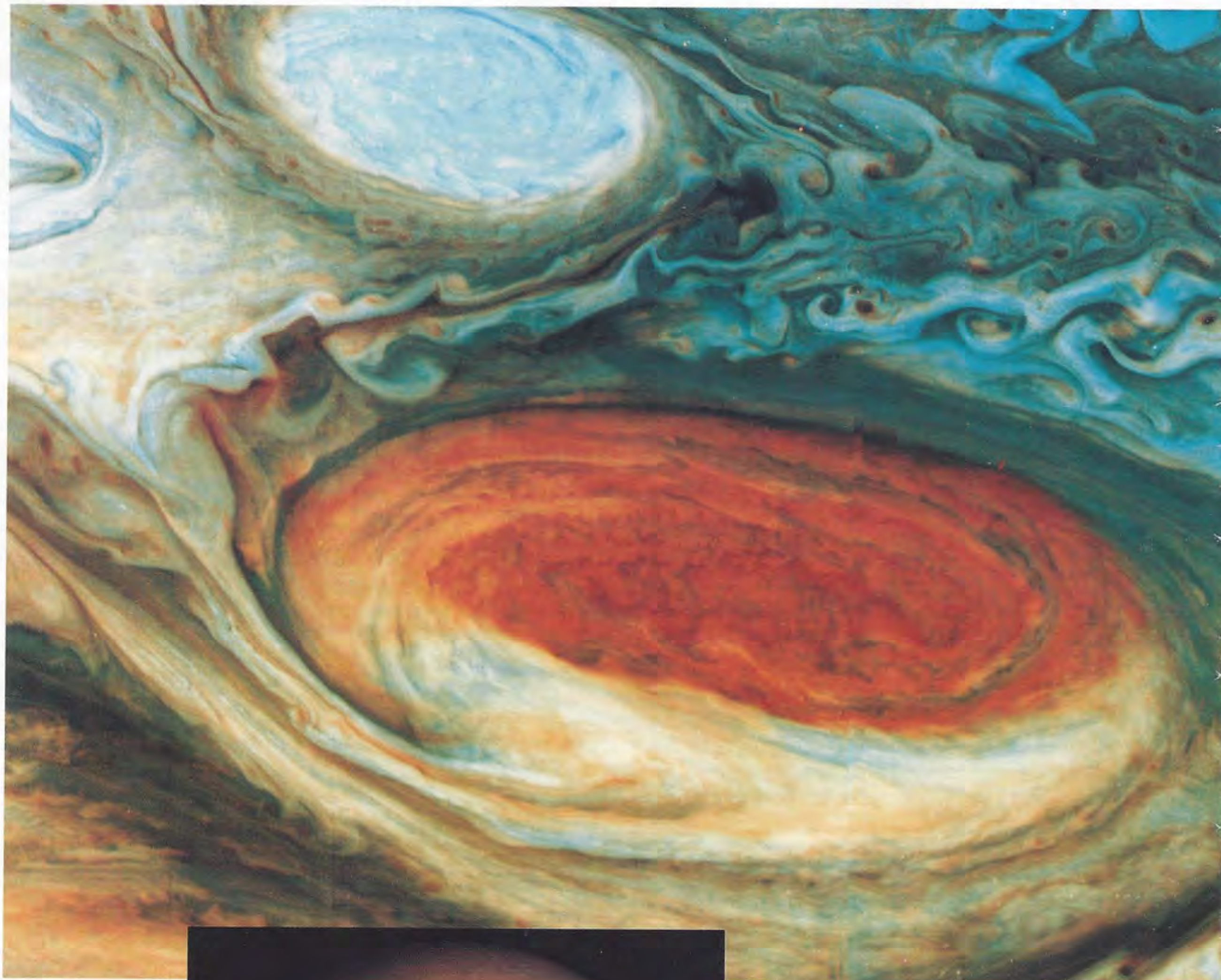
"The data are gone forever. It hit the Earth and there was just nothing there to collect it," said Tommy Thompson, *Magellan* science manager at JPL.

The power outage affected two "noodles," as JPL scientists refer to the long image strips that *Magellan* transmits. Images from an area about 15 miles wide and 10,000 miles long were lost.

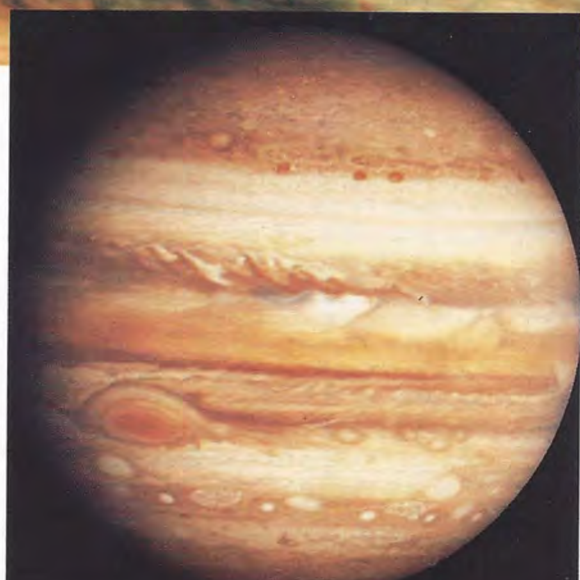
Thompson called the problems a "minor setback" and said the lost images could be recaptured if officials approve an extended mission that would send *Magellan* around the planet again.

—from the Pasadena *Star News*

The Strange Gases of



RIGHT: By combining pictures taken through differently colored filters, *Voyager* image processors could create enhanced color images that increased contrasts between different cloud formations on the gas giant planets. By exaggerating the red and blue in this image of the Great Red Spot, they were able to bring out fine details in the cloud structures of the spot and its environs. The smallest features visible here are about 30 kilometers (20 miles) across.
Image: JPL/NASA



RIGHT: The gas giant planets of our solar system are made primarily of hydrogen and helium, the two most abundant elements in the universe. These gases do not give any color to an atmosphere, so the kaleidoscopic colors we see at Jupiter are probably imparted by traces of phosphorus, sulfur and organic molecules. Ammonia clouds provide white contrasts, and faint traces of pale blue may be, as on Earth, scattering of sunlight by a thick atmosphere.

Voyager images such as these were given color by combining separate black-and-white frames taken with three differently colored filters. The spacecraft's cameras could not record full color directly, so all color pictures were computer-processed images. To produce this new image of Jupiter, Alfred McEwen of the United States Geological Survey reprocessed *Voyager* images and approximated the planet's natural colors more closely than the originally released images.
Image: USGS and JPL/NASA

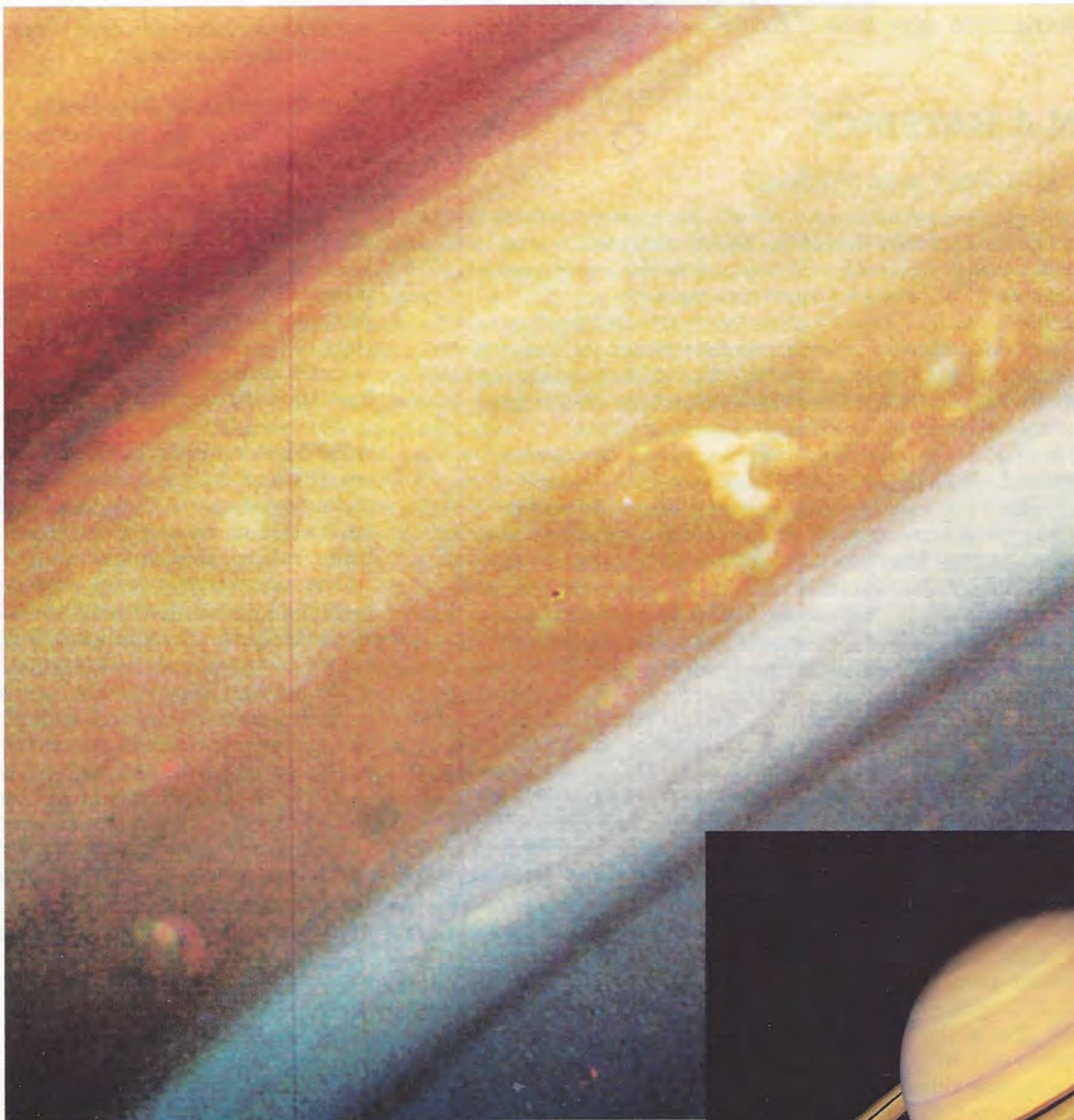
Sometimes, it's the tiny things that are the most telling. Such may be the case with the trace gases in the atmospheres of our solar system's two gas giants, Jupiter and Saturn.

Imagine a hypothetical creature floating in Saturn's atmosphere between the cloud layers. It would breathe a very different mixture of gases from those found here on Earth. The vast majority (about 96 percent) of the molecules inhaled by a Saturnian would be hydrogen (H_2). Most of the remaining four percent would be helium (He). But that is not the whole story.

We Earthlings breathe a mixture that is 99 percent nitrogen (N_2) and oxygen (O_2). But we know from news reports —or just by looking out the window on a hazy day—that less abundant gases in

Jupiter and Saturn

by Keith S. Noll



LEFT: Saturn seen in natural light reveals only a subtly banded face, in contrast to the riotous features of its neighbor, Jupiter. A high haze layer obscuring the features beneath and a slightly different composition may explain this damping down of color. However, this enhanced color image increases the contrast between atmospheric features and makes differences and details in the clouds more apparent. Small convective cloud features pop out of the brownish belt; an isolated cloud ringed with dark material appears in the lighter belt above. The smallest features in this image are about 175 kilometers (110 miles) across. Image: JPL/NASA

ABOVE: Saturn, with its magnificent rings and retinue of moons, is the most immediately recognizable planet in our solar system. What are not so easily discerned are the strange gases that make up this pale, butterscotch-colored world. Its primarily hydrogen and helium atmosphere is flavored with compounds of arsenic and other elements hazardous to earthly life forms. Scientists have laboriously prospected the atmospheric gases—at a safe distance of over a billion kilometers—and discovered traces of compounds whose presence and abundance can teach us about how our solar system formed. Image: USGS and JPL/NASA

the atmosphere exert influence on a global scale. Ozone (O_3) reaches a peak concentration of just 10 parts per million about 35 kilometers (22 miles) above Earth's surface. (For an explanation of what a part per million really means, see "Needle in a Haystack," page 6.)

Though small in number of molecules, ozone's importance is incalculable. Without its ultraviolet absorption properties, life on the surface of our planet would be impossible. Chlorine, the industrial pollutant that is slowly eating away the ozone shield, has an abundance that is only three parts per billion!

Similarly, the minor constituents in the atmospheres of Jupiter, Saturn, Uranus and Neptune reveal many fascinating details about the inner workings and environments of these outer solar system giants. Borrowing from the lexicon of taxonomy, we can classify the molecular species found in these two plan-

(continued on page 6)

ets into several distinct families.

The first family of gases are what we would call equilibrium gases. To see why, imagine that we have a large sample of the gas and dust that formed the Sun and planets 4.5 billion years ago. If we let this mixture slowly cool in the temperatures found in the upper atmospheres of Jupiter and Saturn and then analyzed the molecular content of the gas, we would find molecular hydrogen (H_2), helium (He), methane (CH_4), ammonia (NH_3) and water (H_2O). Observations by German astronomer R. Wildt in 1932 identified methane and ammonia. No other gases were found until molecular hydrogen was seen in spectra in 1960. (For a discussion of spectra, absorption and infrared light, see "A Rainbow by Any Other Name," page 11.) It took more than 40 years from the time of Wildt's work until the first nonequilibrium gases were found in Jupiter.

The next family contains gases formed as the chemical by-products of solar ultraviolet radiation. These are mainly simple hydrocarbons such as acetylene (C_2H_2) and ethane (C_2H_6). Theorists had predicted the presence of these gases before they were found in the mid-1970s. A related group are those molecules formed as charged particles rain down on the atmosphere near the polar auroral regions. So far, only H_3^+ (an ionic form of molecular hydrogen) in Jupiter is demonstrably a product of this process, though simple hydrocarbons again may be produced.

The last family of gases came as a great surprise when first discovered. The surprise came because these compounds are chemically unstable in the parts of Jupiter's and Saturn's atmospheres that we can probe. They are especially strange to those of us familiar with Earth-style chemistry, where elements like germanium (Ge) and arsenic (As) are found in minerals and semiconductor chips (or in poisons) rather than in the atmosphere.

Unraveling how these molecules find their way into the upper reaches of the vast atmospheres of Jupiter and Saturn has led to discoveries about the much deeper and hotter parts of atmospheres that we can never observe directly. And some subtle differences we have found between Jupiter's and Saturn's atmospheres may hold clues to the birth of all the planets.

NEEDLE IN A HAYSTACK

How Much is a Part per Million?

The concentrations of gases in planetary atmospheres are usually expressed in parts per thousand, parts per million, parts per billion and so on. To get a better idea of what this means, imagine a small haystack with a sewing needle in the pile. What fraction of the haystack volume does the needle occupy? Let the haystack be 2 meters high by 1 meter on a side for a total volume of 2 cubic meters, or 2 million cubic centimeters. A sewing needle 4 centimeters long and about 0.05 millimeters thick has a volume of 0.008 cubic centimeters. Dividing these two numbers gives us the answer. The needle occupies just 4 billionths of the haystack volume, or as a scientist would say it, 4 parts per billion.

An even better analogy can be made using time. Imagine that, just after the apple in Times Square drops on January 1, 1991, you count "one-thousand-one." You start your timer and wait. At about a quarter to two on the 11th of January a million seconds will have elapsed; the one-second count is now one part in a million. Not bad. Now you find a comfortable chair and settle in. Early in the second week of August, 2022 your timer will finally pass one billion seconds. You vaguely recall that long-ago count and feel finally satisfied to know what one part in a billion means. Wisely, you decide not to extend your experiment to one part in a trillion—which would take until the year 33,679!

Two Decades of Discovery

About 20 years ago, the first instruments capable of measuring the infrared part of the spectrum were developed (infrared light has longer wavelengths and is more penetrating than visible light). These instruments, called infrared spectrometers, detect molecules by their characteristic absorptions or emissions of light at particular wavelengths. A series of remarkable discoveries followed their introduction.

Observing Jupiter in the fall of 1974 at the McDonald Observatory in western Texas, Reinhard Beer discovered carbon monoxide (CO), a completely unexpected compound in the planet's hydrogen-dominated atmosphere.

Other discoveries soon followed. Astronomer Steven Ridgway and his coworkers at Kitt Peak National Observatory found evidence of phosphine (PH_3), another unexpected molecule, in spectra near 10 microns. (One micron equals one millionth of a meter.) Harold Larson, Uwe Fink and Richard Treffers, astronomers at the Lunar and Planetary Laboratory in Tucson, Arizona, collected spectra using NASA's telescope-in-an-airplane, the Kuiper Airborne Observatory. They soon confirmed this by identifying phosphine as

SPHERES WITHIN SPHERES

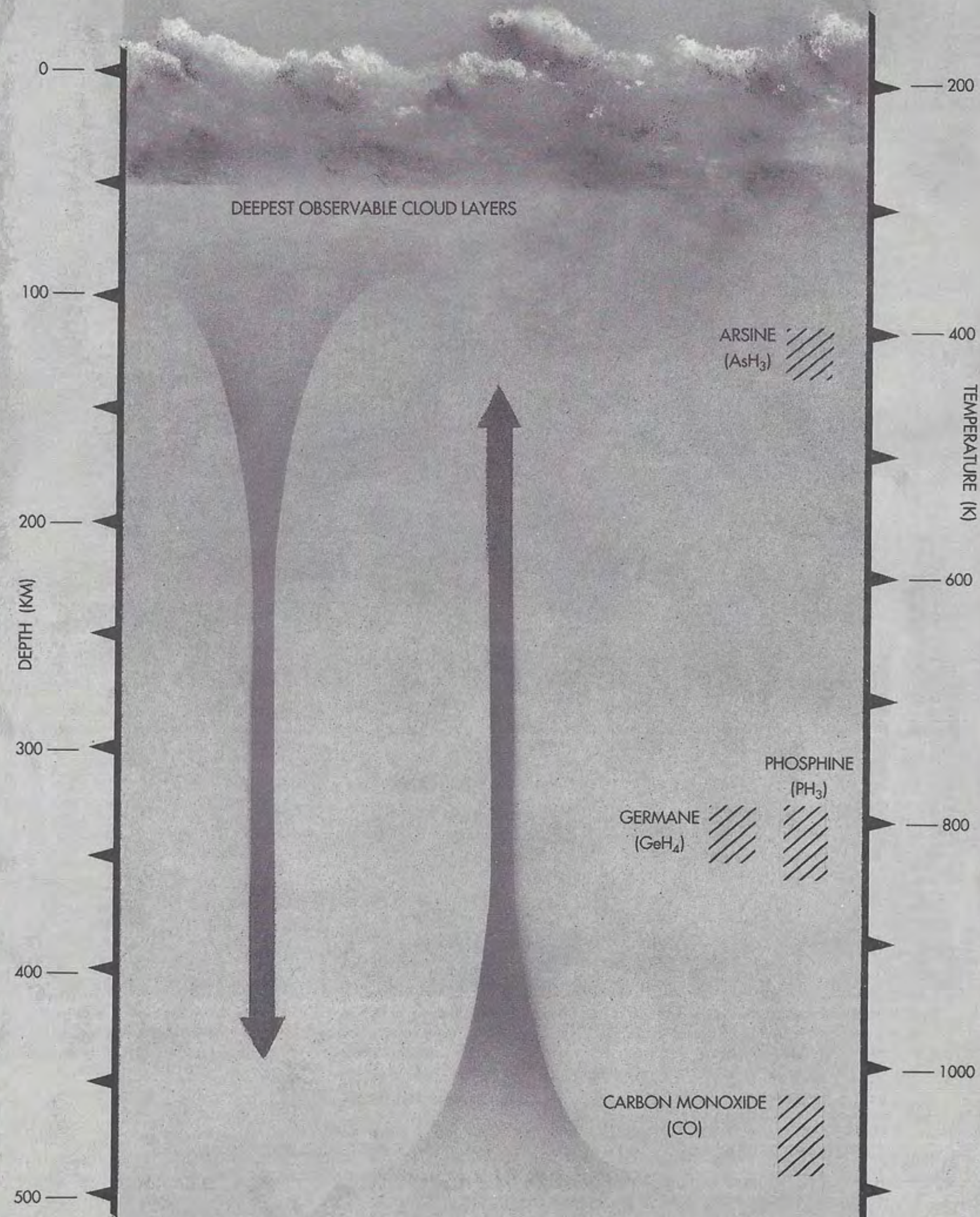
Atmospheric Regions

The atmospheres of the outer planets have several distinct regions, as does Earth's atmosphere. In the lower atmosphere, called the troposphere, the temperature decreases as one moves farther away from the center of the planet. Just looking at the snow-capped peak of Mauna Kea on the island of Hawaii from a poolside chair in Hilo provides evidence of this effect.

Another important characteristic of this part of the atmosphere is that cells of warm gas rise while cooler gas falls in a process known as convection. Towering thunderclouds are dramatic examples of this kind of atmospheric mixing.

Higher up, the cooling trend slows and then reverses as temperatures climb with increasing altitude. This is caused by absorption of ultraviolet sunlight—by ozone in the case of Earth, and by methane and assorted other molecules on the outer planets. This part of the atmosphere is termed the stratosphere. The boundary between the two is a stagnant layer called the tropopause where little vertical movement takes place. Because of this, molecular concentrations are not necessarily the same in the stratosphere and troposphere, a fact that is sometimes a valuable tool in identifying the source of a particular molecule.

Figure 1



Convection is the large-scale atmospheric motion that carries carbon monoxide (CO), phosphine (PH_3), germane (GeH_4), arsine (AsH_3), and other possible out-of-equilibrium gases high enough to be observed. Chart: S. A. Smith

the gas responsible for much of a previously unidentified absorption near 4.73 microns. The same group soon found the remainder of this mystery absorption to be due to the molecule germane (GeH_4), after some very brave laboratory experiments with this highly poisonous gas. Phosphine was present at less than one part per million and germane had the lowest concentration of any gas yet found in Jupiter, just 700 parts per trillion. Jupiter's atmosphere was turning out to be very strange indeed!

What exactly was going on here? If the atmosphere were in chemical equilibrium (a state where the rates of chemical reactions are exactly balanced so that the composition remains stable), the amount of carbon monoxide expected at the temperatures of the atmo-

Through the atmosphere of a gas giant planet float lifeforms strange to our earthly eyes. In a zone where pressure and temperature are amenable, it might be possible for organisms to achieve neutral buoyancy and to propel themselves by taking in air and squirting it out under pressure. Somewhere in the universe a scene like this just might be occurring. **Painting: David A. Hardy**

sphere observed spectroscopically would be utterly negligible. The temperature of the atmosphere that emits most of the 5-micron radiation we detect varies from about 200 to 300 degrees Kelvin (approximately -70 to 30 degrees Celsius, or -100 to 80 degrees Fahrenheit) or, roughly, from midnight at the South Pole to midday in Miami. (The Kelvin scale, often used in planetary science, begins at absolute zero—the point at which all molecular motion ceases—equivalent to approximately -273 degrees Celsius or -454 degrees Fahrenheit.) At these temperatures, the equilibrium concentration of carbon monoxide would be less than 1 part in 10^{31} (that's one in ten million trillion trillion, somewhat less than your odds of winning in your favorite magazine publisher's sweepstakes). Instead, measurements by several groups of scientists found about one part in a billion of carbon monoxide—not a lot, but far more than expected.

A similar situation applied to both phosphine and germane; if equilibrium prevailed, neither of these molecules would be present in anything close to detectable concentrations—yet there they were! Some explanation was necessary.

One Question, Two Answers

The explanation for the carbon monoxide came first. In 1977, Ronald Prinn and Stephen Barshay, scientists working at the Massachusetts Institute of Technology, offered the following suggestion: The equilibrium concentration of carbon monoxide is a strong function of the temperature.

As one goes deeper into Jupiter, the temperature increases continually. At a depth of about 400 kilometers (250 miles) below the one-bar level (one bar is the average pressure on Earth at sea level and a useful reference on the outer planets), the temperature tops 1,000 degrees Kelvin (around 730 degrees Celsius, or 1,340 degrees Fahrenheit).

At this depth, the equilibrium concentration of carbon monoxide is about one part per billion, just what is ob-

served in the infrared spectra. But the carbon monoxide we were detecting in infrared spectra lay more than 300 kilometers (186 miles) higher than this. How could the carbon monoxide we were seeing have been transported the equivalent of the distance from Chicago to Indianapolis without being decimated by reactions with hydrogen that form methane and water?

When Prinn and Barshay compared the rates of rising, cooling columns of gas deep in the atmosphere to the chemical reaction rates that control the relative amounts of carbon monoxide and methane, they found that the two were equal at just about 1,000 degrees Kelvin.

At hotter temperatures, the gas reactions were much faster than the atmospheric motions, so the gas was always in chemical equilibrium as it bobbed up and down in the churning atmosphere. But at temperatures below 1,000 degrees Kelvin, the reaction rates drop rapidly and can no longer keep up with the fairly constant rate of vertical motion. The carbon monoxide-methane balance is "frozen" into a state characteristic of the last temperature where the reactions could keep up—that is, 1,000 degrees Kelvin. (For an illustration of this process, see Figure 1 on page 7.)

Similar arguments could explain the observed amounts of phosphine and germane, although for these gases the reaction rates had to be estimated.

This "deep mixing" hypothesis, attractive as it was, was not the only possible solution. Atmospheric scientist Michael Prather and his associates at Harvard University offered an alternative. They hypothesized that oxygen from small meteoroids was entering Jupiter's stratosphere where, calculations showed, it would soon react to form carbon monoxide. The carbon monoxide made this way would drift down to the cold, stagnant tropopause where it could build up. (For an explanation of tropospheres and other atmospheric zones, see "Spheres Within Spheres," page 6.)

In this case, the carbon monoxide would not be intrinsic to Jupiter at all, but would be the residue of space debris. (For a discussion of common elements and gases found throughout the solar system, see "Cosmic Abundances," this page.)

A third possibility, that carbon monoxide was a byproduct of lightning-produced shock waves (thunder), was also raised. But, although lightning occurs in Jupiter and Saturn, the energy is insufficient to make the quantities of carbon monoxide that we see.

How could we decide between the two viable hypotheses? One test, measuring the temperature of carbon monoxide by comparing the relative strengths of a number of lines in a spectrum, proved too equivocal. Separate research groups reached opposite conclusions using this difficult method. It was not possible to decide if Jupiter's carbon monoxide was in the warm troposphere or concentrated at the cold, stagnant tropopause.

Another lingering question was: Why had phosphine been found in Saturn while neither carbon monoxide nor germane had been detected? In part, this was because Saturn appears as much as 50 times fainter to our detection equipment at these wavelengths than Jupiter. But in 1980, Harold Larson and his colleagues at the Lunar and Planetary Laboratory published a spectrum that showed no sign of the prominent germane line found in Jupiter nor any hint of carbon monoxide.

Finally, it could be asked whether or

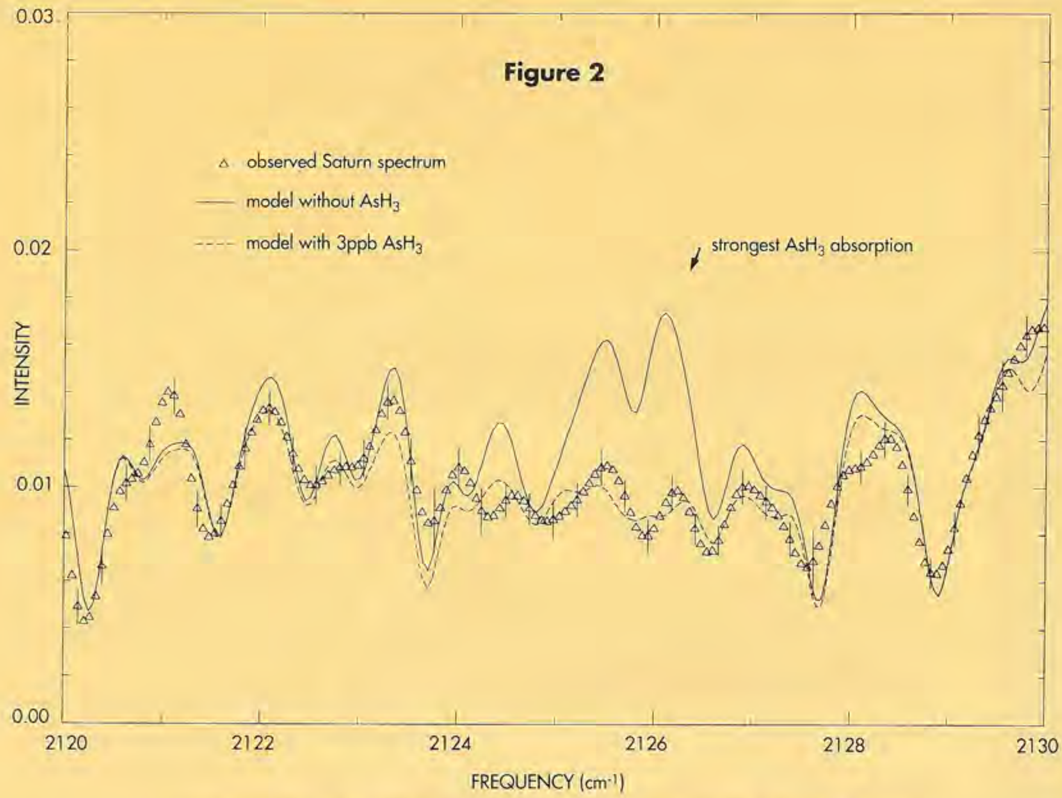
COSMIC ABUNDANCES

Common Elements Found in the Solar System

Just after the Big Bang, the universe consisted of only hydrogen and helium. All the heavier elements that exist were created and recycled through many generations of red giant stars and supernovas. The Sun and planets formed from an interstellar cloud of gas and dust almost 5 billion years ago, whereas the Milky Way is 10 to 15 billion years old. This was time enough for several generations of massive stars to live and die. The legacy of these countless stars is a complex elemental brew of hundreds of stable nuclei.

Studies of primitive meteorites and the outer layers of the Sun have pinned down the detailed mix of elements that were present in the nebula from which our solar system formed. Because we live in a very ordinary place in the universe, we find that this mix of elements is closely reproduced everywhere—and so the amount of a given element in this mixture is often called its "cosmic abundance."

What we find is that for every million silicon atoms, there are 28 billion hydrogen atoms, 2.7 billion helium, 10 million carbon, 3 million nitrogen, 10,000 phosphorus and just 6.6 arsenic atoms. We use this list as a yardstick when we compare it to Jupiter and Saturn to garner clues about their origin and evolution.



The presence of an unidentified gas in Saturn's atmosphere was first hinted at by the failure of computer atmospheric simulations (solid curve) to match observed spectral readings (triangles). When the right amount of arsine (AsH_3) is added (dashed curve), the model fits the observations very nicely.

an effect known as pressure-broadening to determine the pressure of the carbon monoxide gas.

If the carbon monoxide were coming from great depths, the lines would be broad, because most of the absorption comes from pressures of two to seven bars. If the carbon monoxide were concentrated just above the tropopause in the stratosphere where the pressure is only about 0.2 bars, the lines would be much more narrow.

Even as we collected the data at the telescope we could see that Jupiter's carbon monoxide lines were very fat. At last we had the answer to this part of the puzzle. If carbon monoxide from Jupiter were coming up from the hot interior, then the same thing must be true for phosphine and germane. Unfortunately, several complications have prevented us from repeating this experiment for Saturn. But if the mixing occurs in Jupiter, it is at least plausible that it occurs in Saturn, too.

Finally last year, my colleagues and I, along with another group of planetary scientists led by Bruno Bèzard at the Observatoire de Paris in Meudon found a fourth member of the disequilibrium gas family.

The first hint of the presence of an unidentified gas was the failure of computer simulations of Saturn's atmosphere to match the observed spectra near 2126 cm^{-1}. (This number is equivalent to 185 millionths of an inch. The term cm^{-1} is a unit of frequency often used in infrared work, meaning 1 divided by the wavelength measured in centimeters.) In Figure 2, above, the observed spectrum of Saturn is shown as triangles with error bars, and two computer-generated spectra are shown as solid and dashed curves. The bulge at 2126 cm^{-1} in the model represented by the solid line is at the precise position of the strongest absorption of arsine (AsH_3, arsenic with three hydrogen atoms). When the right amount of arsine is added to the model, we get the fine match to the observations, as represented by the dashed curve.

not other molecules that might be wafted upward could be found. A larger assemblage of molecules that could be brought up in this way could bolster logical arguments against coincidental but separate sources for each.

New Observations

This dilemma persisted for almost a decade. The "deep mixing" hypothesis was engaging because it offered the possibility of indirectly sampling inaccessibly deep parts of the giant planets. But it was unproven, with uncertainties in many of its key parameters. These factors, as well as a viable alternative hypothesis, prevented any firm conclusion.

In the fall of 1984, astronomers Roger Knacke, Thomas Geballe, Alan Tokunaga and I began a series of observations of Jupiter and Saturn from the United Kingdom's Infrared Telescope on Mauna Kea, Hawaii. Using a newly developed spectrometer, we set out to answer some of the questions surrounding this group of molecules.

Our first result was the detection of carbon monoxide in Saturn at a concentration that we estimated to be about two parts per billion. Later, we found evidence for germane in Saturn at a concentration of about 400 parts per trillion. So, all three of the disequilibrium molecules were now found on both Jupiter and Saturn. This fact could certainly be used to argue that a common source might be responsible for the nonequilibrium oddities.

But Saturn has an even more abundant source of oxygen than Jupiter—water ice in its rings. The small particles that almost certainly are entering Saturn's upper atmosphere might be sufficient to produce carbon monoxide even if the meteoroids at Jupiter were not. Also, the observed abundances of carbon monoxide and germane did not match some of the predictions made by simply extrapolating the "deep mixing" scenario to Saturn.

So the central question remained: Was carbon monoxide (and, by inference, phosphine and germane) coming from deep, hot layers of the atmosphere, or was it a product of material falling in from outside?

In what turned out to be the crucial test, we observed carbon monoxide in Jupiter with the highest resolution mode of the spectrometer. At this resolution, we were able to measure the width of individual carbon monoxide absorption lines. This enabled us to use

This was an exciting find, not only because it adds even more credence to the "deep mixing" hypothesis, but because it introduces arsenic as only the eighth element so far detected in the outer planets.

The concentration of arsine was 3 parts per billion in Saturn and less than 300 parts per trillion in Jupiter—the least abundant gas yet detected! Obtaining this number was no easy matter, as it required more laboratory experiments with exceedingly poisonous arsine.

Hal Larson and I set out to measure this gas in his University of Arizona laboratory. A guide to hazardous materials noted that arsine was 10 times more poisonous than phosphine—which is already quite dangerous enough. It warned that leaking arsine would smell like garlic. Each time I ventured into the lab I first took a few precautionary sniffs. By a stroke of luck, I was sick for two weeks with Valley Fever (a southwest desert specialty not mentioned in travel brochures) and missed the actual experiments. I can't say that I was sorry.

Combining Hal's spectrum with extensive work of their own, our friends at Meudon eventually came up with the detailed information necessary to create the realistic computer-generated spectra needed to quantify our observations.

Elemental Birthmarks

Why does Saturn have 10 times more phosphorus and arsenic in the form of phosphine (PH_3) and arsine (AsH_3) than Jupiter? That question immediately arises when one considers the details of the elemental abundances. The behavior of these elements appears to be much different from the behavior of carbon or nitrogen found in methane (CH_4) and ammonia (NH_3). The answer may lie in the way in which the planets formed.

Ten years ago, two different models for the formation of the outer planets were current. One proposed that the cloud of gas and dust we call the solar nebula collapsed into several large blobs, which eventually condensed into the outer planets. A second called for a two-stage process. First, the solid material coalesced into ever-larger aggregations, until the gravitational pull finally caused the surrounding gas to collapse around this solid core.

It may seem that these two are very similar, but there is one important difference. In the first scenario, the elements would be mixed in amounts characteristic of this corner of the universe as a whole. The compositions of each of the outer planets should then be similar. In the second picture, the solid matter, which we would call rocks and ice, behaves independently of the gases, which were composed mainly of hydrogen and helium with carbon monoxide, nitrogen, and the noble gases, neon (Ne), argon (Ar), krypton (Kr) and xenon (Xe). In this case, there is no predetermined relationship between the "rock-forming" elements and the "gaseous" elements.

The two *Voyager* spacecraft have already tipped the scales in favor of the second model, the two-stage accretion process, by finding that all 4 of the outer planets have cores with masses of 10 to 20 times the mass of Earth. This is remarkably constant, considering the great variation in total mass: 318 Earth masses for Jupiter, 95 for Saturn and only 15 and 17 for Uranus and Neptune respectively. In Saturn, the solid materials make up a five-times-greater fraction of the total mass than in Jupiter.

This would seem to be, at least in part, a natural explanation for the different patterns of elemental abundances that we are finding. The higher proportion of "rock-forming" elements, like phosphorus and arsenic, in Saturn compared to Jupiter means that more of them might find their way into the atmosphere where they can be observed.

If continued work on the details bears out this view, it will be a powerful means of studying the formation and early development of the outer planets. We will be able, perhaps, to answer questions such as how some of the solid matter is eventually mixed into the surrounding hydrogen and helium. And we may find connections to other nascent planetary systems, such as the particulate disks around young stars like Beta Pictoris, and to giant molecular clouds like the Orion Nebula.

We cannot predict where this path might lead us. It is the nature of scientific research that much of our satisfaction must lie in the investigation process itself and the small discoveries that only hint at answers to larger questions.

Maybe one of the most satisfying results we can take away from all this is the notion that perhaps, somewhere in the vast universe, an unlikely being is slowly exhaling a breath tinged with the faint odor of garlic.

Keith S. Noll is a planetary scientist and currently holds a National Research Council Fellowship at NASA's Marshall Space Flight Center.

A RAINBOW BY ANY OTHER NAME

How Spectra Speak to a Scientist

Astronomy is the science of light. By light, we mean not just visible light, but all the forms of electromagnetic radiation, from radio waves to gamma rays. In planetary science we sometimes have the luxury of sending our experiments to the object that we want to study, but so far, the only thing human instruments have collected from Jupiter and Saturn is light.

There are two ways that light conveys information. Images such as the spectacular pictures returned by the *Voyager* spacecraft are familiar examples. These images can be analyzed to reveal information about cloud structures and winds, spots and plumes—all clues to the motions of the giant atmospheres. When we want to know what the atmospheres are made of, however, we must turn to that other aspect of light, its spectrum.

We have all seen rainbows when sunlight is split into its constituent colors by prisms of glass or raindrops. Each color corresponds to a different wavelength of light, and the splitting of light in this way can be a powerful tool to study the composition of the matter that the light has passed through. The reason is that every molecule absorbs light at a characteristic set of wavelengths. As unique as fingerprints, these absorptions provide the key to discovering the chemical composition of distant planets and stars.

Infrared light has a frequency that is lower (infra) than red light (or, to say the same thing, a wavelength that is longer than red light). It is invisible to human eyes, but we can perceive it with our skin as heat. The infrared part of the spectrum is of special value in spectroscopy because the vibrations of many molecules have energies that correspond to the energies in the various wavelengths of infrared light. Light with the right amount of energy can be absorbed by a molecule, shifting it to a higher vibrational state. Therefore, one of the best places to find absorption lines is in the infrared.

Planetary Maps: Passp

Journey over all the universe in a map, without the expense and fatigue of traveling, without suffering the inconveniences of heat, cold, hunger and thirst.
***— Miguel de Cervantes,* Don Quixote**

Maps have the power to take us worlds away, whether it be while planning a much-needed vacation or dreaming of voyages to other planets. When a map is spread out before you, with the rise and fall of mountains and valleys set down on paper, something happens to the human mind. It goes journeying by way of imagination.

In Cervantes' day, the armchair traveler relied on more adventurous souls to visit bodily other lands and make the observations (or collect the hearsay) needed to make a map. In the Space Age, we've learned to send robots to do the exploring for us.

Ranger, Lunar Orbiter, Luna, Mariner, Venera, Viking, Pioneer and *Voyager* have visited the Moon, Mercury, Venus, Mars and the satellites of the outer solar system. These are all worlds on which a properly protected human might walk. From the information they've returned to Earth, cartographers have created maps that planetary scientists use to help them understand those alien worlds. And we Earthbound travelers can use them as Cervantes suggests, to journey all over the solar system in a map.

Making Maps

Maps of Earth tell us about landforms, such as plains, canyons and shorelines, as well as about the constructs of humans— roads, cities, political boundaries. Planetary maps deal primarily with landforms, which are identified by the names and classifications that humans impose upon them.

Terrestrial map-makers began their craft by drawing what they could see from Earth's surface. Their perspective grew from a local area to a region to the entire globe. Modern technology shifted the perspective to above the surface, giving cartographers the tools of balloons, aircraft and Earth-orbiting satellites to locate, measure and identify mapable features.

Planetary map-makers have worked in the opposite direction, beginning with telescopic views of a planet's disk, advancing to snapshots taken by a spacecraft flying by, then to detailed coverage from orbiters, and finally to landers—at least on the Moon, Venus and Mars.

Their equipment differs, too. Terrestrial cartographers now use aerial cameras, capable of providing detailed views of wide areas with little distortion. The resolution of the photographs is limited only by the grain size of the film emulsion.

Planetary cartographers have had the luxury of aerial photographs only for limited areas of the Moon. Most of the images they work with are obtained by television cameras carried by spacecraft. These images are converted to digital form on the spacecraft, then radioed to Earth as strings of numbers.

Each number is a code for the brightness level detected by the television tubes. A computer then assembles an image from a checkerboard of a million or more pixels ("pixel" is the jargon term for "picture element") forming an array of light and dark patterns that human eyes recognize as a picture. The resolution of these images is limited by pixel size.

Thus the skill in planetary cartography lies in being able to translate electromagnetic radiation bounced off a three-dimensional object and transmitted in digital code, then played out as a two-dimensional image into recognizable and meaningful visual representations on a piece of paper.

It's not an easy job.

Planetary maps come in several types. A planimetric map is a pictorial representation of a planet's round surface flattened into a plane. Controlled photomosaics and shaded relief maps are of this type. Topographic maps are usually made with data from altimeters and stereoscopic images, and they also contain more information about landforms. For example, these maps have contour lines indicating the shapes and elevations of landforms. Geologic

(continued on page 18)

orts for the Mind

by Charlene M. Anderson

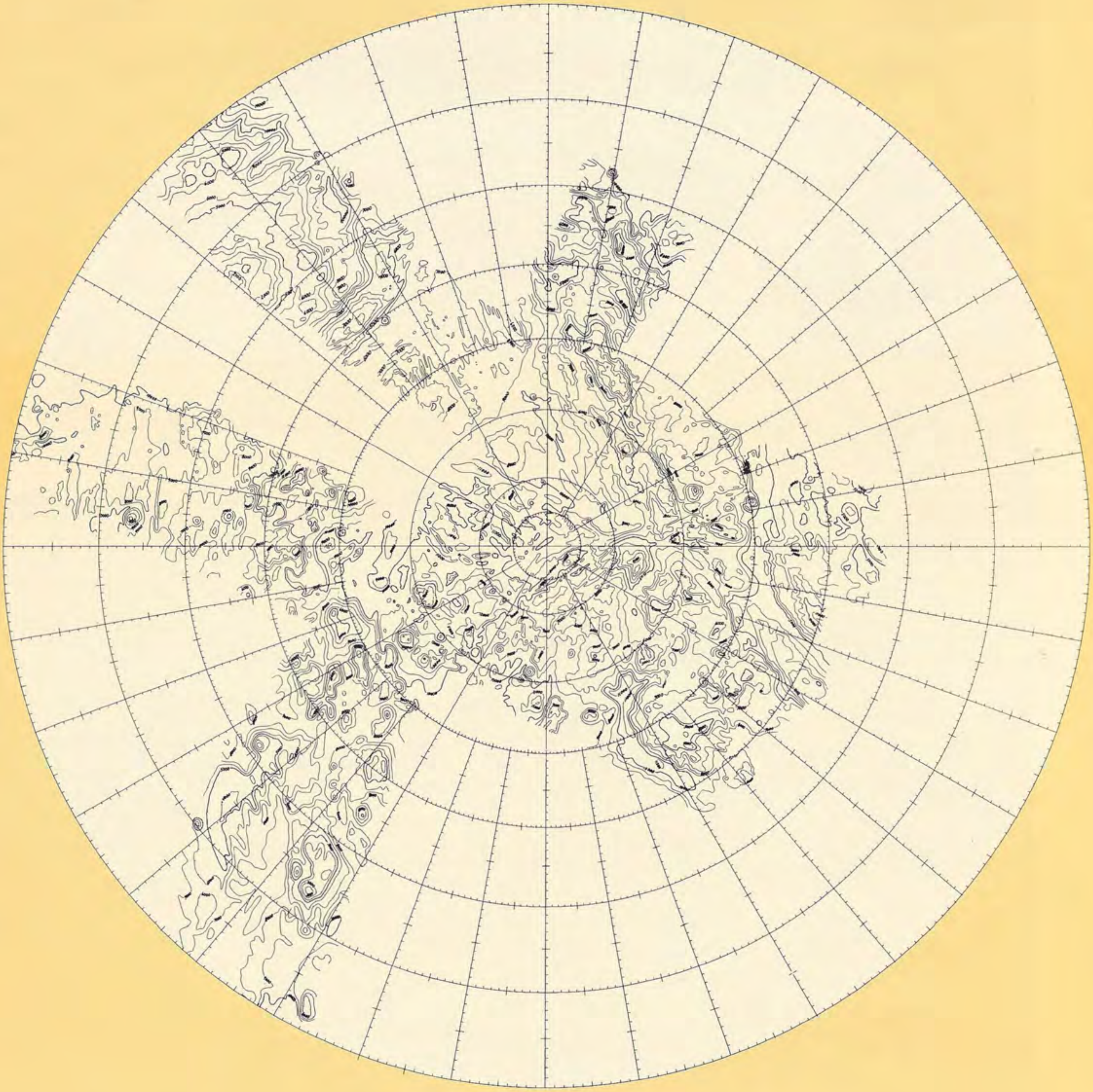
Planimetric Map

Controlled photomosaic of the Tharsis region of Mars. The great volcano Olympus Mons lies in the extreme west, with part of the Tharsis Montes volcano chain running from south to northeast.

Map: United States Geological Survey

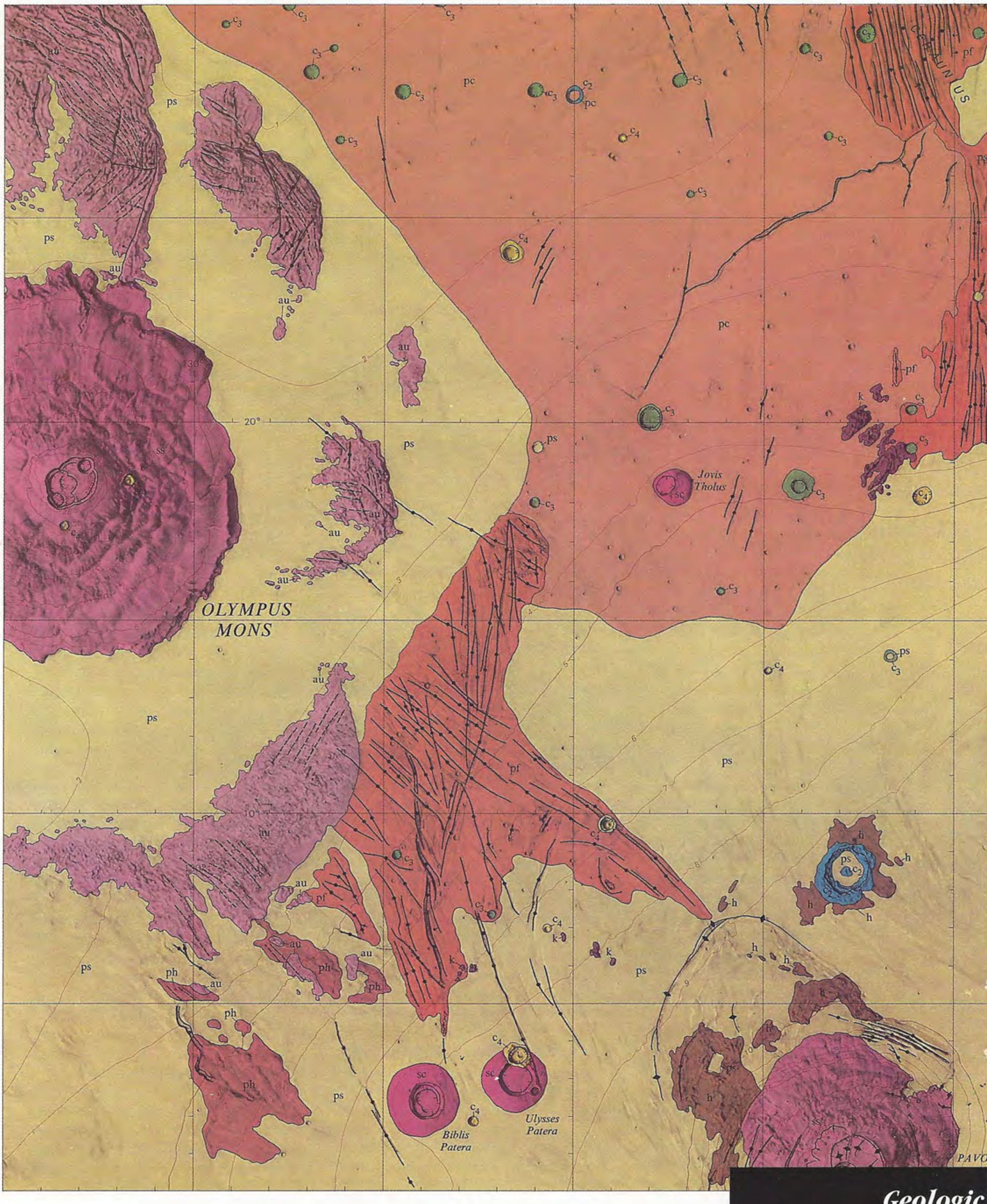
Airbrushed shaded relief map of the south polar regions of Uranus' moon Miranda. The famous chevron feature lies just to the northwest of the pole.

Map: United States Geological Survey



Topographic map of Miranda with contour lines showing elevations. Only limited stereo data, from which elevations can be determined, are available for Miranda, so this map covers only parts of the terrain seen on the opposite page.

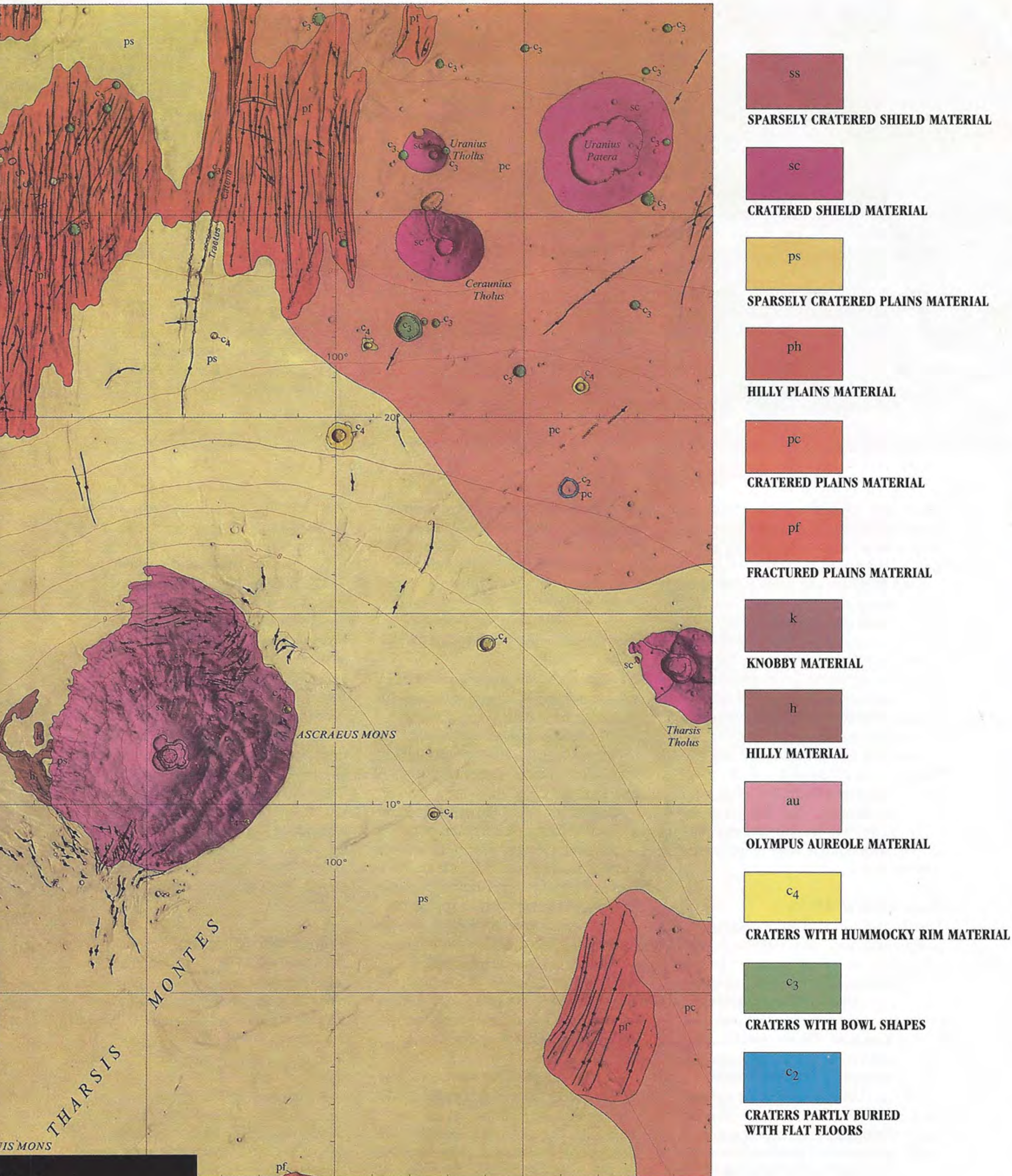
Map: Unpublished work by S. S. C. Wu, F. J. Schafer, Raymond Jordan and S. E. Howington, United States Geological Survey



Geologic

Geologic map of the Tharsis region of Mar
on pages 12 and 13. The different geolo

Map: United States Geo



Map

, covering the same area as the map gic units are identified by colors.

ogical Survey

What to Call the Crater?

By naming a thing we put a handle on it, to lift it more easily to mind or to communicate its image to the mind of another. Planetary mappers name surface features for similar reasons. Since the mid-1600s, when telescopes first revealed surface features on the Moon, earthly map-makers have been placing names on other worlds. Astronomers called features after their friends, revered predecessors and patrons who paid the bills. Maps by German astronomers would sport Teutonic names; those by British map-makers, Saxon and Norman names, and so on. Some names stuck, but with no accepted system to guide the process, the resulting maps became downright confusing.

In 1919 the newly founded International Astronomical Union (IAU) sought to bring order to this chaos. They appointed a committee that began the work of regularizing planetary naming. This process has evolved into a system of rules and conventions for names. For example, an intersecting valley complex would be called a *labyrinthus*; a low plain, a *planitia*; a small domed mountain, a *tholus*.

As advancing technology made it possible to discern ever more surface features, other IAU groups set down more guidelines for naming. For example, on Venus features would be named after goddesses and famous women. On Mars, most craters are named for scientists who studied the planet. The rules preclude naming features for living persons, political or military figures, or for personalities integral to any active religion.

When *Voyager* revealed the amazingly diverse surfaces of 56 outer solar system satellites, they multiplied the IAU's task. Each world was assigned a theme. For example, Miranda is named for the human heroine of Shakespeare's *The Tempest*, so craters are called after the play's human characters, while other features are named for place names in other Shakespearean plays.

The IAU sets out these rules based on 300 years of experience in planetary map-making. The system ensures that an international panel of experts names features in a fair and evenhanded way. As new worlds are discovered and explored, the system for placing handles on them will be firmly in place. —*CMA*

maps carry additional information about landforms, such as rock types, the processes that formed them, and their relative ages.

Each of these four types is commonly printed on paper, but maps may also be presented digitally. They may be stored as computerized banks of data accumulated about a planet's surface. Digital geophysical, geochemical and geological information can be manipulated to produce maps customized to a consumer's needs.

Someday hikers setting off across Mars will go out armed with detailed maps of unfamiliar terrain, as do wise terrestrial trekkers. The success of their explorations will be due, in large part, to the cartographers who prepared the way for them.

Planimetric Maps

The first step in making a planetary planimetric map is to combine images taken by a spacecraft's camera so they cover the area to be mapped. In early versions, this is done by hand, laying printed images down one by one, like tiles in a mosaic. These mosaics are now made in computers. Individual images are simply tied to each other, rather than being forced to fit a planet's coordinate system. With no consistent scale or projection, these maps are called uncontrolled photomosaics.

Since digital images returned by spacecraft are usually taken at different times, from different perspectives and distances, and with different lighting, these early photomosaics can be sloppy-looking landscapes. Sophisticated computer programs can take these factors into account, process the data, correct the discrepancies and produce a mosaic that looks more like we might expect a map to look. Surface features can then be aligned with a set of coordinates, producing a controlled photomosaic, or an image map.

The next step in creating a planetary map is taken by a craftsman. Specially trained airbrush artists, using a controlled photomosaic as a base, paint the surface landforms, adding shading and, sometimes, albedo features (patterns of light and dark).

Airbrushing gives the artist fine control over shading. A common problem for people looking at planetary images is that it's sometimes difficult to tell whether a feature is an elevation or a depression. Features often appear inverted. Some *Planetary Report* readers experienced this problem with the mosaic of the martian canyon Valles Marineris on the cover of our November/December 1988 issue. Many wrote that we were mistaken in our description of the canyon; they saw it as a mountain chain.

To alleviate this problem, terrestrial cartographers have traditionally shaded maps so that the lighting appears to come from the northwest, or upper left. Most people can then read the surface features correctly. Planetary map-makers have a slightly different tradition, which dates from the first lunar maps made with telescopes. In these, most of the Moon appears to be illuminated either from due west or due east. To unify the shading in planetary maps, it was decided to illuminate from due west rather than the traditional northwest.

The map on pages 12-13 is a controlled photomosaic of the Tharsis region of Mars. Extreme tectonic forces have shaped Tharsis, which bulges from the planet like a cornea from an eye. The evidence of these violent forces is readily apparent in this map: A string of caldera-topped volcanoes stretches from the southeast to the northwest. The mighty, 27-kilometer-(17-mile) high volcano, Olympus Mons, sits on the western edge. Great stresses in the planet's crust, generated as internal forces pushed the ground up, fractured large areas of the Tharsis Bulge. Along its northern edge, you can see the evidence of this tectonic activity.

Topographic Maps

Next to road maps, these maps are perhaps the most familiar to the non-geologist. Topographic maps give the elevations of landforms, usually expressed with contour lines, and so are particularly useful for "getting the lay of the land."

A geologist might approach a map with questions like: What is the height of this mountain? How deep is that basin? Which way did that river flow, and what was its volume? A space mission designer might ask: Can a robotic rover climb this slope? Will a spacecraft on this landing trajectory crash into a mountain? Answers might be inferred incorrectly from planimetric images, but the specific numbers of a topographic map lend credence to these answers.

For Earth, cartographers produce topographic maps using stereophotogrammetry, where two overlapping photographs taken from different locations can be used to create a three-dimensional optical model, on which elevations can be measured. A limited amount of stereo data is available for the Moon, Mars and Uranus' moon Miranda, with which *Voyager 2* had a very close encounter. For the other planets, map-makers must use information gotten from Earth-based radars and radar altimeters. Combining these widely differing data types can be a challenge.

Another question cartographers must answer before producing a topographic map is: From what point do we measure elevation? On Earth, the answer is simple: From sea level, for the water that shapes so much of Earth's surface flows downhill to the sea. Since, at the moment, we have seen no ocean on any other world, this standard does not apply elsewhere. Cartographers have had to improvise.

In theory we could calculate the shape of an "equipotential surface" based on global variations in a planet's gravity. In practice, however, the data are rarely available to do this accurately. For the Moon, this surface was calculated only after the mapping had been done. All published lunar maps are based on a sphere with a mean radius of almost exactly 1,738 kilometers (1,850 miles). For Mars, a mathematical model of an ellipsoid was fitted to atmospheric pressure measurements to approximate the equipotential surface. This "sea level" is defined as the elevation at which the atmospheric pressure is equal to the triple point of water (where it can exist simultaneously in gas, liquid or solid form, or 6.1 millibars). Venus is very nearly spherical in shape. For zero elevation on this planet, map-makers have chosen the surface of a sphere with a radius of 6,051.5 kilometers (3,760 miles).

The shaded relief and topographic maps of Miranda's southern hemisphere (pages 14-15) display one of the strangest planetary surfaces ever seen by humans and their robots. On this tiny moon, only 480 kilometers (300 miles) across, are geologic features seen nowhere else in the solar system. Parallel ridges ringed together form unique ovoid features. A distinctive chevron marks the southern polar region. Running off the top of this map is a fault valley that probably extends into the northern hemisphere. A cliff formed by this fault rises 20 kilometers (12 miles) high. *Voyager* project scientists have estimated that, in Miranda's low gravity, a human would take 10 minutes to fall from the cliff top to the valley floor below. (But despite the slow rate of fall, it would still hurt when she or he landed!)

Geologic Maps

These maps are compiled by geologists to help them understand the nature and history of a planet's surface. The mapmaker learns much about a planet as he or she portrays it in a map. Geologic maps contain information on geologic units (types of material, their stratigraphy, what units overlap others) and their placement through time.

Scientists can determine relative ages by examining how geologic features have affected each other. For example, if a fault runs through several different rock types, then it was formed after they were laid down. If an impact crater has been flooded by lava from a volcano, then the crater is the older feature.

The laborious process of crater-counting is a good way to measure age because, in general, heavily cratered surfaces are older than sparsely cratered ones. For example, the far side of the Moon is nearly saturated with craters, so that any new impact would destroy old craters while creating new ones. In contrast, the dark maria regions on the nearside, formed by basaltic lava flows, retain far fewer craters and therefore are much younger.

Various types of remote sensing data can aid the geologic map-maker. Information on the way a surface reflects light can indicate the type of rock it's made from or the surface texture. Radar can measure height and surface roughness, but care must be taken in interpreting these data, for what appears bright to the radar might not appear bright to the eye because the radar sees deeper into the surface than does the eye.

Geologic maps are keyed to different types of units, usually distinguished by different colors. Rock units refer to the types of formations. Time-rock maps give the eras in which rock units were laid down. Time units identify rocks deposited during a certain period.

This geologic map of the Tharsis region of Mars (pages 16-17) shows the same region covered by the controlled photomosaic on pages 12-13. Plains, volcanoes, impact craters and fracture zones are all colored differently and are easy to distinguish from one another. Much of Mars' geologic story can be unraveled by making and using such maps.

Digital Maps

This type of map has only been possible since the advent of remote sensing and digital computers. The robotic instruments of our spacecraft can see far more than the human eye. We see only a very narrow slice of the electromagnetic spectrum. Spacecraft commonly collect data from the ultraviolet on one side of the visible range to infrared and radio on the other. Even an imaging system, designed to produce pictures for the human eye, can return more information than the eye, a television screen or even film can discriminate.

All this information can be held in a computer's memory and manipulated in ways to suit a customer's needs. One researcher might be interested in surface reflectivity, another in relative elevations. Digital map processing can enhance contrasts between surface features, making it easier for a researcher to see boundaries between geologic units. Another scientist might focus on crustal structures, and so ask the computer to exaggerate elevations to produce a more dramatic view of the surface.

The information present on other types of maps can be combined in digital maps, summing up what is known about a planetary surface. These are powerful tools for understanding the natures and histories of other worlds, and as we ponder our future explorations of the planets, these maps will be crucial to our plans.

The amount of information that can be displayed on a planetary map can be bewildering, even to a trained geologist. The armchair traveler would be in danger of being overwhelmed. When planning flights of fancy, it might be more comfortable to use the familiar. A simple image map will suffice for most of us. But someday, road maps of other worlds may be available at local fueling stations. It's a prospect Don Quixote would find irresistible.

Charlene M. Anderson is Director of Publications for The Planetary Society.

Readers who would like more information on this topic can read *Planetary Mapping*, edited by Ronald Greeley and Raymond M. Batson and published by Cambridge University Press.

Magellan at Venus: The Mapping Begins

The radar-mapping spacecraft *Magellan* is now carrying out its mission to study Venus' surface, picking out details only 10 percent as big as those seen by any previous investigation. The first few weeks of the mission have been a bit rocky, with the spacecraft occasionally breaking and reestablishing contact with Earth. The cause of the intermittent interruptions may never be understood, but the problem-solving protocols and redundancies built into the spacecraft were designed for eventualities such as this, and the mission goes on.

Magellan was launched from the space shuttle *Atlantis* on May 4, 1989 and entered orbit about Venus on August 10, 1990. After a few weeks of checking out systems, the spacecraft began to map the planet on September 15. *Magellan* uses radar to pierce the thick shroud of clouds that hide the surface from instruments and eyes that work in visible light. Signals beamed at microwave frequencies pass through the clouds, bounce off the surface and are caught by the spacecraft's antenna. From the characteristics of the reflected signal, radar investigators can determine surface elevations and texture to create pictures of the planet.

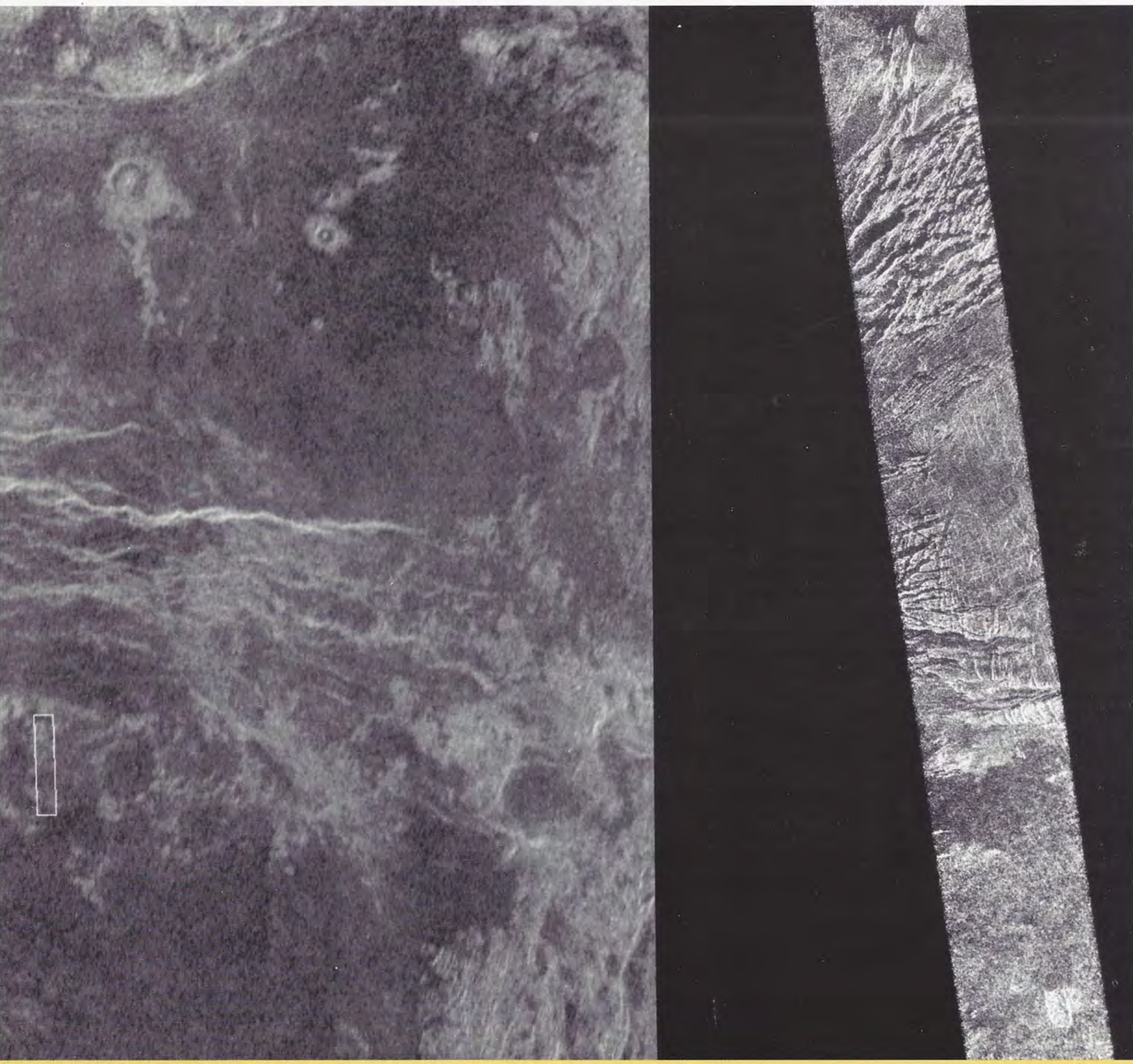
The art of interpreting radar images is very different from reading those formed by visible light. For example, features that appear bright in radar might actually appear dark in visible wavelengths. If you were flying in an aircraft over the landscapes portrayed on these pages, the surface below might look very different to you than it does to *Magellan*'s radar. The brightness in a radar image is determined by surface roughness and electrical properties, and the angle between the radar and the surface.

Magellan's radar will uncover no "smoking gun" as *Voyager 1*'s cameras did with Io's volcanoes and *Voyager 2*'s did with Triton's geysers. The act of discovery using these radar images will be a subtler process. For example, an active volcano might be revealed by fresh lava flows or fallout deposits, not by an eruptive plume. The geologic history of Venus will be unraveled by careful analysis and deduction. And there are many questions to be answered. For example:

—How old is Venus' surface?
—What geologic processes have shaped it?
—How is the greenhouse effect controlled and how long has it heated Venus' atmosphere to the broiling temperature of 480 degrees Celsius (900 degrees Fahrenheit)?
—Did liquid water ever flow on Venus?

These questions may not be answered immediately, but we will keep you informed of *Magellan*'s progress. The images on these pages are just the first installment in what will be continuing *Planetary Report* coverage of the mission. Stay tuned.—*Charlene M. Anderson*

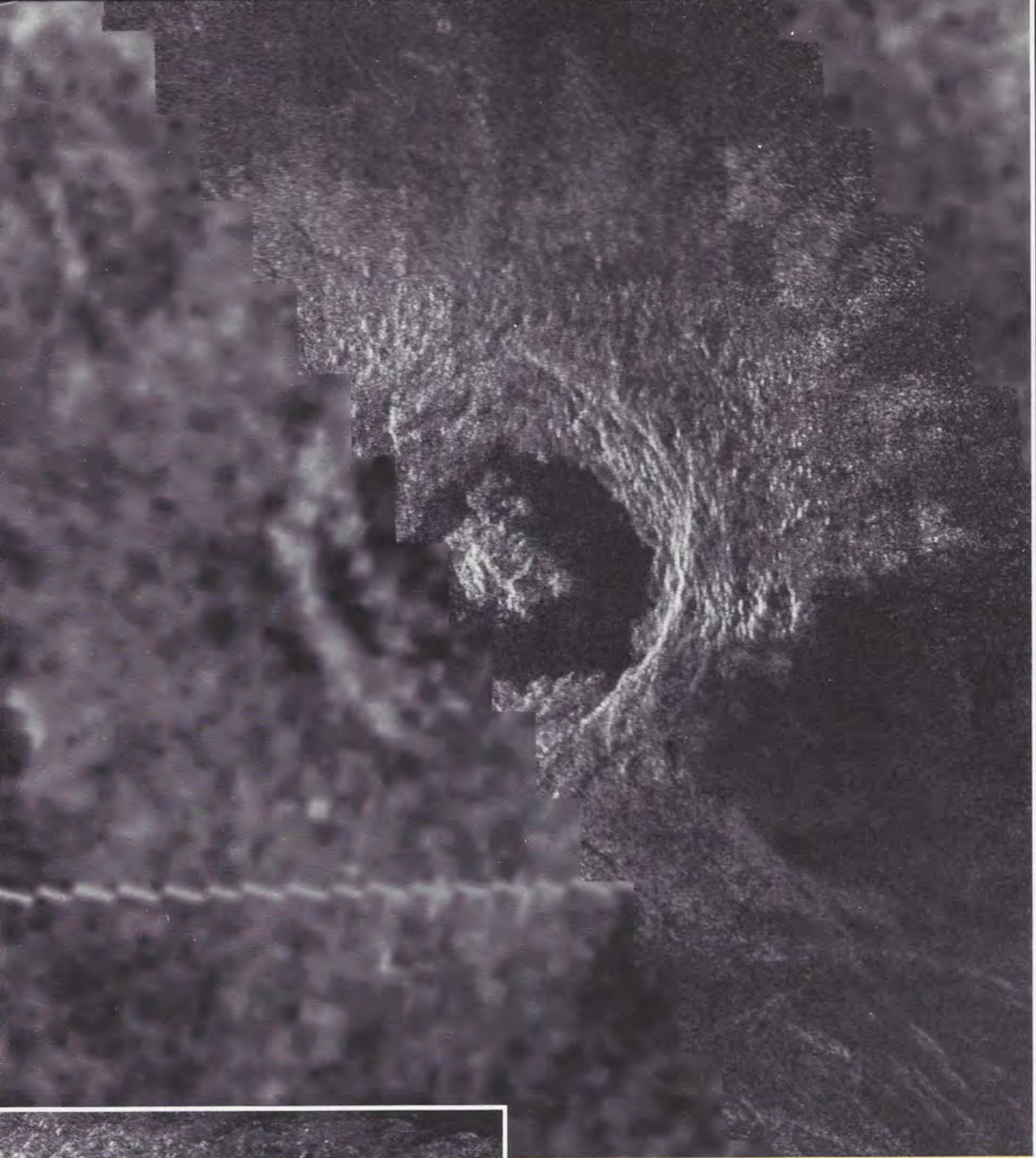
Editor's Note: The *Magellan* mission is particularly close to Planetary Society hearts because one of our members named it. In 1983 NASA's Office for Earth and Planetary Exploration invited our members to suggest names for what was then called the Venus Radar Mapper. We held a contest and submitted the entries to the space agency. Two years later, the slowly grinding wheels of bureaucracy produced a winner: *Magellan*, suggested by Nicholas Cognito of Braddock, Pennsylvania.

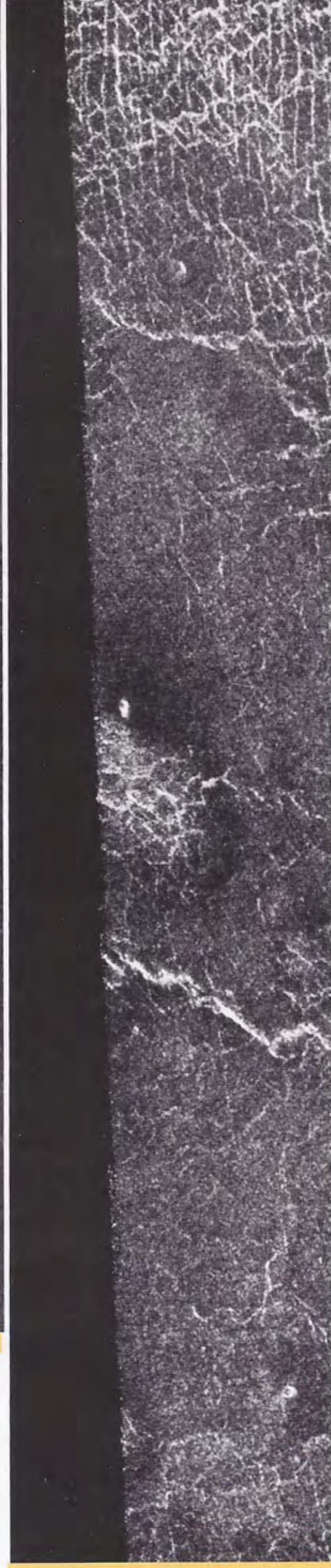


Just how much better are *Magellan* images than previous radar pictures? Compare this piece of the *Magellan* noodle (right) with an image (left) of the volcanic uplands of Beta Regio obtained by the Arecibo Observatory in Puerto Rico. *(Magellan* radar data are displayed in long, narrow strips, hence the term "noodle.") The white outlined area in the Arecibo image, which shows details down to one to three kilometers (0.6 to 1.8 miles) across, covers the same area as the *Magellan* image, which has a resolution of 120 meters (400 feet). This section of the noodle covers an area 20 kilometers (12.4 miles) wide and 150 kilometers (90 miles) long.

A distinctive deformed crust called tessera (from the Latin word for "tile") fills the middle and upper portions of this image. The tessera resembles the Basin and Range region of the western United States. Probable lava flows appear at the top, appearing as a dark, smooth patch about 10 kilometers (6 miles) across. Similar dark features lie within the intersecting tessera valleys, indicating that the lava flows are the younger geologic features.

Arecibo Image: National Astronomy and Ionosphere Center, Cornell University; *Magellan* image: JPL/NASA

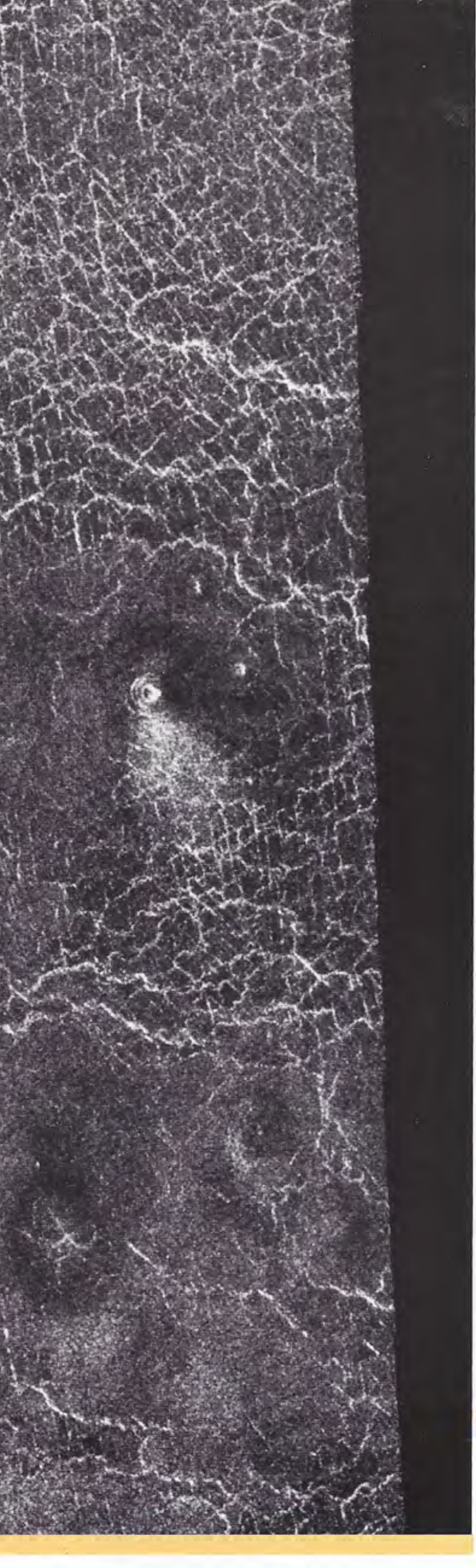




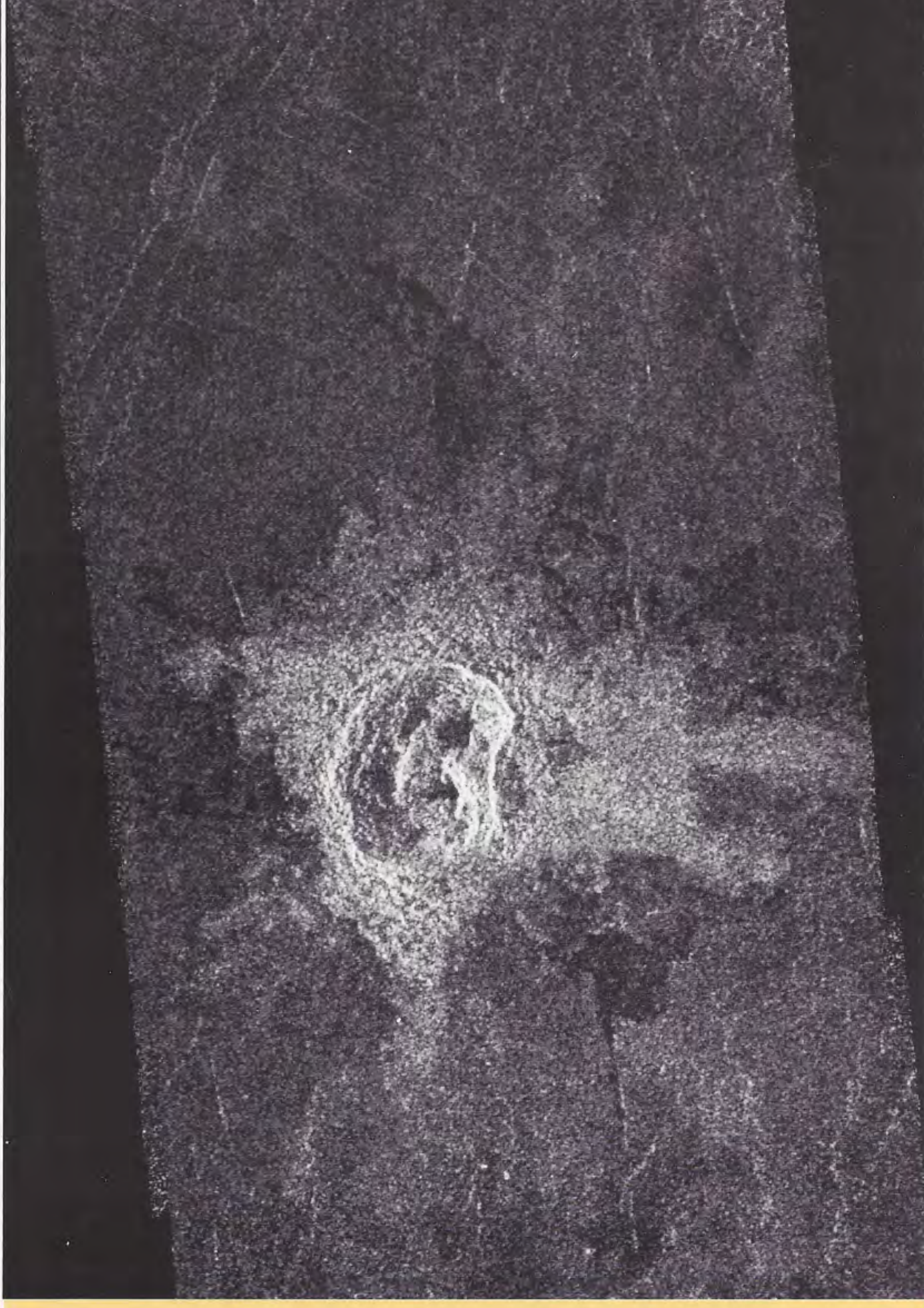
The impact crater Golubkina (above), 34 kilometers (20 miles) in diameter, was covered early in *Magellan*'s mission. Here it is mosaicked with an image of the same feature taken by the Soviet *Venera 15/16* mission. The *Venera* image shows details down to 1 to 2 kilometers (about 1 mile); the *Magellan* data have a resolution of 120 meters (400 feet).

The *Magellan* image reveals the tell-tale central peak of an impact crater, its inner terraced walls and its extremely smooth floor, probably due to pooling of melted rock. The sharpness of these features suggests this crater is relatively uneroded and therefore young.

The inset (left) shows the *Magellan* data projected into a three-dimensional representation of brightness variations. This emphasizes the central peak and the terraced walls. The peak forms as the surface rebounds after the impact. The terraces appear in the late stages of crater formation when the central cavity, formed by the impact, collapses. Images: JPL/NASA



Evidence of explosive volcanic eruptions appears in this *Magellan* image. A radar-bright deposit, about 10 kilometers (6 miles) long, spreads from the crater in the middle, overlying the fractured surrounding plains. The deposit appears to be thicker closer to the crater. Such features on Earth are formed by the fallout from volcanic explosions. The craters to the west show similar deposits. Image: JPL/NASA



This strange, kidney-shaped impact crater, 9 by 12 kilometers (6 by 7 miles) across, lies in the Nauka Region in Venus' southern hemisphere. The sharpness of its features indicates that it has been freshly formed. The light area around it is the ejecta blanket formed of material blasted from the crater by the impact. The blanket's asymmetric shape suggests that the impactor struck at an oblique angle, moving from west to east. The crater's most distinctive feature is its kidney shape. A suggested explanation is that the impactor broke up as it passed through Venus' thick atmosphere, with large hunks striking the ground almost simultaneously. Image: JPL/NASA

World Watch

by Louis D. Friedman

WASHINGTON, DC—NASA's status, and with it, plans for the United States' space exploration during the next 20 years were deeply clouded by some troubling incidents over the past few months. The failure to launch shuttles delayed missions and led to cost increases. The Hubble Space Telescope failure degraded confidence in the agency's ability to manage large projects. Then, NASA discovered a potential space station stumbling block: Over one person-year of extravehicular time per calendar year may be needed just to maintain the station.

Another likely wet blanket over the space station is its dependency on a reliable shuttle launch schedule—something that the program has never had. In addition, administration and congressional budget-cutters, faced with a huge federal deficit, the Mideast crisis and increased costs for projects waiting for launch, had to scale back proposed increases for NASA.

The result was that the 1991 budget passed by Congress shows zero funding for development of a human space exploration initiative leading to Mars, the Moon or anywhere else, and a potential major restructuring of the US space station.

Congress approved the total NASA appropriation for fiscal year 1991 at $13.8 billion, an 11 percent increase from 1990—but $1.2 billion less than the administration's proposal. The space station underwent a major program change. It received 80 percent of the funds requested, but Congress directed NASA to restructure its space station plan.

Instead of developing the space station *Freedom* to house a permanent crew from the outset, the House and Senate Appropriations Conference Committee recommended a three-phase approach: First, build an operational, crew-tended microgravity processing laboratory; second, develop habitats for extended duration life-support; third and finally, arrive at a "permanently manned capability." The committee said each phase should be independent of the others—a complete change from the present program, which integrates all of the requirements into a single design. NASA was given three months to respond to the committee with a revised plan.

The conference committee's action was the final committee step for the NASA appropriations bill before it passed both houses and was signed by the President.

In other action, the Comet Rendezvous Asteroid Flyby (CRAF)/*Cassini* mission received nearly full funding: $47 million out of a requested $50 million. NASA's Search for Extraterrestrial Intelligence (SETI), as we reported in last month's issue, was attacked on the floor of the House of Representatives. However, the final Appropriations Conference Committee action protected the NASA SETI budget at the full amount of $12 million.

A proposed *Lunar Observer* program and augmentation to the *Mars Observer* program were stricken from NASA's request as part of the decision to fund nothing associated with the Space Exploration Initiative.

The House authorization bill passed this year and included language directing NASA to conduct workshop studies of near-Earth asteroids. The Science, Space and Technology Committee noted the importance of studying near-Earth asteroids because of the probability that they could collide with Earth. The committee asked NASA to define a program for increased observation and detection of such objects, leading to missions and possible diversion strategies.

The Planetary Society and NASA's Office of Solar System Exploration are jointly sponsoring and organizing a Conference on near-Earth Asteroids in San Juan Capistrano, California, June 28-July 1, 1991.

WASHINGTON, DC—NASA officials are keeping busy attending lots of meetings in Washington. Two committees have been formed to help NASA look into the future: one to synthesize proposals for human exploration of the Moon and Mars, and one to overview NASA's program and plans.

The synthesis committee, under the chairmanship of *Apollo-Soyuz* veteran Thomas Stafford, is reviewing hundreds of technical ideas submitted in an "outreach" program initiated after dissatisfaction was expressed with NASA's response to President Bush's Moon-Mars Initiative.

The second committee, chaired by Martin Marietta Aerospace President Norman Augustine, addressed NASA's ability to carry out programs following the grounding of the shuttle fleet and the Hubble failure.

With NASA's future plans in disarray and the shuttle problem so apparent, The Planetary Society organized a workshop to examine alternatives for enhancing the space station to better meet US goals in space. Among the alternatives are building a heavy-lift launch vehicle, respecifying the space station's requirements, and greater cooperation with the USSR. A transcript of the summary session of this workshop can be had by sending a check or money order for $5.00 to: The Planetary Society Space Station Workshop, 65 N. Catalina Avenue, Pasadena, CA 91106.

NOORDWIJK, THE NETHERLANDS—Four years after *Giotto* flew past Halley's Comet in 1986, the spacecraft was successfully reactivated and checked out. Although the TV camera is no longer functional (after all, it flew through streams of gas and dust only 483 kilometers [300 miles] from Halley's nucleus), most of its instrumentation will be available for a July 1992 encounter with comet Grigg-Skjellerup.

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

Hungary:
An Able Partner in Exploration

by Karoly Szegó

Space research in Hungary started in 1967 when the Intercosmos agreement was signed between the Soviet Union and several East European countries. Today Hungarian activities extend to many fields of space research, though in this brief article only space physics is discussed.

Hungary's work in this field started with analysis and interpretation of data from deep-space missions such as *Mars 4* and *5*, *Helios* and *Pioneer Venus* as well as many Earth-orbiting Intercosmos satellites. Hungary also contributed to the engineering of spacecraft, building small-scale devices for the *Prognoz*-type satellites. The first microprocessor-controlled experiment within Intercosmos was a Hungarian one aboard *Prognoz 7* in 1978, measuring plasma (hot, electrically charged gases) in Earth's ionosphere. Over time the main objectives of Hungary's space efforts have taken shape as follows:

Science

- to investigate interplanetary plasma and magnetospheres
- to image bodies of the solar system

Engineering

- to build onboard computers
- to develop expertise in certain types of sensors (for example, the CCD, or charge-coupled device)

The two major centers of space instrumentation are the Central Research Institute for Physics (part of the Hungarian Academy of Sciences) and the Technical University, both in Budapest.

Probably the most conspicuous success in the history of Hungarian space physics was our participation in the Soviet *Vega* mission, which explored comet Halley and transmitted back to Earth the first-ever image of a cometary nucleus. The TV system that made the image was the product of Hungarian, Soviet and French cooperation. Hungary was responsible for all of its electronics and integration.

More than just a camera in its capabilities, this imaging system autonomously identified and tracked the nucleus of the comet. In addition, Hungary participated in three plasma-measuring experiments aboard *Vega*, and the central data acquisition system of the spacecraft was also a Hungarian product. If you add it all up, one-third of the payload electronics of that mission was made in Hungary.

Hungary's next stage in solar system exploration was our participation in the Soviet *Phobos* mission, the target of which was Mars and its moon Phobos. The Central Research Institute for Physics helped build the spacecraft's charged-particle measuring devices and took part in a solar-oscillation experiment. The onboard computer of the long-term automated lander was a Hungarian product. Though the *Phobos* mission succeeded in exploring the martian magnetosphere, the spacecraft was lost before it could dispatch its lander to the moon Phobos, and so our computer never had a real test.

However, many other space missions will use computers of that family. The onboard computer of a *Spectr* astrophysical spacecraft to be launched in 1993 is one example. The image-processing system in the remote-sensing unit of the *Mir* orbiting station, and the onboard computers of the *Regatta* probes, which will explore Earth's magnetosphere, also derive from that family.

Currently our main emphasis is on Mars exploration. On the Soviet *Mars '94* mission, the Central Research Institute for Physics is participating in two charged-particle detectors and in the imaging experiment. The Central Research Institute for Physics will also provide the central data processing unit for the balloon experiment, which will be one of the highlights of that mission (for more on the Mars Balloon, see the article by Harris Schurmeier in the September/October 1990 *Planetary Report*). Looking further ahead, Hungary is also involved in activities related to a future Mars rover.

Bertalan Farkas was the first Hungarian cosmonaut to fly aboard **Salyut 6.**
Photo: Courtesty of Bertalan Farkas

Hungary's space projects have always been based on broad international cooperation. In parallel with our excellent cooperation with the USSR's Institute for Space Research, and with many outstanding scientists from East European countries, we have also worked productively with US scientists from the University of Michigan and the University of Arizona, who participated in our experiments on the *Vega* and *Phobos* missions, and with Austrian, French and German co-investigators. Recently, we have begun formal negotiations with NASA and with the European Space Agency to foster cooperation in forthcoming space programs.

Hungary has not set a goal of becoming a major space power. But space activities, proportional to our capabilities and means, may reward Hungarian science with successes out of proportion. And we are working hard for it.

Karoly Szegó of the Central Research Institute for Physics has been a principal experimenter on several Soviet space missions, including the Vega *mission to Halley's Comet.*

News & Reviews

by Clark R. Chapman

At a recent press conference in Salt Lake City, Utah, the Hansen Planetarium announced a new show about potential cosmic catastrophes in our world's future. The lectern was set next to a wooden dinosaur. Though the show will deal with supernovas, runaway greenhouse effects and other cosmic phenomena, the museum staff wanted to highlight the dinosaur wipe-out to whet the media's appetite for the show.

A consulting paleontologist urged that the dinosaur be removed, and so it was. (Like many dinosaur experts, he doubts that the reptiles were done in by an impact.) But, moments later, the creature was back: The media had been promised a dinosaur to tickle the public's fancy. The paleontologist shook his head in resignation.

I have written more than once about asteroids and craters for magazines, later to find dino-art inserted to spice up my words. Perhaps the same thing happened to William Glen, whose excellent review of the Cretaceous-Tertiary (K-T) extinctions (in the July/August 1990 issue of *American Scientist*) was printed under the title, "What Killed the Dinosaurs?" Few sentences in his 17-page article mention the reptiles. *Scientific American*'s October, 1990 cover asks: "What Killed the Dinosaurs—a Meteor or a Volcanic Eruption?" Inside are two articles, juxtaposed as a debate, by Walter Alvarez and Frank Asaro (impact advocates) and Vincent Courtillot (who champions explosive volcanism in India). Neither article says much about dinosaurs.

Inevitable Impacts

I expect that many dinosaur species *did* go extinct 65 million years ago because of ecological havoc wrought by an asteroid. Yet the reptilian evidence *is* cloudy and is legitimately disputed. It may always be difficult to pinpoint the precise layer(s) or the exact time(s) when the dinosaurs disappeared, given the sizes of their bones relative to the inch-thick boundary layer.

The K-T mass extinction 65 million years ago is defined by the instantaneous demise of many species of small marine life, such as algae and plankton. Evidently, many land species disappeared at exactly the same time. Shells, spores and other fossils often cease to be found right at the beginning of the iridium-rich layer that is attributed to impact-dust fallout. The association is sometimes exact within the measurement error of 100 years! Surely these extinctions are related to the clay layer, which is rich in iridium and other elements that are rare in Earth's crust but plentiful in asteroids and comets. A decade of research since the late Luis Alvarez first proposed the idea has verified it in countless ways.

Several impacts approaching the equivalent of a billion megatons of TNT must have happened during the last few billion years. And K-T-like impacts (only a hundred million megatons) happened every 100 million years or so, and will happen again. How do we know this? The cratered surfaces of the Moon and geologically stable parts of Earth (in Canada, Australia and southern Africa) tell us so. And when we search the skies with Schmidt telescopes, we find sufficient Earth-approaching objects to make impacts inevitable.

More uncertain is the response of life to the darkened skies, global fire storms, nitric-acid rains, poisoned oceans and other radical consequences.

Hundred-Million-Megaton Volcano?

The volcanic alternative, given equal space in *Scientific American* and more appropriately modest coverage in *American Scientist*, is a feeble competitor. We need not seek Earthly causes for mass extinctions, given the inevitable cosmic impacts. Of course, ongoing terrestrial processes, like explosive volcanism, do affect climate and the evolution of life. The hundred-times-larger cousins of Mount St. Helens and Krakatoa, preserved in the geological record, *could* have been the major agent for the dinosaurs' demise, even if the impact killed off most other species at about the same time.

But rocks lack the strength to contain a buildup of pressures high enough to allow a hundred-million-megaton volcanic explosion to happen all at once. They would explode long before, with catastrophic local consequences and perhaps global effects. Volcanoes simply cannot approach the magnitude of the larger asteroid impacts. Vincent Courtillot argues that the Deccan eruptions in India 64 to 68 million years ago formed the greatest volcanic episode on Earth in the last 100 million years. But his estimated outpouring of a few cubic kilometers of basalt per year is little more than the annual lava outpourings near mid-ocean ridges today. Why should explosive volcanoes in India be much more powerful than the other volcanic explosions that have had modest global effects?

We still aren't certain what killed the dinosaurs. It remains questionable if the K-T crater has been found. We're just beginning to appreciate the role of impacts in pre-K-T mass extinctions. And there remains much to learn about the environmental and biological consequences of impacts. But we now know what caused most K-T extinctions: an impact. Those who argue that it didn't happen or had little to do with the extinctions, join holdouts against the theory of plate tectonics and the tobacco company doctors who still deny that cigarettes cause lung cancer. I am amazed that *Scientific American* gave equal space to such an inadequate alternative to Alvarez' cosmic scenario.

Clark R. Chapman will chair a 1991 international conference on near-Earth asteroids, to be co-sponsored by NASA, The Planetary Society and other organizations.

SOCIETY Notes

DESERT BALLOON TEST SUCCESS

This fall, The Society organized an intensive, one-week test of the French-designed Mars Balloon and Society-designed SNAKE guide-rope in California's Mojave Desert. Flying over lava flows, sand dunes and boulder fields that simulated terrains they might encounter during the Soviet *Mars '94* mission, the balloon and the SNAKE performed beautifully. French and Soviet space officials participated in the tests, during which the balloon and the guide-rope added several miles of snag-free flight to their records.

Society volunteers, student teams from Utah State University and the California Institute of Technology, and volunteers from the Jet Propulsion Laboratory braved the formidable desert sun to be on hand for the extensive test program.

WASHINGTON HEARS FROM OUR MEMBERS

This has been a tough year for space exploration. But we are proud to report that Planetary Society members have kept busy throughout 1990 pushing forward the cause of space exploration.

Our call in June for letters to Congress in favor of human space exploration programs resulted in nearly every member of Congress being contacted many times.

Similarly, every member of Congress heard from the Society's Officers about the threatened Comet Rendezvous Asteroid Flyby (CRAF)/*Cassini* project. Fortunately, the campaign helped on the floor of Congress (see World Watch, page 24).

It is a sad, yet indisputable fact that, even with our Society's numbers and activism, the purpose behind the NASA programs we support is still inadequately understood by Congress. Thus, we have much more work to do.

Toward that end, the Society will sponsor a symposium on the rationale for human space exploration during the annual meeting of the American Association for the Advancement of Science, to be held February 14 to 19, 1991 at the Washington, DC Sheraton Hotel.

SWITCH-ON DAY COMES FOR SOCIETY'S SETI

On October 12—Columbus Day—under sunny southern skies, Planetary Society Executive Director Louis D. Friedman launched Earth's first continuous global radio search for extraterrestrial intelligence.

At 14:09 Greenwich Mean Time, Dr. Friedman hit the "return" button of the powerful Megachannel Extraterrestrial Assay II (META II) supercomputer at the Argentine Institute of Radio Astronomy near Buenos Aires. Minutes earlier, the Institute's 26-meter (85-foot) antenna had been pointed by Institute Director Raul Colomb at 63 degrees southern declination in the constellation of the Southern Cross. And so the search began. The computer operated the 8.4-million-channel receiver perfectly, to the delight of Argentine engineers Juan Carlos Olalde and Eduardo Hurrel, who built the system at Harvard University.

Approximately 150 people, including Society members from the US and Australia, attended the dedication. The ceremonies took place at the antenna site in Pereyra Iraola Park, some 40 kilometers (25 miles) south of Buenos Aires.

This META II receiver joins our META I, operating at the Oak Ridge Observatory in Harvard, Massachusetts. With our observing posts in both hemispheres, humanity is now searching the entire sky for radio signals from possible extraterrestrial civilizations.

The Planetary Society's whole-sky observing program is the most advanced SETI program on Earth that is continually in operation. This situation seems unlikely to change soon.

We think it is fitting that META II will have its anniversary on a day that commemorates the discovery of a new world, nearly 500 years ago.

H. DUDLEY WRIGHT CONTEST COORDINATORS VISIT SOCIETY

Our Pasadena headquarters received surprise visits on the same day from two of our coordinators for the H. Dudley Wright International Student Contest, "Together to Mars."

First, Sergio Huanaco, contest coordinator for western Mexico, gave us an update on his impressive progress with the contest in Guadalajara. Dropping in later that day was Ronald Chang-Díaz of the Asociación Costarricense de Investigación y Difusión Espacial (ACIDE, the Costa Rican Association for the Investigation and Diffusion of Space), which is administering the contest in Costa Rica. (Ronald happens to be the younger brother of NASA astronaut Franklin Chang-Díaz.)

During a recent visit to Japan, Barbara Bruning-La Belle, our contest coordinator on staff, met with Jun Nishimura, Director-General of Japan's Institute of Space and Astronautical Science (ISAS). Dr. Nishimura, a Society Advisor, was accompanied by Yasunori Matogawa, who is coordinating the "Together to Mars" competition in Japan. The contest will be featured on a new science program being developed by the Tokyo Broadcasting System.

KEEP IN TOUCH

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Questions & Answers

Why can't we reuse known and proven technology and revive the* Saturn V *booster rocket to provide heavy-lift capabilities for the United States?
—Peter M. Dayton, Stuart, Florida

This question has been asked repeatedly ever since *Saturn V* production was stopped at the end of the *Apollo* program. But first we need to answer the more fundamental question: "Does the United States need a launch vehicle in *Saturn V*'s class?"

My answer is a guarded, "Yes." It's guarded because today the US does not have a program, either approved or under serious consideration, that cannot be carried out, from a technical standpoint, without that capability. On the other hand, if the US had retained the *Saturn V* into the early 1980s when it began the studies that led to the space station *Freedom,* it would clearly have been incorporated into the studies. That would have greatly simplified the design, operation and management of the program compared to the situation that exists today.

I believe that a launcher in this class is very close to being a technical requirement for an effective Space Exploration Initiative [to first visit the Moon and then Mars, as proposed by President Bush]. There is certainly an economic requirement for it. I am also certain that other US programs would make use of a vehicle of this size if it existed.

There are many other questions that should be addressed as we consider the need for a launch vehicle of this class: Do we need a backup to the shuttle to transport human beings? How long can we go without a replacement for the shuttle? When *Freedom* is in operation, will there still be a requirement for a combined cargo/crew launch vehicle? What size return-from-orbit vehicle will be needed? If these questions were simple we would already have the answers. But these answers will influence the answer about the need for, as well as the possible design of, a heavy-lift launch vehicle.

I would also argue that US launch requirements for civil, military, intelligence and commercial uses deserve a more integrated analysis than exists today, and that if and when such an analysis is done, a coherent set of decisions on new launch vehicle requirements can be made.

It would be nice to have the answer

To build a robust space station, to send human crews to Mars or simply to expand its capabilities in space, the United States must have a heavy-lift launch vehicle. The Soviet Union already has such a launcher: The *Energia* is capable of lifting 100,000 kilograms (220,000 pounds) into orbit. The United States once shared this capability: The *Saturn Vs* that sent humans to the Moon could loft 150,000 kilograms (331,000 pounds). With the cancellation of the *Apollo* program, NASA had no immediate need for such a powerful rocket, the assembly line was dismantled, and the remaining pieces of *Saturn Vs* were scattered around the country.
Photograph: NASA

to the requirement question agreed upon before responding to your question, but I may not live that long, so I'm going to assume that there is a consensus that the US needs a launch vehicle capable of placing payloads between about 70,000 and 113,000 kilograms (150,000 and 250,000 pounds) into low Earth orbit several times a year for a number of years.

The *Saturn V* was indeed a remarkable vehicle. With the exception of a premature second-stage shutdown during its second developmental flight, its flight record was 100 percent successful. But when the decision was made that *Apollo 17* would be the last of the program, there was no need for continuing its production. One of the *Saturn V*s that remained was successfully used for the *Skylab* program. Today there are enough *Saturn V* stages scattered around the country that it would be possible to assemble two or three complete vehicles. But the extent of rework that would be required, the cost of producing replacement parts, tooling, checkout and launch capability, would make the cost of these two or three unreasonably high. Even if that were not the case, the flight test program that would be required would use up all the vehicles that were possible to assemble.

The electronic systems in the *Saturn V* ran on technology that is no longer used and components that are no longer manufactured. It would be virtually impossible now to produce those components with the same assurance of quality that was possible in the 1960s. This is not meant to impugn today's industry or the people who make it run, but the craftsmen who made those components have retired or developed other skills and have been doing other things for the past 25 years. I feel, therefore, that while the Saturn *V*s produced today might look like those that were so successful during *Apollo*'s time, the similarity would not go far beneath the skin.

There are, however, two lessons we should learn from the *Saturn V*. The first would come from its propulsion systems. Compared with the shuttle's main engines, those used in the *Saturn V* were very conservatively designed. Their performance was lower, but their allowable tolerances were wider and their fabrication and checkout simpler. The *Saturn V* also had a considerably less complex propulsion system than is required by the overall configuration of the shuttle.

A strong argument can be made that serious consideration should be given in the design of a heavy-lift launch vehicle to a return to a *Saturn* design philosophy: the use of a more conservative propulsion system, albeit at the expense of some performance, at least in the first stage. This philosophy is very close to that which is being followed in the Advanced Launch System program being jointly managed by NASA and the US Air Force. That program is also examining the possibility of a stable of launchers using common modular components similar in some respects to the relationships between the *Saturns 1, 1B* and *V*.

The second lesson is that, in the design and fabrication of a multistage launch vehicle, the performance penalty of conservative design in the first stage is relatively low. But this is more than made up for by substantial payoffs that come through the use of larger design margins, less demanding hardware and fabrication, more accessible installation of components, easier inspection, and a range of other considerations. All of these would lead to reductions in cost and improvements in quality, reliability and ease of maintenance.

This is a long answer, but it is not a simple question. The short answer is that I don't believe it would be beneficial or even possible to return to the *Saturn V* vehicle or technology. But I strongly believe that there are many aspects of the philosophy behind the design and fabrication of the *Saturn V* that could be very beneficially applied to a new heavy-lift launch vehicle—if and when such a need is warranted.

—PHILIP CULBERTSON

Mr. Culbertson spent 23 years at NASA, serving in positions including Associate Administrator for the Space Station, Associate Deputy Administrator and General Manager prior to his retirement in 1988.

If you have a question you'd like answered, send it to: *The Planetary Report*, Q&A, 65 N. Catalina Avenue, Pasadena, CA 91106. Please remember to keep the questions short and limit their subjects to planetary exploration and the search for extraterrestrial life.

FACTINOS

Three different studies conducted by Pennsylania State University researchers confirm that exposure to microgravity during spaceflight reduces the release of growth hormone by nearly half. Scientists at the school believe this could be a factor in the loss of muscle mass, bone strength and lowered immune responses seen in rats and astronauts exposed to relatively short periods of microgravity. The three experiments used pituitary gland tissue taken from three different sets of rats. The rats flew on *Spacelab 3* in 1985 and on two Soviet *Cosmos Biosatellite* missions in 1987 and 1989.

Wesley Hymer, director of Penn State's Center for Cell Research said, that "If the two phenomena are linked conclusively, it would be bad news for astronauts on long-term missions where the hormone deficiency could become more acute."

—from *Space News*

The *Magellan* spacecraft will need to make 1,786 trips around Venus to map the entire planet; and 1.9 billion bits of radar data are collected on each orbit.

—from the Jet Propulsion Laboratory

Data collected from a series of 14 flights over Earth's North Pole by instrument-laden aircraft have confirmed what many people had feared: that the ozone layer over the Arctic is indeed thinning. In early September, the scientists doing the study reported in *Nature* that ozone depletion ranged from 12 to 35 percent within the north polar region, and they suggested that peoples' use of chloroflourocarbons has caused the loss. The measurements were made in January and February, 1989, from a converted U-2 spy plane operated by NASA.

Michael Proffitt of the University of Colorado, principal author of the study, said, "The Arctic is not likely to ever see the precipitous decline in ozone found in the Antarctic because of differences in weather patterns. What we have found is certainly not an ozone hole in the sense of what we found in the Antarctic."

Still, it is cause for concern among experts who fear that depletion of the ozone layer could increase the danger on the ground from solar radiation.

—from the *Los Angeles Times*

The Solar System in Pictures and Books

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441	BETA	(30 Min. Videotape)	
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538	***Magellan* Space Craft Science Kit** — paper model **1 lb.**	$ 14.00
542	***Voyager* Medallion 1 lb.**	$ 20.00
543	**Mission Stamps** — 10 sets (4 stamps per set) **1 lb.**	$ 1.00
544	**Note Cards** — Set of 16 cards features 4 views from space **1 lb.**	$ 15.00
545	***The Planetary Report* Binder** — blue with gold lettering (2 for $18.00) **2 lb.**	$ 10.00
560	***Voyager* Space Craft Science Kit** — paper model **1 lb.**	$ 14.00
580	**The Planetary Society Mug 2 lb.** (each) midnight blue with black/gold (set of 3)	$ 8.00 / $ 21.00
670	**The Planetary Society Cloisonne Pin** — gold lettering on black background **1 lb.**	$ 4.00
675	**Glitter Pencils** — different colors (10 for $4.00) **1 lb.**	$ 0.50
676	**Key Ring** — The Planetary Society logo **1 lb.**	$ 5.00

Pamphlet Series

ORDER NUMBER	Pamphlet Series	PRICE (IN US DOLLARS)
701	**Planets and Politics:** Reflections on the Presidential Moon-Mars Initiative by Carl Sagan, 32 pages **1 lb.**	$ 3.00
702	**Mission to Planet Earth** by John L. McLucas, 32 pages **1 lb.**	$ 3.00

Membership

ORDER NUMBER	Membership		PRICE (IN US DOLLARS)
003	**Membership**	U.S.	$ 25.00
		Canadian	$ 25.00
		All other countries	$ 35.00
004	**Gift Membership**	U.S.	$ 25.00
		Canadian	$ 25.00
		All other countries	$ 35.00

All merchandise is subject to availability

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- It takes us from 5-7 business days in our busy season to get your order in the mail.
- Items ordered together are not necessarily shipped together.
- We prefer to use UPS service in the U.S.
  - Please give us your street address and apt. number
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  - California residents add 6.25% sales tax
  - Los Angeles residents add a 6.75% sales tax
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  - ***Surface***—average transit is 6 to 10 weeks
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Bangladesh	France	Mexico	Switzerland
Barbados	Grand Cayman	Netherlands	Taiwan
Belgium	Greece	New Zealand	Thailand
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Member prices are discounted. Any profit made from the sales department is used to support Society programs and projects.

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NAME							
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Many scientists believe that the last of the great dinosaurs were wiped out when a comet or asteroid smashed into Earth 65 million years ago. The immense cloud of debris thrown up by the impact may have lingered in the atmosphere, blocking out the life-giving Sun and cooling Earth. Here a lonely Triceratops trudges over the bleak and dying landscape, with nowhere to go but to a dark, icy death. The small mammal (foreground) is the evolutionary aperture to us.

Don Davis is an astronomical artist whose work has appeared in a wide variety of space magazines, books, television shows and NASA projects. This painting was originally commissioned for the book, Comet, by Carl Sagan and Ann Druyan.

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