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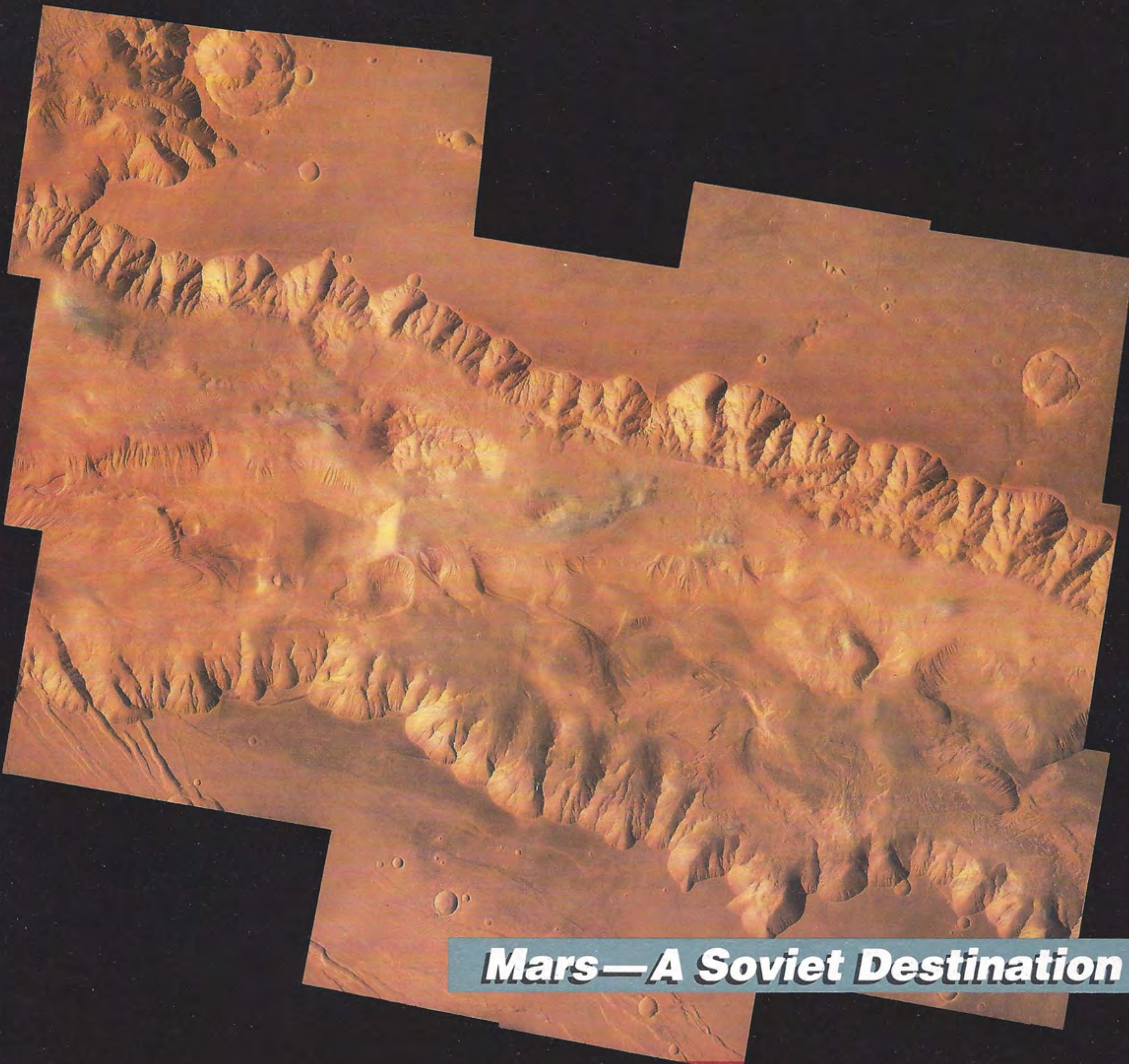

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COVER: Valles Marineris, the Red Planet's "Grand Canyon," stretches one-fifth of the way around Mars. Within its walls lie records of the planet's geologic past. This computer-constructed mosaic of* Viking *images shows a portion of Candor Chasma, a small section of the larger canyon complex. In the region shown, the canyon is about 9 kilometers deep and 100 kilometers wide. Its floor is covered with landslide debris and layered deposits, perhaps the remains of an ancient lake.

Image: Lisa Bertolini and Alfred McEwen, US Geological Survey

FROM THE EDITOR

In 1988 the two major spacefaring nations reached turning points in their programs to explore the planets. The United States returned to Earth orbit with the launch of the space shuttle *Discovery*, and the Soviet Union began intensive investigation of Mars and its moons with the launch of the *Phobos* mission.

Lately in the US, the goal has been simply to get back into space. Despite the loss of the *Phobos 1* spacecraft, the USSR's program has moved steadily toward the goal of Mars. The Soviets have committed to the thorough exploration of the Red Planet with a series of increasingly ambitious missions, culminating in a human landing sometime in the next century. Some in the USSR feel that the way to Mars involves a stop at the Moon to test new systems and to continue the exploration begun by the *Apollo* astronauts. In this issue of *The Planetary Report*, in articles written by scientists deeply involved in charting the USSR's future in space, we will examine in depth Soviet plans.

Page 3—Members' Dialogue—The goal of the US space program has once again dominated the letters we've received from Planetary Society members in the past two months. As you'll see in the articles we've reprinted from the Soviet Union, citizens there are voicing the same concerns. In this column we print some of our members' views plus a short essay by Society President Carl Sagan on what the space goal of both the US and the USSR should be.

Page 4—The Way to Mars—A letter to the Soviet newspaper *Pravda* about plans to send humans to Mars inspired a flurry of responses, much like the flood of mail we've received on the same issue. In a *Planetary Report* exclusive, we reprint the original letter, portions of responses from Soviet citizens, and an article by three leading Soviet space scientists in which they detail plans for a human mission to Mars.

Page 9—A Soviet View of a Lunar Base—As in the United States, in the Soviet Union there is a debate over whether or not humans should return to the Moon. In this article, a leading Soviet lunar scientist discusses what our neighboring world still has to teach us and what a human future there might be like.

Page 13—Oceans on Venus?—One of the hottest topics in planetary science today is whether or not Earth's sister world, Venus, ever held large quantities of water. Although flyby missions, probes, landers, radar orbiters and balloons have investigated Venus, we still do not have enough data to answer the question definitively. So the debate goes on. Here we present views of the problem by two scientists leading the opposing teams. The question of oceans on Venus will engage researchers until spacecraft continue the exploration of our next-door neighbor, resuming with the launch of *Magellan* next year.

Page 20—News & Reviews—Even as Halley's Comet recedes from the inner solar system, scientists continue to pore over the data gathered when it passed through two years ago. Our intrepid reviewer takes a look at two recent summaries of Halley results and then takes us to a microsymposium in Moscow.

Page 21—World Watch—The mission of the space shuttle *Discovery*, the loss of *Phobos 1* and the continuing saga of NASA's budget capture our attention in this issue.

Page 23—Society Notes—Our members and staff have been very busy lately, and here we report on some of their activities.

Page 24—Q & A—What questions about planetary exploration have piqued the curiosity of our members lately? In this column, we tackle questions on capturing satellites, the orbit of the martian moon Phobos and *Voyager 1*'s upcoming meeting with the heliopause. We also follow up on a question from earlier this year on NASA's once-planned Grand Tour of the solar system.

In this issue of *The Planetary Report* we take you on a journey from the Soviet Union to Venus to the edge of the solar system. We hope that you enjoy the ride.
—*Charlene M. Anderson*

Members' Dialogue

As leaders 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 The Planetary Society. We encourage members to write us and create a dialogue with us on topics relating to the planetary program, such as the space station, the lunar base and the exploration of Mars.

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

The Planetary Society is encouraging vigorous scientific exploration of Mars. While I strongly support this, the other side of the coin is equally important and challenging. That is, as we enter the age of intensive exploration of the solar system, specifically exploring, working on and possibly inhabiting Mars, it is also necessary that we vigorously encourage a change in society's "modes of thinking." Pollution, discrimination, nuclear war, third world hunger, etc. here on Earth are all manifestations of wrong "modes of thinking."

Clearly this was Einstein's concern when society entered the atomic age and he said, "The unleashed power of the atom has changed everything save our modes of thinking and we thus drift toward unparalleled catastrophes."
ABEBA ADMASSU, *Addis Ababa, Ethiopia*

To the Moon or Mars? This issue seems to be very divisive amongst Planetary Society members. The fact that this is even an issue makes me question my own membership in the Society. I am a graduate student studying planetary geology. I mostly study *Viking* Mars data. But to me, there is no question of "Moon or Mars?" There is just the answer, "Yes." The Planetary Society is a group of people interested in the exploration of planetary bodies. Our membership should try to unite and to figure out how humans can explore the Moon and Mars *simultaneously.* Both projects by themselves would be very costly. But to bring the projects together in clever ways would be much less expensive.

We know that in the next century there *will* be people living and working on the Moon and Mars—simultaneously. Who will those people be? Soviets, Japanese and Europeans. I'd like to think that The Planetary Society could play a big role in ensuring that there are also North Americans living and working on both planets!
KEN EDGETT, *Tempe, Arizona*

I am surprised to see The Planetary Society, whose birth and growth I have happily followed, become so committed to the exploration of Mars as the single, overriding national space goal. When the Society was created, it called for a balanced approach to the exploration of our solar system, as opposed to NASA that then and now pursues megaprojects (space shuttle, space station) that end up swallowing the budgets for smaller but very important projects.

We desperately need to bring some balance back to the debate over the future of our national space program. The Planetary Society should be a key player in the debate. We need a steady commitment to a civil space program that includes a broad array of projects. Science is and will remain one of the primary "customers" of the space program, but it will suffer if the mania for big projects continues to drain the limited resources that this country commits to civil space projects. In the current budget climate, a human mission to Mars is a bad idea for the same reason that the space station is a mistake, and sadly the leaders of The Planetary Society appear to be pushing the human Mars mission for the same reason that NASA pushes the space station: self-interest, not the national interest.
PETER E. CUNNIFFE, *Hermosa Beach, California*

We thought Society members would like to know more about Carl Sagan's views on why we should go to Mars, so Members' Dialogue continues on page 20 with an article by Dr. Sagan entitled "Mars: Back to the Frontier."

NEWS BRIEFS

After the *Challenger* disaster the International Astronomical Union (IAU) received many proposals to name the 10 recently discovered moons of Uranus after the seven *Challenger* astronauts and the three astronauts of *Apollo 1*. The IAU decided, however, to stick with tradition and bestowed Shakespearean names (with one nod to Alexander Pope) upon the new satellites. Their names are Bianca, Cordelia, Cressida, Desdemona, Juliet, Ophelia, Portia, Puck, Rosalind and Belinda.
—from John Noble Wilford in *The New York Times*

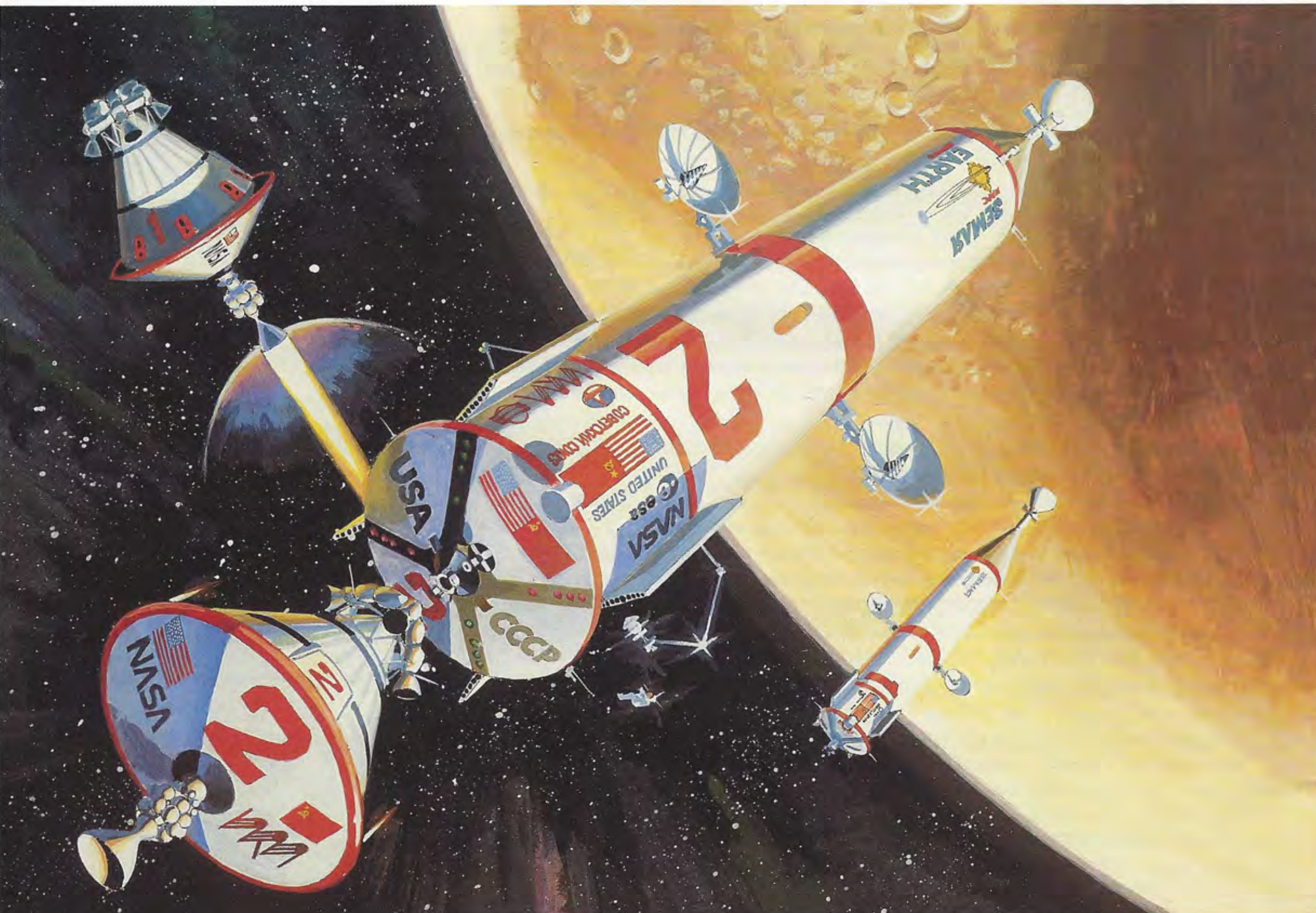
Space agencies from 20 nations are mobilizing a fleet of new spacecraft for an international Mission-to-Earth project.

According to Jerry Soffen, project scientist for NASA's Earth Observing System platform, the project could also show how international efforts like a human flight to Mars could be organized. "It can be a stepping-stone to a manned Mars project," Soffen said. "If we're going to form an international Mars mission we must start on common ground, and Mission to Earth provides that common ground."
—from Craig Covault in *Aviation Week and Space Technology*

Scientists and engineers will add the National Radio Astronomy Observatory's Very Large Array of telescopes to the Jet Propulsion Laboratory's Deep Space Network to boost *Voyager 2*'s signals from Neptune in 1989. By joining forces, the two systems will more than double our ability to hear *Voyager 2*'s signal.
—from a Jet Propulsion Laboratory news release

The Way to Mars

by V. Glushko, Y. Semenov and L. Gorshkov



In this conception of an ambitious international mission to Mars, the artist imagines what the interplanetary spacecraft and landing craft might look like.

Painting: Alexander Zakharov, courtesy of Soviet Life

With ever-increasing openness Soviet space officials have been discussing the possible human exploration of Mars with representatives of other space agencies, with the media, and with politicians representing other spacefaring nations. At The Planetary Society's Spacebridge in July 1987 (see the September/October 1987 Planetary Report*), Soviet scientists and engineers stated that the purpose of their long-duration flights in the* Salyut *and* Mir *space stations was to prepare for a piloted mission to Mars. A description of Soviet planning for human Mars missions was presented by Cosmonaut Vladimir Solovyov at an American Institute of Aeronautics and Astronautics meeting in February 1988. General Secretary Mikhail Gorbachev brought up the notion of a joint American-Soviet Mars mission during his December 1987 visit to the United States and in his interview with the* Washington Post *and* Newsweek *before the May 1988 summit meeting in Moscow.*

On May 24, 1988, a week before that summit, an article appeared in Pravda *detailing "The Way to Mars," co-authored by Soviet space pioneers V. Glushko, Y. Semenov and L. Gorshkov.*

The following article is based on the one in Pravda, *which has been translated into English by Andrey Sergeyevsky, an interplanetary mission specialist at the Jet Propulsion Laboratory, and interpreted by Louis Friedman, Executive Director of The Planetary Society. Dr. Friedman has supplemented it with information from an internal Glavkosmos (the Soviet space agency) report presented by Dr. Gorshkov at a meeting held in Moscow at the time of the* Phobos *launches to Mars. Accompanying this article we print an extraordinary letter published in* Pravda *on February 10, 1988 (page 6) suggesting that before the Soviet Union embarks on the human exploration of Mars, it ought to consider its social problems at home—and have a national referendum on the project. —C. M. A.*

Introduction from Pravda:

The short letter of Professor F. Volkov, "Should We Fly to Mars?", published in *Pravda* on February 10, 1988, has brought a stormy reaction. Responses came in tens from Moscow, Odessa, Voronyezh, Sverdlovsk, Minsk, Tbilisi, Kherson, Ryazan and the faraway Krasnoyarski region. The responses alternate for and against. "It is naive to require successful solutions to our problems on Earth today and only then start to Mars and other planets," writes S. Schardeka, a scientific worker of the Institute of Thermophysics of the Urals Department of the Academy of Sciences of the USSR. "It is an illusion, since the solution of one set of problems generates others more complicated and more threatening. The solution to global problems demands that humanity master space power. It would be unreasonable to delay to an undetermined future the procession toward this potency."

The citizens of Earth, people of many terrestrial professions, are excited. What about specialists, the leaders of space science—what are their opinions, or are they indifferent? Do they view the project as a utopia for our age? It turns out that the answer is no. The attached article speaks of that, that the leading space scientists are seriously concerned with the specifics of this project. Wasn't it F. Tsander, that smart co-worker of the young S. Korolyov,* who seriously exclaimed, starting his work each day in the small basement of GIRD [a study group on jet propulsion in the early 1930s], "Forward to Mars!"? And one more important comment of the letter of S. Schardeka: "The problem is apparently not in the clarification of how many 'for' and how many 'against' votes there are for this or another space program, but in a wider and freer access for the scientific and technical public to the results of space research and technology. The solution is in the democratization of the historically inevitable process of space expansion."

In an interview with the publishers of the newspaper *Washington Post* and the magazine *Newsweek*, Gorbachev has said, "I will offer to President Reagan cooperation in the organization of a joint flight to Mars. That would be worthy of the American and the Soviet people."

**F. Tsander, a Soviet spaceflight pioneer of the early 1930s, wrote on trajectory dynamics and designed early liquid propellant rocket engines. He died in 1933. Academician Sergey Korolyov started to work in rocket design in the 1930s and eventually became Chief Designer of large ballistic rockets and the* Vostok/Voskhod *spacecraft. He died in 1966. Tsander and Korolyov in the USSR could be compared to Hermann Oberth or Robert Goddard and Wernher von Braun in the West.*

A translation of the Pravda *article (with comments by Drs. Sergeyevsky and Friedman in brackets) follows:*

From ancient times interest in Mars was tied to the dream of finding intelligent life on another planet. Today we do not expect to find it in our solar system. However, Mars still attracts humanity's attention because of our natural desire to explore our neighboring world—almost completely unknown, yet most probably dissimilar. We can count on making new discoveries and learning more about Mars by studying its fascinating natural features. Many of these discoveries will directly relate to understanding our own planet.

Sometimes one hears the question "Is it necessary to fly to Mars?" Some assume that because we have many urgent problems on Earth the flight of humans to Mars can wait. If we had always thought that way, there wouldn't have been a *Sputnik* or the flight of Yuri Gagarin. There wouldn't have been any flight of cosmonauts because at its beginning no one assumed that spaceflight would have immediate benefits. Now we know that it did. But still, is it necessary to organize a flight to Mars now? Maybe it would be better to delay it until we have solved all our immediate problems. But we must admit that pressing problems will always exist and that such an approach will only stop development of science and technology.

What kind of technical abilities do we now possess? What kind of spaceship can take human beings from one world to another? One possibility is an interplanetary spacecraft consisting of three parts: the propulsion system, the crew quarters with life-support systems and equipment for navigation and control, and the landing vehicle in which the crew will descend to Mars and return to the interplanetary spacecraft.

The spacecraft will be assembled in near-Earth orbit, built from separate vehicles launched from Earth, perhaps on the rocket *Energia*. After checking out all systems, the expedition will set out for Mars. The crew will consist of four to six people, perhaps with representatives from different countries.

The interplanetary vehicle will be launched from low-Earth orbit into a heliocentric orbit (about the Sun) that intersects the orbit of Mars. The trip will take several months. [Note: One-way trip times from Earth to Mars can vary from 7 to 11 months, depending on the flight paths selected and the relative positions of the planets at time of launch.] At the point where the interplanetary trajectory intersects Mars' path, the spacecraft will enter orbit about the planet.

Landing the entire interplanetary vehicle on Mars would be a complicated undertaking demanding huge amounts of propellant; therefore, only a small vehicle lands with all or part of the crew. After exploring the surface, the crew must launch from the planet to the interplanetary vehicle in Mars orbit. It then will return to Earth on a path similar to its Earth-to-Mars trajectory. One option is to fly inward toward Venus on a long trajectory. [Note: This results in a longer trip time, but because the craft does not have to wait for the proper alignment of Earth and Mars, the total flight time may be reduced.] In this case the expedition lasts about one and one-half years instead of two and one-half to three years, but the fuel requirements are greatly increased. This means that the mass and size of the interplanetary craft and the associated problems of its construction will be much greater. [Note: This tradeoff of total flight time and fuel is the dominant consideration in Mars missions with human crews.] To increase safety the flight to Mars may be conducted simultaneously by two interplanetary vehicles. The crews of each ship, in that case, should be able to come to the help of their comrades in the other.

SHOULD WE FLY TO MARS?
(letter to *Pravda*)

I would like to argue with those who are suggesting that we begin to prepare for a flight to Mars using funds that would be saved from a reduction of nuclear arms.

Of course a flight to Mars is a most interesting and very complicated problem. Of course that flight would give us new knowledge about the world and the solutions to many scientific and technical problems. Of course that would be prestigious, and the names of the conquerors of Mars would enter history together with the names of Columbus and Gagarin.

But aren't we posing this problem too early? Aren't we getting ahead of ourselves? We have many more pressing problems waiting for resolution, and funds should be invested for the time being not in a flight to Mars, but in projects that will make Earthlings live better.

This and a fight with cancer and cardiovascular illness that will carry away millions of human lives.

This and the creation of new forms of domestic plants and animals that would solve the problem of hunger and would improve the quality of nutrition for millions of people.

This and also the global solution of housing problems and the insurance of ecological balance and many other things that can be done for people but for which there are no funds yet available.

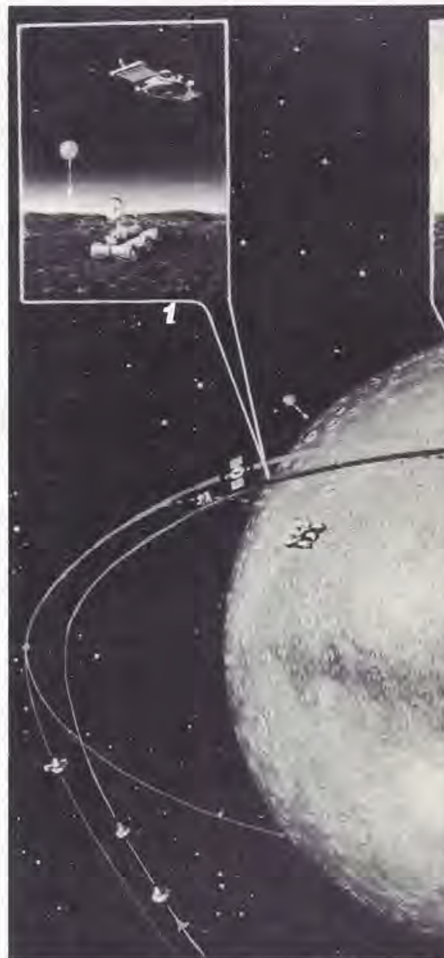
I think that in selecting the final project it would be good to conduct a referendum involving all people and to let them decide for themselves what is better now—to fly to Mars or to solve immediate problems on Earth. —*F. Volkov*

One of the main questions is the selection of the propulsion system to accelerate the interplanetary ship from Earth orbit to Mars, then into Mars orbit, and then back to Earth. For these purposes one could use the already well-developed liquid-rocket propulsion systems that use chemical energy for fuel—for example, hydrogen and oxygen. Such systems are the most effective today and are used on the new *Energia* rocket. The use of chemical propulsion for flights to Mars is not a serious design problem. However, when we consider that the necessary energy for the expedition is quite large and that the piloted vehicle has a much larger mass than previous robotic vehicles, we find that the requirements for propellant will be enormous.

Assembling the vehicle in Earth orbit will be complex. The initial mass of the ship will be more than 2,500 metric tons (5.5 million pounds). It is natural to seek more effective energy sources, such as nuclear power, for the flight. In this case, nuclear reactors provide heat, which then heats a gas, forcing it to flow out of rocket nozzles and create the necessary thrust. Two to three times less propellant (the gas that flows out of the nozzles) is required than for liquid-propellant chemical rockets. The initial mass of a nuclear-powered vehicle may be about 800 tons (1.75 million pounds).

Even more effective would be a nuclear-electric reactor where the reactor's energy is directly transformed into electrical energy. The propellant is accelerated by means of an electric field to create the necessary thrust. The amount of propellant needed in this case is even less than that required for the nuclear heat source. The initial mass for the mission is only about 450 tons (990,000 pounds). [Note: This still would require 5 *Energia* launches or, equivalently, 20 shuttle launches. The liquid-propellant craft requires 25 *Energia* launches.]

[Recently V. Rodin of the Institute for Space Research in Moscow noted that solar-electric propulsion might be a better choice than nuclear electric because of the massive shielding requirements of nuclear electric. Soviet and American citizens are also making some efforts to ban nuclear energy for space power and propulsion for both arms control and environmental reasons.]



Soviet plans for Mars exploration involve several preliminary steps: (1) A balloon and rover will investigate the surface; (2) a special module will land to collect soil samples; (3) the module will carry the samples back to Mars orbit and dock with the return craft; and (4) the interplanetary craft will return to Earth orbit and deliver the sample to a space station.
Painting: Alexander Zakharov, courtesy of Soviet Life

Let's look at the particulars of the other parts of the interplanetary ship. Living quarters are its central part. [Note: This implicitly assumes that weightlessness or zero-gravity flight is acceptable and that a large spinning craft that creates artificial gravity is not required. This seems to be a currently favored position in the Soviet program—especially by Dr. Gorshkov, with whom Dr. Friedman discussed this problem.] It is a hermetically sealed module or several modules with cabins for the crew and frames for the apparatus. The crew must be supplied with oxygen, water, food and means of removing waste. Today the development of such systems already meets the requirements of interplanetary flight.

In the living quarters block, equipment for communication with Earth will be located. The vehicle must be capable of autonomous navigation and steering. [The crew must be able to fly it without help from ground control.]

Comfortable temperatures in the living quarters are maintained by a thermal regulation system similar to

those on orbital stations. Electric energy may come from either a nuclear reactor or from solar batteries. To lower the danger from penetrating cosmic ray or solar radiation, the equipment and various systems are located around the hermetic walls of the living block. To protect the crew from solar flares, a special shelter is required. During Earth-orbital flights crews have been protected from such flares by our planet's powerful magnetic field. But during interplanetary flight such protection is lacking, so additional measures are necessary. The crew need not permanently reside in the shelter, but each crew member must spend enough time in the shelter—including sleep—that the aggregate doses of radiation remain at safe levels.

Another important safety question is protection from meteorites. During spaceflight, including near-Earth orbit, encounters with meteorites are likely. The most effective protection is a special screen surrounding the hermetic walls of the living block. During a meteorite encounter the screen is penetrated, but only a jet into which the particle has converted itself reaches the walls of the living quarters. This is the way the walls of *Salyut* and *Mir* are designed. The probability of encounter with a meteorite with enough mass to penetrate both the screen and the hermetic walls is exceedingly small. But even in this case, the living quarters may be designed as separate sections so that the crew may be able to fix the outside wall if it loses hermetization. [If one section is penetrated, the others will be sealed off. Crew members can abandon damaged sections and stay alive.]

The next part of the interplanetary spacecraft is the landing vehicle. It must have an aerodynamic shape since it will travel through the martian atmosphere to land. At its surface Mars' atmosphere is less than one percent as dense as Earth's. Therefore, one uses liquid rocket propulsion to slow the vehicle for landing. Inside this vehicle is an ascent rocket that will return the crew to the interplanetary vehicle.

There are several options for the return flight to Earth. The ship may use braking rockets to enter Earth orbit. This will require additional propellants. As an alternative, it can use Earth's atmosphere to slow its speed. [Note: This technique is often called aerobraking.] In this case, the interplanetary spacecraft must have a special cabin into which the crew will transfer before arriving at Earth. That cabin will separate from the spacecraft and will independently enter the denser layers of Earth's atmosphere. Final descent will be performed with parachutes.

In choosing a scheme for return, one should also consider problems of protecting Earth from dangerous martian lifeforms, the possibility of which we cannot entirely exclude. After return to Earth the crew and all objects that have been in contact with Mars must be carefully investigated. A lengthy quarantine will be required. If the crew returns to Earth orbit [rather than directly to Earth] the quarantine may be conducted in the orbital station. The advantage of this scheme is that it provides natural isolation from Earth. Its negative aspect is that it limits possibilities for medical and biological investigation. The quarantine after direct landing on Earth may

Soviet Mission Planners Offer Three-Phase Proposal

At meetings held in July 1988, Glavkosmos official L. Gorshkov, co-author of the accompanying article, discussed Soviet planning for Mars exploration. He outlined a three-phase program:

1. Robotic precursor flights in the 1990s, including the *Mars 94* mission that will carry rovers, balloons and penetrators.
2. Development of human flight systems, including automated Mars sample return missions, during the first decade of the 21st century.
3. A piloted mission with a target date of perhaps 2010.

This three-phase program has been proposed by a team working on the *Energia* rocket (see the September/October 1988 *Planetary Report*). The first phase would redefine the *Mars 94* mission to carry a much larger orbiter and rover than now planned. A principal task would be to select sites for future missions.

In the second phase they propose several rover and sample return missions using the vehicle developed for human missions in an automatic mode. It would be a dress rehearsal for the human mission, but without the crew. In this phase they would also test nuclear-electric propulsion.

be conducted in a special isolated device that the crew enters after it is installed in a hangar. More complete medical and biological investigations can be performed in terrestrial quarantine stations than in orbital stations.

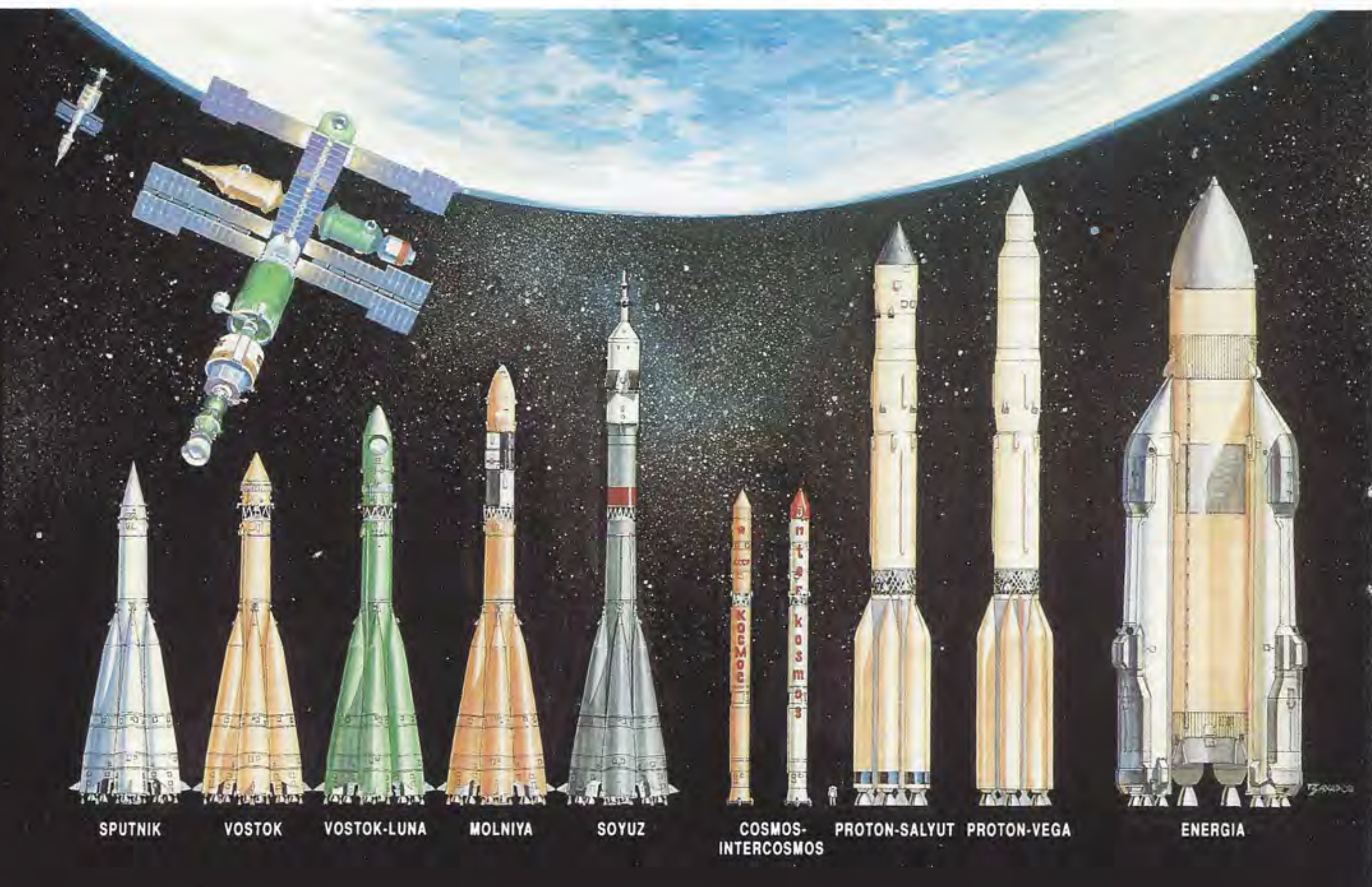
Now let us consider the extent to which world space technology is ready for the first interplanetary flight. What problems must be solved before representatives from Earth can step onto the surface of another planet? The assembly of the spacecraft in Earth orbit from individual components is one requirement. The Soviet Union has great experience with this, having automatically assembled facilities in space for more than 20 years. Both the Soviet Union and the United States have docked spacecraft in orbit. That will also be required during a Mars mission. Both nations have experience in interplanetary trajectories and in flight navigation. Automatic spacecraft have explored the nearby planets, as well as the outer planets of the solar system. The flights of orbital space stations (*Salyut, Skylab, Mir*) have allowed development of means for long-duration human spaceflight. What is important is the safety and reliability of the equipment. It will be difficult to count on help from Earth; therefore, all tools and means for maintenance must be located on the spacecraft.

As far as the landing vehicle is concerned, one can assume that similar problems can be solved. The United States has had the experience of landing and returning a crew from the surface of the Moon. In 1969 through 1972, American *Apollo* astronauts performed six descents to and ascents from the Moon. Soviet automatic spacecraft also landed on and ascended from the Moon. The USSR and the US have both landed automatic spacecraft on Venus and Mars.

The question remains whether the crew can work for long periods in weightlessness. Many years of work have been expended in this direction. The road has been long and bumpy. At moments it has appeared that weightlessness represents an impenetrable barrier in long-duration spaceflight. For instance, after the 18-day flight of A. Nikolayev and V. Seviastianov, their re-adaptation to Earth's gravity was so difficult that any lengthening of future flights appeared problematic. But means have been worked out to support the crew by training the muscles and the cardiovascular system. Work continues. Over several years the flight durations on orbital stations have been lengthened. In December of last year, Cosmonaut Yuri Romanenko recorded the longest flight of a human in weightlessness, 326 days. He returned in excellent physical health. Successful long-duration flight was a result of a special program of physical training on board the station. We have reason to look with optimism at the possibility of long-duration spaceflight.

Of course, we shall not oversimplify the problem. Specialists in space technology will have to solve many technical and medical problems before such a grandiose event as a flight to Mars. This flight stands on today's agenda not only as a technical and scientific problem, but also a problem affecting the progress of Earth's entire civilization.

V. Glushko is a member of the Soviet Academy of Sciences. Y. Semenov is a corresponding member of the Academy. Doctor of technical science L. Gorshkov heads a department of the Soviet space agency.



Since the launch in 1957 of the first satellite,* Sputnik, *Soviets have developed a wide range of expendable launch vehicles. The recently tested* Energia *can lift hundred-ton payloads; multiple launches could send humans on a mission to Mars.

Painting: Alexander Zakharov, courtesy of *Soviet Life*

A Soviet View of a Lunar Base

by Vladislav V. Shevchenko

After a lengthy silence about the Moon, specialists have again turned their attention to our planet's natural satellite. They predict that the last decade of our century may mark a new "lunar renaissance."

The last *Apollo* expedition left the Moon in December 1972. The last flight of robotic spacecraft to the Moon, *Luna 24*, returned to Earth with samples of lunar material in 1976. Launches of new lunar spacecraft are not expected earlier than the end of the 1980s or the beginning of the 1990s.

Perhaps by the 50th anniversary of the launch of Earth's first artificial satellite [*Sputnik* was launched in 1957], the scientific lunar bases will begin to function. Although the project may not be realized before 2000, lunar specialists already consider it necessary to set the strategy of exploration of the Moon toward the creation of a multi-global civilization.

The scientific desirability of lunar laboratories is unquestioned. They can aid in studying the origin and evolution of the solar system, including Earth's early history; they can provide new measurements of near and deep space; and they can support unique experiments in physics, chemistry, biology and other sciences. Less clear are practical questions about how to realize the project and justify the expenditures it requires.

Calculations show that for large constructions in near-Earth orbits, it is more sensible to use lunar materials. Projects such as building solar power satellites are impractical without using lunar resources and lunar industry.

A Museum of Universal Antiquities

Despite intensive study of the Moon by spacecraft in the 1960s and 1970s, many questions remain unsolved. The Moon retains valuable information about the early steps in the evolution of the solar system—processes that took place in the first five hundred million years of its existence.

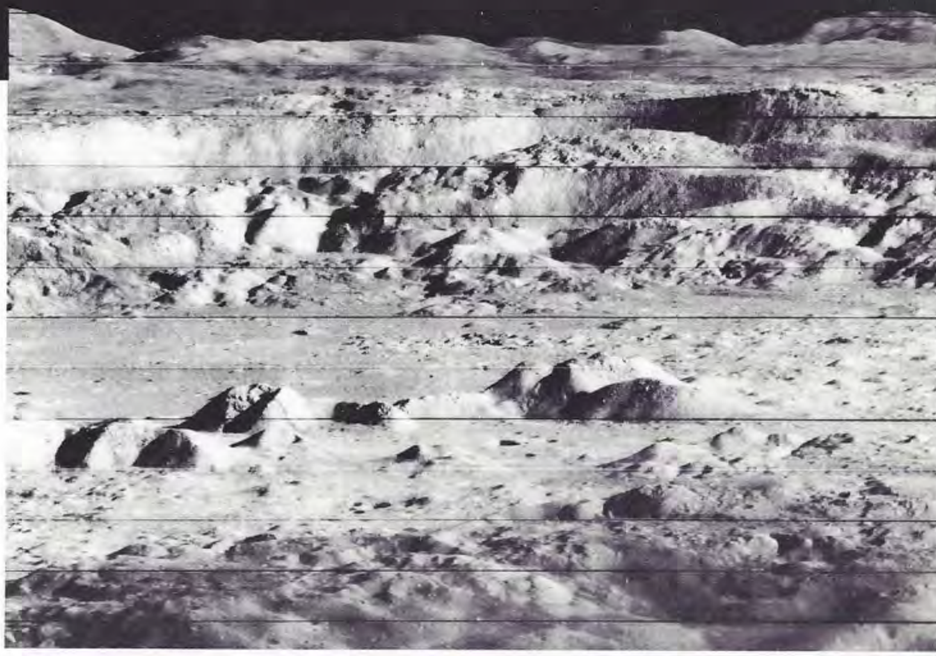
During its formation the lunar crust may have melted to a depth of at least several kilometers. If a similar process occurred on Earth, it would be important to understanding the formation of the core and mantle. More than that, intensive bombardment by falling comets and meteorites, traces of which are clearly visible on the Moon, could have greatly influenced the evolution of Earth's continents more than 3.8 billion years ago. We can determine the age of the Moon's most ancient (bedrock) areas and how the bedrock changed depending on depth using samples from the ancient intrusions and lower parts of the crust.

Such samples may be found among the ejecta of gigantic circular structures called basins. Lunar basins, part of which are filled with maria [*mare*, from the Latin for *sea*, is a dark, smooth region on the Moon's surface] probably were formed by impacting bodies with diameters up to 200 kilometers. These giant basins were formed in the earliest period of lunar history—from 4.25 to 3.85 billion years ago.

Detailed research on the Moon's ancient regolith [the surface layer of loose rock fragments and dust] in the open plains, as well as the study of natural exposures of the deeper layers, may give us unique data about the earliest events in our planet's history. Recently we have learned that fragments thrown out from the Moon by large impacts can be found on Earth's surface. Meteorites recently found in Antarctica are parts of lunar bedrock. We can probably assume the reciprocal: perhaps on the Moon the traces of gigantic ejecta from Earth can be found in noticeable layers.

On the Moon, we might search for a layer of regolith 65 million years old. One of the biggest ecological catastrophes in Earth's history corresponds to this period. More than half of the plant and animal species on our planet at that time, including the dinosaurs, were destroyed. Because geochemical analysis showed a high content of the rare metal iridium in the rocks of that period, scientists have speculated that those tragic events are connected with the intensive bombardment of Earth by comets or as-

As part of its continuing liaison with space-interest groups and publications worldwide, The Planetary Society is now working with the Soviet journal *Earth and Universe* to exchange articles occasionally. This article is one example. *Earth and Universe* is publishing some recent features from *The Planetary Report* and included an "advertisement" for the Society in the July/August issue. This liaison, like the Society's relationship with *Spaceflight News* in Great Britain, (see the September/October *Planetary Report*) permits wider coverage and influences support in many nations for the exploration of the solar system and the search for extraterrestrial life.



***Clockwise from top right:** The Moon's ancient highlands and its dark lava maria show an impact-cratering history extending over eons. Among the younger craters are Tycho in the southern highlands and Copernicus (above center, just south of Mare Imbrium).*
Image: Lick Observatory

Looking obliquely across Copernicus, the scale of this lunar landscape becomes evident. The crater itself is about 95 kilometers across and just over 3 kilometers deep, with cliffs almost 1 kilometer high. The central peaks form a mountain range about 16 kilometers long and about 600 meters high.
Image: Lunar Orbiter 2/NASA

The rays of bright material thrown out by the impact have not yet eroded away, indicating that Copernicus is a young crater.
Image: Lick Observatory and the University of Arizona

(continued from page 9)
teroids. The high iridium content is more characteristic of these cosmic bodies than of Earth's surface materials. Study of the lunar surface may find places where substances were thrown out from Earth.

In recent years, a new subject has attracted interest—the atypical bright formations on the lunar surface. They are not expressed in relief, and their borders do not correspond to topographic features. Their light or dark structures look like turbulent pictures of a gaseous atmosphere.

Scientists have confirmed a connection between these albedo (reflectivity) anomalies and magnetic anomalies. The nature of this relationship is still unsolved. One interesting hypothesis suggests that these structures are the traces of the fall of comet nuclei on the Moon's surface. A lunar base would permit detailed on-site study of such structures related to global catastrophes in the inner solar system.

Sampling the Lunar Surface

The investigation of the first samples brought back to Earth showed that lunar regolith contained tracks of fast and heavy particles of solar and galactic origin. The tracks of these particles allowed us to estimate the time materials were exposed on the surface and to establish the history of soil transport. Knowing the time of irradiation and the speed of erosion, we can calculate the solar particle flux in the past and try to determine the solar activity at that time.

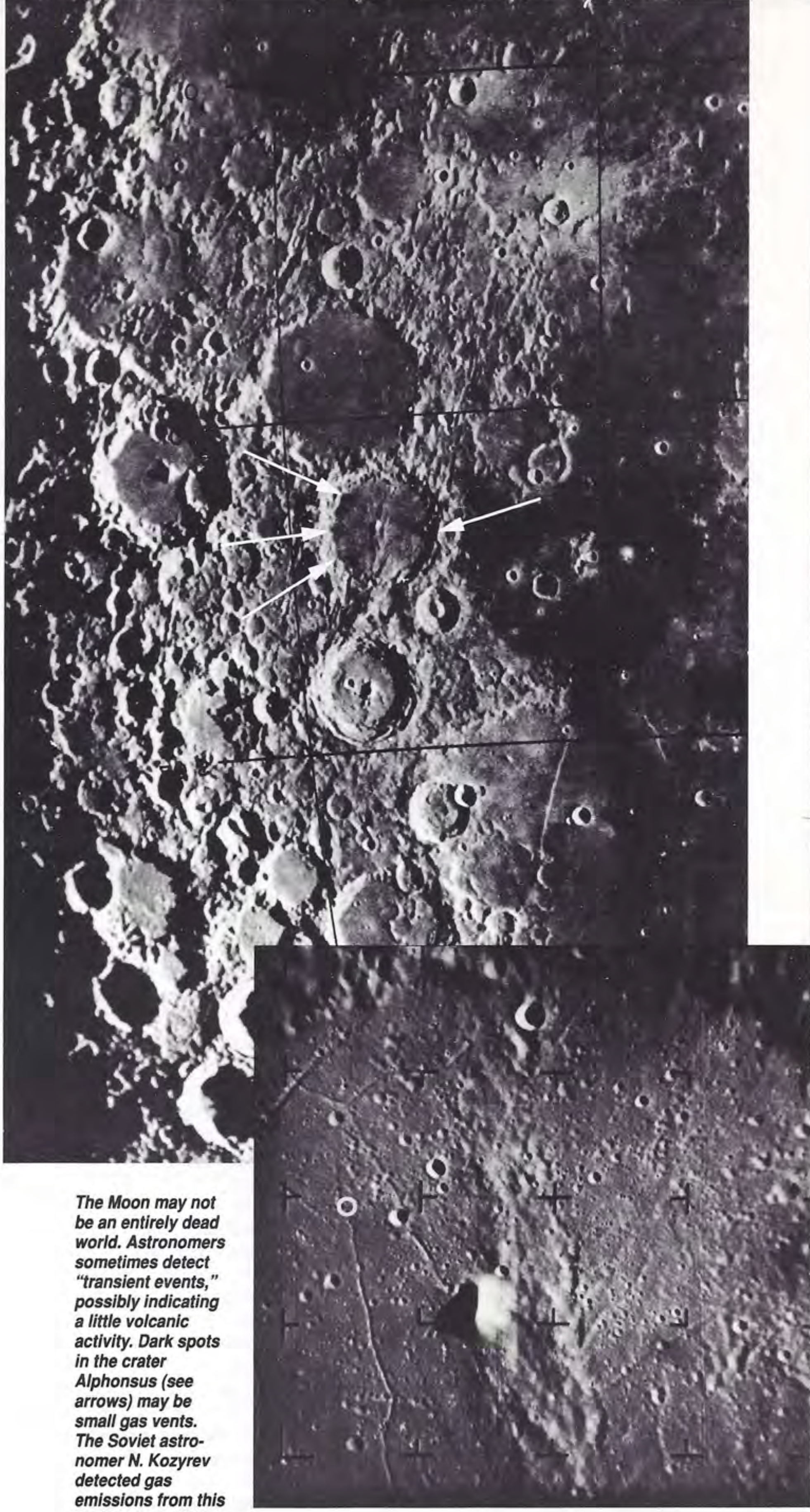
So far, only surface samples or drilled columns no more than two meters deep have been collected and studied by this method. To use field geology methods effectively on the Moon, samples of the ancient layered regolith hundreds of meters thick have to be taken. These can be found inside deep cracks or craters where the steep slopes prohibit the accumulation of overlying regolith.

Material for a Lunar Base

The first use of local material that the designers of lunar settlements will consider will be for life support. The use of volatiles [easily evaporated substances, such as water] and internal lunar processes has intrinsic scientific value as well as very practical meaning for the lunar base.

Although the lunar interior is supposed to be solid to a depth of hundreds of kilometers, the so-called lunar transient phenomena have frequently been observed. [Many observers have report-

(continued on page 12)



The Moon may not be an entirely dead world. Astronomers sometimes detect "transient events," possibly indicating a little volcanic activity. Dark spots in the crater Alphonsus (see arrows) may be small gas vents. The Soviet astronomer N. Kozyrev detected gas emissions from this region, seen close up on the right.

Images: NASA/JPL

ed glowing red spots, gas emissions and possible ash ventings from the Moon's surface, but the nature of these phenomena is not understood.] Unfortunately, most of these sightings were visual. But gas emitted from the lunar interior is verified by experiments left on the Moon and also by mass spectrometers on the *Apollo 15* and *16* orbiting spacecraft.

The connection between the transient phenomena and internal activity is indirectly confirmed by several coincidences of surface effects and interior seismic activity. These processes may be occurring along a system of very deep faults inside the Moon. The driving mechanism could be tides raised by Earth.

It is interesting that the Moon's surface is completely dry. However, two spectrograms of transient phenomena show the presence of hydrogen and carbon in the assumed discharge of subsurface gases. If these outflows are coming from reservoirs located relatively close to the surface, then under certain conditions these gases might accumulate on the surface. So, according to the hypothesis, on the inner sides of polar craters, never illuminated by sunlight, there could be methane, carbon dioxide, hydrogen sulfide and water ice.

An optimistic view might be that layers of water ice mixed with carbon dioxide, methane, argon and other components can reach a thickness of several meters. But at the same time, some laboratory work has shown that the rate of erosion of water ice by interplanetary and magnetospheric particles is approximately equal to the expected rate of formation of water ice layers. Thus, even in the coldest lunar polar regions, permanently shadowed from sunlight, significant accumulation of water ice is not very probable. The question of the existence of lunar polar ice can be solved by specialized experiments on board a spacecraft equipped with a gamma spectrometer and an electromagnetic probe.

We can make more certain predictions about retrieving oxygen and water from the Moon's surface rocks. Three principal rock-forming minerals contain significant amounts of oxygen in different combinations: pyroxene—44 percent, plagioclase—46 percent and ilmenite—32 percent.

The most promising prospect from the technological point of view is the method of deriving water vapor from lunar surface rocks rich in ilmenite. Heating the mineral ore to temperatures of about 1,000 degrees Celsius starts the process, which releases about 10 percent of the ore's oxygen. If the ilmenite soil were used as a raw material, then the resulting product would be pure iron.

Solar radiation could be the first source of energy for a lunar base. But we should not rule out other sources such as nuclear energy that do not depend on a day/night cycle.

The lunar soil should be used for construction of different facilities. Engineers and architects believe that the fine lunar dust, abundant on the surface, would be wonderful material for concrete.

21st Century Lunar Settlements

The first studies of permanently occupied lunar bases appeared more than twenty years ago. The International Astronautical Federation established a special committee to coordinate work on scientific laboratories on the Moon. The joint work of scientific organizations from many countries in studying Antarctica served as a pattern.

After concluding their lunar missions in the '70s, the leading space powers concentrated on near-Earth space using piloted spaceflight. Starting from accumulated experience and predictions for the future, a group of experts at the Johnson Space Center in Houston concluded that in a few decades the term "near-Earth space" will include the Moon. The great possibilities of lunar industry will drive development of all near-Earth space inside the lunar orbit. Therefore, the establishment of a lunar base is once again an urgent subject.

There are several possible versions of such a base. In the simplest one an automatic facility for industrial processing of the lunar soil will land in the Ocean of Storms, near the equator. After the station processes a defined amount of the necessary resources, it will be supplemented by a habitable module. By remote control from Earth, a lunar rover will transport the habitable module into a specially built or existing depression, where a layer of lunar regolith will protect it from radiation as well as from rapid cooling at night.

When the first inhabitants land, the automatic equipment will fully supply the base with oxygen and water from local resources, although the hydrogen will initially be supplied from Earth. Later trips will bring necessary equipment and other crew members, up to a total of twelve people.

A more ambitious program will require a series of reconnaissance and technological trips with both automated and piloted flights. A large station orbiting Earth is assumed for the transportation node, and all lunar operations will be controlled from an orbiting station around the Moon.

Each module of the lunar settlements could consist of an aluminum cylinder located at a depth of about three meters and covered with a layer of soil two to five meters deep. The foundation for life support will be a closed ecological system regenerating water and air. Since oxygen will be supplied from local resources, it will be necessary to transport from Earth only nitrogen and water or hydrogen for producing water under lunar conditions.

It is possible to grow plants on lunar soil in a special greenhouse. Plants will supply sufficient oxygen for breeding small domestic animals (such as rabbits) to provide the inhabitants of the base with balanced nutrition.

The forms of scientific and industrial facilities correspond to their functions. Absence of atmosphere and low gravity will allow us to construct light and economical structures of huge dimensions. For example, a telescope on the Moon with a mirror diameter of 25 meters would give a resolution of 0.0001 arc seconds. [One arc second equals 1/3,600 of a degree. The circle of the sky is divided into 360 degrees.] Using this telescope in the lunar conditions would enable us to observe planets of nearby stars or details in the centers of nearby galaxies.

Accomplishing such a grandiose project would require significant financial resources. International cooperation will substantially decrease the investment required by each individual country. I had an opportunity to discuss lunar bases with experts from Johnson Space Center, the initiators of the project. During these discussions, as well as in their publications, these scientists have emphasized uniting the efforts of different countries, primarily the leading space powers, not only to accomplish scientific goals but also to further develop space for peaceful purposes.

Vladislav V. Shevchenko is a lunar scientist who is currently investigating potential locations and designs for lunar bases. He is chairman of the Lunar Task Group of the International Astronomical Union's Working Group on Solar System Nomenclature.

Oceans on Venus— The Great Debate

Planetary science is not a young discipline. Its roots go back at least to the Babylonians, who carefully tracked the motions of the wandering lights against the background of stars. The invention of the telescope 380 years ago brought the planets a bit closer. But planetary scientists have had a hard time getting hands-on experience with their subjects. Only in the last three decades have planetary scientists been able to send robot surrogates to explore planets for them, and so to visit vicariously the objects of their study.

But while these planetary probes have returned enough data to enlarge greatly our view of the solar system, they have often raised more questions than they have answered. One such question is whether or not Venus once had oceans. As you will read, scientists' opinions on this question have changed over the years, and after the discovery that Venus was exceedingly hot, a consensus almost formed for a negative answer.

But then a single measurement taken by a *Pioneer Venus* probe reopened the question. An unexpectedly high reading of deuterium, a heavy isotope of hydrogen, suggested that Venus might once have held more water than it does now, perhaps enough to form oceans. Without follow-up spacecraft, planetary scientists could confront the question with only limited data and their own ingenuity. They scurried to build complex models of Venus' atmosphere, running them backwards in time to see what an early Venus might have looked like.

These atmospheric models are built on hypotheses of planetary evolution and theories of how the solar system formed. The featured players are chemical compounds such as water and carbon dioxide, with support from various mineral combinations. These may seem to be arcane stories of chemical reactions and geologic processes, but remember that these distant events eventually led to oceans on Earth. The same thread that runs through the story of water on Venus also runs through the history of life on our planet.

The question of past water on Venus has become one of the hottest topics in planetary science, and we present here two sides of the debate. James Kasting is a leader in building the models that he feels strongly suggest that Venus was once relatively rich in liquid water. David Grinspoon feels that the case for a wet Venus is not strong enough to warrant that belief.

Were there ever oceans on Venus? Read on and decide for yourself. —*C. M. A.*

The Water That Got Away

by James F. Kasting

Venus today is an extremely inhospitable place. Its closeness to the Sun and its dense carbon dioxide atmosphere combine to produce a surface temperature of some 460 degrees Celsius (800 degrees Fahrenheit)—far hotter than your kitchen oven. It is also exceedingly dry; the water vapor in Venus' lower atmosphere measured by *Pioneer Venus* and by the Soviet *Venera* probes is about 100 parts per million. The total water on Venus is comparable to that held in Earth's much thinner atmosphere—100,000 times less than the water in Earth's oceans.

Was Venus always this dry? I think not. A much more plausible theory is that Venus once had abundant water. It lost it over time as the water vapor in its upper atmosphere was broken into its component atoms, oxygen and hydrogen, and the lighter hydrogen escaped to space. Venus may also have once been cool enough to form oceans. Indeed, early Venus may not have been all that different from early Earth.

To appreciate why early Venus may have been wet, it helps first to understand the opposing view. The hypothesis that Venus was dry is predicted by the equilibrium condensation model for planetary formation, which has been most vigorously defended by John Lewis and his colleagues at the Massachusetts Institute of Technology and the University of Arizona.

This model begins with a gaseous nebula slowly condensing to form the Sun, planets and assorted debris. It pre-

Above:* This radar map of Venus was generated from data returned by the *Pioneer Venus Orbiter.* *Image: United States Geological Survey

Right:* This computer-generated map shows what Venus might look like if covered by 10 percent of Earth's ocean. Venus' surface is much smoother than Earth's, so even a little water would cover much of the planet. *Image: Michael Kobrick, Jet Propulsion Laboratory

scribes a temperature structure for the nebula: hotter on the inside, cooler farther out. With this information we can calculate the composition of solid materials that condense from the nebula.

This model predicts that most of Earth's water was incorporated into our planet as hydrated (water-containing) minerals, such as tremolite or serpentine. We would expect such minerals to form at the low temperatures beyond the orbit of proto-Earth, but not in the warmer regions near the orbit of proto-Venus. The model presumes that the nebula cooled slowly and peacefully and that materials that condensed at a given distance from the nebula's center would have a uniform composition.

The equilibrium condensation model successfully accounts for the shift from rocky to icy materials as we move outward in the solar system. But there are at least two good reasons why this model's predictions might be misleading. It presumes that the planets formed only from materials that condensed in their immediate vicinity and that there was little or no mixing of planetesimals formed in other regions. (Planetesimals are small, solid bodies that may have grown into planets as they collided and gravitationally stuck together. Asteroids and the meteorites that strike Earth may be leftover planetesimals.) The question of how much mixing actually occurred is unresolved. Gravitational interactions among planetesimals could have jumbled up materials formed in different regions of the nebula.

Another way of thinking about this question is to ask whether the terrestrial planets (Mercury, Venus, Earth and Mars) can be built from known meteorite types. This, of course, presumes a certain amount of nebular mixing so that different materials can be incorporated into each planet. Various researchers have suggested that Earth received its volatiles (substances easily evaporated at low temperatures, such as water) from carbonaceous chondrites (a type of organics-rich meteorite). These meteorites contain water (roughly 10 percent by weight) in the form of hydrated minerals, along with large amounts of carbon with hydrogen atoms attached. Oxidation of this organic carbon by ferric oxides (minerals containing iron and oxygen) would have released carbon dioxide and water to Earth.

Other researchers have suggested that Earth's volatiles were brought in by ordinary chondrites—less highly oxidized meteorites with much fewer volatiles than their carbonaceous cousins. Oxidation of their carbon would have yielded carbon dioxide but no water. Ordinary chondrites do, however, contain some water (about 0.2 percent by weight) in hydrated minerals. Thus, such materials would have to have been completely absent from the neighborhood of proto-Venus for the planet to have been born dry.

Oceans from Comets?

The second problem with the equilibrium condensation model is that it ignores comets—surprising, in a way, because Grinspoon and Lewis have since invoked comets to explain the deuterium enhancement in Venus' clouds (see next article). The comets that now make up the Oort Cloud (a cloud of icy cometary nuclei surrounding the Sun far out beyond the orbits of the nine known planets) are thought to have formed originally in the vicinity of Uranus and Neptune. Orbital perturbations from these giant planets would have sent most of these comets away from the Sun and out of the ecliptic (the plane cut by Earth's orbit about the Sun). Many, however, would have been scattered into the inner solar system, where they could have collided with the recently formed terrestrial planets, including Venus. The flux of comets through the solar system during its first several hundred million years may have been 1,000 to 10,000 times greater than today.

Christopher Chyba of Cornell University has recently estimated that the water in Earth's oceans could have been entirely derived from comets even if they comprised only 10 percent of the impacts recorded on the Moon. (Since Earth's constantly changing crust eventually erases evidence of impacts, the Moon's mostly inert surface is a good record of past bombardments.) Some 10 to 50 percent of recent impacts are attributed to comets, and the rest to asteroids. There is no obvious reason why the ratio of comets to asteroids should have been the same in the early solar system. However, if Earth gained even a small fraction of its water from a late cometary veneer, then it is difficult to understand why Venus would not have received a comparable amount.

Comets would have provided water to Venus (and to Earth) over several hundred million years. (The heavy bombardment of the Moon apparently continued until about about 3.8 billion years ago; this fusillade seems to have ended about the time life arose on Earth.) In contrast, water from the inner solar system should have been incorporated into the terrestrial planets within the first one hundred million years, or about 4.5 billion years ago. The time scale for Venus to have lost its water, as discussed below, is about a hundred million years or less, depending on the energy output of the young Sun and the efficiency with which it helped hydrogen to escape from the planet's atmosphere. A late veneer of cometary water might not have produced its full complement of water at one time, making it less likely that the water condensed to form oceans. Such an atmosphere would have to have held a lot of water, however, for the hydrogen to have escaped from its upper layers into space. Thus, compared to today, Venus' primitive atmosphere would still have been very wet.

Another argument favoring a dry Venus is that it would have been impossible to get rid of large amounts of water. The proposed mechanism to lose water involves photodissociation (when light energy breaks apart a chemical compound) of water vapor in Venus' upper atmosphere, followed by the resulting hydrogen's escape to space.

The specific mechanism for losing hydrogen involves hydrodynamic outflow—a process analogous to the way material is blown off from the Sun as a stream of charged particles called the solar wind. Theoretical studies have shown that hydrodynamic escape would have efficiently removed the hydrogen if the upper atmosphere was rich in that element. But water vapor (and thus hydrogen) could have been confined to the lower atmosphere by a cold trap, an atmospheric region where water vapor condenses to droplets and falls back toward the surface.

Climatic models predict that an atmospheric cold trap does not work well if the lower atmosphere contains more than about 10 percent water vapor (by mass). A wet young Venus would have had at least this much water vapor in its atmosphere, so the cold trap would have been forced up to very high altitudes. There the pressure is so low that water vapor has little urge to condense and fall back to the planet. It would therefore have made its way into the upper atmosphere, where it could have been photodissociated. The hydrogen could then be lost to space.

Lewis and his colleagues have not challenged the idea that early Venus could have lost lots of hydrogen in this way. Rather, they point out what they perceive to be grave difficulties in disposing of the oxygen left behind.

Whether or not this oxygen poses a problem for the wet young Venus model depends in part on when the water was acquired. If much of the water came in as the planet was accreting, then its surface should have been molten and the entire mantle (the planet's interior region between its crust and core) should have been overturning vigorously. A virtually unlimited amount of oxygen could then have entered the mantle. Water would probably have reacted with melted elemental iron and released its hydrogen, forming our old friends, ferric oxides.

Once released, this hydrogen would have made its way to the top of the atmosphere and escaped if enough solar energy was available. If, on the other hand, the inner solar system was still filled with dust blocking the sunlight, then the hydrogen would have remained in Venus' atmosphere until the nebula cleared and it could escape. In either case, lots of water could have been lost without creating much free oxygen.

How Big a Loss?

If Venus got its water from cometary bombardment after it had accreted, that presents a bigger problem. The amount of water that could have been lost might then have been something less than a full terrestrial ocean. If fresh crustal material was produced at the same rate as it is on Earth, it could have taken up oxygen equal to about one-thirtieth of Earth's ocean (or an average depth of 100 meters).

Lewis and his coworkers have ignored other possible oxygen sinks (processes and places that could take up the element). For example, Venus may have originally outgassed its carbon dioxide (CO_2) as carbon monoxide (CO). One-tenth of a terrestrial ocean could have been consumed in oxidizing CO to CO_2. Or oxygen could have escaped to space if the solar energy were strong enough. Indeed, from an energy standpoint, Venus could have lost several oceans, including the oxygen, during its first hundred million years.

The real Achilles heel of the runaway greenhouse hypothesis, as the original wet early Venus model was called, lies in getting rid of the last part of the original water endowment. As mentioned earlier, climatic theory predicts that a cold trap would have developed as the water vapor content of Venus' lower atmosphere fell below 0.1 percent. If Venus already had its massive 90-bar carbon dioxide atmosphere, then roughly 10 Earth atmospheres of water would have remained in its lower atmosphere when the cold trap began to become effective. The rate of this water's escape depends on the temperature and height of the cold trap and so is hard to estimate. But crude calculations suggest that it would have been hard to lose this much water even over several billion years.

Furthermore, at some stage sulfuric acid clouds like those enshrouding Venus today would have started to form. These water-loving clouds would have taken up the errant water and dried out the upper atmosphere even more, further reducing the rate of hydrogen escape.

Why, then, does so little of Venus' original water remain? If we start with an Earth-like planet covered with an ocean and then calculate how much solar heat is needed to vaporize the ocean, climatic models (mine, at least) predict that the Sun's energy today falling on Venus is more than enough to do the job. However, shortly after it formed, the Sun was about 30 percent dimmer than it is now, so the energy falling on primitive Venus could well have been cool enough for liquid water to form. Thus, if Venus did start out with an Earth-like water endowment, much of that water should have condensed to form a hot ocean. That ocean's temperature would have depended on the effects of clouds and on the amount of carbon dioxide in the atmosphere, but it was probably between 100 and 200 degrees Celsius. Since the overlying vapor would have kept the water from boiling, liquid water should have been stable on early Venus even if the planet had only a fraction of Earth's water.

An ocean on early Venus should have caused great changes in its atmosphere. On Earth, water weathers silicate rocks, converting them to carbonates and taking up atmospheric carbon dioxide in the process. Similar weathering reactions, which occur in the presence of liquid water, would have reduced Venus' atmospheric pressure by sequestering carbon dioxide in the planet's crust. This reduction of atmospheric carbon dioxide would have facilitated water's escape because much less water would have been present when the cold trap started to form.

The presence of liquid water would

also have helped solve the problem of the water-trapping sulfuric acid clouds. All common sulfur gases are soluble in water, so if an ocean were present, they would have eventually dissolved to form various sulfur-containing minerals. The sulfuric acid clouds that today hide the planet's surface could not have formed until the ocean had disappeared and sulfur was recycled into the atmosphere by volcanic activity. Carbon dioxide could have been regenerated similarly. Over billions of years, volcanic outgassing would have produced the present atmosphere.

A reasonable history of water on Venus, then, might go like this: Venus started off wet because it could not avoid receiving some of the same volatile-rich material that formed Earth. Once the initial accretion period was over, the combination of a dimmer Sun and protecting clouds would have given Venus a relatively cool surface. If it had anything approaching Earth's water inventory, much of it would have condensed to form oceans. Carbon dioxide would have been slowly converted to carbonate rocks, and the atmosphere would have thinned.

Water would have remained a major component of the atmosphere, its abundance gradually decreasing through photodissociation and hydrogen escape. Some of the oxygen may have been dragged off to space with the hydrogen; the rest was consumed in oxidizing carbon monoxide and in reacting with minerals in the planet's crust. Because the atmosphere was thinner then than it is today, most of Venus' original water would have escaped by rapid, hydrodynamic outflow. The rest was lost over billions of years by slower, nonthermal escape processes. The disappearance of water allowed the carbon dioxide and sulfur dioxide released by volcanos to accumulate, and the atmosphere gradually approached its present state.

James Kasting, who wrote this article while employed as a research scientist in the Space Science Division at NASA Ames Research Center, is currently an Associate Professor in the Department of Geosciences at Pennsylvania State University.

Born Wet or Bone Dry?

by David Grinspoon

If *The Planetary Report* had asked me to argue that "Venus was dry," meaning that we have good reason to believe that Venus never had large quantities of water, I could not have done it in good conscience. We have no evidence to justify this position. But I've been asked to play the skeptic, taking the position that no one has proven that a primordial ocean existed on Venus. In planetary science, "proof" in the strongest sense of the word is often hard to come by since we are starved for data and the problems are so grand. Yet I believe that on the question of ancient oceans on Venus, flimsy or circumstantial evidence has been given more weight than is justified, and that, whether we like it or not, the question still rings truer than any answers we have found.

Comparative planetology is frustrated by the small number of evolutionary examples that we may draw upon to test our models. Restricted at present to our own solar system, we must be content with data from but a few distant laboratories, inventing theories after the fact for ancient experiments beyond our design. Could Gregor Mendel have discovered the laws of genetics if he had had only one pea plant to work with and one hour to observe it, rather than gardens and generations? The limitation of this small array of planets increases the temptation to regard Venus—with its strikingly similar size and closeness to Earth—as a dry, lifeless control for the terrestrial experiment. Thus a persistent approach to the study of Venus has been to assume initial conditions that were essentially identical to those on the primordial Earth and ask, in effect, "What went wrong?"

The realization that Venus' pearly brilliance in our morning and evening skies is due to a permanent planet-wide cloud cover supported scientists' expectations, widespread in the nineteenth and early twentieth centuries, that the surface would be found to be a tropical swamp resembling the carboniferous Earth. However, the discovery in the late 1950s of an unusual source of microwave radiation coming from Venus, found to be the thermal glow of an extremely hot surface (not quite red-hot, but almost) eventually dispelled the notion of oceans on present-day Venus. The very small amount of water measured above the clouds by Earth-based spectroscopy and in the lower atmosphere by Soviet and American spacecraft, coupled with the finding that the clouds are composed of concentrated sulfuric acid, confirmed that "Earth's twin" is an alien, hellish place.

When it was established that Venus has 100,000 times less water than Earth, some scientists tried to account for the "missing" water. Several groups of researchers have applied themselves to this problem, most recently James Kasting and his colleagues. They've built an internally consistent and credible scenario, supported by detailed modeling, of a once-Earthlike Venus that has lost its oceans due to a runaway greenhouse that boiled the oceans, sending much of the water to the upper atmosphere where sunlight tore hydrogen atoms from the water molecules.

This hydrogen would have escaped into space, first by an extremely rapid hydrodynamic outflow (see previous article), and later, when the atmospheric water fell below 10 or 15 percent, by

Did Botticelli paint his Aphrodite on the wrong planet? Perhaps she arose from an ocean on Venus, long since dried up.

Painting by Michael Carroll from an idea by David Grinspoon

various nonthermal escape processes. Nonthermal escape is any mechanism allowing gas to escape from a planet by means of an energy source in addition to the gas' own thermal energy. Something accelerates atoms or molecules to speeds greater than the normal thermal speeds in a gas at that temperature.

Rapid nonthermal escape of hydrogen *is* occurring today on Venus, and according to this wet young Venus story this escape represents the tail end of a constant decline in water that, after eons, has finally led to the pathetically dried-out state of the present planet.

If we take it as a given that Venus had oceans, then James Kasting and his colleagues have been quite successful in showing how to get rid of them.

In this scenario Venus and Earth are identical twins separated at birth, with only environment to blame for their vastly different fates. Venus grew up too close to the Sun and went dry. Earth was brought up farther out in the suburbs of the solar system where it's possible for a decent planet to maintain a stable ocean. But could nature as well as nurture play a role in the unfolding of these lives? Could Venus have been born dry? If so, then the two planets may have followed very different paths throughout their histories. Let us examine our theories of planet formation, keeping this question in mind.

According to the equilibrium condensation theory, first proposed by John Lewis in 1972, the temperature gradient of the solar nebula (the flattened disk of dust and gas out of which the planets formed) sorted the condensing materials by composition into zones. More refractory materials (those with high melting temperatures) such as metal oxides and some silicate minerals formed in the nebula's inner, hot regions, and more volatile (the opposite of refractory) substances such as hydrated silicates (rocks with chemically bound water) and ices formed farther out where temperatures were lower.

The compositions of the planets that later formed from these materials preserved this trend, varying systematically with distance from the Sun. According to this theory, materials forming closer to the Sun were drier. The inner boundary of hydrated silicate formation—where proto-planetary materials contained a lot of water—lay between the orbits of Earth and Mars. This theory predicts that Venus, orbiting even farther in than Earth, would have had much less initial water than our planet.

One crucial question is whether the process of planet building was orderly enough to maintain these chemical zones. After solid grains condensed and began to collide and grow into larger bodies, did these planetesimals stay in nearly circular orbits, like runners confined to specific lanes at a track? This would preserve the planets' chemical differences as they grew. Or did gravitational interactions lead to wild elliptical orbits, allowing planetesimals from inside and outside lanes to mingle, smearing out any initial compositional trends?

Proponents of a wet young Venus argue that there should have been enough mixing among the planetesimals to form the terrestrial planets and provide them with nearly identical amounts of volatile materials, including water. This argument has been supported by recent models by dynamicist George Wetherill, who suggests that elliptical orbits and extensive mixing dominated the growth of the terrestrial planets. Yet Wetherill's numerical simulations assume initial conditions that may unnaturally force the extreme mixing. Modeling the process of accumulation from tiny grains to planet-sized bodies is an extremely difficult problem, and many important processes are still poorly understood.

Not even the staunchest defenders of an equilibrium condensation viewpoint claim that there was no radial mixing during planet formation, but they question whether this mixing was as complete as the more tumultuous pictures suggest. The density differences among the terrestrial planets clearly show that they are not all made of the same stuff, so mixing was not complete. The asteroid belt also shows very clear compositional trends with distance from the Sun, suggesting that in this region radial mixing did not prevail.

In this context, no one would expect Venus to be born completely dry, but whether she was endowed with 1, 10 or 100 percent of a terrestrial ocean is a question related to the process by which the planets assembled themselves. Until we better understand planet formation, we should not assume that Venus was originally endowed with an Earth-ocean's worth of water.

Volcanic activity may have been an important part of the water cycle on Venus, both by releasing the volatile components of water to the atmosphere and by consuming oxygen in the formation of new crustal materials.
Painting: Don Davis

Losing Water or Breaking Even?

If Earth's oceans come from an early massive comet bombardment, then Venus would have received a comparable amount of water regardless of how the planets accumulated. Thus, early oceans on Venus are not incompatible with an equilibrium condensation model of planet formation.

Recently, John Lewis and I have been studying the question of water on Venus without assuming that Venus was once wet. We've concluded that, contrary to prevailing opinion, Venus is probably not losing water, but breaking even in the long run. If you let the hydrogen contained in all the water now on Venus escape at its current rate (about 20 million hydrogen atoms per square centimeter every second), you would run out of water in a fairly short time—87 million to 870 million years depending on whose number you believe for water abundance. Even the high end of this range for water's lifetime is considerably shorter than Venus' age. This suggests to us that rather than simply being in decline, water on Venus is in a steady state, meaning that there is a continuous source of water to balance the sink of nonthermal escape.

What might this source be? One possibility is volcanic outgassing. The gas that hisses and burps from volcanos on Earth is mostly water vapor. Some researchers believe that volcanic activity is occurring on Venus today, but the amount of outgassing, if any, is totally unknown.

We also know that comets and water-rich asteroids occasionally hit Venus, adding water to the planet's atmosphere. The recent international fleet of spacecraft sent to Halley's Comet confirmed Fred Whipple's 1950 "dirty snowball" model of comet nuclei. They appear to be roughly half water ice with many other hydrogen-containing ices. When these objects strike Venus they should vaporize and add their water to the planet's inventory.

The number of comets striking Venus over time and the mass of water they bring in is difficult to estimate. However, using information from the number of craters on the Moon, telescopic observations of comets, and orbital calculations, we can place reasonable bounds on the infalling water. Interestingly enough, the rate of water's escape from Venus falls right in the middle of this range of predicted water infall rates. So cometary infall seems a plausible source for water on Venus. Here we are not talking about the hypothetical massive early comet bombardment that may have contributed to Earth's oceans. We are saying that a constant infall consistent with the *observed* number of comets in the solar system today can explain the water now on Venus.

What a bizarre life these hydrogen atoms lead! Sequestered in cold storage for billions of years in cometary ice, liberated in a violent impact on Venus with an energy of hundreds of millions of megatons, drifting for millions of years in Venus' torrid atmosphere in a variety of chemical combinations, diffusing into the upper atmosphere (perhaps doing some time in the sulfuric acid clouds on the way up), only to be flung back out into interplanetary space.

If comets are now the major source for Venus' water, then virtually all the water we observe there may have come from impacts over the last few billion years. Large comet impacts should also produce dramatic fluctuations in water abundance, which could, in turn, cause strange climatic episodes and affect the surface and atmosphere. Comets strike Earth but don't noticeably affect the water abundance because our planet is so wet. (Who notices a drizzle when swimming?) They may, however, occasionally cause mass biological extinctions here, such as the disappearance of the dinosaurs 65 million years ago.

This steady-state model, in which a cometary source (perhaps with some outgassing thrown in) balances hydrogen escape to space, seems to do a good job of describing Venus today. But was it always like this? Models in which Venus once had oceans are quite popular and have been indirectly supported by some planet formation models. But is there a shred of hard evidence that these oceans ever existed? Some researchers would say that yes, there is a shred: the deuterium-to-hydrogen ratio.

Deuterium is heavy hydrogen. Ordinary hydrogen is the simplest atom conceivable: one proton and one electron. However, the Big Bang blessed some hydrogen atoms with an extra neutron, and these atoms are what we call deu-

terium. Since their electronic structures are identical, these two isotopes behave almost identically in chemical reactions, where electrons rule. But since deuterium is twice as heavy as hydrogen, any mass-dependent process, including the most important nonthermal escape process on Venus, discriminates between them.

In 1982 the American *Pioneer Venus* orbiter measured the deuterium-to-hydrogen (D/H) ratio of Venus' atmosphere. The value was quite high, about 100 times higher than the deuterium-to-hydrogen ratio on Earth. (Earth's water has 160 deuterium atoms for every million hydrogen atoms.) At the time, this observation was seen as the "smoking gun" revealing direct evidence of Venus' wet past. The reasoning went as follows:

We know that nonthermal escape discriminates against deuterium. Hydrogen is half as heavy and is thus much easier to accelerate to escape velocity. So as the hydrogen from Venus' vanishing water supply has escaped over the eons, it has left behind a residue of deuterium, resulting in an ever-increasing D/H ratio. Since Venus probably started with the same D/H as Earth, its modern value of 100 times Earth's D/H implies an initial water abundance at least 100 times the water left there today, perhaps much greater since some deuterium escapes along with the hydrogen.

This interpretation of the D/H ratio has two flaws. First, it involves an assumption about the original D/H on Venus. There is a wide range of D/H values throughout the solar system, and the origin of Earth's value is not well understood. So the assumption that the initial D/H on Venus was identical to the current terrestrial value, while a reasonable possibility, should not be used to draw definitive conclusions about the history of water on the planet. To assume that this terrestrial standard holds currency elsewhere, without a fuller understanding of its origin, is somewhat geocentric.

The other problem is that it assumes that the water abundance has simply been declining over Venus' lifetime. It does not allow for the possibility of hydrogen sources. Yet, as explained above, the short lifetime of water against nonthermal escape strongly suggests, if it does not demand, a hydrogen source. How does this steady-state model affect the interpretation of the D/H ratio? If you bring in enough water and let a lot of hydrogen but very little deuterium escape, then over the ages the D/H will increase, with no change in the total hydrogen abundance.

New mathematical solutions allowing for hydrogen sources show that billions of years of steady-state evolution can lead to a hundredfold increase in the D/H ratio. Thus, the observed D/H ratio does not necessarily imply a past excess of water. Unfortunately, the time required to build up a respectable deuterium excess in this way depends on the average water abundance over time, which is poorly known for Venus.

The observations of water abundance on Venus don't all agree, and a mysterious factor of 10 difference needs to be explained before any of the numbers can be believed. The problem is compounded by the fact that the water abundance has probably fluctuated greatly due to comet impacts, so even an exact knowledge of the abundance now may not reveal the average abundance, which we need to interpret the D/H ratio precisely. In fact, some scientists claim that there is good evidence that Earth was bombarded by a comet shower 38 million years ago. Venus should have been about as good a target as Earth, so the water abundance might still be out of whack from this shower, if it happened.

Resisting Easy Answers

Given these uncertainties, it is hard to tell whether or not the observed D/H really requires an early Venus with 100 times the water it now holds. But either way, 100 times almost nothing is still not very much: A body of water 100 times the present amount on Venus is equal to a layer only a few meters thick over the entire planet. Is this an ocean? Perhaps a small one. But there is really no evidence for the earlier massive hydrodynamic escape that is supposed to have removed most of the ocean.

Of course, there is nothing wrong with modeling the escape of hypothetical oceans. Some models of planet formation and some theories about early comet bombardment indirectly support an ancient ocean on Venus, but at present a preference for these models is the strongest argument that can be made for oceans on Venus. This is not proof, despite a perception in the planetary science community, which has filtered into the popular literature, that we have some hard evidence for past oceans on Venus.

The Venus exhibit at the National Air and Space Museum in Washington, DC, informs visitors that "Earth-based and spacecraft investigations indicate that Venus once had abundant water, but now has only trace amounts in the atmosphere. If Venus and Earth formed with the same amount of water, why is there so little in the modern Venusian atmosphere?"

A recent headline in a Phoenix, Arizona newspaper, reporting on the work of Kasting and his colleagues, declares, "Venus Once Had Huge Oceans, Study Says." I don't mean to imply that Kasting *et al.* have promoted this false impression. It seems to propagate naturally, as if fulfilling some unconscious desire to have another Earth somewhere in the heavens.

The question of whether or not there were ancient oceans on Venus is intimately related to some "big picture" questions: How did the planets form? Where did Earth's water come from? Was the origin of life on Earth an inevitable consequence of cosmic evolution or a freak accident? How nearly unique were the conditions that led to this event?

In our lust for the answers, let's resist jumping on bandwagons that may or may not be heading in the right direction. Perhaps the *Magellan* radar mapper will reveal the telltale signs of ancient shorelines. Wouldn't that be wonderful? Or perhaps future chemical investigations will demonstrate the presence or absence of all the oxygen that would be left behind in the rocks by an escaping ocean. But for now, while we brandish our opinions and push our theories to the limit, let's also admit, without shame, all the gaping holes in our knowledge of solar system history that make this young science such a challenge and a joy to pursue.

David Grinspoon is nearing completion of his doctorate in planetary science at the University of Arizona. His research focuses on the effects of large impact events on atmospheric evolution.

News & Reviews

by Clark R. Chapman

I recently received a thick, large-format, 1,000-page book entitled *Exploration of Halley's Comet* (Springer-Verlag, 1988). The cover bears a false-color likeness of Halley. Inside are reprints of two late-1987 issues of the technical European journal *Astronomy and Astrophysics*, with appended articles about the fly-by missions of Japan, the Soviet Union and the European Space Agency plus an overview of Halley by D.A. Mendis. The book reports the results of less than a year's analysis of the data obtained when the famous comet passed through the inner solar system nearly three years ago. The fuss has faded away, but scientists still pore over the data.

Cometary Reconnaissance

What have we learned so far? How can we extract the new insights from the wealth of technical analyses? Three principals in the European *Giotto* mission have attempted this feat in the September 1988 *Scientific American*. "A Close Look at Halley's Comet" by Hans Balsiger, Hugo Fechtig and Johannes Geiss is based mainly on *Giotto* data. It is a splendid introduction to cometary science but left me unsure of what unexpected things about comets we had learned from Halley.

Of course, the detailed measurements homed in on Halley's specific traits, which had been measured only crudely in 1910, when it last passed by. But despite several revelations, most of the Halley measurements and discoveries were simply confirmations or refinements of long-accepted hypotheses about the nature of comets. This seems true of the measurements of Halley's nearly pristine interstellar composition, studies of its dust, and investigations of the interaction between the comet and the solar wind. And Fred Whipple's "icy conglomerate" model for comet nuclei, devised about four decades ago, had been refined over the years. *Giotto*'s beautiful photograph of Halley's potato-shaped nucleus—the first clear view ever of a comet nucleus—dramatically confirmed Whipple's concept. But hardly anyone had doubted Whipple for years.

Other discoveries focused on details of Whipple's necessarily idealized model. We learned that Halley's nucleus has an irregular shape; that it is extremely dark (although, contrary to Balsiger and his co-authors, Halley's four-percent reflectivity does not make it "the darkest of all known bodies in the solar system"); and that the emissions of gas and dust come mainly from isolated jets, not from the whole sunlit hemisphere of the nucleus. But many specialists had inferred these facts about Halley and other well-observed comets before the spacecraft confirmed them.

I put down my *Scientific American*, again picked up the 1,000-page book and read the overview by D.A. Mendis. He is a bit clearer (and rather more technical) than Balsiger *et al.* about what was known before and what was newly realized from Halley research. But Mendis also left me with the impression that our view of comets has not changed too much.

What should we conclude? That comet scientists have been unexpectedly prescient or that Halley's apparition taught us less than we hoped? I would rather think that the limited new knowledge is about all that we could have expected from Halley's unfavorable apparition (unfavorable in terms of visibility from Earth) and from the fact that the spacecraft missions were fly-bys hurtling along at 70 kilometers per second. Much of the truly important information to be learned from comets, if they are indeed remnants of the primordial solar system, requires rendezvous, landing and penetration of the nucleus by advanced scientific instruments.

What the Halley explorations *have* proven is that comet scientists' pre-Halley expectations were exactly right: comets are, indeed, extremely primitive objects, with many clues to our origins. It is important to *know*, rather than merely surmise, that we can launch second-generation missions to comets with confidence that we will learn answers to fundamental issues about the planets' origins. After all, we could have been fooling ourselves in thinking that comets were so pristine and so old, as some lunar scientists were deceived about the Moon before *Apollo*. *Giotto* and the other Halley endeavors offer important reassurance that our plans to study comets are right on track.

What's a Microsymposium?

A microsymposium is a *very* small scientific meeting. Several years ago, in a more difficult period of bilateral relations, a microsymposium took place between a few planetary scientists at Brown University and their counterparts at Moscow's Vernadsky Institute. Such meetings have happened twice a year since, alternating between the Soviet Union and the United States. I was privileged to attend No. 8 this past summer in Moscow. A couple of dozen US planetary specialists, a few non-Soviet Europeans and numerous Soviet scientists from various institutes and observatories in Moscow and elsewhere attended the four-day event. Soviet scientists alone made over sixty presentations.

With the *Magellan* launch approaching, US scientists had much to learn about the latest processing of the Soviet *Venera* radar maps of Venus. And with the Soviets embarking on an ambitious Mars program, beginning with the *Phobos* spacecraft already en route, US scientists had much to say about continued analysis of *Viking* data. With *Phobos* actually headed toward one of the small martian satellites and the Soviets and Europeans thinking about possible asteroid missions, participants also discussed small, primitive bodies. May the traditions of the microsymposia live on, although future meetings should instead be called "macrosymposia"!

Clark R. Chapman, who found his trip scientifically and culturally rewarding, is happy to report meeting several avid readers of The Planetary Report *in Moscow.*

World Watch

by Louis D. Friedman

CAPE CANAVERAL—On September 29, 1988, at 11:37 am, the space shuttle *Discovery* launched a crew of five and a Tracking Data Relay Satellite (TDRS). The launch symbolized a hoped-for revitalization of the US space program. The flawless launch and subsequent mission indicated that, indeed, the shuttle was ready for return to work and that future launches, albeit on a slower schedule than originally planned, could reduce the backlog of missions in 1989 and 1990.

The *Discovery* mission deployed the TDRS satellite necessary for communications between some Earth-orbital satellites and Earth. The Inertial Upper Stage (IUS) rocket boosted the TDRS to geosynchronous orbit, in which the satellite's orbital period is the same as Earth's rotation, so that the satellite revolves with and appears to hover over a single spot on Earth.

This TDRS is the largest communication satellite the US has ever launched. When it is fully operational, the US will have three TDRS equally spaced in geosynchronous orbit, enabling continuous contact between orbiting satellites and Earth stations.

The shuttle program is scheduled to launch several important scientific missions in the next two years, including *Magellan* to Venus on April 28, 1989; *Galileo* to Jupiter on October 12, 1989; the Hubble Space Telescope to Earth orbit in December 1989; and *Ulysses* to the Sun's poles on October 5, 1990.

MOSCOW—Several weeks after its launch on July 7, 1988, Soviet mission controllers lost contact with the first of their *Phobos* spacecraft on its way to Mars. A flight controller at the Kaliningrad mission control center accidentally sent an erroneous command to the *Phobos 1* spacecraft, shutting off its guidance sensor. The accidental command was one of a long series of commands being sent to update the spacecraft's data system. The single error had catastrophic results.

When the guidance sensor was shut off, the spacecraft was no longer oriented with the solar panels aligned to the Sun, causing a loss of power and loss of the communication link with Earth. Without this link, mission controllers could send no correcting command to the spacecraft, which began to tumble slowly. Without solar power, the instruments could not be kept warm, and so slowly failed.

In the days following the error, mission controllers hoped that the spacecraft might randomly drift into an orientation correctly aligned to Earth so that a command could be sent up to it. To this end, they sent commands continuously from their Crimea tracking station. The NASA Deep Space Network also offered to help. Although gratefully received by the Soviets, this offer was of little use since the command links from the NASA stations operate at frequencies different from those used by the Soviets. After a couple of weeks, all of the instruments would have failed from the lack of power, and thus the spacecraft would be inoperable even if the proper alignment for communications were regained.

The loss of *Phobos 1* is, of course, a serious blow, although *Phobos 2* is still healthy and on its way to Mars. The US suffered a similar loss when the *Mariner 8* mission to Mars in 1971 crashed into the ocean. The *Mariner 9* mission was redesigned so that it eventually accomplished and exceeded the goals of the two spacecraft. Whether the *Phobos 2* spacecraft sequence can be redesigned to accomplish all of the objectives set for both spacecraft is still unclear.

There were some slight differences between the spacecraft. *Phobos 1* carried only the long-lived lander that would have operated on the martian moon for months. Fortunately, *Phobos 2* carries both the long-lived lander and the hopper to sample many sites on Phobos' surface. To accommodate the hopper, two experiments were deleted on *Phobos 2*: studies of neutron radiation on the satellite's surface and radio-based measurements of the martian ionosphere. Also lost was an X-ray camera that would have worked with one aboard the US Solar Max satellite to look at the Sun from different angles, giving scientists their first three-dimensional view.

WASHINGTON—The US Congress passed the 1989 NASA appropriations bill, which was signed into law by President Reagan. The total appropriation for NASA's budget was $10.7 billion.

Included in the fiscal year 1989 budget was a new start for an Advanced X-ray Astrophysical Facility (AXAF)—an X-ray telescope that will enable observations of black holes and galaxies. Planetary exploration received no new starts, although advanced research and development work has begun on a project combining the Comet Rendezvous Asteroid Flyby Mission (CRAF) and the Saturn Orbiter/Titan Probe mission *(Cassini)*. NASA hopes that this project will receive a new start in fiscal year 1990. Preliminary negotiations are now under way with the Office of Management and Budget for this and other elements of NASA's budget.

One casualty of the congressional budget was the planned initiation of NASA's search for extraterrestrial intelligence. NASA had hoped to issue building contracts for the Multi-Channel Signal Analyzer (MCSA), which will be placed on radio telescopes of the Deep Space Network to listen for signals from possible extraterrestrial civilizations. This program, slated to begin in 1992, will now be delayed a year due to a cut in NASA's life sciences program—a cut that also affects research into long-duration life support for interplanetary travel. Pathfinder, the advanced technology program for future human exploration of the solar system, received a new start with $40 million.

The space station received full funding, $900 million. However, Congress added a proviso that more than half the funds must be held in "escrow" until April 1989, pending the new President's decision on whether or not to commit to the space station program.

Louis D. Friedman is the Planetary Society's Executive Director.

 /continued from page 3

Mars: Back to the Frontier by Carl Sagan

Mars is the most Earthlike other world we know. Its hundreds of ancient river valleys point to an earlier epoch that was still more clement. Did life arise on primordial Mars as it did on primordial Earth? Are there fossils or extant life forms awaiting us? How did a warm, wet world become frigid and desiccated? Is there a useful lesson here about climatic instability of Earth? With almost no ozone in the martian atmosphere, ultraviolet light from the Sun strikes the planet unimpeded and, apparently, destroys all the organic matter near the surface. Is this a cautionary tale for us, who are carelessly burning holes in our own ozone layer? Mars is an awesome world with monumental and enigmatic landforms, occasional planetwide dust storms, two tiny organic-rich moons and a surface area equal to all the continents of Earth. It has much to teach us.

But if the exploration of Mars were our only objective, I would recommend sending smart robots—they're much cheaper, they can go to more dangerous locations, and no human lives are risked (although humans are better explorers than any likely robot). For me, the chief reason to send humans is political. The *Apollo* program was fundamentally an American response to the orbital flight of Yuri Gagarin, and a demonstration to the world that the US was fully capable of building rockets that could reliably convey nuclear warheads halfway around the world. The US and the USSR have now booby-trapped the planet with nearly 60,000 nuclear weapons. They have fully demonstrated their talent for mass annihilation. Today, I think, their obligation is different: to demonstrate that they can work together on behalf of the human species; that high technology need not be a gun aimed at our own heads, but a bridge to a new world. Dreams are maps.

There are many other reasons for human missions to Mars, and they are listed in The Planetary Society's Mars Declaration. One that I find compelling is revitalizing a dispirited and unravelling NASA. Virtually all NASA's historic expeditions of exploration and discovery—*Apollo*, *Mariner*, *Surveyor*, *Lunar Orbiter*, *Pioneer*, *Viking*, *Voyager*—were carried out, or at least designed, under the umbrella of the *Apollo* program. But since 1978, long before the *Challenger* disaster, NASA has not launched a single mission—not one—to the Moon or planets. The Mars goal provides a coherent focus for the US civilian space program, including precursor robotic missions to Mars, its moons and other worlds; space science in general; long-duration human spaceflight in microgravity and in "artificial" gravity; forecasting solar flares; and giving a crisp set of objectives for the long-delayed US space station. It unifies NASA's diverse constituencies—field centers, industry, science, technology and a public longing for a grand exploratory vision.

Naturally, there are some objections (O), but I think they all have answers (A).

O: A human mission to Mars is too expensive.

A: It is estimated to cost as much as a single major strategic weapons system.

O: The Russians will steal our technology.

A: Since the USSR is about a decade ahead of the US in long-duration human spaceflight, has been spectacularly successful in its recent Venus and Halley's Comet missions and has a launch booster far more powerful than any American rocket now available, technology transfer, if it occurs, is likely to flow both ways.

O: NASA isn't ready for such ambitious cooperation; it could be a technological embarrassment for the US.

A: With a presidential endorsement and congressional support, NASA will again be capable of legendary achievements.

O: We'll be left high and dry if the Russians pull out midway through the project.

A: We proceed by slow steps—exchanging scientists on the *Phobos* and *Mars Observer* robotic missions, designing collaborative but largely independent balloon, rover and sample return missions. We have plenty of time to build mutual confidence.

O: If we're going by slow steps, let's establish a lunar base first. We can use it to test Mars hardware.

A: For exploration and science, for the technical and human challenge, and in terms of public interest, Mars is far more interesting than the Moon. Mars hardware can be better tested in Earth orbit and on Earth. With finite resources, commitment to a lunar base is likely to delay the Mars goal for decades.

O: If we're after major cooperative projects with the Soviets, why not do them here on Earth?

A: This is the means to bring such projects to pass, as the Soviets have stressed.

O: Such a commitment will make strategic confrontation between the superpowers more difficult.

A: Exactly.

O: Considering what we're doing with *this* planet, can we be trusted with another?

A: This is an open question. But making peace with our enemies, transforming nuclear-armed missiles into vessels of exploration, turning hatred and suspicion into cooperation suggests a hopeful answer.

During the Washington summit last December, General Secretary Gorbachev was asked what could be done to heal the wounds that divide our two nations. His immediate answer was a joint US/Soviet human expedition to Mars. With prior and subsequent endorsements of the idea by leading presidential candidates of both parties, a bill passed by the House to begin establishing the bureaucratic machinery for joint Mars exploration, and a stunningly ecumenical range of American leaders signing the Mars Declaration, there seems to be a chance of actually achieving this dream in the next two decades.

There's plenty of housework to be done here on Earth, and our commitment to it must be steadfast. But we're the kind of species that needs a frontier. Every time humanity stretches itself, turns a new corner, it receives a jolt of productive vitality that can last for centuries or millennia.

There's a new world next door. And we know how to get there.

Carl Sagan is the David Duncan Professor of Astronomy and Space Sciences and Director of the Laboratory for Planetary Studies at Cornell University, as well as President of The Planetary Society. In 1984, Dr. Sagan was first to advocate a joint piloted US/Soviet expedition to Mars.

SOCIETY *Notes*

PLANETARY SOCIETY GREETING CARDS

All US members of The Planetary Society have received an offer for a box of sixteen greeting cards featuring four images from space: the Earthrise from the Moon, Jupiter's Red Spot, the plains of Mars, and Saturn. The cards are sent to all members unless they specifically ask not to receive them. Donations are requested, but members are under no obligation and should feel free to use these cards. Those who do donate can be assured that their gifts will help further the Society's many projects and programs. We welcome your feedback about this new offer.—*Tim Lynch, Director of Programs and Development*

COMPANIES MATCH EMPLOYEE GIFTS

The Planetary Society thanks the following companies for donations received through their Matching Gift Programs: Atlantic Richfield; Cray Research; Digital Equipment; the Equitable Foundation; General Dynamics; Household Finance; John Hancock Life Insurance; Martin Marietta; Morton Thiokol; Newhall Land & Farming; Pepsico; Pfizer; Philip Morris; Quaker Oats; RCA; Security Pacific; Target; Thrifty Corporation; Transamerica; TRW; United Banks Service Company; Olin Corporation; and Westinghouse.

Matching Gift Programs offer our members an exceptional opportunity to double their donations by having their individual contributions matched by gifts from their employers. We urge you to encourage your company to participate.—*Lu Coffing, Financial Manager*

REGIONAL EVENTS CALENDAR

A regional calendar of space-oriented events, including but not limited to Society-sponsored activities, is now available to our members. Write to me c/o The Planetary Society to add to the calendar or to request a copy.—*Susan Lendroth, Manager of Events and Communications*

GEARING UP FOR PLANETFEST '89

We're already making preparations for Planetfest '89, The Planetary Society's celebration and educational outreach program to be held in conjunction with *Voyager 2*'s encounter with Neptune in August 1989. Make your travel plans now! For more information about how you can become involved, write to me c/o The Planetary Society.—*Angela Brown, Planetfest Coordinator*

MODEL OF THE UNIVERSE UNVEILED

New Millennium Committee member George Awad has created an ambitious and remarkable model of the universe. Approximately 75 by 30 feet, with a number of discrete models showing galaxies, star systems, planets, moons, sections of planets and the like in a series scaled by the powers of ten, the model was first unveiled at a Society gathering in New York City in the spring. Organized by the New Millennium Committee, the event helped raise funds for the Society's International Space Art Project.—*Tim Lynch*

"INVENT AN ALIEN" CONTEST

The Graminia Community School in Winterburn, Alberta, Canada will receive a satellite dish and a VCR thanks to the prize-winning efforts of students Jim Foufas and Jeff Smith in this year's National Invent an Alien Contest. The Planetary Society is providing the award. The contest is organized by the National Museum of Science and Technology in Ottawa.—*Donna Stevens, Assistant Editor*

EDBERG HONORED

The Board of the Astronomical Association of Northern California recently presented an award to Stephen Edberg recognizing his support of amateur astronomy. Mr. Edberg's previous work in coordinating amateurs for the International Halley Watch and his volunteer role as The Planetary Society's Mars Watch '88 Coordinator were major factors in his selection.—*Barbara Bowman, Volunteer*

MARS MANIA

Kudos are due to the many faithful Society volunteers around the globe who worked so tirelessly to organize Mars Watch activities in their areas. Activities were greeted enthusiastically by members and nonmembers alike, and some participants peered through a telescope for the first time. Astronomical organizations cosponsoring events with The Planetary Society reported that attendance at least doubled due to our support and publicity. Northern California alone had 24 separate events and over 7,000 people attending. Requests for Mars Watch information packets flooded into the Society's offices from areas as diverse as Iran, Tahiti, Ghana, Italy and Australia.—*Marshalle Wells, Volunteer Network Coordinator*

INTERNATIONAL SPACE UNIVERSITY

The International Space University, a graduate-level program in fields critical to the space industry, will hold its 1989 summer session in Europe. Applicants should hold a bachelor's degree or higher and be fluent in English and at least one other language. To apply, contact: The Director of Admissions, International Space University, 636 Beacon Street—Suite 201, Boston, MA 02215. (Please indicate your nationality in your request.) The application deadline is January 20, 1989. —*Susan Jundanian, Copy Editor*

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Questions & Answers

When* Voyager 1 *crosses the heliopause [the outer edge of the Sun's sphere of magnetic influence], will it be able to send back a photo of the solar system as a whole?
—Bill Porter, Acworth, GA

As the two *Voyager* spacecraft continue to fly outward in the solar system, communication distances become almost unimaginably large. Unfortunately, after the early 1990s, transmitter power on *Voyagers 1* and *2* will be too weak to permit the high rates of data transmission required to return images. Furthermore, since the radioactive power sources on the spacecraft continue to decay with time, the cameras will be shut off in mid-1990 to allow more important and less demanding instruments to continue operating. *Voyager 1* is not expected to reach the heliopause until 2020, so images after that time will be impossible.

An additional problem imposed by the *Voyager*'s increasing remoteness is the inner planets' closeness to the Sun. Even at the great distances of Neptune and Pluto, the Sun is bright enough that if it illuminates the front lenses of the cameras, scattered sunlight completely ruins the pictures. We have tried recently to maneuver the spacecraft so that the cameras remain in the shadow of *Voyager 1*'s large dish antenna while obtaining images as close to the Sun as possible. At present, we cannot use this procedure to view planets any closer to the Sun than Mars! The "picture of the century" (a photo of the whole solar system) will have to be saved for the 21st century and later spacecraft better adapted for that task than *Voyager.*
—ELLIS D. MINER, *Jet Propulsion Laboratory*

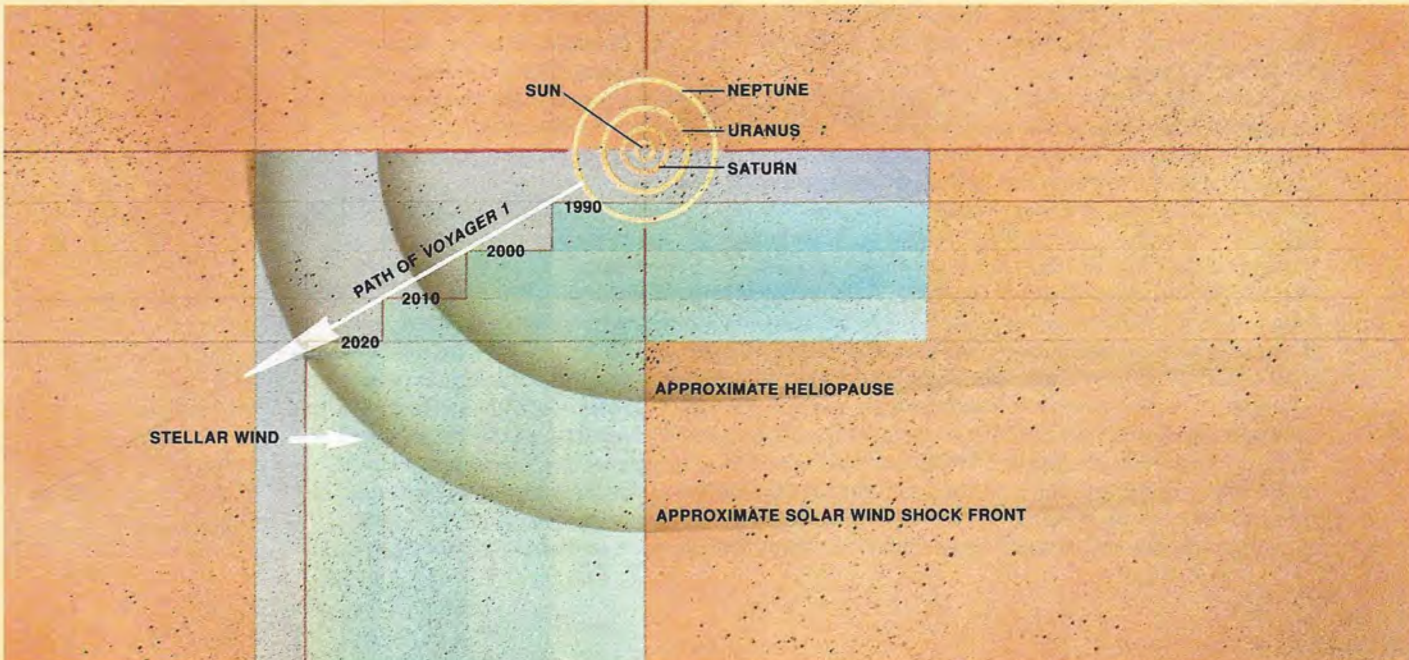
Please describe the process by which a small object wandering through space at high speed can be "captured" by a large object and become its satellite.
—James M. Little, Welwyn Garden City, England

Capture refers to the process in which two initially independent bodies become gravitationally bound to one another. Often one body is much smaller than the other. Hence we speak of a planet capturing a satellite. The small outer satellites of Jupiter (as opposed to the large Galilean satellites Io, Europa, Ganymede and Callisto) are widely thought to be captured asteroids.

For a planet to capture a satellite that wanders too close there must be a loss of energy. For natural bodies, atmospheric drag or collisions are possible causes of energy loss, whereas we use the thrust of a rocket engine (or controlled atmospheric braking) to capture spacecraft. The Soviets will capture their *Phobos* spacecraft into orbit around Mars by rocket braking next January.

Gravitational encounters are like a frictionless roller coaster ride. Imagine that your car has just come over the roller coaster "hill" and is plunging into the trough that leads to the next hill equal in height to the first. If there is no friction or wind resistance (energy loss mechanisms), your car will have the same speed at the top of the second hill that it did at the start of the ride. (If you come to rest momentarily before beginning the heart-stopping fall, then your car will just come to rest at the top of the second hill.) Now, if there is enough friction and wind resistance so that your ride doesn't quite carry to the next crest, then you will slide backward into the trough, oscillating ever lower until the car stops at the bottom of the trough. However, if the car is moving fast enough at the crest of the first hill, it will have enough energy so that the losses by friction and wind can't stop it before topping out at the second hill.

A passing asteroid will encounter a planet and will depart from the planet



with the *same* relative speed unless energy is somehow lost. The greater the energy loss, the higher the encounter velocity can be and still have capture. Furthermore, if orbital energy continues to be lost once capture has taken place, the captured body's orbit will continually decay, leading ultimately to an impact with the planet.

In certain cases involving low velocity approaches, the forces of gravity alone can cause a temporary capture. For example, comets can be captured into orbits around Jupiter (but still far from the giant planet) due to the combined gravity of Jupiter and the Sun. However, after a time, the Sun's gravity will help the comet escape from Jupiter and resume its heliocentric (Sun-orbiting) wandering.

Gravitational capture is an uncommon occurrence. Many small asteroids have had close encounters with Earth over geologic time; some have even struck our planet, but none, so far as we know, has ever been captured to become a new satellite.

—DON DAVIS, *Planetary Science Institute*

Phobos, Mars' small, inner satellite, has an unusual orbit. It revolves around the Red Planet more than three times during one martian day at a very close distance. What causes Phobos to have such a unique orbit?
—Keith M. Warnock, Olympia, WA

We don't really know why any object is in a particular orbit; what we try to do is work back from what we see to some reasonable origin. Tidal forces (the stresses on a celestial body caused by the gravitational pull of another body) from a parent planet cause satellite orbits to change. Unfortunately, the rates of change can't be predicted with present knowledge, even for our own Moon. But we can easily work out the orbits' directions. Our Moon and Deimos, as well as most other moons, have orbital periods longer than the day of their parent planet, and the tidal effects tend to push them along. Since they are in orbit, the extra energy goes into making the orbit bigger, and the speed actually decreases while the period increases.

Phobos is in just the oppposite state: its orbital period is between seven and eight hours, less than a third of a martian day, and the tidal drag acts to speed up Mars' rotation and causes the moon to spiral inward. Artificial satellites behave the same way, with the principal drag in that case being due to the atmosphere.

We can theoretically run this evolution backward and find that both Mars' moons could have started in orbits with periods very near one martian day, with Phobos just inside and Deimos just outside. This distance would have been about 20,400 kilometers, while the present distance of Phobos is about 9,378 kilometers.

None of this answers the question of how either moon got into its original orbit. I like the idea that they may have been small asteroids, captured initially by gas drag in a primitive and transient martian atmosphere. However, they may have accreted in orbit or have some other origin entirely.

—DON HUNTEN, *University of Arizona*

The following letter is in response to a question and answer that recently appeared in this column:

On page 20 of the May/June 1988 issue of The Planetary Report, *Darlene Waddington asked whether* Voyager 2 *could go to Pluto. If things had gone as originally planned, it would have.*

The NASA fiscal year 1973 budget request included the Grand Tour project consisting of two missions, the first to go from Jupiter to Uranus to Neptune (JUN) and the second to go from Jupiter to Saturn to Pluto (JSP). Two spacecraft were requested for each mission. The beauty of the JSP mission was that it passed beneath Saturn, allowing a close encounter without risking collision with any debris near Saturn's rings. The JUN and JSP missions took full advantage of the rare Grand Tour opportunity to visit all five outer planets.

The President's Office of Management and Budget (OMB) readily approved the Grand Tour Project but cut other funds from the NASA budget request. Acting under what I consider poor advice, NASA's top management responded by deleting the Grand Tour in exchange for restoring some of the cut projects. The OMB was so surprised that it made a rare offer to add more funds to the NASA budget if NASA could come back with a Grand Tour of somewhat reduced cost. Voyagers 1 *and* 2 *were the result, and what a great bargain they have been!*

—ROBERT S. KRAEMER, NASA's Director of Lunar and Planetary Exploration, 1970-76

FACTINOS

Two recently discovered comets, Levy and Shoemaker-Holt, may be two halves of one parent body. Astronomers have found their orbits to be almost identical. Comet Shoemaker-Holt is traveling 76 days behind Comet Levy on the same path.

In February astronomers using the 2.2-meter telescope on Mauna Kea in Hawaii found that Comet Wilson, discovered in 1986, had also split in two.
—from *Space Today*

○

Since its discovery in 1949, not much has been known about Nereid, Neptune's smaller moon, except that its highly eccentric orbit takes it between 1.4 and 9.7 million miles from its parent planet. However, Martha and Bradley Schaeffer of the Goddard Space Flight Center find that Nereid is more of an oddball than previously thought.

In the June 2 issue of *Nature* they reported that detailed photometric measurements of Nereid's reflected light taken in June 1987 showed the moon's color spectrum to be unusual compared to that of any other asteroid or satellite. Moreover, Nereid's brightness varied by a factor of four during their observations. The Schaefers think that one cause of this variance might be that Nereid is irregularly shaped; however, they estimate the moon's size to be 660 kilometers, and theorists believe the gravity of any object larger than 400 kilometers makes it spherical.
—from Stefi Weisburd in *Science News*

○

Jeffrey L. Bada and Stanley L. Miller of the University of San Diego say they have quashed a popular idea that primitive life originated in volcanic hot water vents on the ocean floor.

The researchers have examined the chemical reactions the theory requires and concluded that it was just not possible for the precursors of life to have been synthesized in the heat and high pressure of the vent areas. Bada and Miller experimented with the amino acids, peptides, nucleotides, sugars, proteins and other molecules essential to life and found that they rapidly disintegrate in the 350 degree Celsius temperatures common in the vents.

"This is probably *the* most unlikely area for the origin of life to occur," says Bada.
—from Linda Roach Monroe in the *Los Angeles Times*

The Solar System in Pictures and Books

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Ron Miller is a former art director for the Albert Einstein Spacearium at the National Air and Space Museum in Washington, DC. He lives and works in Fredericksburg, Virginia.

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