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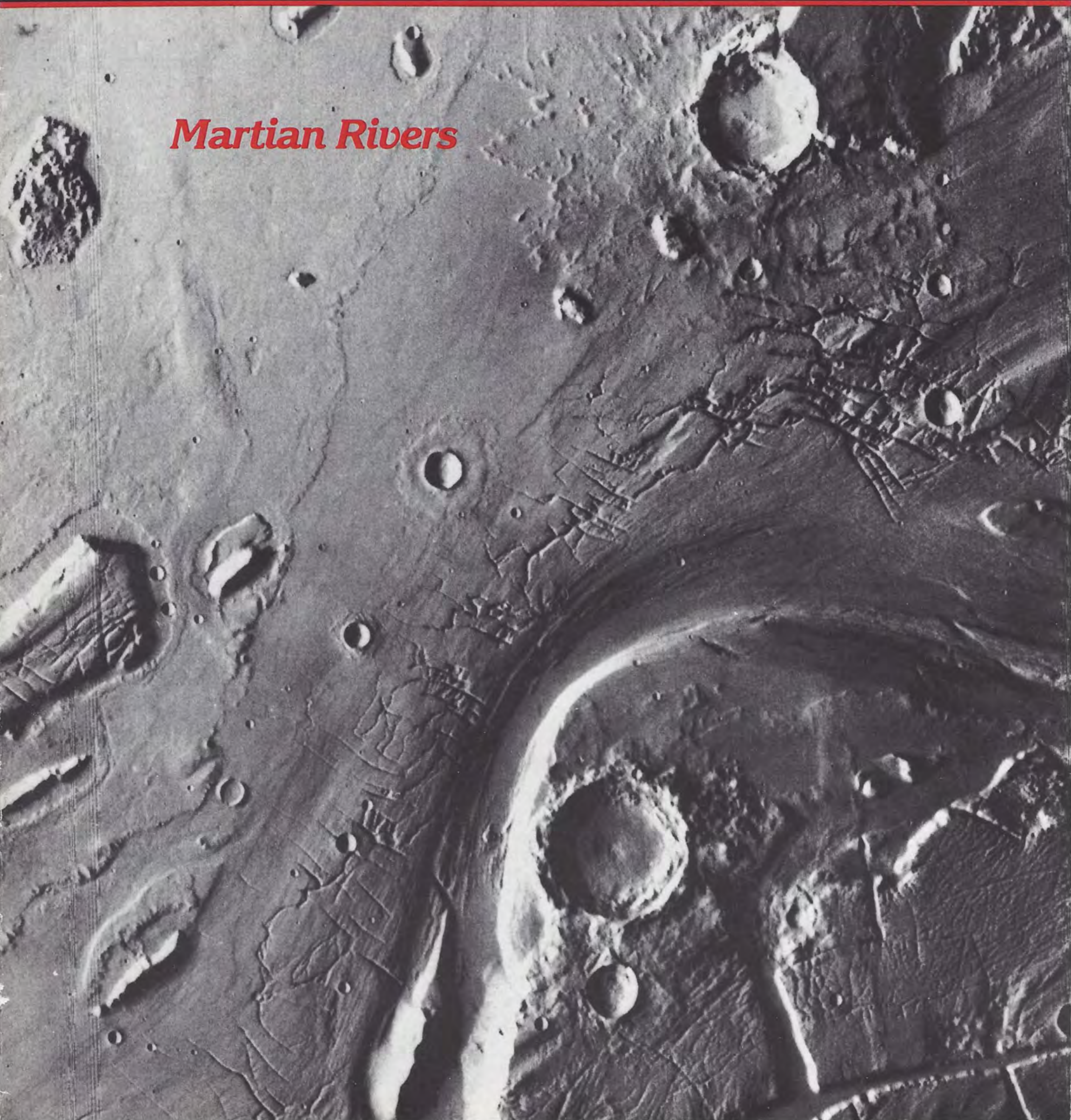

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Cover: Viking Orbiter images suggest that rivers may once have flowed on Mars. Erosive features such as scour marks and teardrop-shaped islands, seen in this section of the Kasei Vallis Channel, indicate sculpting by liquid water. The impact crater at the bend of the channel is 25 km. across.
Photo: JPL/NASA

Where Next for The Planetary Society?

by Bruce Murray

Dr. Bruce Murray, Vice President of The Planetary Society, spoke at the Society's commemoration of the flight of Mariner 2, *the first spacecraft to encounter another planet, held last December in Washington, D.C. The following remarks have been taken from his address:*

The first exploration of Venus by *Mariner 2* was important enough to warrant our gathering here in Washington twenty years later to commemorate it. The Planetary Society exists to continue that kind of human achievement into the future. Tonight I would like to talk briefly about the present status of the Society and to convey some thoughts on its future direction.

What is The Planetary Society? You read about it in *The Planetary Report,* but really, what is it? Well, to me, it is foremost an intercommunicating network of diverse individuals who are bound together by a powerful unifying belief: that reaching out to explore our solar system and other solar systems in search of our analogs is a good thing to do.

People come to that belief in many ways. To some it is almost a religious conviction. Some see planetary exploration in terms of historical determinism. Others value it as an important attribute of contemporary society. Whatever the belief, The Planetary Society brings together the most interesting mixture of hawks and doves, of rich and poor, of old and young, of male and female, in any organization that I know.

This group of people and the organization they compose can be characterized in several dimensions. They must be future-looking, or they're wasting their time. They value the positive aspects of major technological endeavors. They see The Planetary Society as providing continuity of the past into the future. They place a premium on imagination and innovation. Together, all of us in The Planetary Society feel that we are contributing to an expanding spiritual and intellectual process of tremendous long-term importance. The Planetary Society has grown to over 100,000 dues-paying members in less than three years, testifying to the success of this intercommunicating network.

Well, then, where next? The Society obviously has done very well in attracting members and in establishing *The Planetary Report* as an extremely effective communication mechanism. We are now beginning to support interesting new research and to develop innovative programs to motivate young people to scientific achievement. These are things which must be continued and expanded; so we shall.

However, it is important to realize that space exploration originated in the nationalistic rivalry between the Soviet Union and the United States. Now planetary exploration is evolving into a more truly international enterprise. Hence, the Society can and should reach out to become a global enterprise itself. Carl and I have spent a good deal of time during the past year developing international contacts and trying to find the keys to relationships with different nations and different cultures. Academician Roald Sagdeev of the U.S.S.R. has joined our Board of Advisors, providing evidence of the international significance of the Society.

If there is going to be intercommunication about planetary exploration among the people of the world, The Planetary Society must expand the number of communicants. We must effectively reach across cultural and political differences to bring people together internationally as successfully as we've been able to bring them together nationally. So an international extension of the Society is our major new focus. We already have preliminary organizational efforts under way in England, Holland and Canada — countries where English language publications can be easily used. Tentative interactions have begun with scientists and others in the Soviet Union, China, France and Japan. So far, we are encouraged that intercommunication through The Planetary Society can be made significantly trans-national. It really does seem possible for The Planetary Society of the future to be truly worldwide.

I would like to imagine that by 1992, *Mariner 2's* thirtieth anniversary, The Planetary Society will have become an international symbol of the world's faith in its own future. By that time, we hope, the nationalistic energy and drive that led to the burst of exploratory efforts in the 1960's and 70's will have been replaced by a global surge of energy and drive — and willingness to live together — sufficient to make planetary exploration and the search for extraterrestrial intelligence truly a worldwide enterprise.

SETI and The Planetary Society

by Carl Sagan

Among the principal objectives of The Planetary Society are the encouragement of major new programs in the spacecraft exploration of the planets and in the Search for Extraterrestrial Intelligence (SETI). Spacecraft planetary expeditions typically cost hundreds of millions of dollars and are obviously beyond the resources of a membership organization like The Planetary Society, no matter how successful we become. Here, our role is to encourage governments and the public to organize such missions, and ourselves to support critical studies and spacecraft data analyses that are not otherwise being pursued. But SETI is different. Using existing radio telescopes, new electronic and computer technologies, and by encouraging the best minds in the field, it is possible for an organization like The Planetary Society to make a major contribution – not just in setting the climate for such a search, but in actually conducting one.

There is no question that the receipt of a signal from an advanced civilization on a planet of some other star would be a momentous event in human history, and a distinguished international and multi-disciplinary group of scientists has urged that such a search program begin now. The Society has played a key role in organizing this statement (to be published in the next issue of *The Planetary Report*) and in convincing members of Congress to support a long-term SETI search program proposed by the National Aeronautics and Space Administration. But there is an additional and quite remarkable opportunity that the Society now has before it.

The Planetary Society has been supporting the important work of Paul Horowitz, Professor of Physics at Harvard University. Along with Calvin Teague, Kok Chen, and Ivan Linscott, Horowitz has designed and constructed a new signal analyzer, which simultaneously listens to 128,000 adjacent frequencies or channels in the radio spectrum. This is the most advanced such signal analyzer ever constructed. In a SETI program, we do not know beforehand which stars to examine, so we must slowly and laboriously scan the entire sky. We also do not know what frequencies to listen to, although there are a few characteristic or "magic" frequencies, determined by the laws of physics, and (we hope) obvious to an extraterrestrial transmitting civilization as well as to ourselves. But these "magic" frequencies really correspond to broad regions of the radio spectrum. A very sharp, narrow-band signal would immediately stand out as something that could not possibly be generated by some natural process. It would be a clear indication of intelligent origin. The new signal analyzer permits us to examine 128,000 adjacent narrow-band channels in the vicinity of any chosen magic frequency.

The analyzer has now been tested on the Arecibo radio telescope, the largest steerable radio telescope in the world. In 1982 the telescope was pointed to 250 of the nearest stars like the Sun. No signals of intelligent origin were detected, but we did not expect in so short a test to be so lucky. We estimate that something like a million stars must be examined before we have a fair chance of success, even if extraterrestrial civilizations beaming radio signals to their less advanced neighbors are fairly common in the Milky Way galaxy.

Accordingly, The Planetary Society has committed itself to support – morally, intellectually, and financially – a multi-year search program using the new signal analyzer at Harvard University's Oak Ridge Radio Observatory. The search will be supervised by Professor Horowitz, who is without a doubt one of the leading and most innovative figures in the design of such instrumentation. More details on the project, including an article by Professor Horowitz, will be published in a forthcoming issue of *The Planetary Report*.

We think it is very appropriate that a search program of this importance should be supported by the contributions of tens of thousands of people throughout the world. But for our organization, the commitment represents a significant amount of money. Therefore, we urge you to make whatever additional contribution to the Society you are able to afford in support of the Search for Extraterrestrial Intelligence.

BULLETIN

Professor Paul Horowitz has just announced that the SETI program using the new signal analyzer will begin on March 7, 1983 at Harvard University's Oak Ridge Radio Observatory.

Name The Planetary Society's SETI Project

The program on the search for extraterrestrial intelligence (SETI), being carried out under the direction of Professor Paul Horowitz with The Planetary Society's support, needs a name. This name should be appropriate for the project, easy to pronounce in English and other languages, and have no confusing associations. Project Haystack, for example, would be a good choice, because SETI is very much like looking for a needle in a haystack; however, there is already a Haystack Observatory in Massachusetts run by a consortium of universities, and not dedicated to SETI. Project Argus evokes the creature in Greek mythology with a thousand eyes, suggesting the more than 100,000 channels of our search program. But there was a project Argus to examine the effects of the explosion of nuclear weapons in the upper atmosphere some decades ago. Project Starcall carries a sense of an interstellar message, which is desirable; however, it seems to suggest that we are calling rather than receiving. The Planetary Society would like the help of its members in choosing a suitable name for this project. The winning selection will be chosen jointly by Drs. Horowitz and Sagan, and the winner will receive a commemorative plaque bearing the name of the new SETI project and a set of SETI books selected by Bruce Murray and Carl Sagan.

The Ancient Rivers of Mars

by David Pieri

These valley networks (right) are among
Here tributaries can be seen down to the
Networks such as these provide the most
by running water on the Martian surface.

Mars today is a cold, dusty little world with few amenities to recommend it, even to the hard-bitten field geologist. Summer daytime temperatures at the equator only occasionally rise above freezing; at other times temperatures plunge to hundreds of degrees below zero Fahrenheit. The brutally cold Martian winters are twice as long as those on Earth. Mars' atmosphere is a hundred times thinner than the Earth's and so thin that water will go directly to the gas phase from ice, without becoming liquid. If exposed to Martian surface conditions, liquid water would rapidly boil away.

Despite these inhospitable present conditions, we think that Mars once had rivers. Dry riverbeds were one of the most unexpected finds of the *Mariner 9* mission to Mars. And these are not just normal everyday riverbeds; Martian riverbeds are larger than any of the largest similar features on Earth. The largest terrestrial river channels were formed by the bursting of massive glacier-ponded lakes which stretched from the present-day state of Washington into Montana. Huge riverbeds on Mars are typically ten times longer, wider and deeper.

These features were called "channels" by their startled discoverers, a terminology harkening back to the days of the early Italian Mars observer Antoniadi, whose use of the term "channel" (*canali* in Italian) for faint dark markings seen telescopically on Mars led to confusion among English-speaking students of the red planet. That confusion was not helped by Percival Lowell's unabashed use of the word "canal" and his speculations about an indigenous Martian civilization's having undertaken a global irrigation program.

Real Martian Channels

Mariner 9 discovered that there are indeed real, natural Martian channels, thousands of them, ranging in morphology and size from diminutive branching networks perched on the rims of craters and basins to massive, deep, sinuous cuts with huge streamlined craters tens of kilometers in diameter lying inside them. These channels, up to a hundred kilometers wide and a thousand kilometers long, reveal evidence of the movement of tremendous masses of material down their courses. Scientists have debated about the nature of the scouring material, but most now believe that massive floods formed the largest features, while groundwater seepage and even rain may have cut the smaller branching networks. All of these hypotheses face formidable problems in trying to explain the channel and valley features. Currently, investigators are grappling with a still unanswered basic question about these channels, valleys and the rivers that may once have filled them: Where did the water come from and where did it go?

To attempt to answer the first part of our question we must look back in time to the formation of the planet. Mars, orbiting farther from the Sun than Earth, condensed from the solar nebula in a much colder environment. Volatiles such as water vapor should have been more abundant at the orbit of Mars than at the Earth's. As a result, more volatiles were probably included in forming Mars than in the Earth. But was water necessary to carve the channels? Could some other process or combination of processes have done the job? Is a fluid even needed? Let's look at the evidence and decide.

The largest of these possibly fluvial features are the large channels. These huge, sinuous features extend over tremendous distances and cut deeply into the Martian surface. Their interiors show the results of an erosive process which carved obstacles on the channel bed into streamlined forms and cut grooves into the channel floors. We see similar features in the channeled scablands of eastern Washington where glacial Lake Missoula ravaged the landscape on its way through the Columbia River Valley to the Pacific Ocean. Gigantic coulees — dry channels — and falls are carved with grooves meters deep. Other areas were damaged as house-sized pieces of basalt were ripped up by whirlpools with the force of giant tornados. Sandbars (actually made of gravel in this area) have ripples spaced a kilometer apart, dwarfing anything similar in other

the best developed on the planet.
limiting resolution of the picture.
convincing evidence for slow erosion
PHOTOS: JPL/NASA

This is the source of the large channel Mangala Vallis. The channel appears to start in a linear, down-faulted valley (bottom), then extends northward for several hundred kilometers, cutting a channel 100 kilometers wide in places. The flow diverged around two craters (top) and cut several streamlined islands.

streams on Earth. On Mars, at the scales seen from orbital photographs, the channels display many of the same features seen in these terrestrial flood channels. However, they are about five to ten times larger. By analogy we can argue that Mars also experienced massive floods of magnitudes far greater than those visible in the geologic record here on Earth.

Floods or Winds?

Not everyone who has looked at these features in *Mariner 9* and *Viking* Orbiter images agrees that massive flooding formed these channels, or ever happened at all. Some investigators draw attention to the similarity between the streamlined obstacles in the large Martian channels and the large streamlined features found in one of the driest areas of the world, the Peruvian Altiplano. There, large hills called "yardangs" are sculpted into streamlined shapes by persistent and powerful winds. Under these conditions, hills tend to line up with the prevailing wind direction and, seen from orbit, such hill-sets may appear as grooves. These areas are, however, generally quite broad and don't usually have the tightly sinuous and incised appearance of many of the large Martian channels.

Furthermore, the streamlined obstacles on Earth are usually pre-existing topographic highs, such as hills, and there is usually not any well-defined erosion of channels by the wind. Usually, the wind cuts and lowers topography over a broad area and creates what are called "deflation hollows" – broad areas of shallow relief where winds may have removed tens of meters of material. Famous examples of this process occur in the Gobi Desert and in Egypt. Neither of these areas has features that much resemble the large Martian channels. On the other hand, if the channels were carved by some other process, Martian winds, which seem persistent and strong, could well have sculpted and eroded these already extant chasms. Perhaps slope-generated winds are triggered by the existence of the kilometer-or-more deep channels.

Other investigators, also not captivated by the Martian diluvialists, will admit that water is indeed the most likely substance to have carved these channels on Mars, but argue about its form. They claim that rivers of ice cut the Martian channels and point to ice streams in glaciers on Earth and the abundant evidence of Pleistocene glacial erosion as analogies. Features such as streamlined rock obstacles and streamlined sedimentary deposits called "drumlins" are consistent with glacial erosion. Martian channels may occasionally exhibit similar morphologies, but they also have tight curves and streamlined features more consistent with a fluid viscosity nearer to liquid water than to ice. In viscosity and degree of turbulence, a slurry of water and mud best fits a proposed physical model developed from quantitative studies of the high-resolution *Viking* Orbiter images.

Finally, and somewhat on the fringe of opinion, there are those who have suggested that exotic fluids have carved the channels. Liquid organic chemicals and liquid carbon dioxide have been mentioned. The former suffers from problems of abundance and the latter from too low a pressure, even though it is remotely conceivable that there is enough CO_2 on Mars.

In summary, it seems that we need a relatively low-viscosity, highly turbulent fluid, mixed with sediment that can scour obstacles and cut deep channels. From the standpoint of cosmic abundance and fluid mechanics, liquid water is the most likely candidate to have shaped the Martian channels. Nevertheless, puzzles abound, especially the problem of the source for the immense amount of water needed to carve these channels. This is perhaps the most enigmatic part of the story: many kilometers deep and tens of kilometers wide, the channels spring forth from small, chaotic, jumbled areas resembling semi-circular amphitheaters. How could such massive flows, estimated to have been on the order of one hundred million cubic meters per second, emanate from relatively confined areas not much wider than the channels themselves and only as deep, with no indication of drainage basins or any other sustaining source

This Landsat image, covering nearly 20,000 square km. in eastern Washington, shows the effects of the great Missoula flood of the Pleistocene. When an ice dam broke, floodwaters stripped the soil off the Palouse plains and plucked out cavities in the underlying Columbia basalts. These are the only flood channels on Earth whose size compares with that of the Mars channels. Photo: EROS Data Center

This branching network is part of 800- deeply cut into lava plains, and resembles groundwater seepage rather than runoff.

areas? The clue may lie in the study of some obscure deep-sea channels in the Gulf of Mexico.

Clue from Earth

Recent advances in side-scan sonar have allowed scientists to create visual images of the sea-floor with sound waves. Although nearly three-quarters of the Earth is covered by water, compared to the continental environment the marine landscape is relatively unknown. Some of the largest unexplored tracts on any of the terrestrial planets lie beneath the seas of the Earth. Off the coast of Louisiana lies a sloping deposit of sediment called the Mississippi pro-delta. As the name implies, it is an extension of the Mississippi River delta. Much of the offshore oil drilling in the United States occurs in that organic-rich pile of mud. It is well-populated with drilling rigs subject to the stresses of ocean storms and wave action, but more important for our purposes and for the men who work on the rigs, to instabilities in the sea-bed itself.

Organic matter decays within the sediments, producing methane gas. The methane rises through the deposit and exerts a small but significant upward pressure, counteracting the force of gravity. When that pressure exceeds the weight of the overlying sediments, and when the geometry is right, the cohesive forces in the sediment fail and the affected mud begins to slide, taking along whatever happens to be resting on it – including an occasional oil rig. As the sediment fails, the subsiding mud is at once the load of the flow and the flow medium itself. As the flow moves downslope, the zone of failure moves upslope causing more material to slide down the landslide channel. Such a channel has no discrete source region because the channel is its own source of sediment and fluid.

There is a compelling morphological similarity to the large Martian channels that suggests a simple explanation. Perhaps the upper kilometer or so of the Martian surface possesses a large component of ground-ice or even subsurface liquid water (accumulated over a long time by the melting of ice by geothermal heat). Given some kind of disturbance, for example a marsquake or a meteorite impact, water could begin to flow with fine-grained sediment entrained – essentially a gigantic mud flow. If there were enough water, the volume of the affected region would be reduced and the flow would become self-propagating. In effect, the surface would fall into itself. Only the most headward upstream areas would actively supply fluid and sediment, and that zone would propagate rapidly upstream, creating a channel in its wake. The headcut would be a mass of chaotic debris merging to a more flow-dominated smooth channel as one looked downstream. This type of morphology is very close to what is observed in many large channels on Mars.

Where Does It Go?

Where the material goes when it is released is another unanswered question. Do deltas form as on the Earth? If so, why, with very few exceptions, are no depositional features found at the mouths of channels? There may be a couple of answers. On Mars, because of the low gravity, suspended sediment settles more slowly relative to its speed downstream, and thus stays in suspension several times longer than if that same stream were flowing under the gravity of Earth. Martian deltas should be thinner and more diffuse than those on Earth; as a consequence, such deposits may be harder to see from orbit around Mars than if we were looking at the Earth from a similar vantage point.

Additionally, much of the Martian surface upper layers, called regolith, may be composed of sediments originally deposited by the wind. When such material is deposited by a flood, the wind quickly disperses it again, since its particles are still precisely the right size for wind transport. Furthermore, most of the large Martian channels open into low-lying basins; volcanic flows may have covered up earlier fluvial deposits. Unfortunately, in many cases it is difficult to tell whether the channel has flooded over the volcanic

kilometer-long Nirgal Vallis. The valley is terrestrial river valleys that form mainly by
PHOTOS: JPL/NASA

The origin of these channels, lying near volcanos in Elysium, is puzzling. They do not form regular drainage networks like those in the preceding image, nor do they scour broad areas of terrain like the outflow channels around Chryse Planitia. They may have formed by episodic melting of ice by the Elysium volcanos.

unit or was itself covered.

The other part of the question which we originally posed – where did the water come from and where did it go? – is even more uncertain. Mars undoubtedly underwent intense meteorite bombardment up until the waning days of its formation. Because Mars was volatile-rich, volcanic activity probably outgassed large amounts of water vapor and carbon dioxide to combine with the remnants of an early atmosphere. Thus, in the earliest periods of Martian geologic history, its atmosphere was probably much thicker than it is today. In this relatively warm and wet environment, surface water, perhaps even open bodies of water in large impact basins such as Hellas or Huygens, may have been possible. Many of the channels and valleys on Mars are arrayed around, and even cut through, such basins. Even rainfall may have been possible, although evidence of any such pluvial period is not obvious in the spacecraft data. With liquid water mobile at the surface and in the subsurface during this ancient epoch, erosion, seepage, and migration may have occurred. Eventually, substantial volumes of water may have accumulated in the lower areas, perhaps in giant aquifers. During this period, however, the relatively small planet was unable to hold its atmosphere, and rapidly lost it to space. The surface was beginning to cool, freezing much of the water into a very porous rock ground up by the impacts of meteorites and sorted in size by wind.

Warming Mars

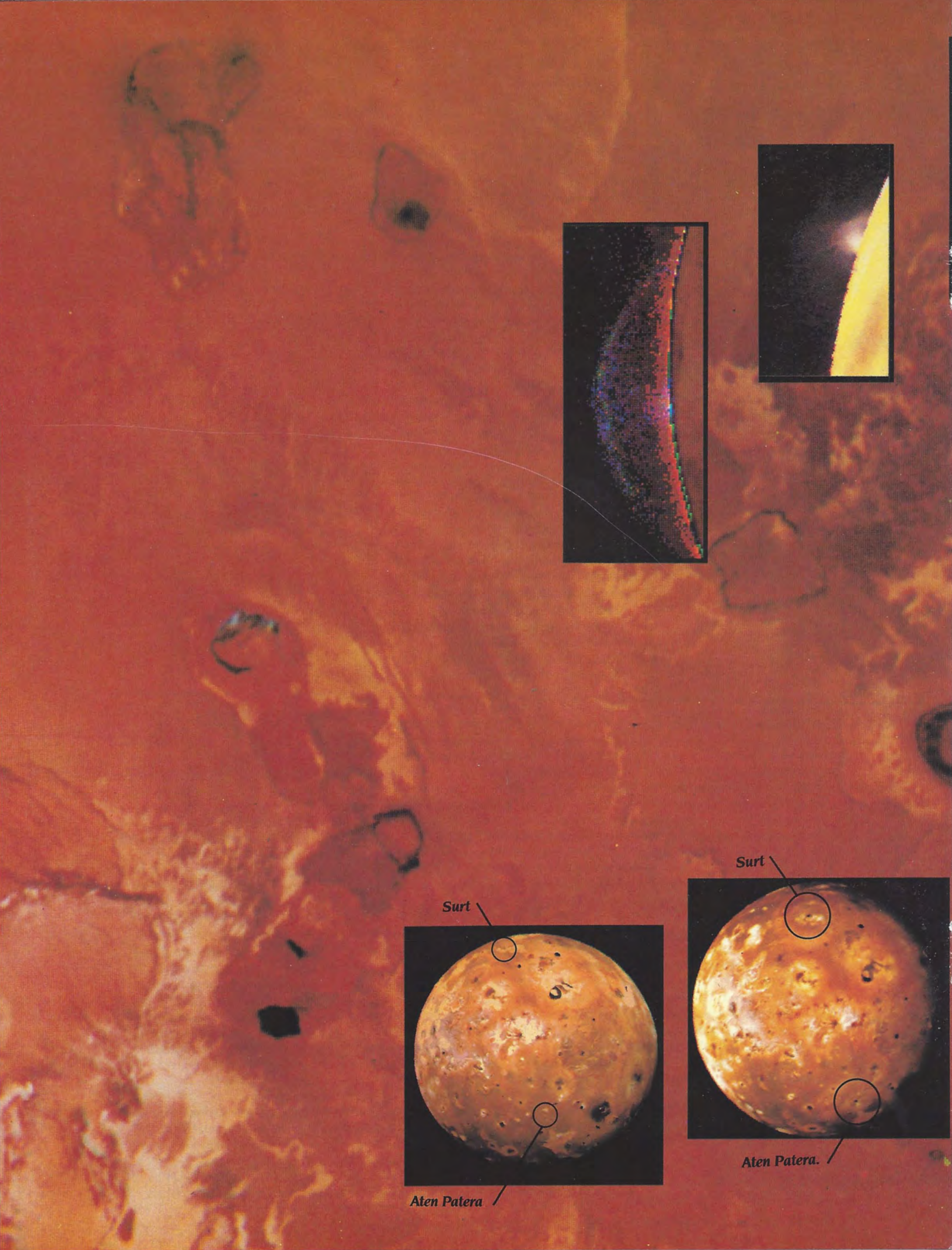
Interestingly, the spin axis of Mars periodically tilts tens of degrees towards the Sun, heating the polar areas. That effect, combined with orbital eccentricities which move Mars periodically closer to the Sun, increases solar heating drastically. This heating probably pumps up the atmosphere, much of which eventually will freeze out at the poles during cold epochs. These periods of a thicker atmosphere may have been times when liquid water could have been mobile, seeping through the regolith. The earliest of these warmer episodes were probably the most effective, with the environmental machine running down over time as the water closest to the surface eventually evaporated or migrated to topographically lower areas and was locked up as a permanent ground-ice when the warm epoch ended. Later, massive deposits of ground-ice may have been involved in the giant floods which formed the large channels.

It is during these early warm periods that the small valley networks were probably formed, eroded by the seepage of groundwater. Despite their superficial resemblance to terrestrial rainfall networks, the individual valleys within the networks and the sparse network structure are far more like the canyons of the arid Colorado Plateau, which were probably eroded by groundwater, than they are like the intricate and well-formed drainage networks cut by repeated rainfall.

None of the features we've discussed are young by terrestrial standards. We can count the number of impact craters on Martian channels and valleys and, by estimating the number of impacts which occurred per unit time, we can estimate their ages. On this basis, it appears that the smallest valley networks are at least several billion years old, dating back to that time when groundwater systems were active. The larger channels with their catastrophic floods may be somewhat younger, although they are probably at least a billion years old. The record of their occurrence, however, is etched indelibly into the Martian surface, telling us in images returned by our far-reaching spacecraft about a Mars long past. A more complete and tantalizing story awaits us in years to come when the first geologists from Earth are able to observe these dusty and ancient watercourses – with their own eyes from the ground.

David Pieri is a planetary scientist at NASA's Jet Propulsion Laboratory.

The editors would like to thank Michael Carr of the U.S. Geological Survey for his help with the photos and captions in this article.


Surt
Aten Patera
Surt
Aten Patera.

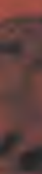
Io's Volcanic Plumes

by Alfred S. McEwen and Laurence A. Soderblom

INSETS—
TOP LEFT: Pele, a very large, short-lived plume; TOP MIDDLE: Loki, a possible hybrid of the large and small plume types that display characteristics of both; TOP RIGHT: Amirani and Maui, both small, very long-lived plumes. [These images are to scale to show relative size.]

BACKGROUND, LEFT: The surface of this region of Io, centered on 300° longitude, is characterized by calderas and lava flows. Where SO_2 is not abundant in the crust, sulfur may be vaporized at high temperatures to drive the large plumes.

INSETS—
BOTTOM LEFT: Voyager 1 image of Io's Jupiter-facing hemisphere; BOTTOM MIDDLE: Voyager 2 image of the same hemisphere, showing the surface changes resulting from the eruption of Surt and Aten Patera; BOTTOM RIGHT: Voyager 1 view of the other side of Io. Small, long-lived plumes are common in the white region near the equator.



PHOTOS: JPL/NASA

As *Voyager 1* began to close in on Jupiter and its moons early in 1979, our scientific speculations were far too cautious — especially concerning Io, the innermost of the four large Galilean satellites. We expected to see a bright orange, cratered, lunar-like and geologically inactive body. Little did we know that we would discover a world with underground sulfur seas, pockmarked by volcanos spewing plumes of sulfur.

Observations from Earth had shown that Io is a brilliant orange ball with dark poles. Observed clouds of ions of sodium, potassium and sulfur suggested that sulfur and sulfur compounds color the surface. We also knew that Io was close in size to our own rocky Moon; it seemed inconceivable that such a small rocky body, in a deep freeze with a surface temperature of about −148° Centigrade, could be geologically active. Just two days before *Voyager 1*'s sweep through the Jovian system, Stanton Peale, Ray Reynolds and Patrick Cassen published their prediction that tidal forces, caused by a tug of war between Jupiter and its other moons, might heat Io's interior to the point of melting. But we still did not actually expect to find a geologically active planet.

The stage was set: when active volcanism was seen on Io, it became the most spectacular discovery of the *Voyager* missions.

We now realize that Io is the most volcanically active body known in the solar system. Lava flows and material ejected in enormous aerial plumes rapidly resurface the moon, burying craters formed by collisions with meteorites. Evidently, as Peale and his co-workers predicted, frictional heat drives the volcanism, generated by the gravitational pulls of Jupiter and its other large moons. White, orange, red and black color patterns can all be explained as eruptions of liquid sulfur. The color of liquid sulfur depends on its temperature, and each color is preserved when the liquid is rapidly frozen on Io's surface.

In *Voyager 1*'s images of Io, we saw eight active plumes — clouds of expanding gas and pyroclastics (dust and sand-sized particles of solid debris entrained in the gas). Pele, the huge 300-kilometer plume first discovered by Linda Morabito, and seven smaller plumes ranging from 50 to 165 kilometers in height were most easily seen in profile when the spacecraft viewed them erupting above the limb (the apparent edge) of the planet.

When *Voyager 2* arrived four months later, at least six of the small plumes were still active, but giant Pele seemed quiet. (*Voyager 2* did not observe the area of the eighth plume.) In addition, a major change had appeared on the surface: a caldera in the north, a large volcanic collapse pit about 50 kilometers across, had changed color from orange to red-black, and was surrounded by large, orange-red concentric patterns about 1400 kilometers across. The patterns around this caldera, named Surt, remarkably resemble those around Pele in both scale and color.

In a recent, more detailed analysis of those *Voyager 1* and *2* images, we found that yet another major plume had erupted during the four months between the encounters. It is located in the south polar region, and is in the same hemisphere as both Surt and Pele. A large fallout pattern, virtually identical to that of Surt, developed around a caldera named Aten Patera, whose floor, like Surt's, had turned dark. The plume eruptions that created the patterns were not active during either *Voyager* flyby; the surface changes show that two major plumes, comparable in size to Pele, had erupted and then quit sometime between the two *Voyager* encounters.

Types of Eruptions

The similarities of Pele, Surt and Aten Patera suggest to us that these very large, short-lived plumes represent a particular type of eruption, different from the smaller, long-lived plumes. The larger plumes deposit rings of material five times the diameter of the white rings deposited by the smaller plumes, and erupt to heights three times as high. They are short-lived, while all of the smaller plumes erupted continuously during both encounters.

Through our analysis of the *Voyager* data and Earth-based observations, we have discerned other differences between the two types of plumes, differences which have implications for basic geologic processes on Io. The very large, short-lived plumes erupt at higher temperatures, at least 327° C, contain little sulfur dioxide (SO_2) in the surface deposits, and occur only in a region of the satellite centered at 300° longitude. In contrast, the smaller, very long-lived plumes erupt at lower temperatures (about 27° C), contain abundant SO_2, and are concentrated within about 30° latitude of the equator, at various longitudes.

Two of the small plumes exhibit characteristics suggesting that they may be hybrids between two classes. These two plumes erupt from the same feature, a dark fissure called Loki. One of them grew from a small plume 165 kilometers high up to about 300 kilometers high during the second encounter. Large, faint orange rings on the surface also suggest that the Loki plumes may occasionally develop into full-blown large plumes. It is extremely interesting that we saw these two intermediate plumes at the overlap of the global distribution of the two plume classes, just where we might have expected such plumes to erupt.

Plumes are driven by the explosive expansion of volatile substances into gas. Two models have been proposed for the plumes, suggesting that the driving volatile is either vaporized sulfur or vaporized SO_2. Both models have drawbacks in trying to explain all the plumes.

Having recognized two distinct classes of plumes, we now contend that sulfur is the driving volatile for the large plumes, originating from deep reservoirs, while SO_2 in shallow reservoirs drives the small plumes. As a ground fluid, SO_2 is very mobile, and can provide a continuous supply of volatiles so that the small plumes are very long-lived, perhaps lasting for years. Sulfur, however, is very fluid at only a narrow range of temperatures, so the volatile supply is not replenished and the large plumes are short-lived, perhaps lasting only a few days.

The distribution of these two plume types suggests a global asymmetry in Io's crust. Where the large plumes occur, from about 240° to 360° longitude covering about 30 percent of the satellite, the surface is darker, redder, low in SO_2 frost and includes huge mountains 9 kilometers high. From 0° to 240° longitude and 30° north latitude to 30° south latitude, where the small plumes dominate, the surface is bright white, high in SO_2 frost, and no mountains can be seen. We propose that differences in the character of Io's crust may provide an explanation for these two types of plume eruptions.

The small plumes deposit bright white material that is probably rich in SO_2 and possibly white sulfur, a form of sulfur stable at Io's surface temperature. One model for the character of the crust near the small plumes suggests that continuous deposition of pyroclastic rocks and SO_2 creates a low-density, porous crust. Solid SO_2 lies near the surface but liquid SO_2 might penetrate perhaps 500 to 1000 meters down, much like water percolating through an aquifier. This model was proposed by Bradford A. Smith, Eugene Shoemaker, Susan Kieffer and Allan Cook. At greater depths, the sulfur melts, forming oceans of molten sulfur. The sulfur magma heats and volatilizes the SO_2 to drive the plumes. Liquid SO_2 in a porous crust can flow up the pressure gradient toward the active plumes, so that the volatile supply is continuous and the plumes are very long-lived. Where the large plumes dominate, the crust may consist of a thinner sulfur-rich crust overlying the silicate subcrust, which is locally exposed close by the mountains.

Properties of Sulfur

Sulfur has some unusual properties which may explain the volcanic processes of this region of Io. Liquid sulfur at its melting point of 120° C has a very low viscosity, about like that of alcohol, but at a higher temperature it thickens dramatically and becomes as viscous as molten basalt. This is contrary to the behavior of most liquids, which become more fluid as they get hotter. With a further rise in temperature, the sulfur's viscosity gradually drops until it is again a low-viscosity fluid at about 900° C. As a result, there will be two zones where sulfur is a low-viscosity fluid, a shallow zone of red sulfur and a deeper zone of high-temperature black sulfur. When gradually heated, the very fluid sulfur will move and rise through fissures and pores in the crust, leading to lava flows and shallow intrusions. Calderas on the surface form by collapse over the underground voids left by the rising sulfur. When sulfur is heated rapidly to high temperatures, such as from molten silicates intruding from the moon's interior, it is rapidly volatized, creating an explosive eruption and throwing a large plume above the surface.

We propose that the large plumes occur in only one region of Io because the hot silicate subcrust is not as deeply buried under sulfur-rich material. Eruptions of black sulfur lava accompany the large plumes, flooding the caldera floors.

On Earth, sulfur is not an abundant element near the surface. However, sulfur is fairly abundant in stony meteorites, on the surfaces of the Moon and Mars, and in the atmosphere of Venus, so the Earth's surface may be unusually low in this element compared to other rocky bodies in the solar system. One proposed explanation for this is that sulfur has been carried from the Earth's surface by the oceanic crust as it is subducted under continental plates. Since sulfur is associated with many valuable mineral ores, a better understanding of sulfur geochemistry could lead to important new mineral discoveries. Geochemical processes are extremely slow on Earth, so it is difficult to study them. But on Io the tremendous volcanic activity accelerates these processes, and it is an ideal place to study planetary geochemistry.

The *Galileo* mission, scheduled to arrive at Jupiter in 1988 and to orbit within the system for almost two years, will include infrared sensors to map the geochemistry of the Jovian system, including Io. As it repeatedly loops through the satellite system, *Galileo* will have many opportunities to observe the cycle of eruptions on this small and intriguing world, and our understanding of geologic processes on both the Earth and Io will be greatly expanded.

Alfred McEwen and Laurence Soderblom are geologists with the Branch of Astrogeologic Studies of the United States Geological Survey.

PHOTOS: JPL/NASA

INSET: The heart-shaped marking on the left is the surface deposit from Pele. The white band shows part of the region dominated by the small plumes, where the crust may consist of porous pyroclastics of sulfur and SO_2. No lava flows are apparent in this white region, but are abundant to the north, south and west.—ABOVE: Pele is erupting from the black spot near the center of this image. Part of the ballistic plume is visible above the satellite.—BELOW: Surface changes from the eruption of Surt and Aten Patera.

Surt, Voyager 1

Surt, Voyager 2

Aten Patera, Voyager 1

Aten Patera, Voyager 2

News & Reviews

by Clark R. Chapman

Ground-based astronomy is the art of trying to learn about something from very little information. Consider the planet Pluto. It is so small, faraway, and dimly illuminated by the sun that it was not even found until a half-century ago. During subsequent decades, astronomers measured the faint pinpoint of light and tried to learn what they could about the ninth planet. A picture emerged, as we learned in school, that the most distant planet is a dark, rocky body about the size of Mars.

"None of this is true," however, writes Texas astronomer Derral Mulholland in the cover story of the December *Science 82*. In an age overshadowed by Earth-orbital and deep-space rocketry, advances in ground-based telescopic instrumentation have kept pace. More sensitive detectors together with new computer techniques are turning our telescopes into much more powerful probes of the heavens. Revelations about Pluto are a case in point. It turns out to be a double planet, but much tinier than had been thought. Its surface is bright (though dimly lit) and is covered at least partly with methane ice. There is now some evidence that Pluto's deep interior may be composed mostly of ices, too.

Mulholland reminds us that Pluto is no longer the most distant planet, because its orbit is eccentric. Nearing its perihelion – or closest orbital distance from the sun – Pluto moved closer than Neptune in 1979 and will remain the eighth planet until 2000. However, Pluto's current proximity will not be much of a boon to "Pluto-ologists." Rather than relying on Pluto to come to us, we (or our spacecraft) must eventually venture forth to Pluto. Yet I predict that long before such a voyage concludes, ground-based telescopes with ever more powerful instruments will have revealed quite a few more unexpected traits of the smallest planet.

Eruption!

I have written before in this column of the mighty volcanic explosion of El Chichón on April 3, 1982. Although the disaster received little attention in the world's news media, at least compared with Mt. St. Helens, its effects have been, and will continue to be, much greater. El Chichón was an obscure volcano, a mere "lump" (hence its Spanish name) on the landscape of southern Mexico. It was only "discovered" in 1928. Scientific understanding of its behavior was so poor prior to its late-March, 1982 pre-eruption activity that insufficient precautions were taken during subsequent days. Result: a disastrous toll on human life in the densely populated region.

As described in the November, 1982 issue of *National Geographic*, hundreds or even thousands of poor Mexican villagers and peasants of the Zoque tribe were killed. Moreover, the blast was aimed straight up towards the stratosphere, instead of off to the side as with Mt. St. Helens. So its effects on the Earth's global climate, by dimming the sunlight, may be greater than that of any volcanic blast since the turn of the century. *National Geographic* shows graphic "before and after" views of the volcano. Infrared satellite pictures of Earth show that within half a day the visible volcanic cloud had spread from Mexico's Pacific shore across the Caribbean to Cuba. Colorful global data from the Solar Mesosphere Explorer show how the cloud subsequently spread around the Earth.

Such space-age pictures document that what would once have been regarded as a purely local disaster was, in reality, the result of fundamental planetary processes of volcanism and tectonism with global repercussions. Some scientists who, a few years ago, were studying climate changes on Mars have now turned their attention to the unusual physical and chemical processes that take place in our own rarified stratosphere when it is suddenly invaded by prodigious amounts of volcanic dust. Our planet has much to teach us.

Astronomy and Creationism

The Astronomical Society of the Pacific last summer adopted a resolution categorizing Creationism as not a science but rather as an expression of minority religious beliefs. David Morrison amplifies on the issue in the ASP's magazine *Mercury* for September/October 1982. He writes that "it is not only the evolution of life that the Creationists abhor, but all concepts of evolution: physical, geological, and biological."

He describes how his own elementary astronomy lecture course at the University of Hawaii would have to be censored or changed if he were forced to give "equal time" to the Creationist view. Much of astronomy deals with our measurements of light that has been traveling from distant objects for a longer period of time than most Creationists believe the universe has existed. Constrained by Creationism, all distant galaxies would become figments of our imagination rather than real objects: their photons would have to have been "created" enroute to us! Planetary science, in particular, makes no sense in terms of Creationism: virtually all of the ages we infer for meteorites, the Moon, and other planets based on precise radioactive clocks and on rates of crater formation from cometary and asteroidal impacts stretch back for billions of years. No one knows how the universe was created, or even if that is a valid concept. But we do know that it is evolving.

Technical Publications

So far I have described articles in the popular literature. For Planetary Society members who want to dig deeper, there are some publications aimed at the professional scientist but still enjoyable – at least in part – by the intelligent lay person willing to hunt for the choice bits. The November, 1982 *Physics Today* features five articles on the theme of new approaches to astronomy. Michael Belton and Eugene Levy summarize the uncertain future of planetary astronomy. Other articles deal with radioastronomy high-energy astrophysics, solar physics, and ground-based and earth-orbital telescopes.

Scientists have had several years since the fantastic *Voyager* encounters with Jupiter's satellites to analyze the data and think about what it all means. The new book *Satellites of Jupiter*, latest in a series of topical textbooks published by the University of Arizona Press, pulls it all together in 26 chapters by 47 collaborating authors. A book on Venus is next in the series; meanwhile the latest technical results from the *Venera* and *Pioneer* missions of 1978–79 may be found in the special Venus issue of *Icarus* (August, 1982).

Clark R. Chapman is Chairman of the Division for Planetary Sciences of the American Astronomical Society. He is author of Planets of Rock and Ice.

WASHINGTON WATCH

by Louis Friedman

The 1982 election had a significant effect on the space committees in Congress. Most notably, the Committee on Commerce, Science and Transportation (the Senate Authorization Committee) lost its ranking minority member, Senator Howard Cannon of Nevada, and the chairman of the subcommittee on space, science and technology, Senator Harrison (Jack) Schmitt of New Mexico. Both were keen supporters of the U.S. space program and Senator Schmitt is a member of our Board of Advisors. As a result, the Authorization Committee will be restructured in a major way as the Senate reconvenes and organizes this month. Hearings before this Committee on the Fiscal Year 1984 budget for NASA will probably begin soon. Senator Schmitt's defeat also creates a vacancy on the Subcommittee on Appropriations that deals with the NASA budget.

Before the election, Congress added funds for planetary science and mission support in the Fiscal Year 1983 budget. Proving that it was responsive to both scientific arguments and public input, Congress added $25 million to NASA's space science authorization and $32 million to its appropriation. These programs advocated by The Planetary Society will now be supported: tracking *Pioneer* Venus, *Pioneers 6–9* in solar orbit, *Pioneers 10–11* on their way out of the solar system, *Viking* on Mars, *Voyagers 1* and *2*, and maintaining the Hawaii Infrared Telescope and the Lunar Curatorial Facility.

The Fiscal Year 1984 budget is scheduled for release by the President on January 20, 1983. NASA has proposed that the Venus Radar Mapper be the primary new start in this budget. It has been 6 years since the last new start in planetary exploration. The planetary science community and space advocates are optimistic that a more active and vital American program is being developed. A headline in the November 12th issue of *Science* reflected this belief: "Planetary Science: Up from the Ashes?"

At The Planetary Society's October forum in Boulder, Colorado on public policy and the planetary program (cosponsored by the Division for Planetary Sciences of the American Astronomical Society) differing views were expressed on this subject. Burt Edelson, NASA's Associate Administrator for Space Science, and Jesse Moore, the head of NASA's Planetary Programs Office, were optimistic about restoring a satisfactory budget for deep space exploration. However, Tom Donahue and Don Hunten, advisors to the Space Science Board of the National Academy of Sciences, were concerned about future planning, and Representative Tim Wirth from Boulder, Colorado, a member of the Congressional Space Caucus, strongly denounced the administration's curtailment of space science activities and predicted further cuts in the Fiscal Year 1984 budget. He felt that planetary exploration would continue to languish. More than 250 scientists of the Division for Planetary Sciences and an equal number of Planetary Society members from the Denver and Boulder areas attended the meeting.

The Venus Radar Mapper Mission is a reworking of the Venus Orbiting Imaging Radar (VOIR) Mission that had been proposed several years ago. To gain administration support, the new mission is designed to be much less expensive. The VOIR would have orbited Venus in a circular path and could have imaged the planet with a resolution of 100 meters. The Venus Radar Mapper will go into a much looser elliptical orbit and image the planet with a resolution of one kilometer. Less imaging data will be returned to Earth, so the spacecraft's data-handling jobs will be easier and its systems simpler. In addition, all related scientific instruments for research auxiliary to the radar data were dropped. As a result the new mission has half the cost of the previous design. If approved, the Radar Mapper would be launched in 1988 and go into orbit about Venus the same year. The project is strongly supported by the Solar System Exploration Committee (a NASA advisory committee) and by the Committee on Planetary and Lunar Exploration (COMPLEX) of the National Academy of Sciences' Space Science Board.

An opportunity to send a *Galileo* spacecraft to Saturn came about when the project was redirected back onto the *Centaur* rocket and the Space Shuttle's Interim Upper Stage (IUS) was cancelled. The *Centaur* is more capable than the IUS and can fly directly to Jupiter instead of using the Venus/Earth gravity assist. Moreover, the launch was delayed from 1985 to 1986, giving the project team considerable flexibility in the schedule for building the spacecraft.

Galileo project scientists and engineers suggested that, since spare hardware already exists, why not build a duplicate spacecraft? For a relatively low cost, it would serve as a backup for the mission which is, after all, using the Shuttle/*Centaur* combination for the very first time. If there is any problem in the launch of the *Galileo* spacecraft, the backup would be available. But if everything goes well, the backup spacecraft could be sent to Saturn. If launched in 1987 it would arrive at Saturn in 1995.

This mission has attracted much interest because it is the only chance we have in this century for a close look at Titan and Saturn's atmosphere. An imaging radar, similar to that being planned for Venus, would be used on the orbiter to probe through Titan's atmosphere to see what must be a very interesting surface. The Solar System Exploration Committee is considering this idea, along with several others, and will issue its final report in the next few weeks. □

To Prevent the Militarization of the Solar System

Congressman Joe Moakley and seventy-eight of his colleagues in the House of Representatives have introduced a joint resolution (H. J. Resolution 120) which calls for immediate negotiations between the United States and the Soviet Union for a ban on weapons of any kind in space. By treaty, the United States and the Soviet Union have already agreed to ban nuclear weapons from space. Specifically, the Representatives ask that the goal of such bilateral negotiations should be a comprehensive treaty to prohibit the testing, deployment or use of weapons from space to Earth, from Earth to space, or entirely within the space environment. Such a treaty, eventually extending to all spacefaring nations, would keep the other worlds of the solar system free of military activities and available for open scientific inquiry.

Although this is not an issue on which The Planetary Society will become involved, each of the Society's officers has endorsed the bill and are supporting it as individuals. Members interested in this resolution who would like more information can write to Congressman Moakley at 221 Cannon Building, House of Representatives, Washington, D.C. 20515, or to their individual representatives in the House.

Society Notes

by Louis Friedman

The Planetary Society is going international. We have always intended to bring together those individuals and groups interested in planetary exploration from all over the world, to encourage exploration of the solar system and the search for extraterrestrial life. In our first years, members joined from every continent. Now we are actively promoting and publicizing planetary exploration around the world.

Why? First, the exploration of other worlds ought to be an enterprise of the people of this world, acting together. Second, space science and exploration offer humanity a chance to rise above narrow, nationalistic viewpoints – not an insignificant offer in the present day world. Third, regardless of the magnitude of the U.S. effort to explore the solar system, other countries will. Japan, the European Space Agency, the Soviet Union, Eastern European countries, France and West Germany are now involved with planetary programs.

In France, we met with representatives of the leading science and astronomy magazines, space organizations and scientists to plan the distribution of *The Planetary Report* and sponsorship of joint activities. In the Netherlands we have already added new members through a Dutch television course on space flight. And in Great Britain, we are pleased to announce the opening of an office in Imperial College, London, under the direction of the Society's newest advisor, Professor Garry Hunt, to expand Society activities and serve British members. We also are planning special lectures and conferences in Europe.

Dr. Murray recently visited Japan and China and promoted the Society there. We gained many new members when a major Japanese newspaper ran a story about The Planetary Society. In China we began liaison with planetaria and amateur astronomy groups, to share information about solar system exploration.

Dr. Sagan participated in the recent UNispace Conference in Vienna. While there, he met with Academician Roald Sagdeev of the Soviet Union, who joined the Society's Board of Advisors and promised to aid us in seeking ways to promote international cooperative endeavors. Dr. Sagdeev worked with Dr. Tomas Gombosi of Hungary to prepare a paper on future Soviet planetary exploration, which Dr. Gombosi delivered at The Planetary Society's commemoration of the 20th anniversary of interplanetary flight held in Washington, D.C. The presentation of the paper on Soviet planning was a unique contribution to the international dialogue for essential space cooperation.

The commemoration was a huge success, with more than eight hundred attendees at the symposium and another three hundred for the Smithsonian reception. The Society's goal of future planetary exploration received considerable publicity in Washington.

I recently attended the International Astronautical Federation Congress and was struck by the broad involvement and interest in planetary exploration around the world. I met students working on solar sail projects from Czechoslovakia and France. Scientists from the Soviet Union, the Netherlands, France, Poland and the U.S. presented papers on their work in SETI. An organization called SETI-France (with whom we now have established a cooperative relationship) gave a public presentation about popularizing SETI in their country. Poland, Japan, Western and Eastern Europe, and the Soviet Union all participated in the Space Exploration sessions. I was gratified to find widespread recognition of The Planetary Society.

Guy Janin of the European Space Operations Centre spoke about plans and concepts for the International Solar Polar Mission, *Giotto* (the European Space Agency mission to Halley's Comet), POLO, a polar lunar orbiter, an orbiter of Mars called *Kepler*, and a mission to the asteroids. Jesse Moore from NASA and Bob Parks from JPL presented a paper about studies for ESA-NASA missions to Mars, to the Moon, to outer planet atmospheres and to comets and asteroids. They also described new cooperative efforts by the European Science Foundation and the Space Science Board of the U.S. National Academy of Sciences to define possible missions for international cooperation. Two working groups – one for terrestrial planets and one for "primitive" bodies, such as comets and asteroids – have been put together to specify potential objectives, targets, orbits and scientific instrumentation.

Thus we see a new opportunity and challenge for The Planetary Society in 1983. We hope to bring the excitement and results of planetary exploration to more people worldwide. This can help to develop a broad and sustained public interest in continued exploration of the solar system, by many countries, on many missions.

[Some members have written to us that they have had to wait several weeks for books that they have ordered from the Society. We apologize for the delays. While we handled the picture, poster and slide orders in our office, the books were sent out directly from their publishers. The system has not worked out and we are now handling the book orders in our office.]

New Earth-Approaching Asteroid Discovered

On the night of December 13, 1982, Eleanor Helin of the Jet Propulsion Laboratory, assisted by Amara Graps and Steve Swanson, discovered a new Earth-approaching asteroid. Helin noticed the tell-tale trail of the asteroid on photographic plates taken with the 46-centimeter Schmidt telescope at Mount Palomar and immediately notified Brian Marsden of the Minor Planet Center at the Harvard-Smithsonian Center for Astrophysics. He gave her the designation 1982XB for the new object. She next reported the discovery to Alan Harris of JPL, who notified a team of observers at Lowell, Table Mountain and Steward Observatories and at the Infrared Telescope Facility on Mauna Kea. The next night they measured the motion, size and surface properties of the new asteroid. Literally overnight, 1982XB became one of the most thoroughly studied asteroids. It will remain visible to Earth-based observers for the next few months and scientists are continuing to study it.

1982XB is an S-type asteroid, reddish in color and probably composed of silicates. It is only 350 meters in diameter and reaches perihelion (its closest point to the Sun) at 1.017 AU (an Astronomical Unit is the distance from the Earth to the Sun, about 150 million kilometers). This places it just outside the orbit of the Earth, in the Amor orbit class, and the asteroid occasionally crosses the Earth's orbit. On Christmas Eve, 1982XB passed within 1/300 AU of the Earth, making it our closest-known astronomical visitor in some time. Neal Hulkower of JPL has done a preliminary analysis of the orbit, revealing that 1982XB is the second-easiest known target for an asteroid rendezvous mission. (See the July/August 1982 *Planetary Report* for a description of the discovery of 1982DB, the best rendezvous target.)

Eleanor Helin's continuing asteroid search is funded, in part, by The Planetary Society.

The Solar System in Pictures and Books

● BOOKS

	PRICE	QUAN.	TOTAL
Voyages to Saturn by David Morrison – Description of both Voyager Saturn encounters, with color photographs.	$14.00		
Voyage to Jupiter by David Morrison and Jane Samz – Description of both Voyager Jupiter encounters, with color photographs. 199 pages.	$10.00		
Pioneer: First to Jupiter/Saturn and Beyond by Richard O. Fimmel, James Van Allen and Eric Burgess – Illustrated accounts of two Pioneer missions. 285 pages.	$14.50		
Beyond the Atmosphere by Homer E. Newell – History of the United States space program. 500 pages.	$14.00		
Voyager 1 Encounters Jupiter – An illustrated booklet with the best pictures of Jupiter from Voyager 1. 40 pages.	$ 5.00		
Voyager 1 Encounters Saturn – An illustrated booklet with the best pictures of Saturn from Voyager 1. 40 pages.	$ 5.00		
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Universe by Don Dixon – a large format look at the universe, illustrated with paintings by the author. 240 pages.	$30.00		
The New Solar System edited by J. Kelly Beatty, Brian O'Leary and Andrew Chaikin – Up-to-date information on our planetary neighborhood. 224 pages. **Soft cover** / **Hard cover**	$ 8.50 / $16.00		
The Moon by Patrick Moore – An atlas and guide to our satellite. 96 pages.	$11.00		
Jupiter by Garry Hunt and Patrick Moore – A well-illustrated look at the largest planet in our solar system. 96 pages.	$11.00		
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Murmurs of Earth by Carl Sagan, Frank Drake, Ann Druyan, Timothy Ferris, Jon Lomberg and Linda Salzman Sagan – Account of the development of the Voyager record, a message from humanity to possible extraterrestrial life forms. 273 pages.	$ 7.00		

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JUPITER AND AMALTHEA—Volcanic Io and its companion Galilean satellites command most of the scientific attention directed to the Jovian moons, but they are not the only objects orbiting Jupiter. Tiny Amalthea circles Jupiter only 110,000 kilometers from the planet's topmost cloud layer. At that distance, the giant planet fills 8,500 times as much sky as a full Moon seen from Earth.

Kazuaki Iwasaki is a renowned space artist living and working in Japan.

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