104

LIFE ON MARS?

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Life on Mars? No. 64, Hearing, 104...

BEFORE THE

SUBCOMMITTEE ON SPACE AND AERONAUTICS

OF THE

COMMITTEE ON SCIENCE

U.S. HOUSE OF REPRESENTATIVES

ONE HUNDRED FOURTH CONGRESS

SECOND SESSION

SEPTEMBER 12, 1996

[No. 64]

Printed for the use of the Committee on Science

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LIFE ON MARS?

THURSDAY, SEPTEMBER 12, 1996

U.S. HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE,
SUBCOMMITTEE ON SPACE AND AERONAUTICS,
Washington, DC.

The Subcommittee met at 10:00 a.m., in Room 2318 of the Rayburn House Office Building, the Honorable F. James Sensenbrenner, Jr., Chairman of the Subcommittee, presiding.

Mr. SENSENBRENNER. Good morning, and welcome to this hearing about the possibility of life on Mars.

The biggest movie this summer was "Independence Day," a story about aliens invading the earth. I don't know if it's a coincidence, but this year and next, England is celebrating the 100th anniversary of the serial publication of H.G. Wells' "War of the Worlds," which was also about aliens invading the earth.

It wasn't that long ago that Orson Welles scared half the country into thinking that H.G. Wells' novel had come true. Even less time has passed since Steven Spielberg gave us a movie about friendly aliens.

So, clearly, we have some sort of cultural fascination with life in outer space.

I suspect that's why NASA's announcement last month made headline news around the world. NASA believes that it has found some evidence that life in its most primitive form can exist in other worlds.

For some, this has cosmological implications. For others, the philosophical meaning of this discovery could be more dramatic than the impact Darwin had on the way humanity views itself. For still others, the discovery is just another ho-hum announcement.

The nationally known paleontologist, Steven J. Gould, titled his editorial in the New York Times, "Life on Mars—So What?"

As fascinating as these discussions might be, that's not why we're here today. This is a subcommittee that deals with science and public policy. Instead of debating the implications of the discovery, we're going to discuss the science behind it. What steps did the National Science Foundation and NASA take to make this discovery? How do these steps relate to our national space exploration efforts? What is NASA planning to study on Mars? Is it appropriate to view this discovery as a reason to change public policy? And what do we do now and where do we go from here?

Today, we have two of the principal scientists, Doctors Richard Zare and David McKay, involved in developing the technology and doing the research that has made this discovery possible.

They're going to tell us how they went about examining the meteorite, ALH-84001, and their confidence in their findings.

Dr. Wesley Huntress is NASA's associate administrator for space science. He is going to review NASA's current plans for exploring Mars and tell us a little bit about how the agency will follow up on the discovery.

Finally, we have Lt. General Thomas Stafford. General Stafford commanded several Gemini and Apollo space missions, including the Apollo-Soyez link-up in 1975. General Stafford, who served his country in the Air Force, NASA and the private sector, chaired the synthesis group on American space exploration initiative in 1990 and 1991, which culminated in a roadmap for Mars exploration with a report, "America at the Threshold."

General Stafford, it appears that we may once again be at a threshold, so I look forward to hearing your comments and those of the other witnesses at the table.

I am informed that there is a Democratic caucus, which is one of the reasons why many more Democratic members are not here. They're busy engaging in seditious activities.

[Laughter.]

But I do appreciate the gentleman from Texas, Mr. Hall, deciding that Mars is more interesting than sedition, and I will now recognize him for whatever comments he wants to make.

Mr. HALL. I thank the very fair and neutral Chairman.

[Laughter.]

My fellow Democrats asked me to announce that these hearings will be continued under my chairmanship.

[Laugher.]

I do like the Chairman, admire him and respect him and we do work well together, and I thank you, Mr. Chairman.

You're exactly right about life on Mars. It does sound like some science fiction to a lot of people. Silly to some people, entertaining to some. But it's dead serious to scientists and men and women of science who pick over the rocks they bring back from the moon and search through the files to bring us honesty and factual information to give us gracious living and to do all those things.

So I think today is very important and will probably be very entertaining because it is interesting. It is mysterious and it does tickle the imagination of people who read and follow.

One of the results of our space program is that we now know a lot more about Mars. I know it's a good and a very harsh environment. It's my belief that many millions of years ago, it may have had a more hospitable climate, with running water, we're led to believe. Whether or not it was hospitable enough to allow life to flourish on Mars in the past is to be continued.

Could some form of Martian life still exist today? I guess that's to be continued?

I hope today's witnesses will be able to answer some of these questions or give us some idea, lead or push us in some direction where we can use your facts and our imagination and still whet our appetite to continue to search and to continue to seek.

The discovery that will be discussed at today's hearing I think is very exciting. I understand that scientists don't yet agree on whether or not fossilized life has been found. That's to be continued. That will require more research. And I'm convinced that whether or not Martian fossils have been found, the research that we're going to get, the answers will prove valuable down the road, just like our efforts to build Star Wars.

While we may or may not have ever succeeded, I think the Russians, as they headed toward the fall of the wall, didn't know whether or not we had succeeded and I think there was a lot of fallout and a lot of things that we gained on the way there.

I think it has been and is and will be and should be a worthwhile project in the future.

So this is an exciting time for the U.S. space program. We're making amazing scientific discoveries almost weekly. We're flying the shuttle and doing important life sciences research. We're building the space station, which will be a national laboratory in space. And we're carrying out other critical space activities.

Yet, I'm convinced that, ultimately, we'll get what we pay for.

We need to make sure, Mr. Chairman, that we aren't just patting NASA's hard-working team on the back for their accomplishments, giving them challenging new assignments and at the same time, continuing to cut their budget.

The consequences may not be seen for a few years, but eventually a "penny-wise, pound-foolish" approach to the space program is going to catch up with us.

NASA has been asked to make deep cuts to their budgets. They're making deep cuts to the budget. I know of no other agency that's made the cuts that they've made the last four years.

I just think NASA has risen to the challenge. And I think it's time to hold the line against further cuts. I'm a cut man myself. I never saw a cut I didn't like up here. But I think you have to finally arrive at the point of where you're going to be reasonable and say, look, we've handed these people the job. We've asked you to cut. You know how to cut. We cut it with a club. You cut it with a knife and make a proper incision for it. You've done that.

I think it's high time for us to gut up and support you.And I thank you, and I yield back my time.

Mr. SENSENBRENNER. I thank the gentleman from Texas. Without objection, other members' opening statements will be inserted into the record at this point.

Hearing none, so ordered.

The first witness this morning will be Dr. Wesley T. Huntress, Jr., Associate Administrator for Space Science at NASA.

I would ask each of the witnesses to summarize their remarks in five to six minutes. Without objection, all of the written prepared statements of each of the witnesses will be inserted into the record at this point.

And Dr. Huntress, you may proceed.

STATEMENT OF DR. WESLEY T. HUNTRESS, JR. ASSOCIATE ADMINISTRATOR FOR SPACE SCIENCE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Dr. HUNTRESS. Thank you, Mr. Chairman, and Members of the Subcommittee.

This is indeed an exciting time, and I'm very glad to be here today to discuss with you the recently announced research results concerning the possibility for life on ancient Mars.

Now, the way I've come to look at this is about 13,000 years ago, a messenger arrived on this planet in the form of a meteorite. It landed in a very remote part of the planet, in Antarctica, and was buried in ice. And for 13 million years, it's waited patiently for the human species to get out of their caves and produce a civilized society and to develop the capability to go to such an inhospitable place and to find it.

It was found in 1984 as part of the annual Antarctic meteorite tour sponsored by the National Science Foundation in its polar research programs.

We found it. We brought it back. We opened it up. And if we're reading the message correctly that it contains, it says, you are not alone.

And if that's true, it's pretty profound.

We're pretty certain that this message comes from Mars. Now Mars among all the planets occupies a real special place in the collective human consciousness. It's been an object of awe and wonder and speculation over the ages. Mr. Chairman, you mentioned some of that in your opening remarks. It's inspired a lot of romance and intrigue and fear about what lies beyond our own earth and in the depths of space.

Scientifically, we've been interested in Mars because it's the most likely place in our solar system where life may have once originated besides our own planet. And our robotic exploration of Mars has shown us that there's clear evidence for warmer and wetter episodes early in Mars' history.

And we believe that Mars, in its early history, 3-1/2 billion years ago, was very similar to our own planet at that time. And over those 3-1/2 billion years, the surface and climate conditions has varied widely in both planets, but Mars' atmosphere has become thin and dry and its surface is now relatively cold and barren, and the water that once flowed on its surface has since frozen out and disappeared.

Now after more than thirty years of planetary exploration throughout the entire solar system, and after examining every planet at close vantage point with our spacecraft, except for Pluto, it's clearer than ever, more clear so, that Mars alone among all those planets is the choice for eventual human exploration. And only Mars among the other planets in the solar system has surface conditions which are similar to the earth, making it the most suitable for human exploration.

And you'll hear more about that from our distinguished colleague here, General Tom Stafford.

And so what's been our reaction at NASA to this announcement? It's simply been one that this evidence is intriguing and our attitude towards it has been one of careful fascination.

The implications are profound, but the evidence is not yet conclusive. So much more work needs to be done in attempting to confirm or refute the conclusions of this team. And while this evidence for potential life on early Mars adds an emphasis to our current planning for the exploration of that planet, clearly the most important first step is to focus more work on these meteorites.

And that could take several years.

In the meantime, we will continue to plan on how to get a sample from the surface of Mars back to earth for study with our spacecraft.

We've been developing this strategy for the past several years for a second era of Mars exploration. It's a systematic plan for the step-by-step robotic exploration of Mars. Our overall strategy is one that will be familiar to any of the explorers of the last century who opened up the last remaining territories on our own planet.

The first step is to map the territory. You get your global maps for the planet from which we can identify the most interesting places. And then after conducting that aerial survey, so to speak, you'll know what are the most interesting places and you send in your scouts to survey the lay of the land. In essence, to conduct a landed survey at those interesting places. And after scouting the surface, the next step is to bring back samples.

Now, the current plan we have been working on before this discovery was to see if we couldn't get a sample back from Mars by the year 2008 with a launch in 2005. But achieving that goal was going to be a challenge within our existing Mars Surveyor Program resources.

Now, instead of the goal of just returning an interesting sample, we're looking at a strategy as to what it would take to maximize the possibility that that sample contained evidence of life on early Mars.

Now that's something quite different. It's not that we just want any sample. We would want a sample that has the right stuff in it. And that requires a great deal more work in identifying the right places.

And so we have asked our Mars science working group to consider what that strategy would be, to focus our goals on Mars to look for early life, and that group will complete its work in early September. And we've asked the folks out at NASA's JPL to work with that team to look at how one would implement that process.

One of the things that I think is important to understand is just how the search for life on Mars fits into this new origins theme in space science and the agency. That program is directed towards asking some of the most fundamental questions we could ask—where do galaxies, stars, planets and life come from? And second, are there worlds like the earth around the nearby stars? And if so, are they habitable or is life as we know it present there?

And the search for evidence on life on Mars is as much about a search for origins as it is about Mars exploration.

If life began at the early stages on the second planet in this solar system, then if two places, why not more than two?

On this planet, where there is water and where there is a source of chemical energy, we find life, even in the most extreme environments.

So if life is so robust, why should we not find it on other planets where those conditions exist? And if in more than one place in this solar system, then why not in other solar systems? And we're beginning to discover evidence of planets around other stars. And if there are other planets like ours around those stars, then could life have emerged there, also?

So it has major implications beyond just Mars.

And although to date, scientists have detected a small number of planets around those stars, these findings suggest that it's likely that many stars are orbited by planets.

Mr. Chairman, members of the Subcommittee, the conclusion by the McKay team from their studies of ALH-84001 that early life existed on Mars remain yet to be proven. However, the implications of the work are profound. And it represents a culmination of a series of fantastic discoveries this past year in space science ranging from the origin of galaxies, new planets around stars, the possibility of subsurface oceans, and Europa.

We're entering an exciting new era of discovery and knowledge about the place in which we live. And I say place in which we live. Not just this planet, but our solar system and our universe, where there is no more exciting question I think we can ask and pursue than—what is the universe? How did it come to be? And are we alone on this planet?

Thank you very much.

Mr. SENSENBRENNER. Thank you.

General Stafford?

[The prepared statement of Dr. Huntress follows:]

Statement of

Dr. Wesley T. Huntress, Jr.
Associate Administrator for Space Science
NASA Headquarters

before the

Subcommittee on Space and Aeronautics
Committee on Science
U.S. House of Representatives

September 12, 1996

Mr. Chairman and Members of the Subcommittee:

I am glad to be here today to discuss with you the recently announced research results concerning the possibility that life existed on ancient Mars.

Thirteen thousand years ago a messenger in the form of a meteorite arrived on this planet. It arrived in a very remote part of this planet, in Antarctica, and was buried in ice. For 13 millennia it waited patiently for the human species to get out of their caves, produce a civilized society and to develop the capability to find it.

The forces of nature also played a role; the movement of ice and wind across Antarctica helped to expose this messenger. It was found in 1984 as part of an annual Antarctic meteorite collection activity sponsored by the National Science Foundation, NASA and the Smithsonian Institution. We found it, we brought it back, we opened it up, and if we are reading the message correctly it may say: "you are not alone." If it is true, that is pretty profound.

Why are we studying Mars?

Mars, among all the planets, occupies a special place in the collective human consciousness. Mars has been an object of awe, wonder and speculation over the ages, and has inspired a lot of romance, intrigue and fear about what lies beyond our own Earth in the depths of space. Inbred curiosity about Mars, along with Earth's own Moon, has done more to fuel man's urge to know more, and to explore space, than all the other planets of our solar system. Mars has been the subject of an enormous amount of speculation, science-fiction, and scientific study -- and that has not been changed by our newer views of the solar system.

Mars is the most likely place where life may have once originated in the solar system besides on our own planet Earth. While Mars may not presently harbor life--although there still remains an outside chance that it does--our robotic exploration of the planet clearly shows that there were warmer and wetter episodes in the past history of Mars in which life may have arisen. We now believe that the conditions on Mars early in its geological history were very similar to those on the early Earth, when life first arose here. Over the past 4.5 billion years, surface and climate conditions have varied widely both on Earth and Mars, but Mars' atmosphere has become thin and dry; its surface cold and barren. The water that once flowed on the surface of Mars has since frozen out at the poles and disappeared below the surface in the form of permafrost. Geological processes have buried Mars' inventory of water and its early atmosphere. Yet there may remain exposed the fossil remnants of early life on Mars.

We know that during the time that life began on Earth (at least 3.5 billion years ago), Mars also had water flowing across its surface. But what we don't know is how far along the path of evolution Mars progressed. Did complex chemistry progress to life? Recent evidence from what we believe to be a Martian meteorite found in Antarctica (called ALH84001) suggests that early Mars might have had life. This finding, however, remains controversial and will only be resolved with further studies of ancient Mars. Fortunately, there is an expanse of ancient terrain on Mars, which promises ample samples for studying the early history of that planet. In exploring Mars, we may find evidence of liquid water, of early chemical evolution, or even of life. In fact, it may be the samples we gather from Mars that will contain the best evidence of life's beginning in our solar system.

After more than 30 years of planetary exploration throughout the entire solar system, after examining every planet at close vantage point except Pluto for the potential for future exploration, it is more clear than ever that Mars alone among the other planets is the choice for possible human exploration. Only Mars among the other planets in the solar system has surface conditions most similar to that of Earth; making it the most suitable for human exploration.

Reaction to the Recent Announcement

NASA's reaction to this announcement is one of careful fascination. The implications are profound, but the inferences are not conclusive. Much more work needs to be done in attempting to confirm, or refute, the conclusions of this team of researchers. While the potential for life on early Mars adds an additional emphasis to our current planning for scientific exploration of Mars, clearly the most important first step is to focus more work on the Martian meteorites.

Additional Meteorite Studies

An important next step is to get confirmation of what we have here on Earth. We need to have other scientific teams attempt to replicate the findings of the McKay Team to ensure the validity of their findings. We need to have scientists

(McKay and others) look to other avenues of inquiry, such as evidence of sub-cellular structures, to augment and expand the areas of analysis. And we need to continue to identify more meteorites from Mars, and to examine the other eleven we already have, for any light they might be able to shed on this area of scientific inquiry.

That could take a year or so. In the meantime, we will continue to plan how to get a sample from Mars to the Earth for study. If a scientific consensus emerges that the finding of the McKay Team are confirmed and that it really does look like life developed on Mars, then I suspect we may accelerate our plans for a Mars Sample Return mission in some way.

And in fact, we should not foreclose the idea that life still might exist in sheltered places on Mars. We have found compelling evidence on our own planet where life has developed and prospered in very unlikely places where we did not suspect it was possible, such as several miles below the surface of the Earth or inside rocks that happened to have liquid water and a source of chemical energy available. I suspect that there are sheltered places on Mars --on the polar caps, in the polar caps, under the surface, or in permafrost -- that contain sources of liquid water we have not yet discovered.

Our current strategy for Mars exploration

NASA has been developing a strategy for the past several years for a new post-Viking, second era of Mars exploration -- a plan for the systematic, step-by-step robotic exploration of the planet, to renew the scientific exploration of the planet and to study the pros and cons of human exploration of Mars sometime in the next century. While we will continue to explore all the planets of the solar system with our robotic spacecraft, it seems clear that there should be a particular focus on Mars, given the scientific and public interest.

Our overall strategy is one that would be familiar to the explorers of the last century, who opened up the last remaining territories on our own planet. The first step is to map the territory; to provide detailed global maps of the planet -- including, surface features, elemental and mineral composition, and topography -- from which we can identify the geologically most interesting parts of the planet and to search for areas where we might possibly find evidence for past warmer and wetter climates. The global orbital survey will determine the distribution of atmospheric water and its change with time, follow the wax and wane of the polar caps with the change of seasons and the transport of water vapor through the atmosphere, and search for potential areas of subsurface permafrost. After conducting a complete survey from orbit, we will know the surface of Mars almost as well as we do that of the Earth. We will then have a global database about Mars, and the roadmaps to the planet, that we will need for missions to send very capable missions to the surface of Mars.

The second part of the strategy is to send in scouts to survey the lay of the land, in essence to conduct a landed survey at the most promising areas around Mars. We will use the orbital global survey maps developed in earlier missions to find the most interesting spots on the surface, and send lander scouts to survey these sites. These interesting areas could be at the mouth of ancient rivers, on the sides of volcanoes, at the bottom of the canyons, or on the edges of the polar caps. Each lander will take images during parachute descent of the landing area, then land and take panoramic images and deploy various instruments from the lander and from small rovers to survey the local area and make chemical measurements of nearby soil and rocks.

After scouting the surface with a series of small landers, the next step is to bring back samples. We do not know where the meteorites we have came from on the surface of Mars, therefore we can not use them for "ground truth" for remote sensing studies. Further, the Martian meteorites we have are all igneous rocks and do not tell us as much about Mars' water and atmosphere as we could learn from studies of old sediments and soils. Igneous rocks are not the best candidates for searching for ancient Martian life. Sample return missions directed to both old sedimentary rocks and young volcanic rocks are needed for "ground truth" and to better understand volatiles and possible life on Mars.

From the series of small landers we will know which are the three or four best sites from which we would like samples. The current plan, before the ALH84001 discovery, was to get a sample back from Mars by the year 2008 from a simple sample return mission in 2005. Achieving that modest achievement was going to be a challenge within our existing Mars Surveyor program plans. This general strategy is changed very little by the ALH84001 inferences, but what could be changed is the nature of the samples that we wish to return from the surface of Mars and the precursor missions and on-surface measurements required to certify which samples to return.

While NASA is exploring all of these approaches to Mars Exploration, the resources needed for these activities must be carefully weighed against all of the Administration's priorities. It will take at least another year to better understand the approach needed and what level of resources are required and available.

A new strategy for getting the right material from Mars

One result of the recent ALH84001 finding is that we are revisiting our Mars strategy to see how it would be changed. Perhaps instead of setting our goal as the return of just an "interesting" sample, we should set the goal of our Mars exploration programs to maximize the probability that the returned samples contain evidence relating to the possible existence of early life on Mars. In other words, we want not just any sample, but a sample containing the "right stuff." That requires a great deal more work, in identifying the right places on Mars, and in locating and returning the right samples.

Immediately after the ALH84001 discovery, NASA asked the Mars Science Working Group to consider what new strategy would be required to focus on possibility of life on early Mars as the driving goal for scientific Mars exploration. Their report is due back at the end of the month, but I can give you a preview of some of their conclusions. The group has identified three environments on Mars that are potentially most favorable to the emergence of life, and where our search should be directed:

1. "ancient" environments in the heavily cratered terrain of the Martian highlands, where incidentally our 1998 lander is to be directed. Sampling this environment will emphasize exploring the ejecta of young impact craters for just the kind of ancient rocks and evidence as is contained in ALH84001. This is the environment from which sample return could occur soonest, since precursor information for site selection is already available from early missions.

2. "old" environments existing after the period of heavy bombardment early in solar system history, when a significant atmosphere was still present with standing liquid water on the surface. Evidence of life may be preserved in the remaining channel systems and basins existing today. Extensive orbital and surface exploration would be required to find areas on the surface with the remnant deposits of sedimentary materials within which to search.

3. "pervasive subsurface" environments where life may have formed at any time, including recently, where liquid water may exist in warmer, protected subsurface niches. For these environments, development of techniques for locating subsurface liquid water are required and orbital/surface exploration techniques for identifying surface or subsurface "hot spots."

The Mars Science Working Group has not yet completed its work, however, it should be finished shortly after its next meeting at the end of September 1996. We have asked mission planners at NASA's Jet Propulsion Laboratory (JPL) to work with the science team to develop implementation scenarios for this strategy, with various options for the rate at which the strategy would be carried out. NASA's Administrator, Daniel S. Goldin, has characterized the rates as "relaxed," "nominal" and "fast." The implementation team will complete its work shortly after the science group is finished. The joint team will also identify the technology requirements needed to carry out the strategy. It is already clear that long-range rovers, high spectral resolution (orbital) sensors, in-situ (surface) instruments, and subsurface sensors and access tools will be required.

Because the search for evidence of life may require finding a specific sample(s) with the "right stuff," the exploration of Mars is best viewed as a series of missions which narrow the focus to the most promising sites for detailed analysis. With increasing resolution, the mission series will progress from global reconnaissance, to high-resolution imaging of minerals characteristic of water activity, to eventually landed mission studies of rocks capable of preserving the signatures of life. The investigation will reach its maturity with a series of mission that will bring the best samples back to Earth for detailed analysis. It is important to note that based on what we know now, we have to return samples to Earth to do the kinds of analysis it will require to answer whether or not life ever existed on Mars.

International Participation

NASA's existing program of Mars Exploration assumes a significant level of international cooperation and we have been taking steps in the last 3 years to increase that level of cooperation. Currently, it would be fair to say that while international collaboration on Mars missions is in its early stages, considerably more cooperation is envisioned for the future. Our goal is to have our Mars exploration activities fully coordinated and to have a significant portion of this exploration completed as joint missions with other nations.

1996 Missions

The three missions to be launched to Mars this year, two U.S. and one Russian, are more national in character with international contributions. The U.S. Mars Global Surveyor mission, for example, will carry communications relay equipment built by France that is necessary to support future Mars Surveyor landers and which will also support data return to Earth from Russian surface probes on Russia's Mars '96. France also is providing an electron reflectometer for the NASA magnetometer experiment and is supporting radio science investigations. Austria is participating through science support of the magnetometer/electron reflectometer investigations. The U.S. Mars Pathfinder mission will carry a German-built instrument to investigate the chemical composition of the Martian surface and German components to support imaging studies. Denmark will provide a magnetic properties experiment. The U.S. will provide soil composition instruments for Russia's small landers that will be carried on Russia's Mars '96 mission. This Russian mission also includes many instruments and subsystems built by European partner nations.

1998 Missions

International participation on essentially U.S. and other national missions continues into the next celestial opportunity for Mars exploration. For the 1998 U.S. Mars Surveyor polar lander mission, several other nations will provide hardware and/or scientific support. Russia will provide a light intensification direction and ranging (lidar) instrument to measure atmospheric properties, Germany will provide a robotic arm camera, Denmark will provide a magnetic properties experiment, and Finland will provide unique pressure sensors. For the 1998 U.S. Mars Surveyor Orbiter, Russia will provide optics for the U.S.-built atmospheric sounder instrument, while the United Kingdom will develop a pressure modulator infrared radiometer. For Japan's 1998 Planet-B mission, NASA will provide an instrument to conduct in situ measurements of the density profile and composition of the Martian atmosphere.

International Mars Exploration Working Group
A number of spacefaring nations agreed in 1993 to form the International Mars Exploration Working Group (IMEWG). Composed of representatives from the U.S., Russia, the European Space Agency, Austria, Canada, France, Germany, Italy, Japan, and the United Kingdom, IMEWG is chartered to develop an international strategy for Mars exploration, to assist in preventing duplication through the exchange of information, and to provide a forum to develop ideas for future collaboration and cooperation. Since 1993, IMEWG has met at least annually to review agency plans and to facilitate agency-level implementation of international agreements. It will meet again in December 1996 and we anticipate briefing them on NASA's plans for Mars exploration. This group is the appropriate science and technical venue in which a truly international strategy for the exploration of Mars can be developed.

How does the search for life on Mars fit into the "Origins" theme

NASA's Origins Program is directed towards answering among the most fundamental questions that we can ask:

1. Where did galaxies, stars, planets and life come from?
2. Are there worlds like the Earth around nearby stars? If so, are they habitable and is life as we know it present there?

The search for evidence of early life on Mars is as much about a search for origins as it is about Mars exploration. If life evolved or began at least at the early stages on a second planet in our solar system, then it begs the question "if in two places, why not more than just two?" In all places where water and a source of chemical energy are present, we find life on Earth. So, why should we not find life on other planets in our solar system? There are many other places in the solar system where there has been at one time or another, or may still be, liquid water and sources of chemical energy.

And if life emerged in more than one place on our home planet and within our solar system, why not in other solar systems? We are beginning to discover evidence of planets around other stars, and if there are other planets like ours, whether it be on Mars or elsewhere, then could life have emerged there also?

The Sun is just one of more than a hundred billion stars in the Milky Way, and our Galaxy is just one of some 40 to 50 billion galaxies in the universe. A vast number of stars are similar to our Sun in size and brightness, and many are as old or older. Although to date scientists have only detected a small number of planets around nearby stars, these findings suggest that it is likely that many stars are orbited by planets. Among the most intriguing of all questions are whether

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any of these planets support life (either past or present) and whether any of that life evolved to develop a civilization. If the answer is yes, then we are not alone in the cosmos.

Although science fiction is filled with tales of alien civilizations in places as close as Mars, planetary probes and other observations have found no evidence of alien intelligence in our solar system. In retrospect, this is not surprising, considering that life existed on Earth only as single-celled, microscopic organisms for most of its history. Thus the question remains, is there the possibility of life, past or present, elsewhere in our solar system?

Life on Earth has been found within the deep subsurface, in hydrothermal vents on the ocean floor at temperatures as high as 118° C (244° F), in permafrost that has remained frozen for millions of years, beneath perennial ice covers, and inside the rocks of cold deserts. Where there has been water, there has been life. Thus, on other planets, the search for the evidence of life requires understanding the history of water and operationally becomes the search for liquid water, both past or present.

In the case of Venus and Mars, both planets had beginnings similar to Earth. Life evolved quickly on early Earth and perhaps it did likewise on Venus or Mars. Today however, a runaway greenhouse effect bakes Venus at 450° C (842° F), far too hot for life as we know it. Mars, on the other hand, is considered a better candidate for the development of life. In 1976, two Viking spacecraft landed on Mars, but found no conclusive evidence of life. This conclusion however, is subject to debate because the spacecraft only sampled two small patches of the planet.

The atmospheres of the giant planets (Jupiter, Saturn, Uranus, Neptune) contain many organic molecules, but water is only found in clouds, and their turbulence makes them unlikely candidates for the development of life. Organic chemicals also are found on Saturn's moon Titan (which will be explored in detail by NASA's upcoming Cassini mission), but its surface appears too cold for liquid water.

The large moons in the outer solar system, like Jupiter's moons Europa, Ganymede, and Callisto (which are being studied by NASA's Galileo spacecraft), and Neptune's moon Triton are frozen, airless worlds that could not support life on their surfaces, but may have complex interior chemistries. Europa may have liquid water deep beneath its frozen surface, perhaps supporting a hydrothermal system capable of originating and sustaining life, analogous to the deep-sea vent communities found at the rift zones in our oceans. Voyager and recent Galileo images show a fractured surface on Europa, not dissimilar to ice-flows seen over polar oceans on Earth. A Galileo fly-by in December could refine our assessment of the possibility of an subsurface ocean.

Conclusion

Mr. Chairman and Members of the Subcommittee, the conclusion by the McKay Team from their studies of ALH84001 that early life existed on Mars remains to be proven; however, the implications of this work are profound. It represents the culmination of a series of fantastic discoveries in Space Science over this past year, ranging from the origin of galaxies to the birthplace of stars and planetary systems, to new planets discovered around nearby stars, to the possibility of a subsurface ocean on Europa, and now evidence of life on early Mars. We are entering an exciting new era of discovery and knowledge about the place in which we live -- not just for planet Earth, but for our solar system and universe -- for there is no more exciting question we could pursue than "Are we alone in this place?"

APPENDIX A:
Description of Current Planned Mars Missions

1996 Missions

The next era of Mars exploration opens in 1996 with Mars Pathfinder, Mars Global Surveyor (MGS), and the Russia/International Mars '96. Mars Pathfinder (which is scheduled to launch in December 1996) will deploy a lander and a small rover on the surface of Mars to explore its terrain and analyze rock composition. Mars Global Surveyor (launch in November 1996) will orbit Mars for at least 2 years mapping the chemical composition of its surface and its geological history. Mars '96 (launch in November 1996) will deploy a larger orbiter with international instrumentation and sample the chemistry of Martian soil from two sites on the Mars surface.

Mars Pathfinder
Mars Pathfinder will be the second of NASA's low-cost planetary Discovery missions to be launched. The mission will consist of a stationary lander and a surface rover. The mission has the primary objective of demonstrating the feasibility of low-cost landings on and exploration of the Martian surface. This objective will be met by tests of communications between the rover and lander, and the lander and Earth and tests of the imaging devices and sensors. The scientific objectives include atmospheric entry science, and long-range and close-up surface imaging, with the general objective being to characterize the Martian environment for further exploration. International participation consists of Germany's provision of an Alpha Proton X-ray Spectrometer (APXS) instrument and of charged coupled devices for imaging investigations, and of Denmark's provision of a magnetic properties experiment.

The spacecraft is scheduled to enter the Martian atmosphere directly on July 4, 1997 without going into orbit around the planet. The lander will be taking atmospheric measurements as it descends through the Martian atmosphere. The entry vehicle's heat shield will slow the craft; an onboard computer will sense the slow-down in speed and then deploy a large parachute. The parachute will further slow the lander and at 100 meters above the surface the landers external air bags will be inflated. Seconds later, three solid rocket motors placed inside the top half of the entry vehicle will be fired. In approximately 2 seconds, the rockets will bring the lander to a stop some 12 meters above the Martian ground. The parachute will be released, and the lander, nestled inside its protective air bag cocoon, will fall to the ground, bouncing and rolling until it stops.

Pathfinder will then open its three metallic triangular solar panels (petals) and stand itself upright from any side that it happens to be lying on. The lander will first transmit the engineering and science data collected during entry and landing. The imaging system (a camera on a pop-up mast) will then obtain a panoramic view of the landing area and transmit it to Earth. Finally, the rover will be deployed. The bulk of the lander's task will be to support the rover by imaging rover operations and relaying data from the rover to Earth. Over 2.5 meters of solar cells, in combination with rechargeable batteries, will power the lander.

The landing site has been chosen for this mission at 19.5 degrees North, 32.8 degrees West in the Ares Vallis region, an outwash plain near Chryse Planitia. This region is one of the largest outflow channels on Mars, the result of a huge flood (possibly equal to the volume of all five Great Lakes) over a short period of time flowing into the Martian northern lowlands. At this point the primary data-taking phase begins, and continues for 30 Martian days or sols (24.6 hours). During this time, the microrover is deployed and operated for at least 7 Martian days. If the lander and rover continue to perform well at the end of this period, an extended mission may continue for up to one Martian year for the lander, and the microrover for up to 30 Martian days.

Sojourner

The Mars Pathfinder rover, which has been named "Sojourner," is a six-wheeled vehicle mounted on a "rocker-bogie" suspension. The rover will be controlled by an Earth-based operator who will use images obtained by both the rover and lander systems. The communications time delay will be between 6 and 41 minutes depending on the relative position of Earth and Mars, requiring some autonomous control. The on-board control system is capable of compressing and storing a single image on-board. The rover is powered by 0.2 square meters of solar cells, which will provide energy for several hours of operations per each Martian day; non-rechargeable lithium D-cell batteries will provide backup power.

The rover is equipped with a black and white imaging system which will be used to image the lander in order to assess its condition after touchdown, and to image the surrounding terrain to study size and distribution of soils and rocks, as well as locations of larger features. Imaging of the rover wheel tracks will be used to estimate soil properties.

UHF Communications between the rover and lander will be studied to determine the effectiveness of the link between the rover and lander as the rover moves away from the lander. Assessments of rock and soil mechanics will be made based on abrasion of the wheels and adherence of dust. An alpha-proton-X-ray spectrometer (APXS) is on-board the rover to assess the composition of rocks and soil. Images of all samples tested will be transmitted to Earth. The primary objectives are scheduled for the first seven Martian days, all within about 10 meters (33 feet) of the lander. The extended mission will include longer trips away from the lander over about 30 Martian days. More information on the Mars Pathfinder mission is available on the World Wide Web at http://mpfwww.jpl.nasa.gov/.

Mars Global Surveyor (MGS)
MGS is the first venture in NASA's Mars Surveyor Program - a new series of missions to explore Mars. The Mars Surveyor Program will launch orbiters or landers every Mars launch opportunity over the next decade, using advanced technology to develop a comprehensive portrait of Mars. By studying Mars scientists hope to better understand the formation and evolution of Earth and the inner solar system. International participation consists of French provision of communications relay equipment and of electron reflectometer for NASA's magnetometer experiment, as well as French support of radio science investigations. It also involves Austrian support of the magnetometer/electron reflectometer investigations.

In September 1997, the Mars Global Surveyor spacecraft, approaching Mars after a 10-month voyage from Earth, will fire its main rocket engine, slowing its journey and allowing itself to be captured by Mars' gravity. The small spacecraft will then swing into an elliptical (highly elongated), near-polar orbit around Mars. In the months that follow, thruster firings and aerobraking maneuvers (periodic shallow dips through the Martian atmosphere), orchestrated by mission controllers hundreds of millions of kilometers away, will gradually reshape the spacecraft's orbit into a nearly circular mapping path, 378 kilometers (235 miles) above the surface.

Once in its mapping orbit, MGS will complete one orbit around Mars in about 2 hours. Each new orbit will bring the spacecraft over a different part of Mars. As the weeks pass, the spacecraft will create a global portrait of Mars, capturing the planet's ancient crater plains, huge canyon system, massive volcanoes, gigantic channels, and frozen polar caps. During its mission, MGS also will pass over the terrain where the two inactive U.S. Viking landers - separated by over 6,400 kilometers (3,975 miles) - have rested for 19 years.

As Mars rotates beneath the spacecraft, a suite of onboard instruments will record detailed information. Detectors will measure radiation - visible and infrared - from the surface to determine the minerals that make up Mars. These same instruments will record radiation from the thin Martian atmosphere, gathering data about its changing pressure, composition, water content, and dust clouds. By firing short pulses of laser light at the surface and measuring the time the reflections take to return, a laser altimeter will map out the heights of Mars' mountains and the depths of its valleys. The camera system will use wide and narrow angle components to record landforms and atmospheric cloud patterns. Another sensor will look for a Martian magnetic field. As the telecommunications subsystem transmits information back to Earth, engineers will use the signal of the orbiting spacecraft to derive knowledge about the planet's atmosphere and gravitational field.

Global mapping operations are scheduled to last 2 years. By the time these operations are over, MGS will have obtained an extensive record of the nature and behavior of the Martian surface, atmosphere, and interior. Such a record will aid in planning more specialized explorations that might involve robots, scientific stations deployed to the Martian surface, soil sample returns to Earth, or perhaps even human landings. Just as important, this record will help us understand our own planet, Earth, from a comparative perspective. More information on the Mars Global Surveyor mission is available on the World Wide Web at http://mgs3.jpl.nasa.gov/.

Mars '96

Mars '96 is a very comprehensive mission addressing a broad range of science questions, and making a variety of pilot measurements on the surface that will be useful for the design of subsequent more definitive experiments. It will consist of an orbiter and four landers (two surface stations and two penetrators); the penetrators and landers will be released to the surface shortly before the orbiter is injected into Mars orbit. Russia is planning to launch Mars '96 in November 1996 and expect it to arrive at Mars in December 1997.

The primary U.S. participation in Mars '96 will be the provision of two copies of the Mars Oxidant Experiment (or MOx), one of which will be part of each of the two surface stations; the two surface stations are slated to land in Mars' Amazonis Planitia, at sites centered on 41.3 N, 153.6 W and 32.5 N, 169.3 W. The objectives of the landers are to determine the vertical structure of the atmosphere at the landing sites, to determine the chemistry of the materials at the sites, and to make prolonged magnetic, seismic, and meteorological measurements. To meet these objectives each lander carries a variety of instruments.

The MOx is designed to return information about the nature and rate of chemical reactions in the Martian soil and atmosphere. By exposing a series of coated fiber-optical detectors to the regolith close to the lander, the MOx will attempt to study the oxidant(s) apparently responsible for elimination of organic matter from the upper Martian regolith.

Mars Global Surveyor has an antenna supplied by France that will help relay the data from the four Russian landers. The U.S. MOx science team is chaired by Dr. Christopher McKay of NASA/Ames Research Center. For more information about Mars '96, see the World Wide Web page at http://www.iki.rssi.ru/mars96/mars96hp.html.

1998 Missions

Mars Orbiter '98

This Mars orbiter (to be launched in December 1998) will carry an advanced technology optical camera to take global maps of the surface and an atmospheric instrument to measure temperature profiles. The orbiter will be designed to document daily weather patterns, study the icy southern polar cap of Mars and conduct a more highly focused search for water in the Martian soil. International participation involves Russia's provision of optics for the atmopsheric sounder instrument and of the United Kingdom's provision of a pressure modulator infrared radiometer.

The 1998 orbiter will be just one-half the weight of Mars Global Surveyor, an orbiter that will be launched in 1996. During and after its primary science mission, the 1998 Mars Surveyor orbiter also will serve as a data relay satellite for the companion lander and for future NASA and international lander missions to Mars.

Mars Polar Lander '98

This lander (to be launched in January 1999) will deliver a high resolution camera and a meteorological package to the surface of Mars. Known as the 1998 Mars Surveyor Lander, this mission will be the first ever sent to the polar regions of Mars, where it should encounter layers of icy terrain that represent a preserved record of the planet's climate history. The 1998 lander will be just half the weight of the 1996 Mars Pathfinder, the smallest planetary lander yet constructed.

A laser-ranging device, or lidar, for this mission will be provided by Russia. Measurements from this device should help us better understand the relationship between the amount of dust and aerosols in the lower-most part of the Martian atmosphere and the planet's regional weather conditions. In addition to this important science goal, this lidar will be the first Russian instrument to fly aboard a U.S. planetary spacecraft, so it represents a new degree of international cooperation in the exploration of our solar system. For the NASA-developed Mars Volatile and Climate Surveyor package, Germany is providing a robotic arm camera, Finland is providing custom-made pressure sensors, and Denmark is providing a magnetic properties experiment.

The 1998 Mars Surveyor Lander also will carry a U.S.-provided lightweight camera to take images of the surrounding terrain during the spacecraft's final descent, and an integrated surface science payload that includes a mast-mounted imager, a meteorological station, a soil composition analyzer and a robotic arm to dig trenches in the icy soil of the south pole.

Planet B

The Japanese Planet B mission is planned for launch during the 1998 Mars launch opportunity. The primary scientific objectives of this mission are to study the Martian upper atmosphere and its interaction with the solar wind through three sets of experiments. The first set of experiments will measure the structure, composition and dynamics of the ionosphere, the effects of interaction of the upper atmosphere with the solar wind, and the escape of atmospheric constituents. The second set of experiments will measure the intrinsic magnetic field, the penetration of the solar-wind magnetic field, and the structure of the magnetosphere. The third set of experiments will measure dust in the upper atmosphere and in orbit around Mars. Among the numerous instruments that will employed to perform this wide range of measurements is a U.S.-supplied neutral mass spectrometer which will measure the elemental and isotopic composition of the upper Martian atmosphere.

STATEMENT OF LT. GEN. THOMAS STAFFORD, STAFFORD, BURKE, AND HECKER

General STAFFORD. Thank you, Mr. Chairman, and Members of the Subcommittee. It's a pleasure to——

Mr. SENSENBRENNER. Please turn on the mike.

General STAFFORD. Mr. Chairman, Members of the Subcommittee, it's a pleasure to appear before the Subcommittee again in reply to your request to address the subject of the future exploration of Mars and a strategy for that exploration beyond the year 2005.

As you outlined, from 1990 to 1991, I had the privilege of chairing an independent group to gather data from all around the Americas and to synthesize it and formulate plans for America to return to the moon and start the initial exploration of Mars.

Our task was to establish the architecture for the exploration, the key technologies, and the important first steps.

Our report, "America at the Threshold," completed these tasks and established a vision for the future of space exploration for America.

I led an in-depth presentation before this very Subcommittee and submitted copies of the report here, "America at the Threshold," at that time. We furnished additional copies here today.

After your request for me to appear, Mr. Chairman, I contacted the senior members of my group to ask if there are any differing views of opinion since the time it was put together. And by and large, the consensus was that the findings that we had then are as much valid today as they were then.

Your call for this hearing is most timely in initiating a review of future missions to explore the Red Planet.

Our space program has made much progress since that review in 1991. This hearing presents a welcome opportunity to revisit this issue. I'm grateful to you for initiating this significant inquiry.

To carry out such a visionary undertaking, I believe now, as then, that a plan must be established that includes technology development, a sound scientific strategy, and both robotic and human spaceflight.

It is not my intention to set priorities among programs, but, rather, identify logical arrangements of program elements that can support space exploration. I am not advocating that the exploration of Mars become "the next NASA program," but, rather, the exploration of Mars itself become the crown jewel for the exploration of space.

We identified several key technologies that are necessary to successfully undertake the exploration of Mars. It is important to note that America's ability to return to the moon and to begin the exploration of Mars depended upon two fundamental technologies—the restoration of a heavy-lift launch capability and the redevelopment of a nuclear thermal rocket. This nation had both of those capabilities in the early 1970s. These two areas plus 12 other technologies are discussed in detail.

NASA will need strong legislative branch support because the challenges of this endeavor to explore Mars cannot be accomplished without it.

What kind of exploration effort can be initiated on a constrained budgetary environment?

There are two points I would like to make. The first, if we want to wait until we have a budgetary surplus, I'm afraid that we'll never take this bold, imaginative step. But it does not require a lot of money to get started and a small amount will generate a lot of leverage today.

Our report highlights that the technologies required can be developed largely through refocusing ongoing efforts in government facilities and encouraging private industry to apply some of their resources.

To have this happen, there needs to be additional money specifically appropriated for space science and human exploration in the NASA budget.

My second point is that in our study process, we anticipated that cost concerns would arise over the life of a Mars exploration effort, no matter how modestly that it began. And the architectures that we developed were executed in an incremental manner so that the Congress can review each increment with the knowledge that the architectures could be modified, the architectures could be terminated any time, and a useful activity will still have been achieved and significant benefits will be obtained therein.

International cooperation is an important issue to be addressed. Sharing the development and operational costs with other nations will definitely reduce our costs. However, I believe that before engaging in discussions with potential international partners, we should first establish the exploration of Mars as part of our national strategic plan.

Mars exploration will rejuvenate our sense of challenge, our sense of competitiveness, and of national pride. As Americans, we must ask ourselves what our role will be in the human exploration of the solar system—to lead, to follow, or just step aside.

Let me emphasize that the safe and affordable exploration of Mars should not be our only goal, it should be our national purpose.

I hope that these recommendations will be the basis for a national commitment to education, to research, and to space exploration.

You and your Subcommittee, Mr. Chairman, are essential to that national commitment. I would earnestly hope that these hearings being held will be just the first step in reaching the consensus necessary to make a national commitment a reality.

Armed with this commitment, we can then meet the challenges of the next millennium to carry the mantle of world space leadership and then, through a series of bold and imaginative steps, blaze new trails into the 21st century.

Our destiny demands no less.

Thank you, Mr. Chairman, and I welcome the opportunity to answer any questions of you or the Members of the Committee.

[The prepared statement of General Stafford follows:]

Statement of

Lieutenant General Thomas P. Stafford
USAF (Retired)

before the

Subcommittee on Space and Aeronautics

Committee on Science

U.S. House of Representatives

September 12, 1996

Mr. Chairman and Members of the Subcommittee:

It is a pleasure to appear before this subcommittee again and to reply to your request to address the subject of the future exploration of Mars and a strategy for Mars explorations beyond 2005.

In 1990-1991, I had the privilege of chairing an independent group, with the goal of gathering and synthesizing data and ideas from all interested parties. We were then to formulate a plan for America to return to the Moon and start the initial exploration of Mars.

To carry out this task, I assembled a team that consisted of representatives of NASA, the Department of Defense, the Department of Energy, the National Geological Survey and other interested Federal Agencies. Our task was to establish the architecture for exploration, the key technologies, and the important first steps. Our report, "America at the Threshold," completed these important tasks and established a vision for the future of space exploration for America. I led an in-depth presentation before this committee and submitted copies of the report to the hearing record at that time. I have furnished additional copies of the report to the subcommittee today.

Your call for this hearing is most timely in initiating a review of future missions to explore the Red Planet. Our space program has made much progress since your last review. This hearing presents a welcome opportunity to revisit this issue. I am grateful to you for initiating this significant inquiry.

To carry out such a visionary undertaking, I believe now, as I believed then, that a plan must be established that includes technology development, a sound scientific strategy, and both robotic and human spaceflight. It is not my intention to set priorities among programs, but rather to identify logical arrangements of program elements that can support space exploration. I am not advocating that the exploration of Mars become "the next NASA program," but rather that the exploration of Mars itself become the crown jewel for the exploration of space.

"America at the Threshold" defined what we do - not specifically how we do it. Each architecture envisions activity on both the Moon and on Mars. We called for a return to the Moon early in the new century, and a human trip to Mars in the second decade of that century.

We identified several key technologies that are necessary to successfully undertake the exploration of Mars. It is important to note that America's ability to return to the Moon and to begin the exploration of Mars depends on two fundamental technologies: restoration of a heavy lift launch capability and redevelopment of a nuclear thermal rocket. This nation had both of these capabilities in the early 1970's. These two areas and twelve other technologies are discussed in detail in the report.

NASA will need strong legislative branch support because the challenges of this endeavor cannot be accomplished without it.

What kind of exploration effort can be initiated in this constrained budgetary environment? There are two points I want to make. First, if we wait until we have a budgetary surplus, I am afraid we will never take this bold, imaginative step. But, it does not require a lot of money to get started and a small amount now will generate much leverage. Our report highlights what technologies are required and that they can be developed largely through refocusing ongoing efforts in government facilities and encouraging private industry to apply some of their resources. For this to happen, there needs to be additional money specifically appropriated for space science and human exploration in the NASA budget.

My second point is that in our study process, we anticipated the cost concerns that would arise over the life of the initiative no matter how modestly it began. That is why we formulated the architectures so that they can be executed in an incremental manner. Stated another way, the Congress can review each and every increment with the knowledge that the architecture could be modified or terminated at any time and useful activity will have been achieved and significant benefits attained.

International cooperation is an important issue to be addressed. Sharing the development and operational costs with other nations will reduce our costs. However, I believe that before engaging in discussions with potential international partners, we should first establish the exploration of Mars as part of our national strategic plan for space.

Space Exploration will rejuvenate our sense of challenge, of competitiveness, and of national pride. Benefits from space and the technologies needed to journey there become increasingly important in the next century. As Americans, we must ask ourselves what our role will be in the human exploration of the solar system: to lead, to follow, or to just step aside.

Let me emphasize that the safe and affordable exploration of Mars should not only be our goal, it should also be our national purpose. I hope that these recommendations will be the basis for a national commitment to education, to research and to space exploration. You and your subcommittee, Mr. Chairman, are essential to that national commitment.

It is a feasible undertaking requiring our national commitment. I would earnestly hope that these hearings would be but the first step in reaching the consensus necessary to make that national commitment a reality.

Armed with this commitment, we can then meet the challenge of the next millennium "to carry the mantle of world space leadership and, through a series of bold and imaginative steps, blaze new trails into the 21st Century."

Our destiny demands no less.

Thank you Mr. Chairman. I welcome the opportunity to answer any questions you and the members of the subcommittee may have.

Mr. SENSENBRENNER. Thank you very much, General Stafford.

The next witness will be Dr. David S. McKay, Assistant for Exploration, Earth Science and Solar System Exploration Division, at the Johnson Space Center of NASA.

Dr. McKay?

STATEMENT OF DR. DAVID S. MC KAY ASSISTANT FOR EXPLORATION EARTH SCIENCE AND SOLAR SYSTEM EXPLORATION DIVISION JOHNSON SPACE CENTER NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Dr. MCKAY. Mr. Chairman, and Members of the Subcommittee, it's certainly my pleasure to be here today to discuss the results of our two-year investigation of this meteorite. The meteorite is on the table here in front of me, a piece of it provided by the Smithsonian. The rest of the meteorite is at Johnson Space Center in Houston.

What I want to talk about today is a detective story.

We went through a very interesting chain of logic to come to our conclusions. The conclusions are controversial. We're the first to admit that. But we think that they are valid with the kind of data that we have.

First of all, my team consisted of myself, Everett Gibson, Kathie Thomas-Keprta of Lockheed- Martin. We also had a partnership with Stanford University, Dr. Richard Zare, who is on my right.

The publication came on August 16th, and there's a copy of it attached to the testimony.

What we did was, first of all, go through the evidence that this rock is actually from Mars. And that evidence consists of really two basic things. The chemistry of the rock itself is unique, but shared by 11 other rocks that we know about, meteorites.

That chemistry is different from any earth chemistry, particularly for things like oxygen isotopes. And that chemistry defines a tight family of rocks, which came from some place other than the earth or the moon.

It turns out that one of these, no. 79001, is a Rosetta Stone which has not only this unique chemistry, but which also was shown to be identical in composition to the Viking data from 1976. That is, the gases analyzed were identical to the Viking data.

So that we believe that the evidence is now overwhelming that these 12 rocks, six of which were found in Antarctica, come from Mars.

Now we started looking at this rock two years ago and we noted a number of important features. The first is the rock contains tiny bits of carbonate, like limestone or calcite. And these carbonate grains have very unusual textures. They're zoned. They're circular or pancake-shaped.

And so we started analyzing these, along with some other groups, and we found that these carbonates were formed on Mars. They had a unique composition that meant they were formed on Mars. They had unique textures. And as we looked at these carbonates more carefully, we found that they contained very tiny minerals—oxides of iron magnetite, and oxides of sulfur—not oxides, but iron sulfides of different kinds.

So we analyzed these minerals.

Well, it turns out that these tiny minerals are very similar to minerals which are made on the earth by bacteria, certain kinds of bacteria.

Another thing we found was that the rock itself in the area of these carbonate grains contained organic molecules. And Dr. Zare will talk a little bit more about those. But these organic molecules, called polycyclic aromatic hydrocarbons, are found everywhere on the earth. They're products of combustion of coal and so forth.

But the ones in this meteorite are fairly unique and have a unique fingerprint. We have deduced or we have interpreted that they're formed by the decay of possible organic matter in this meteorite.

And then, finally, the thing that we saw that was drawing the most public attention were these tiny structures which we interpreted as possible microfossils from Mars. This is perhaps very controversial.

We're now taking additional steps to establish whether indeed these are microfossils from Mars.

So it's a combination of those four lines of evidence that have in fact provided us with the interpretation that we're dealing with with possible fossil life. Whether or not we're ultimately proved right or wrong, we believe that the study of these Martian meteorites will set some new standards for the search for life in our solar system. They're pushing the state of the art in analytical technology and efficient use of small amounts of material.

The studies will develop techniques and force instrument advances that can be used very profitably in the future to investigate samples brought back not only from Mars but from comets, from asteroids, and from satellites of other planets.

So, if I might make an analogy, just as the whole area of chemical, analytical technology took a major jump forward during the Apollo days, after the lunar samples came back, I am confident that the quest for evidence for life on Mars will force some major improvements in this technology for the fields of chemistry and microbiology.

So, Mr. Chairman, that concludes my statement. I'd be happy to respond to any questions which you or the Subcommittee might have.

[The prepared statement of Dr. McKay follows:]

Statement of

Dr David S. McKay
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before the

Subcommittee on Space and Aeronautics
Committee on Science
U.S. House of Representatives

September 12, 1996

Mr. Chairman and Members of the Subcommittee:

It is my pleasure to be here today to discuss the results of the two-year investigation co-led by myself and Dr. Everett Gibson of NASA's Johnson Space Center and Kathie Thomas-Keprta of Lockheed-Martin, with major collaboration of a Stanford team headed by Professor of Chemistry Dr. Richard Zare, as well as six other NASA and university research partners. The results of this research were published in SCIENCE on August 16, 1996, Vol. 273, pages 924-930. A copy of the article is appended to my statement.

We believe that we have found a number of lines of evidence in a meteorite from Mars which could be interpreted as remains of early life on that planet. This meteorite, ALH84001, was found in Antarctica by a joint NASA/NSF field party in 1984. It was brought back to the Johnson Space Center where it was originally classified as another kind of meteorite, a diogenite. This misclassification occurred because only a small chip was used and the chip did not contain some of the unusual features of the whole meteorite. In 1994, David Mittlefehldt, a planetary researcher at the Johnson Space Center studied this rock along with other diogenites and discovered, based on chemical analyses of minerals and detailed study of thin sections, that this meteorite was not a diogenite but was a member of the SNC family of meteorites which has recently come to be accepted as coming from Mars. This family now includes 12 meteorites, half of which were found in Antarctica. Several lines of evidence link these SNC meteorites closely together including their oxygen isotopes which are as distinctive as a fingerprint and are clearly different from any earth rock, moon rock, or other kinds of meteorites. One member of this closely linked family, ETA79001, was discovered to contain gas trapped in small glass pockets by the impact which ejected it from Mars. Detailed analysis of this trapped gas showed that it was identical to the gas of the Mars atmosphere as measured by the two U. S. Viking spacecraft which landed on Mars in 1976. This match was nearly perfect. This meteorite became a kind a Rosetta Stone which linked the atmosphere of Mars to the SNC family of meteorites.

We initiated a detailed study of this meteorite once we realized it was a new Mars meteorite. Using radioactive isotopic age methods, other researchers found that the rock was formed 4.5 billion years ago and was part of the early crust of Mars. The rock was battered by nearby meteorite impacts so that it now contains shattered zones caused by those impacts. At some point in time, estimated to be 3.6 billion years ago by one group, the rock was invaded by water containing mineral salts which were precipitated out in cracks to form small carbonate globules which had intricate chemical zoning. Another group has now estimated that these carbonates may be younger, perhaps between 1 and 2 billion years old. In any case, about 16 million years ago, an object from space, possibly a small asteroid or comet, impacted Mars and blasted off some rocks from the upper few kilometers. The time spent in space is estimated by analyzing a number of isotopes which were formed by the hard radiation, cosmic rays, which are everywhere in space. One of these rocks traveled in space until it got close enough to the earth that it was captured by the earth's gravity and fell to the ice in Antarctica. Age dating using carbon-14 methods showed that this rock has been on the earth about 13000 years, presumably on or inside the ice sheets in Antarctica.

We analyzed the carbonate globules in this rock using two electron microscopes and an electron microprobe at Johnson Space Center. We also sent a small chip of the rock to our colleagues at Stanford University led by Dr. Richard Zare, who analyzed the chips for a specific kind of hydrocarbon, called polycyclic aromatic hydrocarbons or PAHs for short. This analysis was performed using a laser extraction system and laser excitation system which is unique to Stanford and is capable of exceedingly sensitive analysis of these hydrocarbons.

We found that the carbonate globules contained very small crystals of an iron oxide (magnetite) as well as at least two kinds of iron sulfide (pyrrhotite and another mineral, possible greigite). Small crystals of these minerals are commonly formed on earth by various kinds of bacteria, although they can also be formed by completely inorganic processes. Another kind of iron sulfide, pyrite, is also found in the rock but the crystals appear to be a thousand times larger than the pyrrhotite and greigite crystals. In addition, we found a complex zoning in which the manganese was most concentrated in the center of each carbonate globule, and most of the larger globules had rims consisting of iron-rich carbonate, magnesium rich carbonate, and iron-rich carbonate again. The compositional variation of these carbonates is not what would be expected from high temperature equilibrium crystallization, but is more like low temperature crystallization (0 to 80 degrees centigrade). It is also consistent with formation by non-equilibrium precipitation induced by microorganisms.

The Stanford group found an unusually high concentration of hydrocarbons (PAHs) on the chip surfaces where the carbonates were common. These PAHs have a pattern or fingerprint which is unusually simple compared to most PAHs that we are familiar with, including PAHs from the burning of coal, oil, or gasoline or the decay of vegetation. Some other meteorites contain PAHs, but the pattern and abundances are usually rather different from those found in the martian meteorite. The presence of PAHs is by no means an indication of past or present life forms. PAHs can be formed by strictly inorganic chemical reactions and abundant PAHs were formed in the early solar system and are preserved on some asteroids and comets. Meteorites from these objects fall to earth and enable us to analyze the PAHs contained within the parent bodies. While some of these are similar to the PAHs that we found in the martian meteorite, all show some major differences. One reasonable interpretation of the PAHs is that they are decay products from bacteria, and therefore an indication of some kind of past life within the meteorite.

Another feature which we found within the meteorite is the presence of unusual, very small objects or forms, which could be interpreted as the remains of microorganisms or microfossils. These spherical, ovoid, and elongated objects closely resemble the morphology of known bacteria, but many of them are smaller by a factor of 2 to 3 than any known bacteria on earth. Furthermore, microfossil forms from very old earth rocks are typically much larger than the forms that we see in the Mars meteorite. Unfortunately, we do not yet have good chemical data or thin section electron microscope data so that we cannot verify that they are indeed microfossils. We recognize that there may be several other possible explanations. The microfossil-like forms may really be minerals and artifacts which superficially resemble small bacteria. We do not believe this to be the case for most of the forms that we have seen, but additional detailed studies with the electron microscopes may resolve that question. Next, why are they smaller than known bacteria or known fossil microorganisms? Perhaps conditions on Mars such as lower gravity and more restricted pore space in rocks promoted the development of smaller forms of microorganisms. Or perhaps such forms exist on earth and in the fossil record but have not yet been found. If the small objects which we see are truly microfossils, are they really from Mars, the contamination from our lab, or from Antarctica? We have looked at many other kinds of material in our lab and have never seen forms resembling the ones we found in the martian meteorite. We believe that we can eliminate laboratory contamination as a source of these microorganism-like forms. Little is known about microorganisms associated with the big ice sheets of Antarctica, although rocks, soils, and lakes near the coast have abundant microorganisms, and we have studied some of these other Antarctic samples and their microorganism populations. Our studies so far show that the other Antarctic samples do not contain PAHs or microorganisms which closely resemble those found in the martian meteorite.

New data shows that the martian meteorite may contain other types of microorganism-like forms which can be revealed by etching the rocks. These forms include sheath-like hollow spheres, delicate membrane-like material which may be related to cell structure, and other unusual features within the shock-fractured zones of this meteorite. Clearly additional data are needed.

Where are we now? Our paper published in Science contains a number of lines of evidence, each of which can be interpreted as relating to some other cause, but which taken together can be interpreted as evidence for possible early life forms on Mars. We have seen nothing since the publication of the paper to cause us to abandon this interpretation, although other interpretations have been forcefully advanced by the scientific community. We are currently trying to find cell walls in the microorganism-like forms. We are also studying terrestrial microorganisms in a variety of environments, both present day and fossil. We are also looking at bacteria and their products formed in the laboratory. We have found examples of carbonates formed with the help of bacteria and we are comparing these carbonates to the martian carbonate globules. We are pursuing the question of what is the lower size limit for bacteria. We are forming several consortia and will work with scientists from other institutions and other countries to continue this research.

Have we found past life on Mars? The answer is neither yes or no, leaving a strong maybe. We still argue that past life on Mars is a reasonable interpretation of the data on hand. We believe there is considerable evidence in the martian meteorite that must be explained by other means if we are to definitely rule out evidence for past martian life in this meteorites. So far, we have not seen a reasonable explanation by others which can explain all of the data.

In my view, the question of past life on Mars may never be completely resolved by additional detailed studies of this meteorite, although such studies are clearly necessary. Each of the other 12 meteorites from Mars should also be carefully studied. Perhaps they might contain additional or alternative evidence of life on Mars. The question of life on Mars, whether fossil or existing, will never be completely solved until we can bring back the right samples from that planet.

The study of these martian meteorites will set new standards for the search for life in our solar system. These studies will push the state-of-the-art in analytical technology and promote efficient use of very small amounts of material. These studies will develop techniques and force instrument advances that can be used very profitably in the future to investigate samples brought back not only from Mars but from comets, asteroids, and satellites of other planets. Just as analytical instrument technology took a major advance when the lunar rocks were brought back, so will the quest for evidence of life in Mars meteorites and returned samples also cause improvements and advances in chemistry and microbiology.

Mr. Chairman, this concludes my statement. I would be happy to respond to any questions which you or the Subcommittee members may have at this time.

RESEARCH ARTICLE

Search for Past Life on Mars: Possible Relic Biogenic Activity in Martian Meteorite ALH84001

David S. McKay, Everett K. Gibson Jr., Kathie L. Thomas-Keprta, Hojatollah Vali, Christopher S. Romanek, Simon J. Clemett, Xavier D. F. Chillier, Claude R. Maechling, Richard N. Zare

Fresh fracture surfaces of the martian meteorite ALH84001 contain abundant polycyclic aromatic hydrocarbons (PAHs). These fresh fracture surfaces also display carbonate globules. Contamination studies suggest that the PAHs are indigenous to the meteorite. High-resolution scanning and transmission electron microscopy study of surface textures and internal structures of selected carbonate globules show that the globules contain fine-grained, secondary phases of single-domain magnetite and Fe-sulfides. The carbonate globules are similar in texture and size to some terrestrial bacterially induced carbonate precipitates. Although inorganic formation is possible, formation of the globules by biogenic processes could explain many of the observed features, including the PAHs. The PAHs, the carbonate globules, and their associated secondary mineral phases and textures could thus be fossil remains of a past martian biota.

A long-standing debate over the possibility [of p]resent-day life on Mars was addressed by . . Viking lander experiments in 1976. Although the results were generally interpreted to be negative for life in the tested surface soils, the possibility of life at other locations on Mars could not be ruled out (*1*). The Viking lander's mass spectrometry experiments failed to confirm the existence of organics for the martian surface samples analyzed. Furthermore, the Viking results contained no information on possible fossils. Another source of information about possible ancient martian life is the Shergotty-Nakhla-Chassigny (SNC) class of meteorites, which appear to have come to the Earth by impact events on Mars (*2*, *3*). We have examined ALH84001, collected in Antarctica and recently recognized as a meteorite from Mars (*4*). Our objective was to look for signs of past (fossil) life within the pore space or secondary minerals of this martian meteorite. Our task is difficult because we only have a small piece of rock from Mars and we are searching for martian biomarkers on the basis of what we know about life on Earth. Therefore, if there is a martian biomarker, we may not be able to recognize it, unless it is similar to an earthly biomarker. Additionally, no information is available on the geologic context of this rock on Mars.

ALH84001 is an igneous orthopyroxenite consisting of coarse-grained orthopyroxene [$(Mg,Fe)SiO_3$] and minor maskelynite ($NaAlSi_3O_8$), olivine [$(Mg,Fe)SiO_4$], chromite ($FeCr_2O_4$), pyrite (FeS_2), and apatite [$Ca_3(PO_4)_2$] (*4*–*6*). It crystallized 4.5 billion years ago (Ga) (*6*). It records at least two shock events separated by a period of annealing. The age of the first shock event has been estimated to be 4.0 Ga (*7*). Unlike the other SNC meteorites, which contain only trace carbonate phases, ALH84001 contains secondary carbonate minerals that form globules from 1 to ~250 μm across (*4*, *6*, *8*, *9*). These carbonate globules have been estimated to have formed 3.6 Ga (*10*). Petrographic and electron microprobe results (*4*, *11*) indicate that the carbonates formed at relatively high temperatures (~700°C); however, the stable oxygen isotope data indicate that the carbonates formed between 0° and 80°C (*12*). The carbonate globules are found along fractures and in pore spaces. Some of the carbonate globules were shock-faulted (*4*, *5*). This shock event occurred on Mars or in space, and thus rules out a terrestrial origin for the globules (*3*, *8*, *13*). The isotopic composition of the carbon and oxygen associated with the carbonate globules also indicates that they are indigenous to the meteorite and were not formed during its 13,000-year residence in the Antarctic environment (*13*).

The $\delta^{13}C$ values of the carbonate in ALH84001 range up to 42 per mil for the large carbonate spheroids (*12*) and are higher than values for carbonates in other SNC meteorites. The source of the carbon is the martian atmospheric CO_2, which has been recycled through water into the carbonate (*12*). The carbon isotopic compositions of ALH84001 are similar to those measured in CM2 carbonaceous chondrites (*14*). Consequently, the carbonates in ALH84001 and the CM2 meteorites are believed to have been formed by aqueous processes on parent bodies. The $\delta^{13}C$ in martian meteorite carbonates ranges from −17 to +42 per mil (*12*, *15*, *16*). This range of ^{13}C values exceeds the range of ^{13}C generated by most terrestrial inorganic processes (*17*, *18*). Alternatively, biogenic processes are known to produce wide ranges in $\delta^{13}C$ on Earth (*19*, *20*).

ALH84001 arrived on Earth 13,000 years ago (*15*, *21*) and appears to be essentially free of terrestrial weathering (*8*). ALH84001 does not have the carbon isotopic compositions typically associated with weathered meteorites (*12*, *15*), and detailed mineralogical studies (*8*) show that ALH84001 has not been significantly affected by terrestrial weathering processes.

ALH84001 is somewhat friable and breaks relatively easily along preexisting fractures. It is these fracture surfaces that display the carbonate globules. We analyzed freshly broken fracture surfaces on small chips of ALH84001 for polycyclic aromatic hydrocarbons (PAHs) using a microprobe two-step laser mass spectrometer (μL^2MS) (*22*, *23*).

Polycyclic aromatic hydrocarbons. Spatial distribution maps of individual PAHs on interior fracture surfaces of ALH84001 demonstrate that both total PAH abundance and the relative intensities of individual species have a heterogeneous distribution at the 50-μm scale. This distribution appears to be consistent with partial geochromatographic mobilization of the PAHs (*24*). The average PAH concentration in the interior fracture surfaces is estimated to be in excess of 1 part per million (*25*). The PAHs were found in highest concentration in regions rich in carbonates.

From averaged spectra we identified two groupings of PAHs by mass (Fig. 1A). A middle-mass envelope of 178 to 276 atomic mass units (amu) dominates and is composed mostly of simple 3- to 6-ring PAH skeletons with alkylated homologs accounting for less than 10% of the total integrated signal intensity. Principal peaks at 178, 202,

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178, 252, and 278 amu are assigned to phenanthrene ($C_{14}H_{10}$), pyrene ($C_{16}H_{10}$), chrysene ($C_{18}H_{12}$), perylene or benzopyrene ($C_{20}H_{12}$), and anthanthracene ($C_{22}H_{12}$) (*26*). A second weak, diffuse high-mass envelope extends from about 300 to beyond 450 amu. The peak density is high and shows a periodicity at 14 and 2 amu. This distribution implies that there is a complex mixture of PAHs whose parent skeletons have alkylated side chains with varying degrees of dehydrogenation; specific assignments are ambiguous.

Contamination checks and control experiments indicate that the observed organic material is indigenous to ALH84001. The accumulation of PAHs on the Greenland ice sheet over the past 400 years has been studied in ice cores (*27*). The total concentration of PAHs in the cores varies from 10 parts per trillion for preindustrial times to 1 part per billion for recent snow deposition. Because Antarctica is in the less industrialized Southern Hemisphere, we may expect that concentrations of PAHs in Antarctic ice lie between these two limits. The primary source of PAHs is anthropogenic emissions, which are characterized by extensive alkylation (~10-fold greater than that of the parent PAHs) (*28*) and by the presence of abundant aromatic heterocycles, primarily dibenzothiophene ($C_{12}H_8S$, 184 amu). In contrast, the PAHs in ALH84001 are present at the part per million level (~10^2 to 10^5 times higher concentration) and show little alkylation, and dibenzothiophene was not observed in any of the samples we studied.

Analysis of Antarctic salt deposits on a heavily weathered meteorite (LEW 85320) by µL²MS did not show the presence of terrestrial PAHs within detection limits, which suggests an upper limit for terrestrial contamination of ALH84001 of 1%. Measurements of four interior fragments of two Antarctic ordinary chondrites (ALH83013 and ALH83101) of petrologic classes H6 and L6 showed no evidence of indigenous PAHs. These represent equivalent desorption matrix blanks; previous studies have shown that no indigenous organic material is present in meteorites of petrologic class six (*29*).

Studies of exterior fragments of ALH84001 with intact fusion crust show that no PAHs are present within the fusion crust or a zone extending into the interior of the meteorite to a depth of ~500 µm (Fig. 1, B through E). The PAH signal increases with increasing depth, leveling off at ~1200 µm within the interior, well away from the fusion crust. This concentration profile is consistent with volatilization and pyrolysis of indigenous PAHs during atmospheric entry of the meteorite and formation of a fusion crust (*30*), but inconsistent with terrestrial introduction of organic material into the interior of ALH84001 along cracks and pore spaces during burial in the Antarctic ice sheet. These results indicate that the PAHs are indigenous to ALH84001.

No evidence can be found for laboratory-based contamination introduced during processing. Samples for analysis were prepared at the meteorite clean labs at NASA Johnson Space Center and sealed in containers before they were transported to Stanford University. A contamination study conducted prior to analysis of these samples showed no evidence for any PAH contamination (*31*). We also conducted experiments in which chips of ALH84001 were cultured in nutrient medium under aerobic and anaerobic conditions; we found the chips to be sterile.

With the use of the µL²MS technique, PAHs have been found in a wide range of extraterrestrial materials, including carbonaceous and ordinary chondrites (*29*), interplanetary dust particles (*23*, *32*), and interstellar graphite grains (*33*). Each material is characterized by differing PAH distributions reflecting the different environments in which the PAHs formed and their subsequent evolution (for example, as a result of aqueous alteration and thermal metamorphism). Comparison of the mass distribution of PAHs observed in ALH84001 with that of PAHs in other extraterrestrial materials indicates that the closest match is with the CM2 carbonaceous chondrites (*34*). The PAHs in ALH84001, however, differ in several respects from the CM2 chondrites. Low-mass PAHs such as naphthalene ($C_{10}H_8$, 128 amu) and acenaphthalene ($C_{12}H_8$, 152 amu) are absent in ALH84001; the middle-mass envelope shows no alkylation, and the relative intensity of the 5- and 6-ring PAHs and the relative intensity and complexity of the extended high-mass distribution are different.

On Earth, PAHs are abundant as fossil molecules in ancient sedimentary rocks, coal, and petroleum, where they are derived from chemical aromatization of biological precursors such as marine plankton and early plant life (*35*). In such samples, PAHs are typically present as thousands, if not hundreds of thousands, of homologous and isomeric series. In contrast, the PAHs we ob-

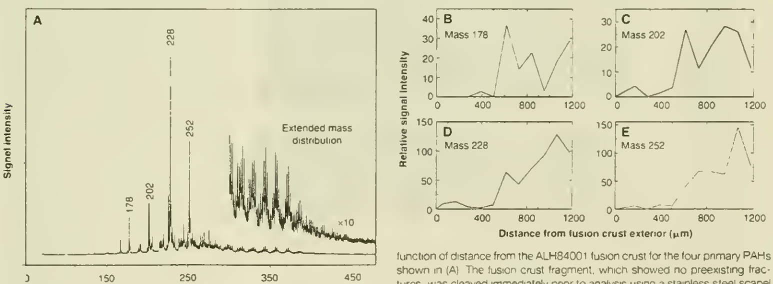

Fig. 1. (A) Averaged mass spectrum of an interior, carbonate-rich, fracture surface of ALH84001. The spectrum represents the average of 1280 individual spectra defining an analyzed surface region of 750 by 750 µm mapped at a spatial resolution of 50 by 50 µm. (**B** through **E**) PAH signal intensity as a function of distance from the ALH84001 fusion crust for the four primary PAHs shown in (A). The fusion crust fragment, which showed no preexisting fractures, was cleaved immediately prior to analysis using a stainless steel scapel and introduced in <2 min into the µL²MS. Each plot represents a section perpendicular to the fusion crust surface, which starts at the exterior and extends a distance of 1200 µm inward. The spatial resolution is 100 µm along the section line and is the average of a 2 by 2 array of 50 by 50 µm analyses, with each analysis spot being the summed average of 5 time-of-flight spectra.

served in ALH84001 appear to be relatively simple. The in situ chemical aromatization of naturally occurring biological cyclic compounds in early diagenesis can produce a restricted number of PAHs (36). Hence, we would expect that diagenesis of microorganisms on ALH84001 could produce what we observed—a few specific PAHs—rather than a complex mixture involving alkylated homologs.

Chemistry and mineralogy of the carbonates. The freshly broken but preexisting fracture surfaces rich in PAHs also typically display carbonate globules. The globules tend to be discoid rather than spherical and are flattened parallel to the fracture surface. Intact carbonate globules appear orange in visible light and have a rounded appearance; many display alternating black and white rims. Under high magnification stereo light microscopy or SEM stereo imaging, some of the globules appear to be quite thin and pancake-like, suggesting that the carbonates formed in the restricted width of a thin fracture. This geometry limited their growth perpendicular to, but not parallel to, the fracture.

We selected a typical globule, ~50 µm in diameter, for analysis by TEM and electron microprobe (37). On the basis of backscatter electron (BSE) images (Fig. 2), the larger globules (>10 µm) have Ca-rich cores (which also contain the highest Mn abundances) surrounded by alternating Fe- and Mg-rich bands (Fig. 3). Near the edge of the globule, several sharp thin bands are present. The first band is rich in Fe and S, the second is rich in Mg with no Fe, and the third is rich in Fe and S again (Fig. 3). Detectable S is also present in patchy areas throughout the globule.

In situ TEM analyses of the globule in Fig. 4 revealed that Fe- and Mg-rich carbonates located nearer to the rim range in composition from ferroan magnesite to pure magnesite. The Fe-rich rims are composed mainly of fine-grained magnetite ranging in size from ~10 to 100 nm and minor amounts of pyrrhotite (~5 vol%) (Fig. 3, region I, and Fig. 4A). Magnetite crystals are cuboid, teardrop, and irregular in shape. Individual crystals have well-preserved structures with no lattice defects. The magnetite and Fe-sulfide are in a fine-grained carbonate matrix (Fig. 4, A through C). Composition of the fine-grained carbonate matrix matches that of coarse-grained carbonates located adjacent to the rim (Fig. 4A).

High-resolution transmission electron microscopy (HRTEM) and energy dispersive spectroscopy (EDS) showed that the Fe-sulfide phase associated with the Fe-rich rims is pyrrhotite (Fig. 4C). Pyrrhotite particles are composed of S and Fe only; no oxygen was observed in the spectra. Particles have atomic Fe/S ratios ranging from ~0.92 to 0.97. The size and shape of the FeS particles vary. Single euhedral crystals of pyrrhotite range up to ~100 nm across; polycrystalline particles have more rounded shapes ranging from ~20 to 60 nm across (Fig. 4C). HRTEM of these particles showed that their basal spacing is 0.57 nm, which corresponds to the {111} reflection of the pyrrhotite in a 4C monoclinic system. The magnetite is distributed uniformly in the rim, whereas the pyrrhotite seems to be distributed randomly in distinct domains ~5 to 10 µm long (Fig. 3C). Magnetite grains in ALH84001 did not contain detectable amounts of minor elements. In addition, these magnetite grains are single-domain crystals having no structural defects.

A distinct region, located toward the center of the carbonate spheroid but completely separate from the magnetite-rich rim described above, also shows accumulation of magnetite and an Fe-rich sulfide (Fig. 3A, region II, and Fig. 5A). This region displays two types of textures: The first one is more massive and electron-dense

Fig. 2. False-color backscatter electron (BSE) image of fractured surface of a chip from ALH84001 meteorite showing distribution of the carbonate globules. Orthopyroxene is green and the carbonate globules are orange. Surrounding the Mg-carbonate are a black rim (magnesite) and a white Fe-rich rim. Scale bar is 0.1 mm. (False color [illegible] by C. Schwandt)

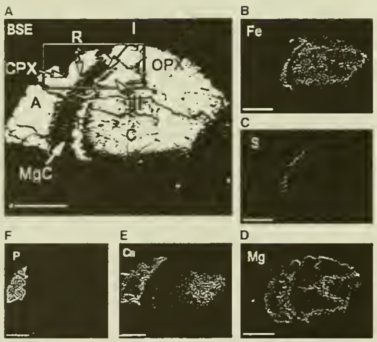

Fig. 3. BSE image and electron microprobe maps showing the concentration of five elements in a carbonate from ALH84001. The element maps show that the carbonate is chemically zoned. Colors range through red, green, light blue, and deep blue, reflecting the highest to lowest element concentrations. Scale bars for all images are 20 µm. (**A**) BSE image showing location of orthopyroxene (OPX), clinopyroxene (CPX), apatite (A), and carbonate (MgC, C). Iron-rich rims (R) separate the center of the carbonate (C) from a Mg-rich carbonate (MgC) rim. Region in the box is described in Figs. 5 and 6. (**B**) Iron is most abundant in the parallel rims, ~3 µm across, and in a region of the carbonate ~20 µm in size. (**C**) Highest S is associated with an Fe-rich rim; it is not homogeneously distributed, but rather located in discrete regions or hot spots in the rim. A lower S abundance is present throughout the globule in patchy areas. (**D**) Higher concentrations of Mg are shown in the Fe-poor outer region of the carbonate. A Mg-rich region (MgC), ~8 µm across, is located between the two Fe-rich rims. (**E**) Ca-rich regions are associated with the apatite, the Fe-rich core of the carbonate, and the clinopyroxene. (**F**) P-rich regions are associated with the apatite.

der the TEM. The second region is much less electron-dense and is fine-grained and porous. The porous material occurs mainly in crosscutting bands and rarely in isolated patches. We interpret this porous texture as a region in which the massive carbonate has been partially dissolved. The nanometer-size magnetite and Fe-sulfide phases are everywhere associated with the fine-grained, porous Mg-Fe–rich carbonate. In the regions containing high concentrations of magnetite, dissolution of carbonate is evident (Fig. 5A). In contrast to the magnetite-rich rim, the core area contains few magnetite particles. The Fe-sulfide phases in this magnetite-poor region have chemical compositions similar to that of the pyrrhotite. However, unlike pyrrhotite grains that have a large variety of morphologies, most of these Fe-sulfide particles have elongated shapes (Fig. 5B). We could not obtain a diffraction pattern of these Fe-sulfide particles because they were unstable in the electron beam. Possible candidates for these Fe-sulfide minerals include mackinawite (FeS_{1-x}), greigite (Fe_3S_4), and smythite (Fe_9S_{11}). Because of the morphological similarity to terrestrial greigite (Fig. 5C), we suggest that these Fe-sulfide minerals are probably greigite (38).

Formation of the magnetite and iron sulfides. The occurrence of the fine-grained carbonate, Fe-sulfide, and magnetite phases could be explained by either inorganic or biogenic processes. Single-domain magnetite can precipitate inorganically under ambient temperature and neutral pH conditions by partial oxidation of ferrous solutions (39). This synthetic magnetite ranges in size from about 1 to more than 100 nm and is chemically very pure (39). Simultaneous inorganic precipitation of magnetite and pyrrhotite requires strongly reducing conditions at high pH (40). However, carbonate is normally stable at high pH, and the observed dissolution of carbonate would normally require low pH acidic conditions. It is possible that the Fe-sulfides, magnetite, and carbonates all formed under high pH conditions, and the acidity changed at some point to low pH, causing the partial dissolution of the carbonates. But the Fe-sulfide and magnetite do not appear to have undergone any corrosion or dissolution, which would have likely occurred under acidic conditions (41). Moreover, as previously mentioned, the dissolution of carbonate is always intimately associated with the presence of Fe-sulfides and magnetite. Consequently, neither simultaneous precipitation of Fe-sulfides and magnetite along with dissolution of carbonates nor sequential dissolution of carbonate at a later time without concurrent dissolution of Fe-sulfides and magnetite seems plausible in simple inorganic models, although more complex models could be proposed.

In contrast, the coexistence of magnetite and Fe-sulfide phases within partially dissolved carbonate could be explained by biogenic processes, which are known to operate under extreme disequilibrium conditions. Intracellular coprecipitation of Fe-sulfides and magnetite within individual bacteria has been reported (42). In ...

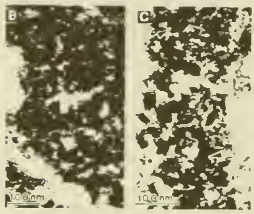

Fig. 4. TEM images of a thin section obtained from part of the same fragment shown in Fig. 3A (from the region of arrow I, Fig. 3A). (**A**) Image at low magnification showing the Fe-rich rim containing fine-grain magnetite and Fe-sulfide phases and their association with the surrounding carbonate (C) and orthopyroxene (opx). (**B**) High magnification of a magnetite-rich area in (A) showing the distribution of individual magnetite crystals (high contrast) within the fine-grain carbonate (low contrast). (**C**) High magnification of a pyrrhotite-rich region showing the distribution of individual pyrrhotite particles (two black arrows in the center) together with magnetite (other arrows) within the fine-grained carbonate (low contrast).

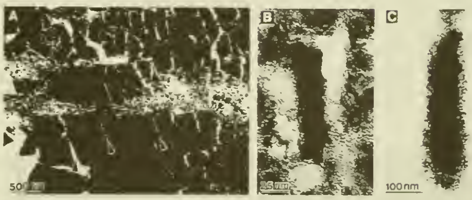

Fig. 5. TEM images of a thin section showing the morphology of the Fe-sulfide phases present in ALH84001 and a terrestrial soil sample. Iron sulfide phase (greigite?—Fe_3S_4) is located in a magnetite-poor region separate and distinct from the magnetite-rich rims (Fig. 3A, arrow II). (**A**) TEM of a thin section showing a cross section of a single carbonate crystal (large black regions; the apparent cleavage features are due to knife damage by ultramicrotomy). A vein of fine-grained carbonate (light gray) is observed within the large carbonate crystal. Possibly greigite and secondary magnetite (fine, dark crystals) have been precipitated in this fine-grained matrix. There is a direct relation between the presence of carbonate dissolution and the concentration of the fine-grained magnetite and Fe-sulfide phases. This region shows fewer Fe-rich particles, while regions shown in Fig. 4 contain abundant Fe-rich particles. The cleavage surface of the carbonate crystal does not show any dissolution features (arrows); there is no evidence of structural selective dissolution of carbonate. (**B**) A representative elongated Fe-sulfide particle, located in the dissolution region of the carbonate described in (A), is most likely composed of greigite. The morphology and chemical composition of these particles are similar to the biogenic greigite described in (C). (**C**) High magnification of an individual microorganism within a root cell of a soil sample showing an elongated, multicrystalline core of greigite within an organic envelope.

tion, extracellular biomediated precipitation of Fe-sulfides and magnetite can take place under anaerobic conditions (43, 44).

Magnetite particles in ALH84001 are similar (chemically, structurally, and morphologically) to terrestrial magnetite particles known as magnetofossils (45), which are fossil remains of bacterial magnetosomes (46) found in a variety of sediments and soils (41, 47, 48) and classified as single-domain (~20 to 100 nm) or superparamagnetic (<20 nm) magnetite (49). Single-domain magnetite has been reported in ancient limestones and interpreted as biogenic (48). Some of the magnetite crystals in the ALH84001 carbonates resemble extracellular precipitated superparamagnetic magnetite particles produced by the growth of anaerobic bacterium strain GS-15 (43).

Surface features and origin of the carbonates. We examined carbonate surfaces on a number of small chips of ALH84001 with the use of high-resolution SEM (50). The Fe-rich rim of globules typically consists of an aggregate of tiny ovoids intermixed with small irregular to angular objects (Fig. 6A). Ovoids in the example are about 100 nm in longest dimension, and the irregular objects range from 20 to 80 nm across. These features are typical of those on the Fe-rich rims of many carbonate globules. These objects are similar in size and shape to features in the Fe-rich rims identified as magnetite and pyrrhotite (Fig. 4, B and C). These objects are too small to obtain compositional analysis under the SEM.

In the center of some of the globules (Fig. 2), the surface of the carbonate shows an irregular, grainy texture. This surface texture does not resemble either cleavage or a growth surface of synthetic and diagenetic carbonates (51). These surfaces also display small regularly shaped ovoid and elongated forms ranging from about 20 to 100 nm in longest dimension (Fig. 6B). Similar textures containing ovoids have been found on the surface of calcite concretions grown from Pleistocene ground water in southern Italy (52), where they are interpreted as nannobacteria that have assisted the calcite precipitation.

The origin of these textures on the surface of the ALH84001 carbonates (Fig. 6, A and B) is unclear. One possible explanation is that the textures observed on the carbonate surface are a result of the partial dissolution of the carbonate—that is, they are erosional remnants of the carbonate that happen to be in the shape of ovoids and elongate forms, perhaps because the carbonate has preferentially eroded along grain boundaries or dislocations. Shock effects may have enhanced such textures. However, because we know of no similar example from the terrestrial geologic record or from laboratory experiments, we cannot fully evaluate this possible explanation for the textures. A second possibility is that artifacts can be created during sample preparation or may result from laboratory contamination. For example, the application of a thick Au-conductive coating can produce textures resembling mud cracks, and even droplets or blobs of Au. Laboratory contamination can include dust grains, residue from sample cleaning, and organic contamination from epoxy. For comparison, we examined several control samples treated identically to the meteorite chips. We conclude that the complex textures (Fig. 6) did not result from procedures used in our laboratory. Only interior or freshly broken surfaces of chips were used (50). We did observe an artifact texture from our Au-Pd conductive coating that consists of a mud crack–like texture visible only at 50,000× magnification or greater. None of the controls display concentrations or blobs of coating material. A lunar rock chip carried through the same procedures and examined at high magnification showed none of the features seen in Fig. 6.

An alternative explanation is that these textures, as well as the nanosize magnetite and Fe-sulfides, are the products of microbiological activity. It could be argued that these features in ALH84001 formed in Antarctica by biogenic processes or inorganic weathering. It is unlikely that reduced phases, such as iron sulfides, would form in Antarctica during inorganic weathering because reported authigenic sulfur-bearing phases from Antarctic soils and meteorites are sulfates or hydrated sulfates. In general, authigenic secondary minerals in Antarctica are oxidized or hydrated (53). The lack of PAHs in the other analyzed Antarctic meteorites, the sterility of the sample, and the nearly unweathered nature of ALH84001 argue against an Antarctic biogenic origin. As a control we examined three Antarctic ordinary chondrites (ALH78119, ALH76004, and ALH81024, all of which do not have indigenous PAHs) from the same ice field where ALH84001 was collected, as well as a heavily weathered ordinary chondrite that gave negative results for PAHs (LEW 85320). These meteorites were chosen to cover the different degrees of weathering observed on Antarctic meteorites. Examination of grain surfaces at all magnifications in weathered and unweathered regions of these meteorites showed no sign of the ovoid and elongate forms seen in ALH84001. However, none of these control meteorites contained detectable carbonate.

Ovoid features in Fig. 6 are similar in size and shape to nannobacteria in travertine and limestone (54). The elongate forms (Fig. 6B) resemble some forms of fossilized filamentous bacteria in the terrestrial fossil record. In general, the terrestrial bacteria microfossils (55) are more than an order of magnitude larger than the forms seen in the ALH84001 carbonates.

The carbonate globules in ALH84001 are clearly a key element in the interpretation of this martian meteorite. The origin of these globules is controversial; Harvey and McSween (11) and Mittlefehldt (4) argued, on the basis of microprobe chemistry and equilibrium phase relationships, that the globules were formed by high-temperature metamorphic or hydrothermal reactions. Alternatively, Romanek et al. (12) argued on the basis of isotopic relationships that the carbonates were formed under low-temperature hydrothermal conditions (56). The nanophase magnetite and Fe-sulfides present in these globules would likely not be detected in microprobe analyses, which normally have a spatial resolution of about 1 μm. Our TEM observations and our S maps suggest that nanophase magnetite and Fe-sulfides, while concentrated in some zones, are present in discrete regions throughout the globules. The effect of these

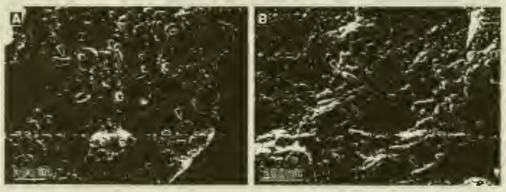

Fig. 6. High-resolution SEM images showing ovoid and elongate features associated with ALH84001 carbonate globules. **(A)** Surface of Fe-rich rim area. Numerous ovoids, about 100 nm in diameter, are present (arrows). Tubular-shaped bodies are also apparent (arrows). Smaller angular grains may be the magnetite and pyrrhotite found by TEM. **(B)** Close view of central region of carbonate (away from rim areas) showing textured surface and nanometer ovoids and elongated forms (arrows).

detected oxide and sulfide minerals on the carbonate microprobe analyses may make the interpretation of the microprobe data (4, 11) uncertain. Alternatively, if the globules are products of biologic activity, a low-temperature formation would be indicated. The textures of the carbonate globules are similar to bacterially induced carbonate crystal bundle precipitates produced in the laboratory and in a freshwater pond (57). Moreover, the observed sequence in the martian carbonate globules—Mn-containing carbonate production early (in the core) followed by Fe carbonate and finishing with the abundant production of reduced Fe-sulfides—is a sequence that is common in terrestrial settings, because Mn is first reduced by biogenic action, followed by ferric iron and sulfate (57). Pure Mg-carbonate (magnesite) can also be produced by biomineralization under alkaline conditions (59). On the basis of these observations, we interpret that the carbonate globules have a biogenic origin and were likely formed at low temperatures.

It is possible that all of the described features in ALH84001 can be explained by inorganic processes, but these explanations appear to require restricted conditions—for example, sulfate-reducing conditions in Antarctic ice sheets, which are not known to occur. Formation of the described features by organic activity in Antarctica is also possible, but such activity is only poorly understood at present. However, many of the described features are closely associated with the carbonate globules which, based on textural and isotopic evidence, were likely formed on Mars before the meteorite came to Antarctica. Consequently, the formation of possible organic products (magnetite and Fe-sulfides) within the globules is difficult to understand if the carbonates formed on Mars and the magnetite and Fe-sulfides formed in Antarctica. Additionally, these products might require anerobic bacteria, and the Antarctic ice sheet environment appears to be oxygen-rich, ferric oxide formed from metallic Fe is a common weathering product in Antarctic meteorites.

In examining the martian meteorite ALH84001 we have found that the following evidence is compatible with the existence of past life on Mars: (i) an igneous Mars rock (of unknown geologic context) that was penetrated by a fluid along fractures and pore spaces, which then became the sites of secondary mineral formation and possible biogenic activity, (ii) a formation age for the carbonate globules younger than the age of the igneous rock; (iii) SEM and TEM images of carbonate globules and features resembling terrestrial microorganisms, terrestrial biogenic carbonate structures, or microfossils, (iv) magnetite and iron sulfide particles that could have resulted from oxidation and reduction reactions known to be important in terrestrial microbial systems; and (v) the presence of PAHs associated with surfaces rich in carbonate globules. None of these observations is in itself conclusive for the existence of past life. Although there are alternative explanations for each of these phenomena taken individually, when they are considered collectively, particularly in view of their spatial association, we conclude that they are evidence for primitive life on early Mars.

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31 Sources of laboratory contamination fall into three categories sample handling laboratory air and virtual leaks (that is sources of PAHs inside the μL²MS vacuum chamber) Possible contamination during sample preparation was minimized by performing nearly all sample preparation at the NASA-JSC meteorite curation facility In cases where subsequent sample handling was required at Stanford all manipulation was performed in less than 15 minutes, using only stainless steel tools previously rinsed and ultrasonicated in methanol and acetone Dust-free gloves were worn at all times and work was performed on a clean aluminum foil surface To quantify airborne contamination from exposure to laboratory air two clean quartz discs were exposed to ambient laboratory environments both at NASA-JSC and Stanford Each disc received an exposure typical of that experienced subsequently by samples of ALH84001 during sample preparation No PAHs were observed on either quartz disk at or above detection limits Because contamination can depend on the physical characteristics of the individual sample (for example a porous material will likely give a larger contamination signal than a nonporous one), additional contamination studies have been previously conducted at Stanford [see (29)] Briefly, samples of the meteoritic acid residues of Barwell (L6) and Bishunpur

(L3 1) were exposed to laboratory air for 1 and 4 days, respectively. Barwell (L6) is known to contain no indigenous PAHs and none were observed on the exposed sample. Bishunpur (L3 1), in contrast, contains a rich suite of PAHs but no discernible differences in signal intensities were observed between exposed and unexposed samples. To test for contamination from virtual leaks, the μL^2MS instrument was periodically checked using samples of Murchison (CM2) meteorite matrix whose PAH distribution has been previously well characterized. No variations in either signal intensity or distribution of PAHs were observed for μL^2MS instrument exposure times in excess of 3 days. No sample of ALH84001 was in the instrument for longer than 6 hours. The μL^2MS vacuum chamber is pumped by an oil-free system: two turbomolecular pumps and a liquid nitrogen–cooled cyropump.

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50 We handpicked small chips in a clean bench from our curatorial allocation of ALH84001. Most chips were from a region near the central part of the meteorite and away from the fusion crust, although for comparison we also looked at chips containing some fusion crust. For high-resolution work we used an Au-Pd coating estimated to be ~2 nm thick in most cases. On some samples we used a thin (<1 nm) coating, about 10 s with our sputter coater; these samples usually showed charging effects and could not be used for highest resolution imaging. We more typically used 20 to 30 s. For backscatter and chemical mapping we used a carbon coat of about 5 to 10 nm thick. We monitored the possible artifacts from the coating using other reference samples or by looking at fresh mineral surfaces on ALH84001. We could also estimate relative coating thicknesses by the size of the Au and Pd peaks in the energy dispersive x-ray spectrum. For our heaviest coating, a slight crazing texture from the coating is barely visible at a magnification of 50,000× on the cleanest fresh grain surfaces. The complex textures shown in most of the SEM photographs are not artifacts of the coating process but are the real texture of the sample. We used a JEOL 35 CF and a Philips SEM with a field emission gun (FEG) at the JSC. The JEOL and Philips SEMs are equipped, respectively, with a PGT and Link EDS system. We achieved about 2.0 nm resolution at 30kV. Some images were also taken at lower kV, ranging from 1 to 10 kV. In most cases the chips were coated after handpicking with no further treatment. For comparison, several chips were ultrasonically cleaned for a few seconds in liquid Freon before coating to remove adhering dust. Several samples were examined uncoated at low kV. We carbon-coated and examined all of the surfaces analyzed for PAHs only after the PAH analyses had been completed.

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60 We thank L. P. Keller, V. Yang, C. Le, R. A. Socki, M. F. McKay, M. S. Gibson, and S. R. Kepria for assistance, and R. Score and M. Lindstrom for their help in sample selection and preparation. The guidance of J. W. Schopf at an early stage of this study is appreciated. We also thank G. Horuchi, L. Hulse, L. L. Darrow, D. Pierson, and personnel from Building 37. The work was supported in part by NASA's Planetary Materials Program (D.S.M. and R.N.Z.) and the Exobiology Program (D.S.M.). Additional support from NASA-JSC Center Director's Discretionary Program (E.K.G.) is recognized. C.S.R. and H.V. acknowledge support from the National Research Council. X.D.F.C. acknowledges support from the Swiss National Science Foundation.

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Mr. SENSENBRENNER. Thank you, Dr. McKay.

The final witness today will be Dr. Richard N. Zare, Chair of the National Science Board and a member of the Department of Chemistry at Stanford University.

Dr. Zare?

STATEMENT OF DR. RICHARD N. ZARE CHAIR, NATIONAL SCIENCE BOARD DEPARTMENT OF CHEMISTRY STANFORD UNIVERSITY

Dr. ZARE. Thank you, Mr. Chairman.

I come before you to tell you a story. It's a story of the inherent unpredictability of fundamental research, the importance of leading-edge instrumentation of facilities for research, and for stable, long-term investment across the full spectrum of sciences.

It is a story which has very much been capturing and consuming my life since this happened in this August 16th publication of "Science" magazine.

It's also a story of individuals brave enough to explore the unknown and of the will of the American people, through its elected Representatives, to back this endeavor.

Let me begin by discussing my research on the Martian meteorite that is the topic of this hearing.

Using an invention of ours called microprobe two-step laser mass spectrometry, we have searched for a class of organic molecules, these so-called PAHs—polycyclic aromatic hydrocarbons.

Such molecules occur commonly in the incomplete combustion of organic molecules, such as what comes out of a diesel exhaust engine or what is found in a footing flame of a candle, or what is found if you leave meat too long on the barbecue.

It is also a telltale sign of fossilization of living matter, as seen, for example, in oil and coal deposits.

Let me also emphasize that PAHs can be produced by processes having nothing whatsoever to do with life, such as passing methane gas over hot metal or running an electrical discharge in a methane atmosphere.

Although somewhat different distributions of PAHs result from these processes, the identification of PAHs themselves is not proof that they came from some biological origin.

In our procedure, the meteorite—you have an example before you—is cleaved with a stainless steel knife and transferred into a high-vacuum chamber. Using a shooting gallery of lasers, we cause molecules to evaporate from the surface of the meteorite. Then we ionize them so that their mass can be weighed and determined.

By scanning the location of the spot we irradiate on the surface of the meteorite, we can map out the spatial distribution of the molecules being detected.

So what did we find?

By this means we have found that PAHs are present in the Martian meteorite ALH-84001, that they are more concentrated on the inside than the outside of this meteorite, and moreover, their concentration peaks at the same places where, as you've heard from Dr. David McKay, the NASA Johnson Space Center found mineralogical and morphological features that suggest the presence of some primitive life forms.

It seems to us well established that the PAHs we find in ALH-84001 are indigenous to this meteorite. Moreover, they seem to be intimately associated with the carbonate globules for which isotope data suggest a temperature of formation between the freezing and boiling points of water.

If the PAHs formed at the same time as the carbonates, then it would seem highly improbable that they had an abiotic or inorganic origin.

Because the concentration of organics in this meteorite seem rather high, it also seems unlikely that they were preferentially absorbed by the carbonates.

The simplest explanation for these observations taken together is that some primitive type of life existed in this meteorite at the same time of the carbonate formation, which is dated about 3.6 billion years ago.

Let me interrupt this narrative to tell you how the device we call microprobe two-step laser mass spectrometer came about.

More than 20 years ago, under support from the National Science Foundation, I was trying to understand chemical reactions in the gas phase, one collision at a time, at Columbia University.

I had heard from Professor Philip M. Johnson, State University of New York at Stony Brook, about a new spectroscopic technique for making molecules gulp down photons more than one at a time and ionize. This method seemed to have just the high sensitivity we needed.

And it worked splendidly.

About ten years ago at Stanford University, I had the idea that we could use the same technique to look at those molecules that cover a surface. The original motivation was to look at biological molecules to make a more sensitive analyzer for the sequence of amino acids present in proteins—something we actually did.

It was only a chance encounter with a person spending a sabbatical in Stanford University's School of Earth Sciences, Professor Peter R. Buseck, Arizona State University, that convinced me that it would be interesting to study meteoritic samples.

It took the successive efforts of four very bright graduate students studying for their Ph.D.s to develop this technique to its present state.

I share with you this tortuous history because I believe it is fairly typical of how science advances.

Our two-step laser mass spectrometer was not originally built to search for past life on Mars. Clearly, it now has that capability, but like all advances in instrumentation, it may have a multitude of other uses, some of which may be much more directly relevant to mankind's welfare, such as searching for pollutants in soil samples or determining the structures of new polymers.

The point I'm trying to make is that the power of investing in frontier instrumentation is that its applications have a way of expanding with time so that such advances can bring important economic and health benefits as well as help us explore the unknown.

This summary of my research points to a number of issues that I think are extremely important for Congress to consider. Perhaps the most significant underlying lesson is the value of consistent, long-term support for basic research to provide the nation with the tools and the trained human resources necessary to take advantage of, and benefit from, unanticipated research developments.

The nation receives maximum benefit from a healthy and well-balanced scientific enterprise having the flexibility and nimbleness to respond to opportunities and challenges as they occur.

When the original investigations began that resulted in the development of the laser, which was crucial to my research, no one dreamed that it would be used some day for probing for possible evidence of primitive life on early Mars.

Similarly, when the National Science Foundation became responsible for the single-point management of the United States Antarctic Program 20 years ago, who would have thought that the Antarctic would provide important information about another planet.

At that time, no one fully realized that the Antarctic would prove to be a treasure trove of research opportunities, including a rich source of meteorites. Nearly half of the 16,000 meteorites so far found on Earth have been retrieved in the Antarctic.

But the annual expeditions for meteorites represent only a small portion of the research supported by the Foundation in the Antarctic. Other activities include an understanding of life forms that exist in very extreme environments—a topic that I believe deserves increased attention.

Researchers have actually found life forms that actually live inside of rocks in the Antarctic. Other extreme environments have also yielded living microorganisms, including temperatures well in excess of boiling water, and under atmospheric pressures many hundreds of times that of sea level.

Finding life in conditions that would have seemed unthinkable 20 years ago at the time of the Viking missions to Mars is one of the reasons it made sense to look for life forms in a meteorite.

The message I would like to leave with this Committee today is that the research we have undertaken to understand whether life once existed on Mars is only the most recent in a long line of inquiries into a multitude of fundamental questions.

These questions range from planetary astronomy to molecular biology. We have traveled this road only as far as we have because those before us have had faith in the ultimate value of new knowledge, even when its immediate utility may not have been apparent.

The research that has led us to suggest that we might have uncovered fossilized remains of life on ancient Mars could not have been done were it not for contributions across many areas of science and technology. Nor could we have been successful without the contributions, ideas, and assistance of my colleagues and especially my students.

This research endeavor has been one of the most exciting and humbling activities I have had the privilege to be associated with.

Thank you again for this opportunity to testify

[The prepared statement of Dr. Zare follows:]

Testimony of

~~Dr.~~ Richard N. Zare

Marguerite Blake WIlbur Professor of Chemistry

Stanford University, Stanford, CA 94305-5080

Before The

Subcommittee on Space and Aeronautics

Committee on Science

U.S. House of Representatives

September 12, 1996

Mr. Chairman, members of the Committee, I appreciate the opportunity to be a part of this panel and testify before you this morning. I am Dr. Richard N. Zare, Marguerite Blake Wilbur Professor of Chemistry at Stanford University. In addition, I am also the Chairman of the National Science Board, the policy-making body of the National Science Foundation, which among other tasks is charged with focusing national attention on major issues with respect to science and engineering research and education.

I appear here today principally to discuss my role and my research on the Martian meteorite ALH84001 that is the topic of this hearing. In addition, I hope to convey how important it is to maintain a strong national research enterprise so that we can respond to tomorrow's challenges and opportunities in science and engineering, wherever they may occur.

I have led the Stanford University research group of Simon J. Clemett, Claude R. Maechling, and Xavier D. F. Chillier that looked for organic molecules in ALH84001. Using an invention of ours called microprobe two-step laser mass spectrometry we have searched for a class of organic molecules called polycyclic aromatic hydrocarbons (PAHs). Such molecules commonly occur in the incomplete combustion of organic molecules, such as what comes out of a diesel exhaust engine, or what is found in the sooting flame of a candle, or what is found on the surface of meat that has been left on the barbecue too long. It is also a telltale sign of the fossilization of animal and plant life, as observed in oil and shale deposits. Let me also emphasize that PAHs can be produced by processes having nothing whatsoever to do with life, such as passing methane gas over hot metal or in running discharges in a hydrocarbon atmosphere. Although somewhat different distributions of PAHs result from these processes, the identification of PAHs, themselves, is not proof that they came from some biological origin. I will return to this point later.

In our procedure, the meteorite sample is cleaved with a stainless steel knife blade and transferred into a high vacuum chamber for analysis in less than three minutes exposure to the laboratory air. Under visualization with a microscope, a pulsed infrared laser beam is fired at the sample, which heats a small spot of the sample surface that is approximately 40 microns in diameter. For reference purposes, the diameter of a typical human hair is about 100 microns. The heating rate is rapid and causes molecules in the focal spot of the laser to evaporate and leave the surface.

This rising gas plume of evaporated molecules is intercepted by a second pulsed laser beam whose wavelength is in the ultraviolet. Those molecules in the gas plume that absorb these more energetic photons go on to ionize. In the ionization process, an electron is knocked off the neutral molecule and flies away, leaving the molecule as a positively charged molecular ion. Different molecules produce ions with different weights or masses. The ions are produced between two metal screens held at different voltages. The resulting electric field between the two screens exerts a force on each ion of the same amount because the charge on each ion is the same. Recall that according to Newton 's second law of motion, force equals mass times acceleration. Consequently, ions with differing masses receive differing accelerations from being born in the electric field. As a result, lighter ions hit an ion collector in a shorter time than heavier ions.

By recording the arrival times of the ions at the ion collector we are able to weigh the different ions, that is, to determine their mass distribution, which is called a mass spectrum. The laser vaporization and the laser ionization steps are gentle so that the ions stay intact. Consequently, by measuring the mass spectrum we are able to identify what molecules are present in a mixture without the usual need to separate the mixture into its substituent components prior to analysis. By scanning the location of the spot irradiated by the pulsed infrared laser, we can map out the spatial distribution of the molecules on the surface of the meteorite sample.

By this means we have found that PAHs are present in the Martian meteorite ALH84001, that they are more concentrated on the inside than the outside of this meteorite, and moreover, their concentration peaks at the same place where, as you have heard from Dr. David S. McKay, the NASA Johnson Space Center team found mineralogical and morphological features that suggest the presence of some primitive life forms. It seems to us well established that the PAHs we find in ALH84001 are indigenous to this meteorite. Moreover, they seem to be intimately associated with the carbonate globules for which isotope data suggest a temperature of formation between the freezing and boiling points of water. If the PAHs formed at the same time as the carbonates, then it would seem improbable that they had an abiotic or inorganic origin. Because the concentration of organics in ALH84001 seems rather high, it also seems unlikely that they were preferentially adsorbed by the carbonates from Martian groundwater. All observations taken together suggests that some primitive type of life existed in this meteorite at the time of the carbonate formation, which is estimated to be about 3.6 billion years ago.

Let me interrupt this narrative to tell you how the device we call microprobe two-step laser mass spectrometry came about. More than twenty years ago in the Department of Chemistry, Columbia University, I was trying to understand chemical reactions in the gas phase, one collision at a time, under the support of the National Science Foundation. I had heard from Professor Philip M. Johnson, State University of New York at Stony Brook, about a new spectroscopic technique for making molecules gulp down more than one photon at a time and ionize, so-called resonance enhanced multiphoton ionization. We were one of the first research groups to apply this method to the study of chemical reactions under molecular beam conditions. Because you can count individual ions, its sensitivity met the challenge of looking at those rare collisions between reagents that went on to react. About ten years ago at Stanford University I had the idea that we could use the same technique to look at those molecules that cover a surface. The original motivation was to look at biological molecules in hopes of making a more sensitive analyzer for the sequence of amino acids present in proteins. It was only a chance encounter with a person spending a sabbatical in Stanford University's School of Earth Sciences, Professor Peter R. Buseck, who holds joint appointments in the Departments of Chemistry and Geology at Arizona State University, that convinced me that it would be interesting to study meteoritic samples. The time of four Ph. D. theses would need to elapse before this technique matured to its present state, providing excellent training to those graduate students brave enough to pursue this line of inquiry, a project that has been supported by NASA but uses NSF-purchased laser equipment.

I share with you this tortuous history because I believe it is fairly typical of how science advances. Our two-step laser mass spectrometer was not originally built to search for past life on Mars. Clearly, it now has that capability, but like all advances in instrumentation, it does have a multitude of other uses, some of which may be much more directly relevant to mankind's welfare. The point I am trying to make is that the power of investing in frontier instrumentation is that its applications have a way of expanding with time so that such advances can bring important economic and health benefits as well as help us explore the unknown.

This summary of my research points to a number of issues that I think are extremely important for Congress to consider. Perhaps the most significant underlying lesson is the value of consistent, long-term support for basic research, to provide the nation with the tools and the trained human resources necessary to take advantage of -- and benefit from -- unanticipated research developments. The Nation receives maximum benefit from a healthy and well-balanced scientific enterprise having the flexibility and nimbleness to respond to opportunities and challenges as they occur.

The basic science and engineering contributions that permitted us to conduct meaningful research on this meteorite come from many disciplines, including geology, astronomy, chemistry, molecular biology, physics, paleontology, and materials science. The contributions made over the years by researchers in these areas have in common the fact that the ultimate value of the research could not have been anticipated at the time the research was conducted. That is not at all surprising. The basic nature of scientific investigation is exploration, and the value of exploration is learning things that were not previously known.

When the original investigations began that resulted in the development of the laser, which was crucial to my research, no one dreamed that it would be used some day for probing for possible evidence of primitive life on early Mars, much less that it would have myriad applications in medicine, data storage, communication, engineering, and manufacturing.

Similarly, when the National Science Foundation became responsible for the single-point management of the United States Antarctic Program 20 years ago, who would have thought that the Antarctic would provide important information about another planet! At the time, no one fully realized that the Antarctic would prove to be a treasure trove of research opportunities, including a rich source of meteorites. Nearly half of 16,000 meteorites so far found on Earth have been retrieved in the Antarctic. Although meteorites do not seem to strike Antarctica with unusual frequency, they do stand out against the bluish-white Antarctic ice. In addition, the frigid climate preserves the rocks from weathering and breaking down into soil.

But the annual expeditions for meteorites represent only a small portion of the research supported by the Foundation in the Antarctic. Other activities include atmospheric research at one of the most isolated and pristine locations on the planet. Because of the low temperatures and dry air, the Antarctic also provides a unique platform for infrared and submillimeter astronomy observatories. Finally, the Antarctic provides a unique site for research in astrophysics, glaciology, global climate change, and, perhaps most relevant to this hearing, an understanding of life forms that exist in very extreme environments -- a topic that I believe deserves increased attention.

Researchers have recently found life forms that actually live inside of rocks in the Antarctic. Other extreme environments have also yielded living microorganisms, including temperatures well in excess of boiling water, and under atmospheric pressures many hundreds of times that at sea level. Finding life in conditions that would have seemed unthinkable twenty years ago at the time of the Viking missions to Mars is one of the reasons it made sense to look for life forms in a meteorite.

These discoveries have extended our understanding of life and the conditions under which it can occur to include other planets and their moons in the solar system. They have also generated knowledge and techniques that hold great promise for addressing practical problems on this planet Earth, such as in genetics, biochemistry, environmental clean-up, and resource recovery, to name but a few.

The message I would like to leave with this committee today is that the research we have undertaken to understand whether life once existed on Mars is only the most recent in a long line of inquiries into a multitude of fundamental questions. These questions range from planetary astronomy to molecular biology. We have traveled this road only as far as we have because those before us have had faith in the ultimate value of new knowledge, even when its immediate utility may not have been apparent.

Mr. Chairman, I know that you and your colleagues on this committee have been strong supporters of federal funding for research. I commend you for these efforts and hope that you will continue to impress upon your colleagues the importance of broad-based support for research for our future well-being.

The research that has led us to suggest that we might have uncovered fossilized remains of life on ancient Mars could not have been done were it not for contributions across many areas of science and technology. Nor could we have been successful without the contributions, ideas, and assistance of my colleagues and especially my students. This research endeavor has been one of the most exciting, yet humbling, activities that I have had the privilege to be associated with.

Thank you again for this opportunity to testify and I would be pleased to respond to any questions that you might have.

Mr. SENSENBRENNER. Thank you, Dr. Zare. Every once in a while the lawyer in me comes to the top in the Science Committee. And one of the things that you learn about in law school is what's called the chain of evidence.

Dr. McKay and Dr. Zare, you've done a very good job of dealing with two parts of the chain of evidence. But there's a missing link.

Dr. McKay, can you tell us how you think a piece of Mars became a meteorite and ended up landing in Antarctica?

Dr. MCKAY. That is a very good question. I think that there are a number of people that have looked at that and essentially concluded that somehow, an impact of perhaps a small asteroid or comet on Mars ejected some of the rock, the rock very near the surface.

As the shockwave became reflected back to the surface, it pushed with it some of the near-surface rock and that rock was accelerated enough to escape the gravity of Mars. It wandered in space for 16 million years in a chaotic orbit, probably back and forth a few times, influenced perhaps by Jupiter.

Finally, it got within reach of the earth's gravity field after 16 million years and it fell then into Antarctica about 12,000 or 13,000 years ago.

People didn't believe you could do this until we found the first lunar sample in Antarctica. Once we found a lunar sample there, we knew there had to be a mechanism that blasted rocks off of other planets and sent them to earth as meteorites.

And that's really—that's the story of why we believe it came from Mars.

Mr. SENSENBRENNER. Now you said in your testimony that there were 11 other rocks, meteorites that have been recovered that you also believe came from Mars.

Have these other meteorites been looked at to see if there is any evidence of organic life?

Dr. MCKAY. Several of them have been analyzed for organic material, and they all contain a little bit of organic material. Mostly that is interpreted as contamination from the earth.

Some of these meteorites have been sitting around in museums for 100 years, people have handled them, and so forth.

So contamination is possible.

The specific search for the signs of life that we did here have not been done on any of these other 11. And so that is certainly something that should be done in the future. And we intend to start doing that. I think other groups as well will do that.

Mr. SENSENBRENNER. Okay. Thank you. The gentleman from Texas, Mr. Hall.

Mr. HALL. Thank you, Mr. Chairman.

Not to emphasize the fact that Congress probably has too many lawyers, but the lawyer in me comes out also.

You use the word "probably" several times in the examples that you've shown here. On the back, there were things that say here, possible microscopic fossils.

I realized that you're not trying to be exact, but we're really dealing with what I guess us lawyers would call circumstantial evidence at this time, highly circumstantial evidence.

I know you believe because you're more skilled and more trained and more knowledgeable, you believe that what you've found is what you've reported.

But to the American people who pay taxes, when you use the word probably, and we're dealing with the kind of money that we're going to be talking about, to actually get a verdict out of this—by the way, the test in civil cases is by preponderance of the evidence, and the test in a criminal case is beyond a reasonable doubt.

I don't think you're anywhere close to either of those at this stage.

I'm just wondering about—and I believe that at the proper time, and the General suggested that we couldn't wait until we had either before-tax money to spend or however we're going to spend it, that we need to go forward on this.

I don't know about that. I think, certainly, I'm told that $20 million for this little machine over here, this creepy-crawly looking—whatever that is over there—to fly to Mars, and maybe anywhere from $200 or $300 million to a billion to send it to Mars and actually bring us back some real in-hand evidence that could be beyond a reasonable doubt or in all reasonable probability or by a preponderance of the evidence, could tell us, yes, we're right.

Now, frankly, I've had letters from people about this situation that encouraged us to look and to seek and to find and usually they were from men and women of great knowledge and great imagination about the future. But I've had some letters from said who have said not to spend a dollar on anything like this as long as we had a baby's bottle that was empty in this country. And both are legitimate concerns.

And a lot of letters and calls in between.

But I guess, what do the skeptics say about it? We have four people here who have a thrust on this. What do other men and women of science say about it?

Dr. McKAY. Well, you're clearly right that we have circumstantial evidence here. We do not have the smoking gun.

However, we conclude that the circumstantial evidence, the four lines of evidence that I talked about, are strong enough for us to conclude what we concluded about possible fossil life on early Mars.

Now there are skeptics that don't believe that. They don't really question our data. Our data, I think, are going to stand up. But they do question our interpretation.

Now what we really need, I think, are additional kinds of data beyond what we showed. And we will get those kind of data and other groups are working on them as well.

So I think for a very small amount of money compared to space missions, we'll be able to analyze these meteorites in enough detail to solve the question in a year or two.

Dr. ZARE. May I add on to that?

Mr. HALL. Yes, sir. Please do.

Dr. ZARE. If I might.

Mr. HALL. Yes, sir.

Dr. ZARE. I think you're really listening to a scientific story unfolding. And it may frustrate you, as it frustrates me, not yet to know the answer.

But we're in a situation where it's important to maintain a healthy skepticism, particularly among those who are involved deeply with the data.

So when we put forward an interpretation, we put it forward as the best explanation we now think of. But we have to reserve the right to change the interpretation, if somebody can show us a different way of thinking about it or get new data. That's part of what goes on.

And so, you can't yet expect certainty from this.

But the fact that these things seem so possible should encourage everyone, I believe, about looking further at this question and also considering very seriously the possibility that there was life long ago on Mars, which raises the question, might there still be some life on Mars?

Mr. HALL. Say we were in the '50s, early '50s, when we had the greatest position of financial strength in this country and the strongest geopolitical, I guess, position in the history of our nation. And Congress looked for things to invest in.

Say we had that situation again. How long would it take to tell us what Martian life should look like, and how long would it take to confirm or refute the research that you have, if we had those situations, which we clearly do not?

Dr. MCKAY. Well, ultimately, we will not know until we go to Mars and get some samples and bring them back. And under the funding situation that you propose, we could certainly do that within ten years. Five years for robotic systems.

Whether we can tell certainly about life on Mars from these 12 meteorites remains to be seen. I think perhaps we can and we can do that very cheaply.

Mr. HALL. Thank you, and I thank you, Mr. Chairman.

Mr. SENSENBRENNER. The gentleman from Florida, Dr. Weldon.

Mr. WELDON. I thank the Chairman. I thank the Chairman especially for having this hearing because I, for one, have followed this issue very closely with a tremendous amount of fascination.

Representing Kennedy Space Center, as I do, I have many, many constituents who are people who formerly worked on the Mercury and Gemini and Apollo programs. One of the comments or questions I'm frequently confronted with is, gee, we thought at the end of the Apollo program it was not going to be very long before we would either be going back to the moon or, preferably, going to Mars.

The Ranking Member raises a very, very good point, which is the economic point associated with it. I think if our nation was not spending $300 billion this year paying interest on the national debt, that we all in this room could indeed probably go to Mars with that kind of money.

It's just an essential problem that our nation faces, a crushing burden of debt, an explosive growth of entitlement programs.

Mr. SENSENBRENNER. Would the gentleman yield?

Mr. WELDON. I'd be happy to yield.

Mr. SENSENBRENNER. Would you like me to arrange for a ticket for your opponent in the election campaign to go to Mars?

[Laughter.]

Mr. WELDON. Be my guest, Mr. Chairman.

But the question I was going to get to because, to me, this is really a fascinating issue, understanding the budgetary constraints we're working in, I understand, Dr. Huntress, how you're talking about sending probes and possibly a probe, as Mr. Hall alluded to, that would return a sample.

Could you really get the information that you need from an inanimate probe? And maybe Lt. General Stafford would like to comment on this.

Is this kind of question ultimately going to require putting men and women on Mars, where they can actually walk around on the surface and look for the kind of samples and terrain necessary so that the question you're posing can really be answered?

Dr. HUNTRESS. Let me start first, Mr. Weldon, and then I'll pass it to Tom Stafford.

What we're talking about here is essentially field geology, walking around on a field or roving around on a field and looking for the right kinds of samples—rocks, material, soil, whatever it is—that has the evidence in it that you're looking for.

Now, robotically, there's a long way that we can go. And in fact, before we would send human geologists to Mars, we would do it like we did the moon—you send your robotics scouts there to find the right places to go and what it's like there, so when you finally end up sending your human explorers, they're in the right place and have the maximum probability to come back with the right stuff.

Now it depends on how hard it's going to be to find evidence for early life on Mars.

If the dinosaur bones are laying on the surface, it's real easy. If you've got to go digging for them or if you've got to look for the minutest of evidence, it will probably take a human being to do that.

Now the human has the advantage, and will still have for sometime to come yet, the reservoir of knowledge that it would require sometimes to do a hard search.

The advantage he has over the machine is that he has knowledge of experience, which machines are difficult to do. They can have a knowledge data base, but they don't have the experience sometimes that a trained field geologist would have.

On robotic missions, we'll learn a lot about Mars, about its climate, about the structure of the planet, what it's made of, and what it's like there on that planet and find all the evidence for where is the water and where is the best places to look for life, and may even find it when we bring the right kinds of samples back.

But whether that works or not, there's still a compelling reason ultimately to be sending human explorers to Mars.

Mr. WELDON. General Stafford?

General STAFFORD. The evidence we had back, particularly from Apollo 17 when we had Dr. Jack Schmitt, who was a geologist who flew on that last lunar landing mission and found the orange rock, he knew exactly what he was looking for—was a good example of using the final logic of the human mind to focus in for the fine-tuning on field scientific expedition.

So the exploration of Mars is both a strong robotic, but then, finally, eventually, the human exploration of Mars.

The question that Mr. Hall brought up concerning about the economic problems, and I recall back when President Kennedy made the commitment for the Apollo program, there was a lot of problems in the United States at that time, problems as far as the economy, health care, and a series of things, and there are still problems today.

But he made that bold commitment to go. And based on the evidence here, there are things that can be done in a very modest way, Mr. Weldon, that can start like refocusing on some of our technology development in our national laboratories, encouraging the private sector to work and focus some of their resources on us, to get us started down the road.

Mr. WELDON. Do you really feel that the technology that you were talking about we need breakthroughs in, is necessary to go to Mars?

You talked about a nuclear engine for a Mars probe, manned Mars probe. And also a heavy-lift capability.

I assume you're talking about a less expensive heavy lift capability. Could you just elaborate on those two issues a little bit?

General STAFFORD. Well, in the synthesis group, in using data from all around the United States, in NASA, the Department of Defense, the industrial sector, it was determined that to have a manned expedition or human expedition to Mars, you need approximately a minimum of about 500 metric tons in low-earth orbit.

And so what you're talking about is a payload of two enhanced Saturn V boosters docked together. And that is with a nuclear thermal rocket to use in the upper stage.

The nuclear thermal rocket is only from low-earth orbit for transit to Mars and the impulse back.

If you do not use a nuclear thermal rocket from low-earth orbit to the Martian orbit and back, it's going to require approximately the mass in low-earth orbit, which requires a far more amount of lift, number of launches, and it requires far more cost.

So that is the reason for the nuclear thermal rocket, it is for the transfer out there.

For certain cargo missions, you can use electric propulsion that goes very slow and it takes a long time out there, but that kind could be used.

Mr. WELDON. You talk about solar electric propulsion.

General STAFFORD. Solar. But that would be very, very slow. You'd like to use a very low-powered nuclear electric, perhaps a radio-isotope electric propulsion.

Mr. WELDON. If the Chairman would allow, I just have one more question. I guess it's the doctor in me coming to the surface, or the biochemist in me coming to the surface.

Can you explain to me a little bit more about these aromatic hydrocarbons that you're looking at? What are they? How big are they? Are they six-carbon rings? Are you looking at five-carbon rings?

Can you just elaborate a little bit more on what that is?

Dr. ZARE. I'd be glad to. The aromatic hydrocarbons are six-carbon aromatics like benzene.

Mr. WELDON. Benzene, right.

Dr. ZARE. That are fused together. Sometimes they have some five-ring members in them, but mostly, they're made of six.

They're things like naphthalene, that you'd find in mothballs, although we tend to find yet heavier things.

The type of structure we see are very much the bare skeleton of these aromatics, as opposed to what are called side chains that hang off of them, other types of chemical groups. They're similar to what you'd see if you were to actually analyze anthracite coal, is what you'd see.

Mr. WELDON. This kind of analysis that you've done, it has not been done on any other meteorites collected from anywhere else?

Dr. ZARE. No. We have done this on somewhere around 17 to 20 other meteorites. The particular distribution that we see is fairly special in the case of this meteorite, compared to some of the others we've seen.

Mr. WELDON. Okay.

Dr. ZARE. And it seems to be consistent. It's permissive evidence for fossilization, but to me, doesn't prove this, necessarily.

So it's a story in which you put pieces together and taken and looked at as a whole, it led us to this conclusion. I still don't know a better conclusion.

Mr. WELDON. One more question. The Chairman is being very generous with the gavel.

But has there been any speculation to the possibility that life could have originated on Earth, been transferred to Mars through solar winds because what you're talking about is very microscopic life forms, or maybe—you're saying in the chain of evidence that a meteor or an asteroid or comet struck Mars and ejected something out.

Could there be another step in all of this that a meteorite or an asteroid hit the Earth——

Dr. ZARE. You're asking a really huge question that intrigues us all about origins of life. Where did life of this sort start? Did it start independently? Or is it possible that life was transported from one planet to the other since, as we've heard, with asteroid impacts, comet impacts, they can exchange matter back and forth.

There's been a theory called panspermia that originated in, oh, the last century. People thought there were seeds or spores of fungi or something that came in. Then, when we understood better how harsh space was in terms of cosmic rays and other matters, that theory has been put aside.

But perhaps this theory can be reborn again in terms of being protected inside rocks.

Mr. WELDON. Inside a rock.

Dr. ZARE. And therefore, the question you ask is a very fascinating one. And turning it backwards, for all we know, whatever we found in Mars first came from earth to Mars.

We don't know.

Mr. WELDON. I thank the Chairman.

Mr. SENSENBRENNER. The gentleman from Indiana, Mr. Roemer.

Mr. ROEMER. Thank you, Mr. Chairman.

I am fascinated by some of the newspaper articles and periodicals and so forth coming out with this whole story. Certainly here in NASA, we have a host of new things, new programs, new, exciting technologies that we have heard about over the last year or two that Mr. Goldin and others have been up here to promote that we're excited about, as Members of Congress, as supporters of parts of the space program, especially those efficient and productive parts of the space program that are returning us good science and good results and good benefits for the taxpayer and good benefits for the future.

I guess one of my first questions to Dr. Huntress would be, what's it going to take and how long will it take to make the decision as to whether or not we have something here, we have conclusive evidence here to move Mars up the priority list to then begin doing some of the things that we're speculating about now?

Dr. HUNTRESS. Well, one of the things that's interesting to me here is that, in some sense, we've anticipated this result. We had no idea, of course, that it would come along. But we've anticipated the result in the sense that, since we began the second era of Mars exploration that I talked about by starting the Mars surveyor program, and we thank this Committee for supporting us in doing that, one of our goals in that program has been to look for evidence that life may have once existed on that planet because our previous era of exploration which ended with the Viking mission in '76 clearly told us that there were warmer and wetter climates early in the history of Mars. There's clear evidence of running water on that planet and ancient lake basins and catastrophic flooding.

And if that's the case, then why in those early days would not Mars have generated life as this planet may have once done, and its ultimate fate undetermined, of course?

So that's been one of our goals in the Mars surveyor program among looking for climate changes that are relevant to those that occur in our own earth here and understanding Mars as a potential target for human exploration.

So that's been part of our game plan in developing the Mars surveyor program all along, which, as you know, is intended to send one, if not two, launches to Mars every 26 months, when the planets are appropriately aligned.

What this announcement has done for us, however, is to force us to kind of go back to the drawing board a little bit and look at a different strategy, which is, instead of ultimately looking to get any sample from the surface that's interesting—geochemically, whatever—what would it take to try to maximize the probability that that sample we brought back contained evidence in it on early life on Mars?

That's a different story. That's a very selected sample.

Mr. ROEMER. Dr. Huntress, let me just interrupt for a second and try to clarify what you've already said.

So far, to the best of my understanding, there is testimony here today that says that we don't have anything—it's not conclusive, but there's good evidence that there may be something.

The first part of my question was how long will it take for us to determine whether there is something and whether we can come to some kind of conclusion on this?

Is it a year? Is it two years?

Dr. HUNTRESS. It's a year or two. That in fact is our first order of business, is to make sure that we do all the research on this suite of Martian meteorites, these 12 Martian meteorites, that we can in order to try to come to some consensus within the science community as to what this evidence really does mean or does not mean.

We should also, working with the National Science Foundation, go back and look for more of these things because most of the rocks in this collection are much younger than this old one.

So that's the first order of business.

And the second is that, at the same time, figuring out what our strategy ought to be if in fact this evidence turns out to be true.

Mr. ROEMER. Now what do we do, Dr. Huntress, if this is true?

There's a great deal of skepticism out there right now. We've got some critics. Maybe we should have the critics testify and tell us their side of the story as well, too.

But let's say that what we found truly has evidence that there may have been life on Mars or there could be some kind of future potential.

What do we do with the declining NASA budget? And how do we shift priorities around when we have had priorities on Pluto, on the new discovery from Galileo that one of Jupiter's moons has liquid water, the new generation telescope, Mission to Planet Earth.

We've got a host of things that have been taking priority here. How do we do that given that we have a declining budget?

Dr. HUNTRESS. I think that if this evidence holds up, that it really adds an imperative that we not only continue to do those things because they're all headed in the direction of trying to understand our place in this solar system and universe, but I think it would speak to a need to accelerate what we're doing in trying to understand the origin of not just life, but of planets themselves as the abode of life in the universe, and are there other planets out there where life could have started? Are there other places in this solar system, such as Europa, for example, where life might have started?

Our current Mars surveyor program is highly, highly constrained, as you know. And to get a sample back from Mars within the current resource budget of that program, even as early as 2005, is going to be extremely difficult.

In fact, we're not quite sure we know how to do it yet.

But if it turns out that the evidence points in the direction that life started on some place other than the earth, that's pretty profound and I think goes right to the gut level of what people are interested in.

And that is, are we alone in this solar system or this universe?

Mr. ROEMER. Thank you, Dr. Huntress.

Mr. SENSENBRENNER. The gentleman's time has expired. The gentleman from Arizona, Mr. Salmon.

Mr. SALMON. No questions, Mr. Chairman.

Mr. SENSENBRENNER. The gentleman from Pennsylvania, Mr. Walker.

Chairman WALKER. Thank you, Mr. Chairman.

I am delighted to be here to welcome the panel here today and discuss this particular topic, which of course adds a note of excitement to all that we have been doing in space activities for many, many years, and of course, begins to very much justify the kinds of efforts that have been put forward in exploring our solar system and exploring as far out into the universe as human kind can possibly go because the potentials for these kinds of finds are greater with each step we take.

And so, I thank you for coming here today. I thank you for bringing the meteorite sample and for being a part of this.

I'm interested in a couple of things and I'm sorry that I wasn't here earlier. I had to be over on the floor for a few minutes.

Do I understand correctly that at least the testimony up until now, Dr. Huntress, is that the missions that we have previously planned to go to Mars are in fact the right steps to be taking in order to begin exploiting this new discovery?

Dr. HUNTRESS. Yes. In fact, the Mars surveyor program is intended to be kind of a long-term series of missions to explore Mars and looking for evidence of life was one of the objectives of that program, and to do that at a measured and systematic pace.

The idea of a sample return has always been part of the long-term scenario for that series. But the earliest possible date we've been thinking about prior to this announcement was 2005 launch, 2008 return.

Chairman WALKER. But this new information is likely to have us look at some different sites that may have a far greater potential for giving us evidence of these life forms.

Is that correct?

Dr. HUNTRESS. Yes, that's correct. So we're looking at a different strategy, a different approach, which would be to get a different kind of sample back that would have this type of evidence.

And that requires a lot of prior work before you actually go there and pick it up and bring it home.

Chairman WALKER. And obviously, there is some desirability at some point in the future for us to be able to have men and women go to Mars and actually do the kind of sampling that human beings are capable of doing.

But it seems to me that there are two things that enter into that picture as well.

General Stafford, would you agree, we have to do a good bit of life sciences work, for instance, aboard the Space Station before we probably are ready to embark upon that kind of a human mission?

General STAFFORD. Well, Mr. Walker, the life science we outlined in the synthesis report group from the Space Station, would primary focus there—it's just the long duration mission to determine.

Chairman WALKER. Right.

General STAFFORD. Since the time out there is probably a maximum of 270 days each way. The minimum could be 150 days each way.

Chairman WALKER. But, as I say, the kind of work that we're going to do aboard the Space Station in terms of long duration orbiting and humans is in fact a contribution to a long-term flight that would be required to go to Mars.

Is that correct?

General STAFFORD. Yes, sir, it is a contribution.

Chairman WALKER. I don't believe it's been raised yet, but it seems to me that this is one of the arenas where we may want to begin to explore the potential of internationalizing any kind of mission.

Would there be agreement by this panel that some kind of an international effort to combine resources toward doing a long-range mission that would ultimately involve humans on Mars would be a good idea?

Dr. HUNTRESS. The answer is yes, wholeheartedly.

In the science part of the program, the robotic scientific missions to Mars, we are doing our best to internationalize the current Mars surveyor program. In fact, we've been talking to the Russians about a really truly joint mission in 2001.

The way I'd characterize our current approach is one in which some nations participate in another's mission. But we're going to try to change that so that we are actually true partners, at least in the robotic mission. And I think General Stafford will tell you where that needs to be done in the human scope.

Dr. ZARE. May I add on to that?

Chairman WALKER. Sure.

Dr. ZARE. We've already benefited from international cooperation. It was actually Japanese research scientists who first identified that there were meteorites in Antarctica. It wasn't recognized right away. What were these stones doing in this bluish-white icesheet?

And if I might, let me express my thanks to Chairman Walker and all his Committee for the help yesterday in getting the House to approve a sensible environmental protection program for Antarctica so that we can continue to do research there while preserving the environment.

Thank you so much.

Chairman WALKER. Thank you.

General STAFFORD. On the manned mission, Mr. Chairman, we outlined in the synthesis group that it was a potential for cost savings to work in an international effort.

But we didn't have the resources to go into details. But very definitely, from some of the technologies that the Russians developed, and some of the other countries, it would do that.

But before we would talk, really, in a focused way, I think we should also set our own priorities in this country, sir.

Chairman WALKER. My time has expired, but I just wanted to make one point.

And that is, I agree with the last point you made—we need to set our own priorities. But I do believe that there is an opportunity here to get the international community very excited about all of this, too.

In talking to some parliamentarians from other nations in recent weeks since this has been announced, a lot of them are expressing a lot of excitement about this potential find. And I think there's an opportunity here to begin to weld together a coalition that goes beyond just some bilateral associations with the Russians, but combines many nations in the world that would be willing to put resources into the ongoing efforts to learn more about this discovery.

Dr. MCKAY. If I might make a brief comment on that.

That process has already started in a way because we are forming up teams with people in England, with people in Japan, to study these meteorites. And each one of those labs that is working with us is in contact with their government and with their space activities. And there's a tremendous interest being stirred up by this.

Chairman WALKER. Yes. Having been to the South Pole, there are a lot of these little black rocks that are all over the place down there. So there may be lots of potential.

[Laughter.]

Dr. ZARE. In that matter, I might add, we get sample returns ready at the rate of about two tons a year coming to the earth. They're just unplanned-for sample returns and most of them go into the ocean and are lost.

Mr. SENSENBRENNER. The gentleman from Texas, Mr. Hall.

Mr. HALL. I have a question. I'm not real sure what I want to ask.

But I think as in asteroids, we've had hearings on asteroids and had testimony to the effect that it seemed like in '89, one missed the earth only by about 15 minutes and we didn't know about it until it was passed and gone.

It would be pretty hard to gather up tax money to plan for a way to split asteroids if they were headed in this direction if we knew they were.

I don't know how much money we're talking about there, but as Congressman Walker talked about, that's a world problem and ought to be handled—it's a global experiment and ought to be handled globally by global tax money as something like this should be.

But I have some concern about all of these figures that we use—a 4-1/2 billion-year-old rock on Mars, a huge impact, about 16-million years ago.

We have a lot of people who are pretty satisfied with the bible's reflection of the creation and of time. I have a hard time pulling those together.

I know the bible says Methusala, I think, lived to be 869 years and he died. I doubt that anybody lived that long. They probably figured time a little bit different then.

But the bible tells us that God created the earth and on the seventh day, he rested. And here, we're 16 million years and 4½ billion-year-old rocks and things.

How do we know whether life developed independently on Earth and Mars? Or I guess that's the reason you want to probe. How do we know whether or not life spread from Earth to Mars or from Mars to Earth?

Or maybe from somewhere else in the solar system to earth and then to Mars, or from Mars and then to Earth.

Does anybody want to touch that?

[Laughter.]

Dr. HUNTRESS. Well, one of us is going to have to, I think.

[Laughter.]

Mr. SENSENBRENNER. Going once——

[Laughter.]

Mr. HALL. Or to be continued, maybe.

[Laughter.]

Mr. SENSENBRENNER. Dr. Huntress?

Dr. HUNTRESS. Well, I don't think we do know. And you're right. That's one of the things that we would like to try to find out.

It's going to be fantastic enough if we find out in fact that life got a foothold by whatever means on another planet in this solar system.

As to whether or not it arose independently on Earth or Mars or whether one of the other planets seeded the other through this mass exchange through large impacts, or whether or not, in the formation of the solar system, material entered our solar system in part of the natural formation process through cometary material or whatever seeded these planets with the right ingredients.

All these things are speculations that actually drive a lot of the science community in trying to find out what the origin of life is in this universe and on this planet.

So those are cosmic questions that are going to drive our science for some time.

Dr. ZARE. I'd like to talk about this question of life on earth.

When I grew up, I was told about various animal and plant kingdoms and I had the picture of most life being on the ground or above-ground.

Now I'm learning there's lots of life, not only in the ocean, but below the ocean's floor and in our ground miles down deep, people find things.

Just last week, there was a report of a new type of bacteria that's never been seen before that seems to eat hydrogen and give out methane—methanococcus bacteria.

We have lots to learn still about just what life is on earth.

Mr. HALL. Are these worm-looking things on the black and white picture that you've given us, are they supposedly Martian bacteria?

Dr. MCKAY. That is our interpretation, that those may be the fossil remains of Martian bacteria. That's a possible interpretation of what we see there.

Mr. HALL. Do you find any evidence of cell walls or other small cell organs?

Dr. MCKAY. We are in the process of carefully looking for cell walls. We have not yet found cell walls. But we have developed a new technique that will enable us to cut very thin sections through features like the one in the picture and look for cell walls.

Mr. HALL. Has your work or your probe since the initial release changed any or confirmed the fact that we are dealing with bacteria?

Dr. MCKAY. We really have no new data to change our mind or add to our story. We have developed this technique to try to picture the cell walls. And that's what we plan to do very soon.

We have set up some collaborative teams using other techniques, other instruments all over the world. One thing that we're going to do is use a fluorescence technique which will enable us to see organic material visually as it fluoresces.

So the answer is that we don't have—we've not made real progress on the data, but we're setting up so that we plan to in the future.

Mr. HALL. Thank you. I thank the Chair.

Mr. SENSENBRENNER. The gentleman from Minnesota, Mr. Luther.

Mr. LUTHER. No questions, Mr. Chairman. Thank you.

Mr. SENSENBRENNER. I would like to thank all of the witnesses for their very interesting testimony. I can say that during this two-year term of Congress, this has been the most interesting hearing that we've had.

And I hope that we'll be able to build on that in future times as the science develops.

We have received written testimony from the Planetary Society, the Space Frontier Foundation, and the National Space Society, which the Chair asks unanimous consent be included at the end of the hearing record.

Hearing no objection, it will be included.

And with that, the Subcommittee stands adjourned.

[Whereupon, at 11:25 a.m., the Subcommittee was adjourned.]

[The following material was received for the record:]

NASA'S ROCKY FUTURE

Dr. Louis Friedman
Executive Director, The Planetary Society
Statement to the Science Subcommittee on Space and Aeronautics
U.S. House of Representatives
September 12, 1996

Thank you for the invitation to appear before the Space and Aeronautics Subcommittee. Unfortunately, I am unable to attend and offer this statement for the record.

A team of NASA and university scientists presented to the world on August 7 the first substantial evidence that life may have arisen on Mars. The discovery must still be confirmed and the scientific process must be exercised. But, if confirmed, the detection of fossilized microbes beyond Earth would a profound revelation that would change forever how humanity views its place in the universe.

The evidence of life on Mars comes from a meteorite that fell to Earth apparently after it was blasted off the surface of the red planet by the impact of a comet or an asteroid. Within the rock are tiny fissures, where scientists have identified organic matter they believe to be microfossils that lived 3.5 billion years ago.

The possible discovery of fossil remains in the meteorite is the most provocative and evocative piece of evidence for life beyond Earth. If verified, it suggests that life exists not just on planets in our solar system, but throughout the universe.

The implications of the announcement reach beyond science and touch our society in many far-reaching ways. For all of history, we have asked if life on Earth is unique. Now, for the first time, there is scientific data to examine so that we can begin to answer the question.

The evidence of microfossils from Mars requires additional study. There is much we still do not know. The discovery does not indicate conclusively that life on Mars once existed or exists there now; nor does it tell us about the origin of life. The findings must be confirmed by additional investigations, and even then we will have just begun to understand the processes involved.

Exploring Mars to Learn About Earth

Mars and Earth formed about 4.6 billion years ago. Both bodies experienced complex evolutions and may have cooled in a similar fashion. Carved on the surface of Mars are ancient flood plains that suggest the climate once was warm and wet, with a thick atmosphere. Today, the planet is cold, arid, and forbidding, with a thin atmosphere of mostly carbon dioxide and no protective ozone layer.

Through comparative planetology, scientists hope to learn why the climate of Mars changed over time. They want to understand why the planetary bodies evolved with different internal structures, surface features, chemical composition, and atmospheres. The knowledge is essential to understanding the universe and answering questions about Earth. For instance, by investigating the atmosphere of Mars -- and that of Venus, which has a dense atmosphere of carbon dioxide and is suffering from a runaway greenhouse effect -- scientists can better understand Earth's global climate, including the problem of ozone depletion and the impact of carbon dioxide emissions from automobiles and burning fossil fuels.

Within the Martian soil there may be clues to the origin of life on Earth. The oldest fossil remains discovered on our planet date back 3.5 billion years ago. Because of tectonic activity and the recycling of the planet's crust, older records have not been recovered. Most of the surface features on Earth were formed in the past 100 million years. On Mars, because much of its crust has not substantially changed over time, scientists may be able to locate fossil remains to piece together the earliest stages of life. The organic matter in the meteorite from Mars offers a tantalizing glimpse of discoveries that may lie ahead for scientists in their investigation of the planet.

The Mars Program

More than 20 years have passed since America placed a spacecraft on Mars. NASA attempted to send the Mars Observer to the planet in 1992, but as it prepared for insertion into orbit, it suffered a catastrophic explosion. Instead of replacing the probe with another large and expensive vehicle to recover the lost science, the space agency initiated the Mars Surveyor Program, which relies on small, low-cost spacecraft to gather scientific data. Every 26 months, when Earth comes into favorable alignment with Mars, NASA plans to launch probes to the red planet.

NASA can afford to send a series of missions to Mars because of its new policy of building probes that are "faster, cheaper, and better." The fruits of the Mars Surveyor Program are just coming to bloom. In November of this year, NASA is scheduled to launch the Mars Global Surveyor, which fulfills many of the scientific objectives of the Mars Observer. The spacecraft will orbit the planet to compile a detailed map of its topography, determine the mineral distribution, and measure the water content in the soil. The module also will serve as a communication relay station for future spacecraft that land on the planet's surface, including the Mars Pathfinder, which also is scheduled for launch late this year.

Mars Pathfinder is the second project in NASA's Discovery Program, begun in 1993 to promote the development of small, highly-capable, low-cost probes to explore the solar system. Mars Pathfinder is designed to validate new technology and landing methods that, if successful, will reduce substantially the cost of future missions to Mars.

The 1,870 pound Pathfinder will approach the red planet at 17,000 mph, then steer into the upper atmosphere to reduce its speed in a process called aerobraking. At 32,000 feet a parachute will deploy. After airbags that surround the vehicle inflate, small rockets will ignite. The spacecraft will slow to a stop a short distance above the surface, then drop to the ground, cushioned by the airbags.

Pathfinder resembles a three-sided metal pod. Once on the surface of Mars, it will unfold like "pedals of a giant metallic flower," revealing several scientific instruments and a six-wheeled rover attached to one side. The semi-autonomous vehicle, named Sojourner, after the 19th century human rights advocate and abolitionist, Sojourner Truth, is powered by a solar panel and will drive onto the alien landscape, taking pictures and examining the chemical composition of rocks and soil.

In 1998, NASA plans to launch another orbiter and lander to Mars. The two modules will incorporate new, miniaturized technology to reduce by half the weight of the overall payload, as well as the size of the launch vehicle needed to boost the craft to Mars. In 2001, the space agency is scheduled to again send an orbiter and a lander to the planet that are even more compact than those of the previous mission.

As now planned, none of the future spacecraft are carrying instruments specifically designed to look for evidence of life. In 2005, NASA is looking to return to Earth the first soil sample from the Martian terrain. But now, in light of the discovery of possible life on Mars, this timetable is being reexamined, as well as the selection of instruments for future missions.

Between the Mars Rock and a Hard Place

In space science, America is entering a new dawn of discovery, in which low-cost probes are being launched every year to explore different facets of the solar system. Adding to the excitement, raised by the suggestion of life on Mars, there is growing speculation that conditions for life may exist on Europa, a Jovian moon whose icy surface may conceal a global ocean.

Given this spirited agenda, NASA's future may seem promising. But, in fact, the space agency is facing potential disaster because of deep budget cuts proposed by the White House and Congress. NASA currently operates on 12-percent less funding than what it received in 1992. The Administration wants to cut the agency's budget by a further 22 percent, from $13.8 billion in 1997 to just $10.7 billion in 2000 (1997 dollars adjusted for inflation). Future spending levels proposed by Congress are almost as bad, with members supporting an 18-percent reduction during the same period.

So far the space agency has been able to operate on declining budgets by eliminating waste and streamlining operations. But the future proposed cuts are too severe to absorb. NASA cannot hope to achieve the rollbacks in funding without terminating major scientific programs and probably shutting down research centers.

It is under this darkening cloud that scientists are examining what options may be available to collect additional evidence of life on Mars. One possibility being discussed is to advance the timetable for a sample return, now being planned for 2005. But as we learned from the Viking mission in 1976, taking soil samples from only two sites, with stationary spacecraft and without careful *a priori* site selection, restricts our ability to learn about potential life on Mars. To aggressively seek out evidence of life on the planet, we need rovers to explore the most promising terrain, then we need to take core samples from several locations and return them to Earth for examination -- a formidable challenge. More than a single sample from Mars will be required.

But the budget cutbacks at NASA will squeeze out the possibility of a useful sample return. Indeed, as The Planetary Society testified in July of this year, the projected cuts in space science will probably force the curtailment of missions already in the pipeline. If the future budgets proposed by either the White House or Congress hold fast, missions to rove and dig on Mars, and return samples, will be impossible.

Stabilize NASA's Budget

NASA's space science program receives about $2 billion annually, and it is shrinking rapidly. In FY 1997, the program will be cut by $175 million. Cynics quoted in the media suggest the meteorite discovery is a ruse to prompt a big jump in funding for the space agency. But it seems good news is hard to accept. A boost in NASA's budget is not necessary -- just no more decreases. To explore Mars, the space agency does not need an Apollo-size infusion of money. America can ill afford to open its federal coffers and spend tens of billions of dollars, as it did in the 1960s when President Kennedy committed the U.S. to landing a human on the Moon. At the same time, NASA cannot be expected to perform a worthy exploration of Mars when future budgets decline by more than eight percent a year and funding remains doubtful for the projects now underway.

With this in mind, the most important first step to take in response to the Mars discovery is to stabilize NASA's budget and stop the debilitating cuts that now are proposed. Within NASA, space science should be made a high priority, a recommendation often voiced in theory, but as yet not implemented.

Operating faster, cheaper and better is an ongoing process at the new NASA. The agency can be expected to continue to implement reforms to stretch every dollar. If the space agency's budget can be held steady and funding for space science maintained at the 1997 level with adjustments for inflation, I'm convinced NASA can find a way to get to Mars and affordably continue the exciting search for extraterrestrial life -- an adventure that will make our nation and the world proud.

In a few years, we will know substantially more about Mars and can plan the next stages of exploration by robots and humans. By 2002, the International Space Station should be operational. By the following year, assuming funding is made available, scientists will have had an opportunity to rove the surface of Mars and study a half dozen new sites. By 2005, we should have our first sample returned.

NASA is not alone in the quest to explore the red planet. Internationally, expertise and interest in planetary science is growing. The United States and Russia have agreed to explore Mars together in a series of cooperative efforts. The 2001 mission, as now planned, includes a Russian-launched spacecraft with a highly mobile rover. Japan, too, has a Mars mission scheduled in 1998. By working together and pooling resources, The Planetary Society believes the international community can aggressively explore Mars and determine in a reasonable period of time whether life there once existed or possibly continues to exist. The exploration of Mars can be the hallmark of this century's end and the beginning of the new millennium.

But once again, NASA cannot hope for such achievements when its budget is tumbling downward, creating chaos and forcing officials to deal with internal problems, instead of creatively finding ways to explore Mars.

Are We Alone?

Humans have long pondered the origins of the planets and of life itself. With modern robotic probes, we have leaned more about our solar system the past 30 years than in all previous history. The journey into space finally has evolved to the point where scientists can begin to answer how our solar system originated and life evolved on Earth, and possibly on other planets.

It is this quest that we now have before us. Confirming the possibility of life on another world is within our grasp. Since humans first gazed at the stars, we have questioned whether we are alone. The issue is fundamental to who we are and how we see ourselves. Now, as a nation, we must decide whether we have the vision and the will to venture forward, to vigorously explore Mars to answer underlying questions about our solar system and the origin of life itself.

SPACE FRONTIER FOUNDATION

News Release

Contact: Rick Tumlinson @ (800) 631-0627 or Charles Miller @ (707)649-0225

Citizen's Group Warns Against Bureaucratic Rush to Mars

FOR IMMEDIATE RELEASE — (August 7, 1996) - The Space Frontier Foundation, a national grass roots space policy and media organization, today warned against any effort to create a massive international program to explore Mars Citing the huge costs and almost decade long delays caused by a similar approach to building the International Space Station, the Foundation called for the President to order NASA to try new, innovative and much lower cost methods in the quest for knowledge about the possibility of life on Mars. For example, as a first step, the organization wants the U.S. to offer to buy Martian soil samples from U.S. firms, saving taxpayers billions of dollars, while encouraging a now struggling domestic space industry

According to Rick N. Tumlinson, President of the Foundation, "NASA's traditional methods to return a sample of Mars soil would cost around $8 billion, a far better way would be for the space agency to procure soil samples from private firms, which are better equipped to mount low cost missions than the government. We believe this would cost the taxpayers a tenth of the traditional government-does-it-all approach."

Today's news of the possibility of life on Mars will inevitably lead to calls for sample return missions from the red planet, to provide definitive answers to the questions raised by this exciting discovery. The Foundation believes that the traditional NASA bureaucratic style has been discredited, and points to NASA Administrator Dan Goldin's own move toward producing "cheaper, faster, and better" results by procuring launch services from private firms, privatizing shuttle operations, and the new X-33 government-commercial sector partnership.

Tumlinson stated: "We can spend tens of billions of dollars today on a series of huge international projects that might someday in the future repeat the old Apollo flags and footsteps stunt in the red sands of Mars, or we can toss out the old way of doing things, save billions, get there faster and create a new and vital space industry that can provide the infrastructure we need to permanently open the space frontier to our children. It all boils down to making the right decisions today."

The Space Frontier Foundation is a grass-roots organization of American citizens dedicated to opening space to economic development and human settlement as soon as possible.

For information on the Foundation call 1-800-78SPACE
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NATIONAL
SPACE SOCIETY

Submitted for Insertion into the Record of the Hearing entitled

"Life on Mars?"

Space Subcommittee, United States House of Representatives
September 12, 1996

by

The National Space Society

CHAIRMAN'S MESSAGE (an editorial column)
reprinted from Ad Astra Sept./Oct. 1996. A similar version of this appeared in the Sept. 2-8 Space News.

Life on Mars

As we go to press, NASA scientists have announced a startling discovery revealing strong circumstantial evidence of past microbial life within Antarctic rock samples that had previously been ejected from Mars by meteoric impact. The evidence includes complex organic molecules, magnetite and other typical bacterial mineralogical residues, and ovoid structures consistent with bacterial forms.

The response to this discovery has been electric, with banner headlines in thousands of leading newspapers, non-stop coverage on CNN, and a call by President Clinton for a national space summit to reconsider the future strategy and priority of the American space program by the end of the year. Said Clinton: "the American space program will put its full intellectual power and technological prowess behind the search for further evidence of life on Mars ...For if the discovery can be confirmed it will surely be one of the most stunning insights into the universe that science has ever uncovered."

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The President's move could not have been better conceived or better timed. Just the day before, a National Space Society press release called for precisely such a summit.

This is a historic moment, and the President needs to seize the time, as John F. Kennedy did in the spring of 1961, to launch the American space program into a bold new initiative.

The United States needs to set itself the goal of landing humans on Mars within a decade. There is no doubt this can be done- despite the greater distance to Mars, we are much better prepared today to send humans to Mars than we were to launch humans to the Moon in 1961 when JFK committed the nation to that goal. Cost is not really the central issue either; NASA's average budget during the period 1961 to 1973, when it built up from near-zero space capability to storm heaven with the Mercury, Gemini, Ranger, Surveyor, Mariner, NERVA, Apollo, and Skylab, programs was $15.4 billion in 1994 dollars. That is only 18% greater than NASA's current budget. The problem is not lack of money but lack of focus and direction. For the past two decades the US space program has floundered without any central motivating goal. As a result, funds have been spent at a rate comparable to that of the 1960s without producing anything approaching commensurate results.

The discovery of micro-fossils in Martian meteorites makes the presence of human explorers on the Red Planet essential, because it shifts the focus of Mars exploration to fossil hunting, an activity in which human mobility, versatility, adaptive intelligence, and intuition are mandatory. America's mountain states abound in dinosaur fossils, yet you could spend the next ten thousand years parachuting cameras into the Rockies without finding any. To find the fossil beds that will reveal the ancient Martian biosphere in its true glory will take human explorers, real live rock hounds, on the scene. To drill deep into the ground to bring up sub-surface water in which Martian life may yet exist will take human prospectors and drill-rig teams working out of a permanent Mars base.

In the 1960s the Moon was the goal that forced the nation's reach to exceed its grasp, in the process forcing us to develop computers and many other technologies whose resulting economic spin-off is still unfolding today. The space program of the 1960s was an invitation to every youth in the nation to join in a great adventure by developing their minds. Today, such an invitation is absent, and the result is the existential Generation X.

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