



## Earth, Moon and Mars



Mankind finds itself thrown into a hostile universe. While our bodies are subject to the soulless laws of chemistry and physics governing physical processes on even the most distant star, our minds, our hopes and fears find no spiritual equivalent. The intriguing sketches on the walls of the Altamira cave, for example, may have been the attempt of our early ancestors to create humanlike beings simply in order to alleviate their spiritual loneliness. The Greeks later filled their heavens with a great variety of deities who, by virtue of their human features, clearly betray the intent of their creators.

Little has changed since. The past two thousand years have seen mankind struggling to find a rationale for its existence, hopefully given by an entity beyond its transitory existence. These days, evidence seems to take precedence over belief. Hence, modern science seeks to provide answers to these age-old questions. It is only logical to begin with the nearby celestial bodies, i.e. with the Earth, Moon and Mars, to which the present issue of *Spatium* is devoted, and to search there for traces of life. But, while this endeavour has provided us with deep insight into the history of our own planet, the feasibility of life on the Moon has meanwhile been excluded, and corroboratory proof of life on Mars has not yet been found.

We are still alone.

Prof. Johannes Geiss is the *spiritus rector* of the International Space Science Institute in Bern and its Executive Director. We are very

grateful for his kind permission to publish herewith an adapted version of his address at the Fourth Anniversary of the ISSI foundation.

*Bern, June 2000*  
**Hansjörg Schlaepfer**

## Impressum

SPATIUM  
Published by the  
Association Pro ISSI  
twice a year



Association Pro ISSI  
Hallerstrasse 6, CH-3012 Bern  
Phone ++41 31 631 48 96  
Fax ++41 31 631 48 97

### **President**

Prof. Hermann Debrunner,  
University of Bern

### **Publisher**

Dr. Hansjörg Schlaepfer,  
Contraves Space, Zurich

### **Layout**

Marcel Künzi, marketing · kom-  
munikation, CH-8483 Kollbrunn

### **Printing**

Drucklade AG, CH-8008 Zurich

Frontcover

Mars: South of Candor Chasma  
(NASA/JPL)

# Earth, Moon and Mars <sup>\*)</sup>

Johannes Geiss, International Space Science Institute, Bern

## Introduction

The ultimate goal of planetary research is to find answers to the big questions: What happened when 4'600 million years ago the Sun and the planets formed out of an interstellar cloud? What were the external circumstances and specific processes that governed the origin of the Earth and determined its evolution to the present state? Is there – or was there – life in the past on another planet or on one of the moons in the solar system? From the presence or absence of signs of life outside the Earth, can we draw conclusions about the origin of life on our own planet?

To an interplanetary traveller, Earth, Moon and Mars would present themselves as entirely different worlds (**Figure 1**). For earth and planetary scientists, however, these three members of the solar system have important similarities. Their sizes, their chemical compositions and their distances to the Sun are relatively similar, so that comparative studies yield results on their origin and their evolution. Moreover, Earth, Moon and Mars are the only objects in the universe where we have detailed geological observations and at the same time possess rock samples for laboratory analysis.

Nineteenth century scientists realised that evolution is central to biology and geology. On the basis of characteristic fossils, the sequence

of geologic epochs from the Cambrian to the Quarternary was identified. Then, at the turn to the 20<sup>th</sup> century, radioactivity was discovered, opening up a new era for many branches of science, including the earth sciences. The decay of uranium, thorium and potassium isotopes was found to be the main source of energy in the interior of the Earth, maintaining there a high temperature and driving geological processes. The application of radioactive decay for measuring ages of rocks was an equally important breakthrough. By using various “radioactive clocks”, the age of the Earth was derived and an absolute time scale was established for the larger part of its history (**Figure 2**). Thus, it became possible to gain a quantitative understanding of the causes of geological evolution and identify the underlying physical processes.

In the second half of the 20<sup>th</sup> century, Apollo and other programmes enabled scientists to use the experience gained from the earth sciences and apply their concepts and methods to the investigation of the Moon. By combining observations at the lunar surface and from orbit with the chemical data obtained from the analyses of lunar rocks brought back to Earth, scientists reconstructed a large part of lunar history.

Thirty years after astronauts set foot on the Moon and explored its geology, scientists and space agencies are turning their attention increasingly to Mars, the Red Planet (**Figure 1**). Let me emphasise that the exploration of Mars for quite a while will be by robots. Human exploration will be a great challenge, because Mars is at least 200 times more distant than the Moon.

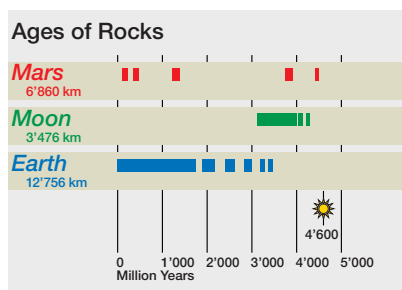


**Figure 1**

**Earth, Moon and Mars.** The “Blue Planet” Earth, the “Red Planet” Mars and the grey Moon. The relative sizes are to scale. We have evidence that on Mars there were large quantities of water at some time in the past. Today we see only small ice caps of CO<sub>2</sub> and H<sub>2</sub>O, which are seasonally distilled from pole to pole, giving rise to strong winds.

<sup>\*)</sup> Keynote address at the Fourth Anniversary of the International Space Science Institute, 21<sup>th</sup> October 1999

We have on Earth a dozen Martian meteorites. There is little doubt that their origin is the Red Planet, but we do not know the exact location they came from. The Mars meteorites were expelled from the planet by a large impact, as a result of which they were badly shocked. This makes radioactive dating difficult. Still, ages of Mars meteorites have given us a general idea of the times of formation of geological features on Mars. However, samples returned by spacecraft from a few well-defined geological units will probably be needed to obtain a definite time scale for Martian geology.



**Figure 2**  
**The ages of Earth, Moon and Mars.**

This diagram shows the distribution of ages of rocks from Earth, Moon and Mars. Earth has been geologically very active throughout history. As a result, the geological record of the early times has largely been overwritten. The Moon is much smaller than the Earth, and consequently, the geological activity of the Moon ended about 3,000 million years ago. We have, however, a good geological record with absolute times by radioactive dating for the epoch 4,100–3,200 million years ago for our companion. For 3,000 million years, the Moon has been geologically dead. For Mars, we have only a rudimentary time scale of geological events, since we only have 13 Mars meteorites for radioactive dating.

## The Early Days of the Solar System

### Sun and planets

Stars are created when an interstellar molecular cloud collapses. We can observe this process in the Orion Nebula, where star formation is presently going on. The Sun was born 4,600 million years ago in a collapsing interstellar cloud that was dispersed long ago. Once initiated, it took only a few million years to form the Sun and to allow the nuclear fusion process in its interior to start working and hence for the Sun to shine.

As predicted by Pierre Laplace early in the 19<sup>th</sup> century, a portion of the gas and dust of the protosolar cloud remained in a rotating disc from which the planets were formed by accretion (Figure 3). This process followed the principle of “big fish eats small fish”, well known in the behavioural and social sciences. It began with dust particles attaching to each other. After they reached a certain size, gravitation took over, and larger bodies attracted and swallowed smaller ones. In the end, a number of planets were left, most of them well separated from each other, so that they could safely orbit the Sun for more than four billion years.



### The Earth

In the case of the Earth, the accretion process did not go so smoothly. A second object, about the size of Mars, formed on a nearby orbit, so that the two were bound to collide. All the evidence indicates that this collision did occur, and it created the pair of Earth and Moon as we know it, circling around the common center of mass, thus avoiding any further collision.



**Figure 3**  
**Our Sun is born.** The Sun was born by a collapse of an interstellar cloud 4'600 million years ago. Some of the material could not be collected into the central star, the Sun, due to the law of physics, which requires conservation of angular momentum. This material eventually accreted into planets (painting by William K. Hartmann).

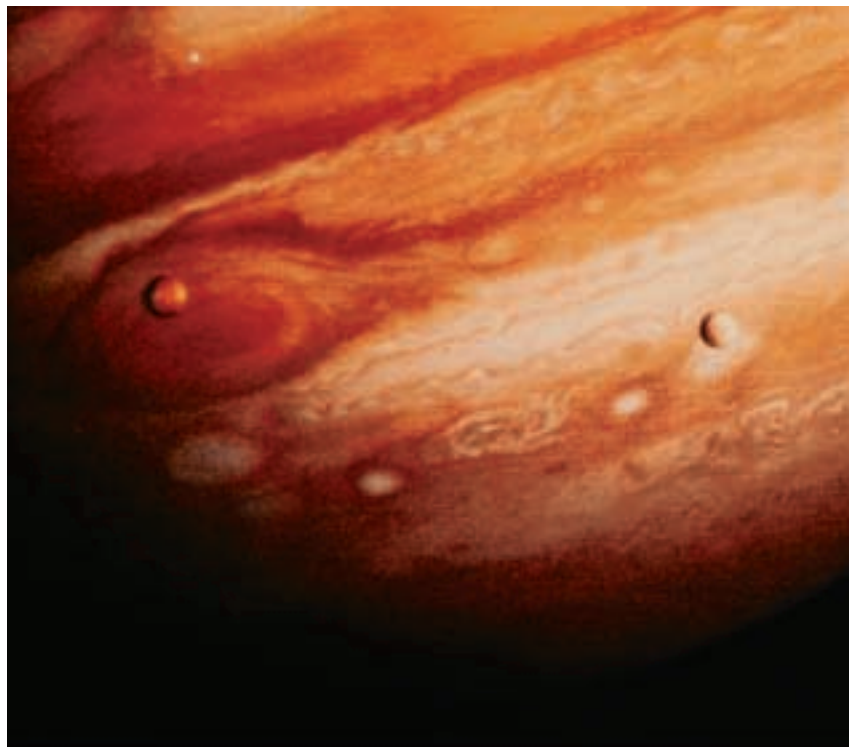
## The Origin of the Earth–Moon System

For centuries, scientists have wondered about the large size of the Moon. Many planets in the solar system are circled by moons, but, with the exception of the satellites of Earth and Pluto, all these moons are tiny in comparison to the planet they accompany (**Figure 4**). The giant planets, Jupiter and Saturn, have satellite systems consisting of more than ten moons each. They were probably formed from protoplanetary discs that surrounded Jupiter and Saturn at

the time of their formation. The exceptional size of our Moon, however, calls for an entirely different origin.

### The Giant Collision

Among the various hypotheses about the origin of our Moon, there is only one, the “Giant Collision Theory” that explains all relevant observations. This theory was originally proposed by William K. Hartmann and colleagues in the United States. The sequence (**Figures 5 to 7**) depicting three stages of the creation of the Earth–Moon system were painted by him. They are based on quantitative modeling by A. G. W. Cameron, W. Benz and others.



**Figure 4**  
**Jupiter with its moons Io and Europa.** The giant planet Jupiter with two of its moons, Io (reddish) and Europa (white). While Io and Europa are nearly the same size as our Moon, they are tiny in comparison to the planet they orbit.



**Figure 5**  
**A Giant Collision created the Moon: half an hour after impact.** All evidence indicates that our Moon was created by a collision between Earth and another large object, ten percent of the Earth's mass, formed in a nearby orbit (painting by William K. Hartmann).



**Figure 6**  
**Five hours after the Giant Collision:** Because of the enormous heat created by the impact, all volatiles escaped, so that only non-volatile material remained in Earth orbit (painting by William K. Hartmann).



**Figure 7**  
**1'000 Years after the Collision:** The formation of the Moon is essentially complete. In its early history, the Moon was molten ("Magma Ocean"). The "tidal forces" at that time were more than a thousand times stronger than they are today and contributed to heating the Moon. Data from the Apollo missions showed us that the Moon is covered by a crust of light material. Thus, the Moon is chemically highly differentiated, and this could only have happened if the Moon was molten early on (painting by William K. Hartmann).

The Giant Collision Theory is consistent with all the relevant pieces of evidence we have. In particular, it explains in a natural way some unexpected results of the analyses of lunar rocks and some observations made by the Apollo astronauts and by photogeologists. These are:

- The lunar rocks are completely free of crystalline water and hydrogen-containing minerals, such as mica or clay minerals (**Figure 8**). Not only hydrogen, but also the other volatile elements such as carbon and nitrogen are virtually absent. Astronaut observations and all the

pictures taken from orbit and on the lunar surface did not reveal any traces of past water flows or products of sedimentation. The complete lack of volatile material and the relatively low abundances of sodium, potassium and other alkalis are readily explained by the extremely high temperatures of the material ejected by the giant collision.

- Relative to the Earth and meteorites, the Moon has much less iron. This would be expected, if the giant impact occurred after the Earth had formed its iron core and if the impact ejected only material from the Earth's crust and mantle.

- The relative abundances of the three isotopes of oxygen show small characteristic differences in the material of different objects in the solar system. Thus meteorites coming from different asteroids, meteorites coming from Mars and rocks on Earth all have their characteristic, but different isotopic signature. The exception is that oxygen in terrestrial and in lunar rocks has exactly the same isotopic composition. The Giant Collision Theory explains this finding, because most of the lunar material was originally part of the Earth. Moreover, the two collision partners accreted from the same region in the protosolar disc.



**Figure 8**

**Landscape on the Moon:** This beautiful landscape in Mare Imbrium was visited by the Apollo 15 crew. Like everywhere else on the Moon, the rocks in this mare plain and in the distant highlands are extremely dry. There is no trace of past water flows nor have we found crystalline water in rocks. The rocks and the soil are also devoid of carbon and nitrogen. Thus, there was never any chance for life on the Moon. Small amounts of water ice or other condensates exist in polar areas. They are probably mostly secondary, stemming perhaps from impacting comets (NASA Photo AS-15 9212430).

The accretion process likely left behind some sizeable objects that were bound to collide at the end of the epoch of planet formation. There are indeed indications that large collisions happened elsewhere in the solar system, though the collision producing our Moon may have been the most violent. It has been postulated that the high density of Mercury and the high inclination of the rotation axis of Uranus were caused by large collisions at the end of the accretion process.

According to the Austrian-British philosopher Karl Popper science progresses by *falsification* of theories. The story of the origin of the Moon is a good example of this postulate. As data, observations and theory increased in quality and quantity, one hypothesis after the other about the Moon's origin encountered severe difficulties, the giant collision theory being the only one that remained consistent with observation. Of course, we do not know what kind of new evidence may turn up, but most of us think that with the giant collision theory we have the right scenario for the origin of the Moon.

## Evolution of the Moon

The time scale of evolution of the Moon was reconstructed from the radioactive ages of lunar rocks determined by several laboratories in the United States and in Europe.

Accretion of the Moon from the material circling the Earth probably took only a few years. The original heat content, the gravitational energy liberated in the accretion process and heating from the extremely strong tidal forces caused by the proximity of the Earth combined to melt the Moon in its early history. Chemical differentiation set in and produced a crust of light material that has been preserved up to today, especially in the oldest region on the Moon, the highlands on its backside.

### The early Moon

Initially, the tidal forces between Earth and Moon were more than a thousand times stronger than they are today, causing significant heating of the Moon and enormous tides on Earth. These tidal forces led to a transfer of angular momentum from the rotation of Earth and Moon to the orbital motion of the Moon. When Moon and Earth were close, the transfer was fast; the Moon receded quickly from Earth, the days lengthened, and soon the Moon's rotation slowed down, so that

we always see the same side of it. With the receding of the Moon to its present distance, the tidal forces lost most of their strength. Dangerous tides occur only in a few coastal regions, but there may be another important effect: it has been calculated that the orbiting Moon has stabilized the rotation axis of the Earth, and this in turn has a stabilising effect on the Earth's climate.

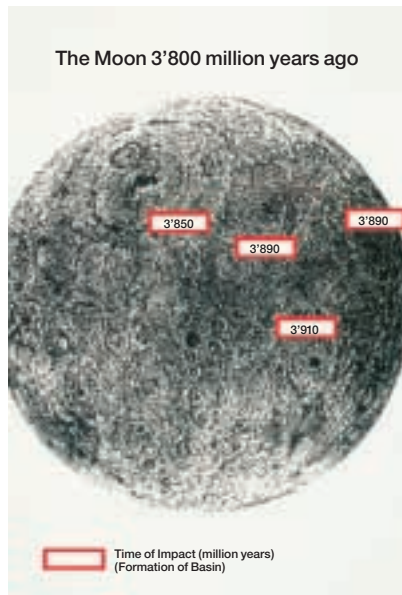
Using various 'radioactive clocks', laboratories in the United States and Europe measured the absolute ages of numerous lunar rocks brought back by the Apollo astronauts and reconstructed the time scale of lunar evolution. The **figures 9, 10 and 11** show the Moon at the end of important epochs in its evolution.

The accretion process in the solar system did not end abruptly: large chunks of material were still roaming around in the spaces between the planets, even several hundred million years after the Sun was born. On the Moon, the last major impacts occurred in the time-span 4'050–3'850 million years ago (**Figure 9**). These late impacts excavated the large mare basins that were later filled with basaltic lava rising up from below. More than ten impacts, forming craters with diameters of more than 500 km, occurred during this time-span. On Earth, we have no record of this catastrophic epoch. However, taking into account the larger size and gravity field of the Earth, we estimate that more than a hundred craters of these dimensions were excavated on our plan-



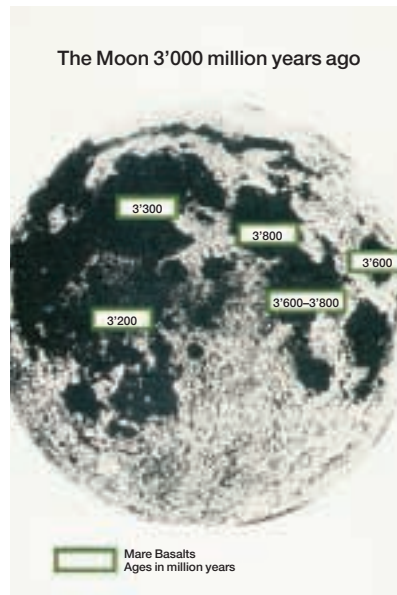
**Figure 9**  
**The Moon 3'800 million years ago.**

500 to 700 million years after its formation, the Moon was still bombarded by large chunks of material, forming the huge basins that are still distinguishable. Within about 200 million years, more than ten craters with diameters of more than 500 km were formed. On Earth the record of this bombardment has been lost, but we can estimate that more than 100 such craters were formed on Earth during the same epoch. This must have been a fantastically catastrophic period in the Earth's history, at a time when oceans and atmosphere were in an early stage. We would not know about this catastrophe if we had not investigated lunar rocks in Earth-bound laboratories.



**Figure 10**  
**The Moon 3'000 million years ago.**

At about 3'800 million years ago, the basins began to fill with lava. Shown are the ages of the local mare basalts in million years, determined by radioactive clocks. From West to East: Oceanus Procellarum (3'200 million years), Mare Imbrium (3'300), Mare Serenitatis (3'800), Mare Tranquillitatis (3'600–3'800), Mare Crisium (3'600). These ages show that this process was largely completed 3'000 million years ago. The large plains, which Galileo called Maria, have existed on the Moon since that time. We know now that their dark colour is due to a titanium-iron mineral that is relatively abundant in the mare basalts.



**Figure 11**  
**The Moon today.** About 3'000 million years ago, the Moon cooled down sufficiently, so that geological activity afterwards did not change the face of the Moon very much. The main changes are from occasional impacts. On the front side of the Moon, the largest 'fresh' crater is Copernicus, which was created by an impact about 900 million years ago.



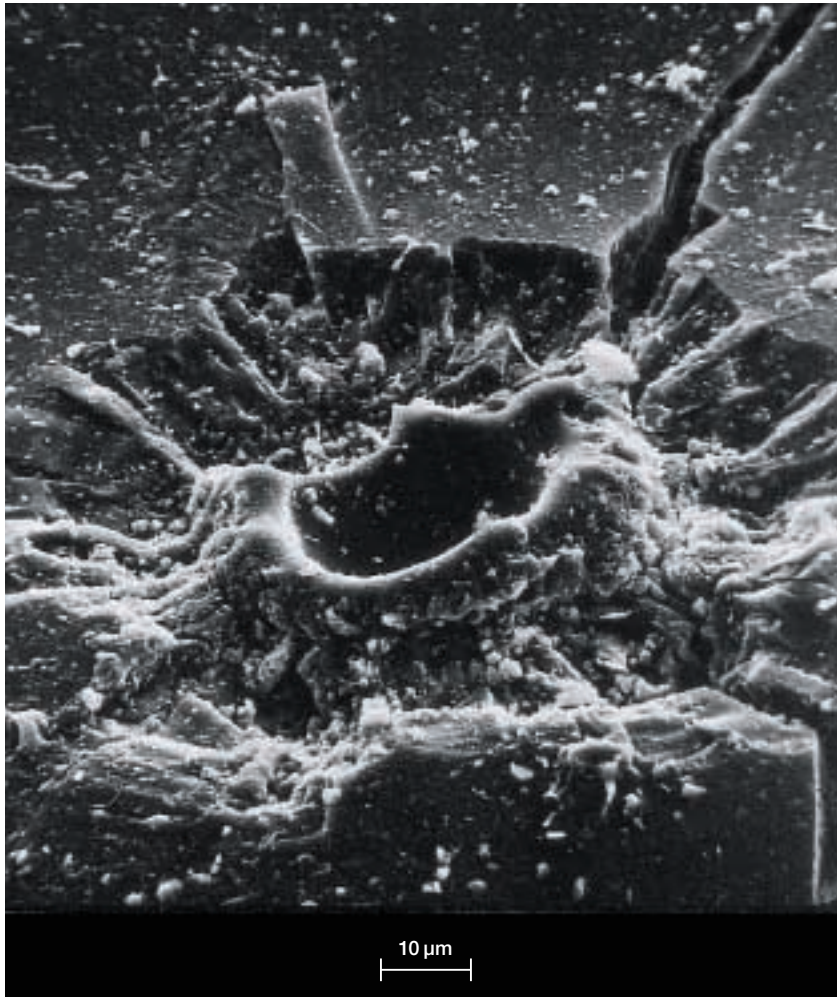
et during that period. For the emerging atmosphere and oceans, this must have been a catastrophic epoch.

Even before the last mare basins were excavated on the Moon, lava had begun to rise and fill these basins. These were basaltic lavas, richer than the crust in iron, magnesium and titanium. The dark colour of the Maria on the Moon

is due to minerals containing these elements, in particular the titanium-iron oxide called ilmenite.

The ages of the mare basalts brought back by the Apollo astronauts and Russian Lunar missions were found to range from 3'800 to 3'200 million years (Figure 10). A few small rock pieces in the Oceanus Procellarum were as young as 3'000 million years. Fur-

ther east there may be some areas covered with even younger basalts, but there are no samples and no absolute ages from this region. In any case, the formation of mare basalts that marks the last major geologic epoch on the Moon ended not much later than 3'000 million years ago. Since then, the Moon has been geologically inactive, its energy reserves exhausted.



**Figure 12**

A microcrater in a piece of lunar glass. In the present epoch, small impacts are the main cause of erosion, “gardening” and lateral transport (photo by Norbert Grögler, University of Bern).

### **The serene Moon**

In the absence of geological processes and without water or winds, the face of the Moon has not changed very much during the last 3'000 million years, as a comparison of figure 11 with figure 10 shows. Erosion at the lunar surface is now mainly caused by small impacts (Figure 12). This pro-

cess is extremely slow, so that even small surface features last for a long time (Figure 13). Major impacts were very rare during the last billion years. On the frontside of the Moon, the impact creating the Copernicus crater is the most prominent among them. It occurred about 900 million years ago (Figure 11). Sometimes Copernicus is called a young crater. This expression illustrates the funda-



**Figure 13**

**The footprint of Neil Armstrong.** There are neither winds nor rain on the Moon and erosion is very slow. Thus, the chances are good that this footprint of Neil Armstrong, the first man on the Moon, will still be visible a million years from now. There is, of course, a minute statistical chance that this footprint will be impacted by a larger object, but then other footprints of the Apollo crews would survive (NASA photo).

mental difference in the evolution of Earth and Moon. Copernicus was formed before the Cambrian, the earliest of the classical geologic epochs. Since on Earth plate tectonics and volcanism continue to the present time, the effect of impacts on the geologic evolution is minor. However, the catastrophes caused by large impacts have had a major influence on biological evolution (Figure 14).



**Figure 14**  
**The Cretaceous/Tertiary boundary.**

On Earth, impacts did not have a large effect on the geological or geographical evolution of the surface, because volcanism and plate tectonics were dominant. Impacts of meteorites, however, had a major effect on the biological evolution. The best-documented case is the event that occurred 65 million years ago, marking the boundary between the Cretaceous and the Tertiary age. At that time, a large impact – probably located at the edge of the Gulf of Mexico – caused the extinction of many species, giving way to the evolution of new species. Thus, in sedimentary deposits, the CT boundary is marked not only by impact-specific materials (iridium, soot), but also by an abruptly changing micro-fauna over a very short interval (Figure by O.Eugster).

## Mars

Mars is intermediate in size between Earth and Moon, and it seems to be intermediate as well in the degree of geological evolution (Figure 2). This is to be expected: Small bodies cool faster than large bodies, since energy production and energy content are basically proportional to the volume, whereas energy losses are proportional to the surface. It is for the same reason that warm-blooded animals need a minimum size to be able to maintain a body temperature that is above the ambient temperature.

Asteroids have diameters below 1'000 km. Thus, they cooled down and became geologically inactive only one or two hundred million years after they were formed. This has been confirmed by radioactive dating of meteorites that are rock pieces from asteroids. The Moon, with a diameter of 3'476 km, became geologically inactive about 3'000 million years ago. Because of its size, the Earth has remained geologically active throughout its history. As a consequence, the geological record of the first 1'000 million years of its lifetime is essentially lost.

The ages of the few Mars meteorites range from 4'500 to 150 million years. Apparently, some rock-forming processes have been going on quite recently. On the other hand, the old ages indicate that the record of the early Martian history was not overwrit-

ten as much as on Earth. This is in line with the size of Mars, which is in between the sizes of Earth and Moon (Figure 1).

### The Exploration of Mars

The radioactive dating of Martian meteorites gives a general idea of the absolute ages of geologic features on the Red Planet. A relative time scale of the sequence of geologic epochs identifiable on Mars is being set up by scientific groups at the Deutsches Zentrum für Luft- und Raumfahrt, Berlin, and the Planetary Science Institute in Tucson, Arizona. The method is by counting craters, which has been successfully applied on the Moon.

Presently, earth and planetary scientists are engaged in reconstructing the geological evolution of Mars and in estimating absolute time scales for the most prominent events in the Martian history. These issues were discussed in a recent workshop on “the Evolution of Mars” at the International Space Science Institute. The results from Martian meteorites were compared with photogeological evidence obtained from orbit and with the data obtained by the Sojourner, the vehicle landed by NASA on the Martian surface on July 4, 1997. The whole world watched as the Jet Propulsion Laboratory in Pasadena steered the Sojourner to some nearby rocks, so that the chemical sensor of the Max-Planck-Institut für Chemie, Mainz could analyse

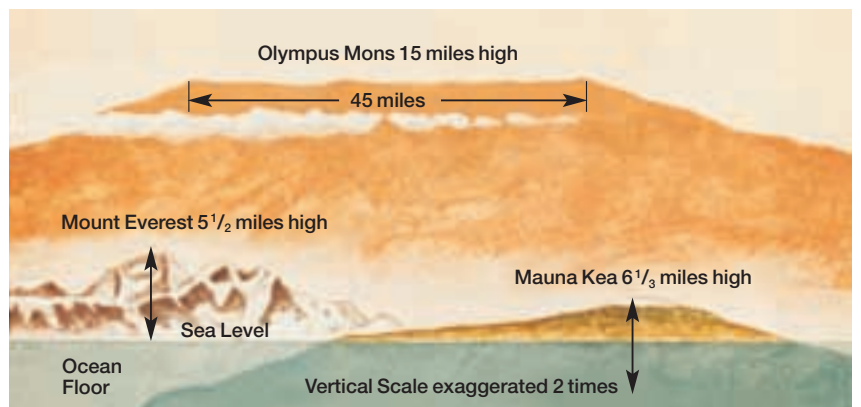


**Figure 15**  
**The Olympus Mons.** The most outstanding geographical feature on Mars is the large volcanoes (photo by Viking Orbiter, NASA).

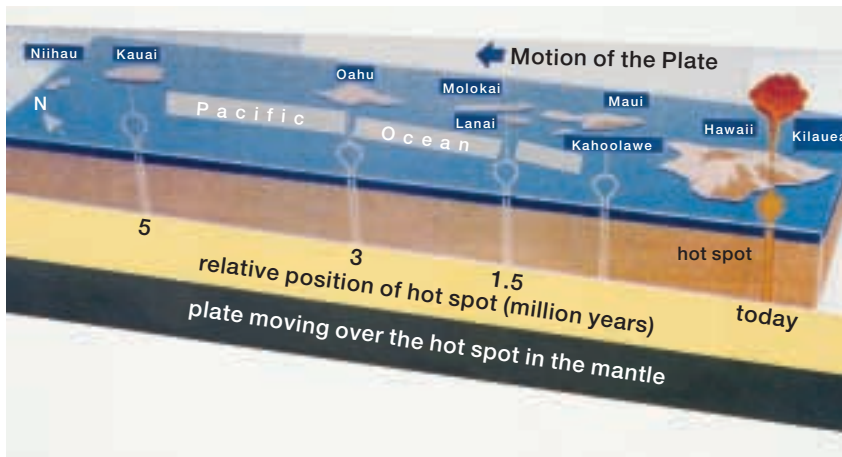
## The evolution of Mars

The two most outstanding geological features on the Martian surface are the huge volcanoes and the evidence of the existence of liquid water in a past epoch. The largest of the Martian volcanoes, Olympus Mons, is shown in **Figure 15**. It came as a great surprise that the volcanoes on Mars are higher and more massive than the highest mountains on Earth (**Figure 16**). The principal reason is depicted in **Figure 17**. On Earth, plate tectonics causes continental drifts as predicted by Alfred Wegener early in the 20<sup>th</sup> century. Thus, plate tectonics determines the global geography on Earth, and it produces the high continental mountain ranges. On Mars, the internal energy is not sufficient to drive plate tectonics. Thus, volcanoes are the dominant mountains, and they can grow without being cut off from their hot spots below.

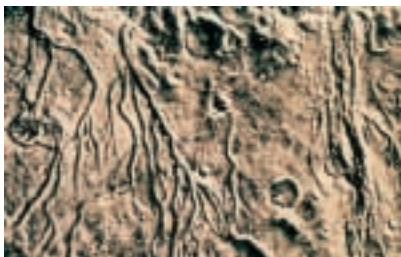
them. At first, the outcome seemed surprising: the chemical abundances were completely different from the abundances in the Martian meteorites. However, the Sojourner investigated rocks in one of the dry riverbeds, the Ares Valley, whereas most of the Martian meteorites probably come from volcanic highlands. Thanks to the Sojourner we now know of the very large variety in the composition of Martian rocks. This indicates that chemical differentiation was much more intense on Mars than on the Moon.



**Figure 16**  
**Olympus Mons versus Mauna Kea:** Olympus Mons and other volcanoes on Mars are much higher than the largest volcanoes on Earth, even if we measure these from the bottom of the ocean. This may seem surprising, since one might expect less intense volcanic activity on Mars than on Earth, because of the difference in size.



**Figure 17**  
**Origin of the Hawaiian volcanic islands:** Plate tectonics (“continental drift”) on Earth is the answer to the apparent contradiction shown in Figure 16. The oceanic plate moves with a speed of a few centimetres per year over a hot spot in the mantle, creating a chain of volcanic islands. On Mars such plate motions are absent and, therefore, the lava coming from a hot region in the mantle is piled up in one place over a long period of time.



**Figure 18**  
**River system on Mars:** Sometime in the history of Mars there was a fluvial period. The extensive river systems are evidence of this.

Contrary to the Moon, where there are no traces of past water flows, we see large dry riverbeds on Mars. The difference between the lunar rills and the Martian riverbeds is demonstrated in pictures taken from orbit: Martian riverbeds have extensive tributary systems (**Figure 18**). The long lunar rills on the Moon have no tributaries, the rills are thought to stem from lava flows (**Figure 19**).



**Figure 19**  
**The Hadley Rille:** On the Moon there is no indication of liquid water, present or past. But how do we know this? Hadley Rille and the other lunar rills have no tributaries: they were probably made by lava flows. On Mars, the tributary systems of valleys are the most obvious proof that they are dry riverbeds.

The larger riverbeds on Mars compare with the Nile valley. At some – as yet – unknown time in the past, large amounts of water were transported, and they must have filled significant portions of the low lands. **Figure 20** is a topographic map, with the area that might have been temporarily filled by

the rivers shown in blue. The exact extension of this temporary ocean is still debated, but all indications are that it covered a significant portion of the Martian surface. Jim Head of Brown University, Phillip Masson of the Université de Paris and other photogeologists are working to identify the ancient shorelines. If successful, we can quantitatively determine the amount of water that was present.

Where did these water masses go? A considerable fraction has probably been lost, but some must have leaked through the ocean bottom and is preserved as a permafrost layer.

## Life on Mars?

Liquid water is a prerequisite for the emergence of life, at least of the form of life we know. Since water is liquid only in the temperature range of about 0 °C to 100 °C, we could expect life on a planet only in a narrow range of distances from the central star. Thus in the solar system, we have presently only one body, the Earth, with liquid water on its surface. Because of radioactive heating, planetary temperatures increase with depth, and therefore it is believed that water could be liquid at certain layers below the surfaces of Mars and some moons of distant planets with icy surfaces, such as Europa.

We have strong evidence that during an earlier epoch there were large volumes of liquid water on the surface of Mars. It is not yet known during which epoch in Martian history the rivers and the ocean existed (**Figures 18 and 20**), nor do we know whether there were several fluvial periods or only one. In any case, since Mars is relatively close, the Red Planet offers the best chance for discovering extraterrestrial life or for identifying relics of extinct life.

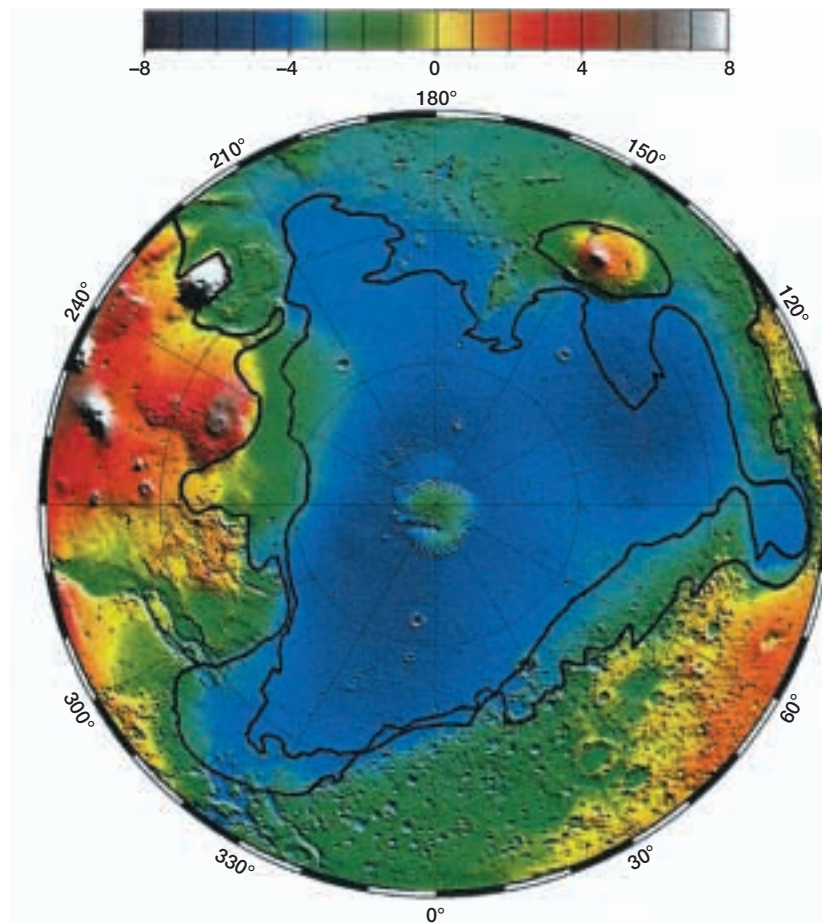
### **Traces of life in Martian meteorites?**

Reports on the observation of long straight “channels” on Mars were not confirmed by orbital photography. The Viking spacecraft, landed by NASA in the 1970s, did not turn up any evidence of life, although they were equipped with some suitable instruments. Then, a few years ago, a group of scientists in the United States found spherules in the oldest Martian



**Figure 21**  
**Buhwa iron ore deposit.**

This sedimentary iron ore deposit in Zimbabwe is about three billion years old. The iron in this ore is highly oxidised. It is thought, that these ores are the oldest indication for the presence of oxygen produced by photosynthesis of algae (photo by Jan D. Kramers, University of Bern).



**Figure 20**  
**Ancient ocean on Mars.** The dry riverbeds on Mars with their tributaries go towards the large low-altitude plains in the north. Considering the amounts of water that have cut the large valleys, the water masses must have fed large oceans. The estimated extent of the ocean is shown here in blue. Elevation is given in kilometers (from J.W. Head, *Science*, 286, pp. 2134–2137, 1999).

meteorite, and after elaborate microscopic investigations and chemical analyses, they concluded that these spherules could very well be relics of life. The evidence is intriguing, but the discussion of its significance is continuing. Indeed, we cannot expect to have a consensus concerning the biological nature of these spherules unless corroborative evidence is found on Mars.

If life on a planet were confined to a limited area, a puddle of water or a cave, it would be extremely difficult to discover. After all, the surface of Mars is nearly as large as all continents on Earth taken together. Fortunately, however, once created or imported, life seems to be extremely adaptable and prolific. This opens up another method of searching for life, which we may call the geochemical approach. On Earth, this approach has proven to be valuable for searching for early traces of life. Large ferric iron deposits that

formed only in the early Precambrium (**Figure 21**) are thought to be the oldest evidence of life. Most limestone deposits, such as those lifted to the top of Mount Everest or the Bernese Alps, are produced by life. If life existed on Mars during a fluvial epoch, it would have spread over a large area. Thus, searching for geochemical traces of life on Mars should be considered. G. Turner and J.D. Gilmour of the University of Manchester proposed to look for a life-specific iodine distribution on Mars.

### **Life on Earth!**

Let me finish this evening's lecture with a tale that may illuminate the geochemical search for life. The society on a planet orbiting a nearby star decided to explore their stellar neighbourhood. In a planet-wide effort, they built a fleet of extraordinary spaceships that would enable them to reach a dozen or so stars in their neighbourhood during a crew's lifetime. However, by giving so much priority to rocketry, they neglect-

**Figure 22**  
**The Bernese Alps shown above the clouds** From right to left: Jungfrau, Mönch and Eiger.

ed to develop other equipment, such as high-performance telescopes and sensitive detectors. Ulysses, when cruising in the Mediterranean, found himself in a comparable situation. He had a marvellous ship, but no telescope, poor maps, and no idea of the dangers awaiting him. The spaceship with the extraterrestrials on board going towards the solar system was successful. After short, unrewarding visits to the Jovian moons and to Mars, they turned towards the Earth. In a direct approach and without much "reconnaissance", they chose to land on the western flank of the Jungfrau, because the Bernese Alps were among the few places that protruded through the cloud layer covering all Europe at the time of their landing. All they could see was snow and rocks (**Figure 22**). One of them tested the rock with a knife: "It's limestone, there is life on this planet or at least there was in the past!" Cautiously, he opened his suit and found he could breathe. So there was oxygen. On their homeplanet the oxygen was produced and continuously replenished by plants. This convinced them that there was a rich flora below the clouds. Slowly, they climbed down. Suddenly, the cloud cover broke up, and there it was: grass, cows

and even some people at a distance. When the visitors cautiously approached, one of the earthlings began to talk, and it sounded strange, but friendly. "So that is the language of the people on this planet, for us impossible to understand", they concluded. It was only much later that they found out that almost nobody else on Earth understands these nice people living in the foothills of the Bernese Alps either.

### **Acknowledgements**

I am indebted to Hansjorg Schlaepfer, the editor of *Spatium*, for his help with the manuscript and his perseverance in getting this issue published. I thank Silvia Wenger, Ursula Pfander and Gabriela Indermuhle for their help with the manuscript and the figures, and Diane Taylor for critically reading the manuscript. With this issue of *Spatium* I would like to remember two distinguished colleagues and friends, Paul Gast of Columbia University and NASA Johnson Space Center and Norbert Grogler of the University of Bern, with whom I had close cooperation during the Apollo period.



# SPATIUM

## The author



Prof. Johannes Geiss received his doctorate in 1953 from the University of Göttingen and, after several research positions in the USA, became a lecturer (“Habilitation”) at the University of Bern in 1957. After a professorship in oceanic science at the University of Miami, he returned to the University of Bern as a professor in 1960, where he was named director of the Physikalisches Institut in 1966. In 1982/83 he was rector of the University of Bern, as well.

During his tenure at the University of Bern, he had extended stays as a visiting scientist in France and the USA. The public connects the name of Professor Geiss with the solar wind experiment, the first experiment the American astronauts set up on the Moon in 1969.

Since then, Professor Geiss has been heavily involved in scientific projects of NASA and the European Space Agency, ESA.

Johannes Geiss is co-founder of the Association Pro ISSI and presently the Executive Director of the International Space Science Institute, ISSI, in Bern. ISSI is supported by a foundation of the same name, endowed initially by Contraves Space in Zurich. The Institute is primarily funded by ESA, the Swiss Confederation, the Canton of Bern and the Swiss National Science Foundation. ISSI is dedicated to interdisciplinary research of the solar system and the universe, inviting scientists from around the world to working group meetings and workshops and offering them the opportunity to exchange ideas and evaluate their newest research results. The basis for ISSI’s research activity is the data provided by the scientific missions of the space agencies of Europe, the US, Russia and Japan as well as laboratory experiments and computer simulations.