MOON

MARS

EARTH (VREDEFORT CRATER)

CONCISE ATLAS ON THE SOLAR SYSTEM (6):

online edition

ATLAS OF MICROENVIRONMENTS OF PLANETARY SURFACES

Szaniszló Bérczi, Henrik Hargitai, Erzsébet Illés, Ákos Kereszturi, András Sik, Tivadar Földi, Sándor Hegyi, Zsolt Kovács, Mária Mörtl, Tamás Weidinger

Eötvös Loránd University, Cosmic Materials Space Research Group, UNICONSTANT Budapest—Püspökladány, 2004

VENUS

Szaniszló Bérczi, Henrik Hargitai,
Erzsébet Illés, Ákos Kereszturi, András Sik,
Tivadar Földi, Sándor Hegyi, Zsolt Kovács,
Mária Mörtl, Tamás Weidinger

Concise Atlas on the Solar System (6):
ATLAS OF MICRO ENVIRONMENTS OF PLANETARY SURFACES

Eötvös Loránd University, Cosmic Materials Space Research Group; Hungarian Academy of Sciences, Geonomy Committee, Budapest, 2004

Landscapes of the Moon are already well known, and we can also imagine the surfaces of other planets around us. The microenvironment is defined as the landscape around a standing person. The first space probes landing smoothly on the surface of Moon and Mars had sizes comparable to that of a person. The probes operated analogously to a living person; looked around the landscape, with extended arms they shifted through the surface. The idea of producing a Concise Atlas on microenvironments was conceived by this possibility of looking around on the surface of planets.

In addition to the operation just looking around, the various space probes (Surveyor, Luna, Lunakhod, Viking, as well as Pathfinder on the Mars) executed measurements as well. Researchers collected the most important information by means of measurements and analysis. It is possible to enrich and to rediscover this treasury of knowledge by comparing the microenvironments of the surfaces of the four best investigated planets, i.e. those of Earth, Moon, Mars and Venus. The lunar environment has a particular significance, because man actually landed on the Moon following the survey by robots. In this way the microenvironments of Moon and Earth can also be compared in the aspects of personal observations and activities in addition to the results of instrumental measurements. On the basis of such comparison it is also possible to imagine and plan potential tasks of astronauts who are going to land on Mars.

Nevertheless, our main objective by issuing this Concise Atlas was to provide aspect for the observation of the environment as a whole. Various processes take place in the environment, and such observations give us the opportunity to test how we can utilise our knowledge in a new environment. The various processes can be observed also separately, but groups may also be established from associated processes. For example the phenomena associated with the atmosphere are closely related (think of a meteorological measuring station). The geological, and morphologic phenomena which can be observed around a spacecraft on the soil and on the rocks are also closely associated. The wind carries dust, the dust hit the rocks and regularly shave the surface of the rock. Then the dust settles, and again becomes airborne as a result of the wind. If precipitation occurs on the planet, then it covers the dust, and gets evaporated later. We can observe many associate phenomena in the deserts of Mars and Earth.

Yet another category of phenomena can be formed according to the effects of radiation. Such associated phenomena include the reflected light from sunshine, thermal emission of rocks and soil, effects of gases getting warmed close to the soil. By cumulating the information obtained from more and more measurements and observations we establish an increasingly deep knowledge on the microenvironment of the planet around a landed spacecraft.

As a next step, it could be a very exciting exercise to study all of those phenomena at a selected microenvironment on Earth. For example we can study the saline soil in Hortobágy, Hungary, including the scarce vegetation, the rain, water courses, or we can observe the sand dunes of the region Kiskunság, Hungary, how the wind established the various shapes, barkans, or the warming of the air close to the surface etc. The partial results are again assembled to form an overall picture, and at the same time, the investigation can be conducted in a way that the various aspects are compared from time to time to the microenvironment of another planet. In the 21st century the comparative planetology will be a science which provides objectives and exciting scenery for reprocessing, reviewing categorising and systematising scientific knowledge. Such rethinking is driven by the objectives and by various projects. Nowadays, one of the most important questions to be answered regarding the teaching of natural sciences is why we have to study the various principles at all.

Now we extend the circle of activities by deploying a home made root in the terrestrial environment. This is the Hunveyor *(Hungarian University Surveyor)* experimental educational space probe model, where measuring instruments and systems are attached to carry out experiments planned for the planetary surfaces. It is well known from the actual space missions, that a small mobile companion is also used in association with the spacecraft landing on the planet. In this case the mobile unit is a rover called Husar *(Hungarian University Surface Analyser Rover)*. This is suitable to get close to the various objects of the microenvironment for performing on site measurements. In order to actually produce the robots it is necessary to utilise technological processes, information technology and engineering knowledge. Certain portions of the microenvironments can be modelled also on the laboratory test-table. In this way the investigation of the microenvironment leads us to the utilisation of the modern technologies also used by various museums. For this purpose a number of simulators can be deployed in a room (ground based control centre), and the visitors can walk into another room where works to be done on the surface of planets (in space suits) are exhibited (space simulators). As a result, the visitor is not just a passive observer, but could become an active participant of the process. The Concise Atlas is also a significant contribution in introducing the results of space research.

The most exciting human activities are characterised by personal initiatives and by a joint effort of several people of various background. The complexity of the activity calls for many of the resources of the participants. A natural coherence is established among the participants all through the experiment. This complexity and the need for many skills of the individual are among the factors which make the space research exciting and attractive. It is fascinating how one can imagine oneself into the real processes by being an active participant of various missions. Such works establish an intimate relationship among the human personality and the knowledge, thinking and the objective of the activities. By releasing this 6th volume of the Concise Atlas (2nd volume in English) we urge the reader to consider these ideas while studying the microenvironments of planets, and to participate in the measurements and activities so that he/she would be able to contribute to the forthcoming volumes of the Concise Atlas series with her/his experimental ideas.

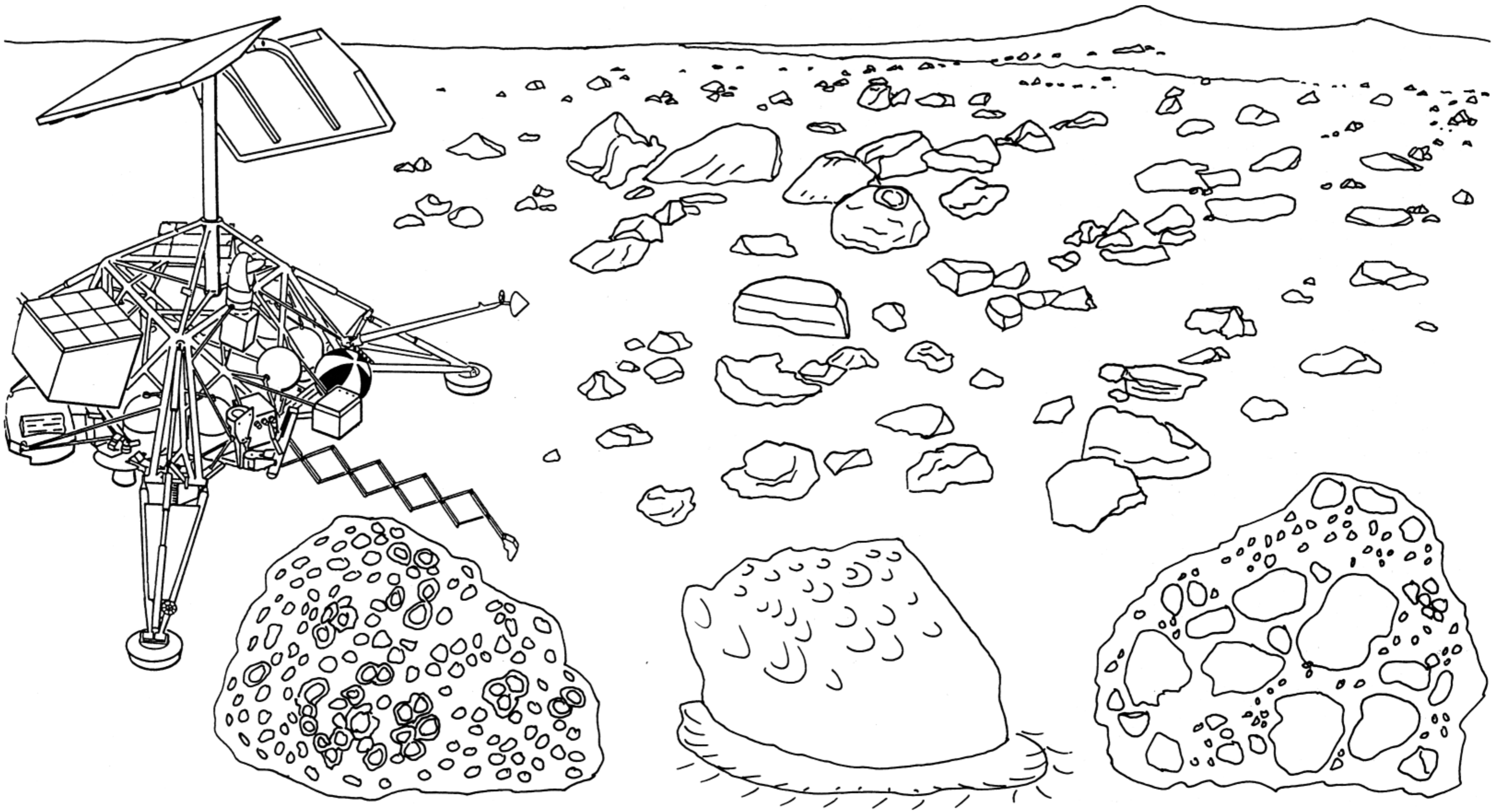
We wish you good work and pleasant time reading through the Atlas.

The Authors

CONTENTS

Published by Eötvös Loránd University Cosmic Materials Space Research Group and UNICONSTANT, Püspökladány, Honvéd u. 3.
Supported by Hungarian Space Office grant No TP-154/2003.
CONCISE ATLAS ON THE SOLAR SYSTEM (6):
ATLAS OF MICROENVIRONMENTS OF PLANETARY SURFACES

ISBN 963 00 6314 XÖ
963 86401 6 2



ATLAS OF MICROENVIRONMENTS OF PLANETARY SURFACES

Szaniszló Bérczi, Henrik Hargitai, Erzsébet Illés, Ákos Kereszturi, András Sik,
Tivadar Földi, Sándor Hegyi, Zsolt Kovács, Mária Mörtl, Tamás Weidinger

Eötvös Loránd University, Cosmic Materials Space Research Group, UNICONSTANT Budapest—Püspökladány, 2004

I. LOOKING AROUND AFTER LANDING: A ROCKY DESERT

1.1 Surveyor-7 on the Moon at Tycho crater

Surveyor-7 was the last of the series of space probes which landed smoothly on the Moon. It touched down on the north-west slope of the Tycho crater on a terrain which had not been encountered by the former probes of the series. Its camera scanned the landscape and photographed desert scenery with many boulders, scattered all over the surface.

The most important instrument of the probe included: TV camera (all Surveyor were equipped with such a camera; there has been 5 successful landings: 1, 3, 5 6, 7), soil investigating arm (only Surveyor-3 worked with such a device formerly), alpha radiation detector soil analyser (such instrument was mounted on Surveyor-5 and -6), magnet for collecting magnetic particles (also Surveyor 5 and 6 included such device). Surveyor-7 carried 7 small mirrors also, attached to various parts of the frame. These small mirrors, having the size of coins, were used to observe the settling dust.

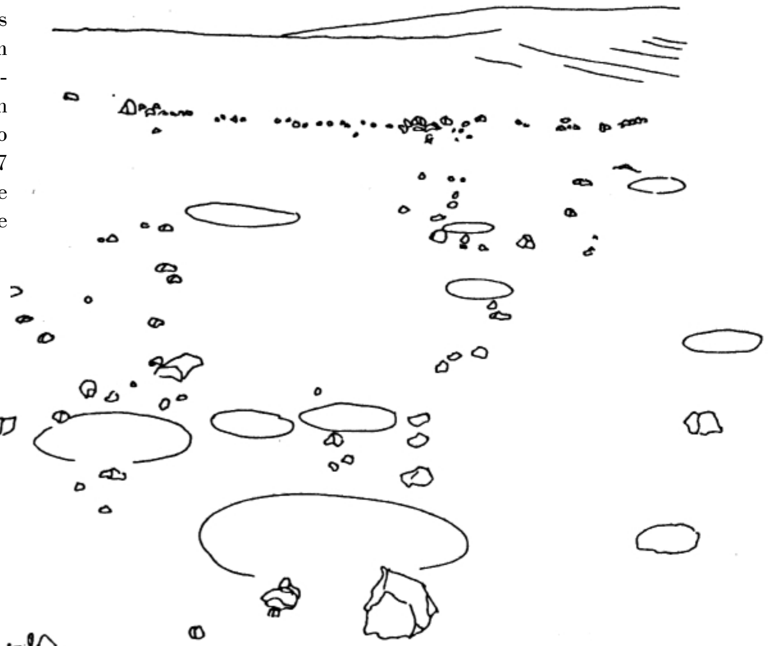
It is worthwhile to interpret the landscape around Surveyor-7 in comparison with the Martian scenery seen by Pathfinder. One can see on the picture shown on the right that the boulders are not as frequent as on the Martian surface. The broken surfaces of the rocks in the Moon are sharp, while they are mostly rounded in Mars. No prolonged transport process took place in the Moon. Pieces of rock were expelled by the impacts, some of which collided during the flights, then rolled to a short distance after falling back to occupy their present locations. As the Moon has no atmosphere, the dust generated by the constant "bombardment" of meteorites and debris of various size settles all over the surface without hindrance. At the Pathfinder landing site on Mars, the boulders were carried to their present locations by surging water. In this process the pieces of rocks became rounded as a result of friction and collision. When the velocity of the water subsides the boulders, they became embedded in the fine silt and then came to the surface only after the water has evaporated.

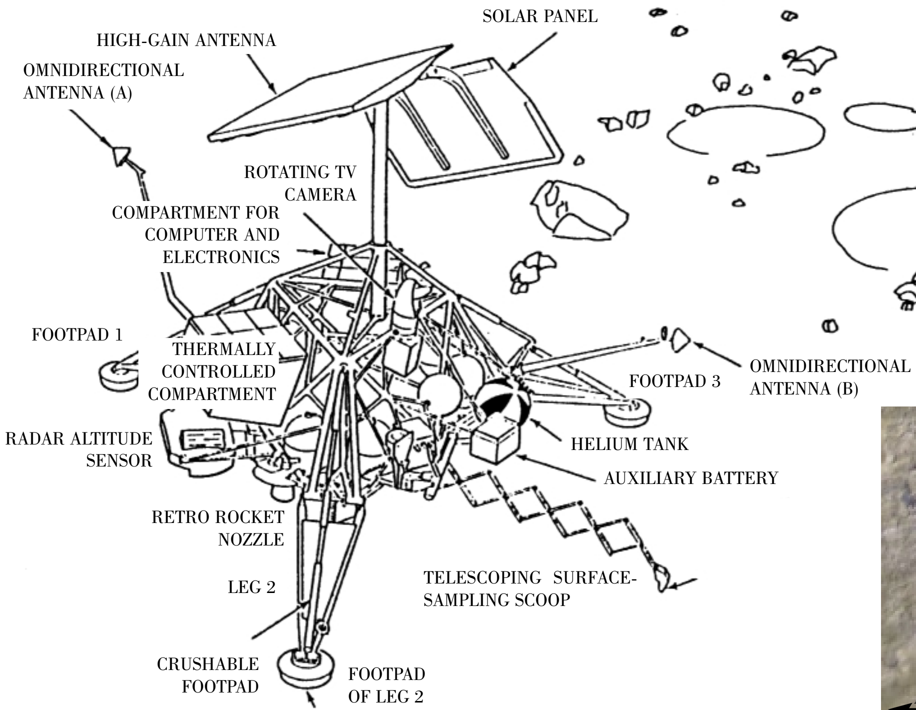
The alpha particle detector of Surveyor-7 could be manipulated into proper position only by the digging arm. This instrument measured the chemical composition of the soil. The results indicated that the quantity of iron and calcium was less than in the mare basalt measured by the former Surveyor probes. This was the first measurement of this kind on the soil of the lunar highland.

Surveyor-7 worked for two lunar days (one day on the Moon corresponds to two weeks). It was found that the albedo (light reflecting ability) of the fine grained dust on the highland around Tycho crater was higher relative to what had been measured by former Surveyors. The thickness of the dust layer (regolith) is less, and the small craters are less numerous then at the mare landing spots.

In this concise atlas Surveyor is regarded as exemplary in terms of the completed measurements, as well as regarding the structural design. The concept, design and construction of the experimental space probe Hunveyor (***H**ungarian **Un**iversity Sur**veyor***) is based on the Surveyor.

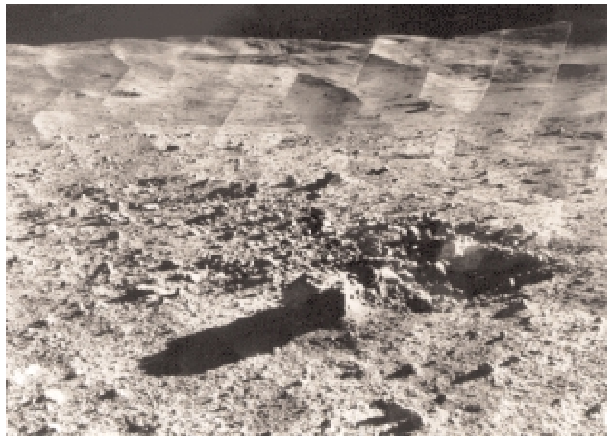
Other solutions used in the subsequent space probes were also considered for utilisation. The example for us was the small robot (rover) of the Martian probe Pathfinder. This was taken as a basis for establishing a much simplified two wheel "rover" to be deployed by the side of Hunveyor, which was finally dubbed Husar (***H**ungarian **U**niversity **S**urface **A**nalyser **R**over*).





Tycho crater from above (1994, Clementine)

Mosaic of images transmitted by Surveyor 7 from Tycho crater (1968)

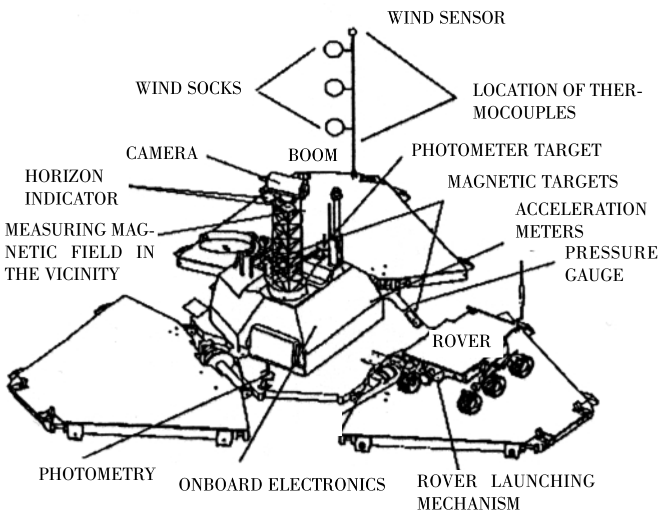


1.2 Martian rocky desert

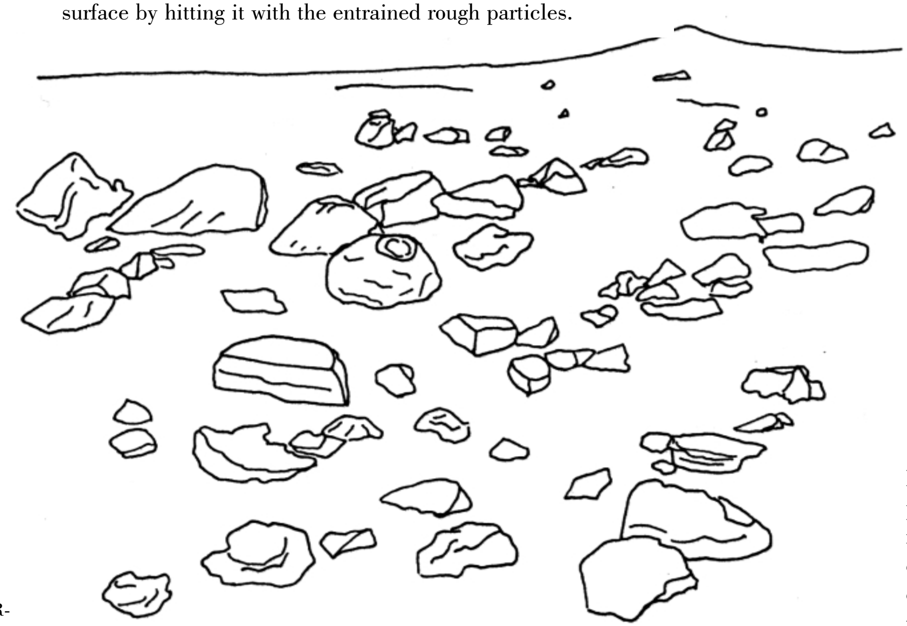
Many different kinds of rocks were found by the two Viking space probes and by Pathfinder after their landing on Mars. At first look the objects within the microenvironment of the space probe can be categorised in two major groups: boulders and moving sediment. The boulders are partly embedded in the desert soil consisting of small particles. The moving sediment is arranged in various shapes, such as dunes, wind streaks and ripples. First let us have a look at the boulders. What textures can be observed on their surfaces? Then we can examine the wind blown dust and sand, and can observe the soil horizon. Using the locations and relative positions of the rocks within the microenvironment it is possible to make conclusions regarding the events leading to the present appearance of the surface.

1.3 Textures of Martian rocks

Many textures can be observed on the surface of the Martian rock, including spongy and/or pitted surfaces, protruding knuckles, or uniform, sometimes quite smooth surfaces. There are some rocks which has a uniform surface and which are covered with grooved and striped patterns. Certain rocks are granular and include many inclusions. The textures of such conglomerates are similar to the breccia rock textures characterising the lunar surface.



Basalt rocks with spongy, vesicular surface texture were found in large quantities at the landing site of Viking-2 (in 1976). Various processes could be the origin of rocks having relatively low quantities of voids and pits (up to 10 % of the surface area). Such processes include the breakdown by ice, which has already started at several points of the surface. Such pit could also be caused by the selective dissolution of minerals having dissimilar stability. The wind can also cause such surface pits, when it bombards the surface with the carried debris. Among terrestrial conditions, e.g. in the Arizona desert, wind can cause voided rock surface by hitting it with the entrained rough particles.



The opposite phenomenon of the pitting includes a stable inclusion protruding from the surface. A number of such rocks could be observed around Pathfinder. One of them was the so called Squash, which exhibited sharp protrusion at one of its sides. Such protruding parts of Squash were darker than the rest of the rock. This texture can be interpreted as breccia, as well as a conglomerate. The same interpretation can be used when investigating the differently coloured surface of macroscopic rock samples.

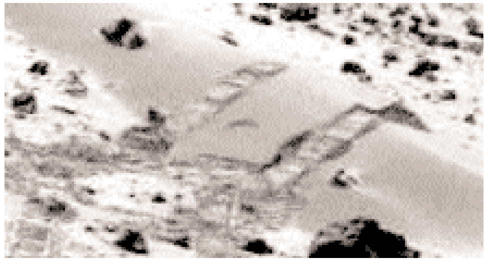
The variations of pits and protrusions on the surface of rocks can cause a characteristically striped or layered appearance of the rock. Such striped surface texture can be produced in a number of ways. It may be cause by the heterogeneous materials within the rock. The layered appearance of rocks can also caused by the fusion of voids. (It has to be noted here, that the resolution of the camera influences the appearance of the broken rock surface significantly.) A layered structure can also be caused by pressure, and sedimentary rocks can also be stratified. Until now we mentioned the layered nature as a result of internal propeties,

but external effect may also play a role in the process. For instance, slight erosion on the surface may be caused by windblown particles. The layered nature on the picture of a rock is more apparent if the dust carried by the wind is different from the rock in material and colour, and it settles in the grooves of the rock.

Several rocks have a shell structure, which follows the shape of the rock. Such occurrences are known also on Earth, where it is produced by spheroidal weathering. In such cases the water infiltrated the weaker minerals, and their disintegration makes the entire external layer of the rock weaker. This kind of disintegrating process is particularly characteristic of granite rocks. Most of the shapes observed on the Martian rock around Pathfinder is interpreted by Bridges et al. as the surface forming effect of dry desert wind. From the Arizona desert they were able to collect a counterpart for each of the rocks seen by Pathfinder, where the rock textures were mostly shaped by the wind and the windblown debris.

II. CLOSE UP VIEW OF ROCKY SURFACES

It could be observed that the surfaces rocks of the Martian microenvironment had been formed by internal and external forces. Wind played a major role in shaping the surfaces, but the work of water can also be considered, which carried the rocks to their present locations. The wind also contributed significantly to the movement of small particles of debris. Now we will review the arrangement of such debris. The effect of wind could be three fold: destruction, transport and accumulation. The characteristic windblown forms of sand can be categorised accordingly.



The destructive effect of wind (abrasion, wind grinding) is significant up to a height of 15 cm from the ground, because this is the usual travel level of the particles carried in jumps. As a result, the larger boulders are bordered by erosion groove because of the excavating effect of the wind, the velocity of which is increased locally. These erosion grooves are mostly filled with debris particles originated from the boulder. The grinding effect of wind is shown by small pits and several cm long chiselled grooves (wind scratches) on the rock surfaces. As much as 50-60 % of the full surface of the rock is affected by wind grinding.

In addition to the sand ripples, the several m long and one-two decimetre tall small dunes are among the accumulation forms, which can be found behind the boulders. They are light coloured because of the atmospheric dust settled on the surface. When the Sojourner rover rolled over such micro-dunes, the wheels exposed the darker material of the dunes.

One decimetre to several metres long wind streaks can be seen at the shade at the downwind side of many small boulders within the area investigated by Pathfinder. The height of such wind streaks are several cms, the colour is reddish, and the material is fine grained.

2.1 Windblown shapes around Pathfinder

Let us start studying of windblown debris (dust and sand) in the vicinity of the boulders. Mild wind deposits dust also on the top of the boulders. In this way many boulders are covered with dust. Such dust cover could be observed at all landing locations. Corresponding to Bernoulli law the strong current, high wind carries sand. The wind is stronger behind and by the boulders, for this reason small trenches are excavated around the boulders. Such trenches can be observed frequently at the foot of the boulders around Pathfinder. Part of the sand is rearranged by the wind also in addition to just carrying. Pathfinder photographed long wind streaks behind small boulders. The prevailing wind could be determined from the orientation of wind

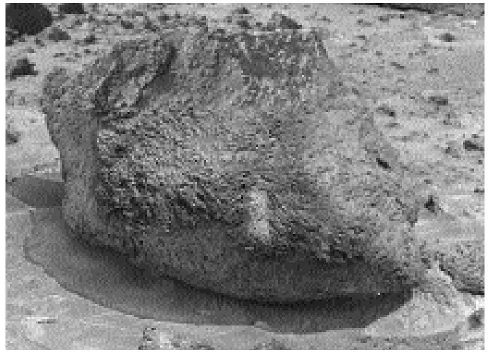
streaks at the region of Pathfinder during the season of the landing (NW-SE).

The forms established by the wind have many different sizes. Until now we mentioned those situated close to the landing site within the planetary microenvironment. Various forms can be observed at larger distances from Pathfinder. Such forms can already be seen from larger height. These are larger sand dune crests, which are situated at the verge of the micro-environment which could be observed directly from the space probe, and which connects the forms of local environment to the topographical features of the regional environment.

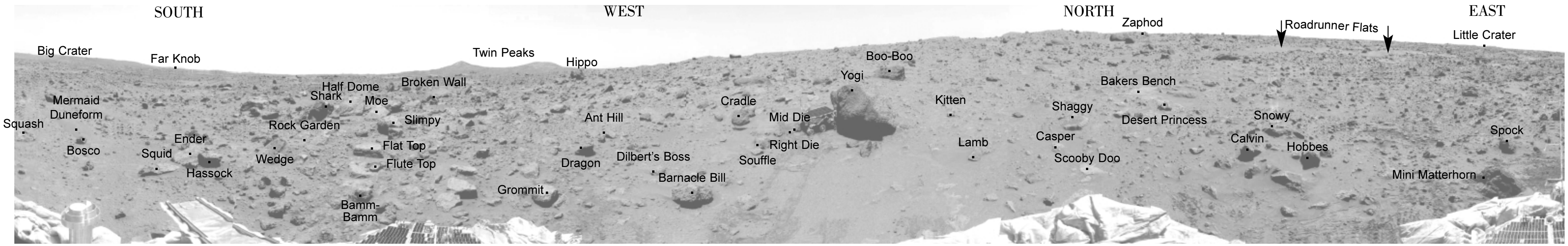
2.2 Windblown shapes on the rocks and in the region

The wider environment of the landing location of Pathfinder has been shaped by the floods that had produced the Tiu and Ares Valles, i.e. the carrying potential of the flowing water. Following the floods the surface was mostly shaped by the wind, and by the material carried by the wind, i.e. the aeolic processes. The moving air carries fine particle debris and performs destroying and building activities on the forms of microenvironment. Three different kinds of wind-shaped features were observed in the vicinity of Pathfinder.

Accumulation formed with ripple like patters, entrained settling and dunes. The erosion patterns (wind furrows) can be observed mostly in the form of trenches around the boulders. The result of abrasion can be seen most often in the from of holes and pits excavated by the windblown dust and debris.



It can be seen from the pictures taken by Pathfinder, that the direction of wind accumulating and settling the debris or causing an erosion is identical to the prevailing winter wind on the northern hemispheres of Mars (NW-SE). This direction was already observed in the pictures taken by Viking orbiters.

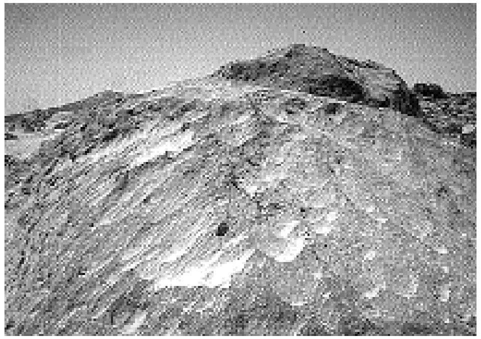


Panoramic view from the landing place of Mars Pathfinder showing the names of the boulders. Only the higher elevations appear beyond the nearby horizon because of the rolling surface (e.g. Twin Peaks, Big Crater, Far Knob). Such map of microenvironment could be used even after millions of years, because the surface of Mars does not change too much.

The topography of the wider environment of Pathfinder can be studies from the pictures taken by Mars Global Surveyor. A number of different surface shapes can be detected on the Tiu-Ares flood plain, including the pale linear structures following the direction of the Tiu Valles, which consists mainly of light coloured parallel or arched hills in addition to craters (the length of such lines varies from several tens of meters to several hundreds of meters). The distance between the hills varies in the range 25-60 m, they are 7-20 m wide, so they are similar to transversal dunes that can be found at other areas. Their NW-SE direction is identical to that of the small dunes and wind streaks located close to Pathfinder, as well as with that of the wind zones shown in the pictures taken by Viking orbiter. These hills are young eolic forms, which were established after the flooding era, as they intersect the edges of craters produced after the flooding era. They cover the crater slopes, and cover also the sides of the earlier forms. In Pathfinder pictures one can observe light blue zones on the eastern slopes as well as on the saddle of Twin Peaks. These are two parallel hills as can be well recognised when photographed from above.

Wind scratches (ventifacts) can be seen on many rocks situated in the vicinity of the Pathfinder landing location. The orientation of the wind scratches indicates a wind direction blowing from ESE to WNW, which is definitely different from the presently prevailing wind direction (NE-SW). This is an evidence of significant change in the prevailing wind direction. (Changes in wind direction can happen in cycles of 125 000 years in association with the oscillation cycle of the orbit inclination. The equinox coincides with the perihelion point in each 51 000 years (Bridges et al., 2000).

Further evidences of the origin from a more ancient windy period include the smaller craters (60-300 m in diameter), most of which are of secondary origin. The rim of some of these craters has been eroded, and these craters seem to be partly filled with windblown sediments (they have diminished or destroyed rim section at the W-NW side).



The direction of the destroyed section of the crater rims is identical to the azimuth of the wind scratches, but deviated from the orientation of the wind furrows and wind zones. About 1 km east of Pathfinder landing location a group of above mentioned hills can be observed, and they are orientated mostly north-south direction.

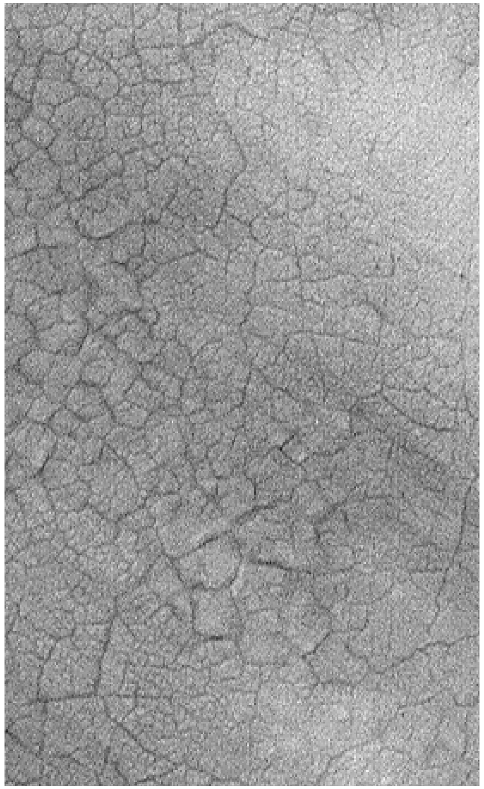
Geological survey of the Pathfinder landing site has indicated that the system of hills, sediments within craters and wind zones associated with craters (which all can be seen from orbit), are wind formed features of a relatively young surface formation process. The small dunes and sand accumulation around Pathfinder could have also produced by the (winter) winds, according to their orientation.

The wind grooves seen on the rock around Pathfinder, as well as the carved crater rims are evidences of another, more ancient windy period. These winds used to carry large quantities of sand as well, and the debris carried by the wind carved out the wind grooves on the rock surfaces. Such wind grooves are produced mostly at locations where the large proportions of particles carried by the strong winds are moved in a saltation manner (hopping). Such areas may also be found on Earth primarily in deserts and along glaciers. The wind grooves that can be observed on terrestrial rocks were primarily produced during an ancient windy period. They are present now as residual shapes from a process taking place 6-8000 years ago in the dry period of the ice age.

It is probable that the sand fraction of the particles at the landing site of Pathfinder are also ancient, originating from the floods of Tiu Valles and Ares Valles occurring 2 billion years ago. The light coloured hills located east of Pathfinder might be residual forms of ancient dunes. Probably these dunes provided the sand for the wind to carve out the wind scratches on the rocks around Pathfinder.

2.3 Ice in the desert

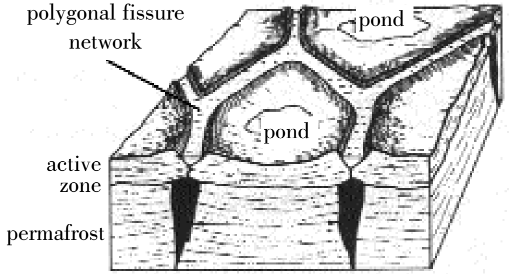
The most important landscape forming factor is the lack of water in most of the deserts of Earth, as well as on the Moon and Venus. On the other hand, H_2O molecules were abundant in the rocky deserts and debris covered areas of Mars, though in the form of ice and not as a liquid in the layers close to the surface. In view of this fact it is reasonable to



Windblown polygons on Mars in a crater at 71.2° S. 282.6° W. Picture E12-02319 taken on 21 January 2002. There is summer at the location shown. Image width: 1.5 km (NASA/JPL/MSSS)

Siberia and in the area of dry valleys of Antarctica.

In frozen deserts the ice is not on the surface, but underground in the permafrost, where it fills the pores of the rocks, and thus acts as a cement-



ing medium. The thickness of such layer could be several hundred meters. The top several metres thick layer is the active zone, which is affected by the temperature variation on the surface, for this reason it thaws periodically. This change of state is the primary determining factor of the many periglacial forms. In the active zone vertical wedge-like fissures are generated. Debris fall into these fissures. The fissures close upon thawing, but open up again at the same places in the freezing period. In this way the locations of wedges become permanent. At the same time, a polygonal fissure network develops on the surface, the nodes of which are at the vertical fissures.

The Martian polygons occur mostly at the floor of craters and on intercrater plains between 60° and 80° latitudes. In satellite images these are most conspicuous, when their fissures are filled with light coloured frost or dark sand.

Yet another consequence of the periodic thawing is the stratified creep of the surface debris blanket (moving in the direction of slope), which is happening in Earth at a number of locations, and its ancient occurrence on Mars can be observed. As a result, huge debris slopes are formed, which are similar to terrestrial glaciers, but the share of debris is much higher in the total mass (rock glaciers).

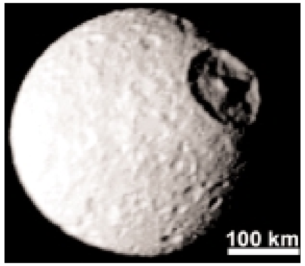
III. CHARACTERISTICS OF DEBRIS

The surfaces of planets having solid crust are generally covered with debris. Such debris is the result of a number of processes:

– cosmic erosion, i.e. effects of impacts (ejection, crust quake, breaking, vibration), against which only an atmosphere can provide some protection.

– rock disintegrating mechanisms, including physical breakdown of rocks, reduction of size (crushing, caused mostly by large temperature fluctuation), chemical change in the mineral components (decomposition, which generally requires some solvent, e.g. liquid water, which is the most frequent solvent on Earth, but reaction with the gases of the atmosphere can also occur, such as on Venus);

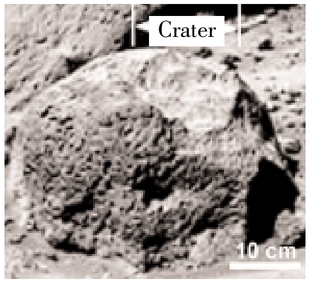
– mass movements and other external forces (water, ice, wind), for which some kind of volatile atmosphere is necessary on the planet.



The giant Herschel crater on Mimas, satellite of Saturn

Debris has many names, and such names could be different for each planet. The debris being on the surface of Moon is called regolith. Megaregolith is often the name of the less homogeneous debris covering Mars. In case of Earth the generally used term is soil.

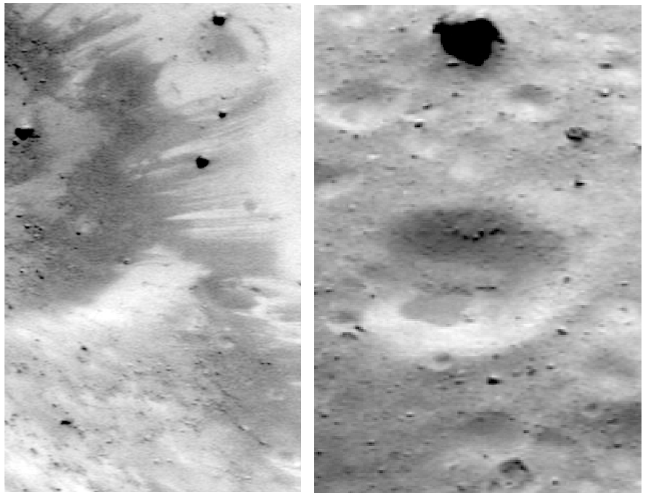
In geological terms, however, soil is the outermost productive layer of the Earth crust (pedosphere), i.e. it is partly a biological product. In this respect the name is not useable all the time for identifying the debris blanket covering the surface. The conditions are very harsh for the formation of soil at certain locations of Earth, such as dry deserts and frozen polar regions, where actually a blanket of debris is present instead of soil (i.e. non productive framework soil). That is why such areas are similar to the landscapes of Moon and Mars.



Impact mark of a small meteorite on a Martian rock.

3.1 Physical properties of debris

Debris covering the surface can be studied in detail with sophisticated methods. Test results can then be used to reveal the past history of the landing location as well as to identify the present processes shaping the surface.

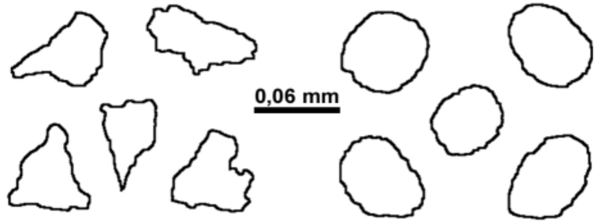


The regolith of an Asteroid: it is slowly creeping downwards, especially at crater walls. Where it is removed, the underlying, less eroded, brighter material can be seen. (Eros, left)
Dust on the surface can be electrically charged by solar radiation. Some of the equally charged particles start levitating. After sunset, the electrostatic levitation stops. The grains can move horizontally too and take part in the regolith redistribution. During long time the material is slowly accumulating in the depressions, this way the interior of craters get filled up with very fine dust, creating dust pools. (Eros, right)

Particle size, shape and grading of components are in close relationship to the appearance of the landscape. Often characteristic measuring ranges can be assigned to various media of different viscosity and to various external forces. As a result, the particle size distribution diagram could be used to determine the dominant surface shaping process. This can be further clarified by studying the shapes of the particles. Among the distinguishable sand materials are the sharp and prolate shiny sand carried by water, as well as the fully isometric, spherical mat windblown particles (the latter can also be recognised by a minimum difference in size).

Grain size	*Debris*	*Rock*
>200 mm	*block/boulder*	*breccia/conglomerate*
200-2 mm	*gravel*	*breccia/conglomerate*
2-0.06 mm	*sand*	*sandstone*
0.06-0.02	*rock flour*	*aleurite*
<0.004 mm	*clay/silt*	*claystone*

Terrestrial system of alluvial rocks

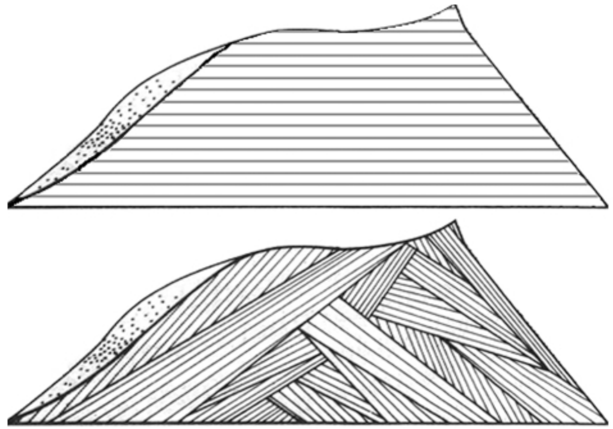


Carried in river: sand particles with edges not rounded too much

Windblown: rounded sand particles

– The thickness of the debris blanket is a clue for estimating the time while the area has been developing without major changes.

– The vertical stratification of the debris is an indication of the mechanism, and time sequence of surface formation. Parallel structures are usually caused by wind blowing constantly in the same direction. On the other hand, cross stratification occurs characteristically when debris is carried by rivers.



Parallel and crosswise stratification

– It is important to check the volume ratio of voids and pores among the particles, which decreases gradually as the debris becomes more compact. For this reason the void ratio is an indication of “maturity”, age of the debris.

– The voids can be filled by atmospheric gases as well as by other materials. On Earth this filling material is groundwater or aquifer water, but H_2O is much less frequent on other silicate planets, except Mars, where large quantities of H_2O can be found in the pores of megaregolith, the particles of which are cemented by water, thus creating the global permafrost layer. It is expected, however, that debris areas cemented with iron oxide are present at other locations of the Red Planet (on Earth instances of debris can be found where the cementing is done by clay, silica, salt, carbonate or sulphate compounds).

3.2 Chemical composition of debris

Areas having different composition can be delineated on the basis of deviating stability and shades, but it is necessary to use spectrometer to determine their actual mineral composition accurately.

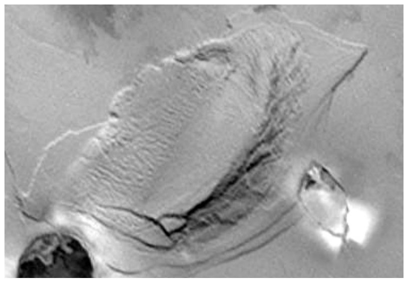
Such equipments are often used in orbiting units, which are capable of a nearly global survey by using remote sensing methods. Landing units can also carry such equipment, which is capable of a very accurate chemical-mineral analysis of the microenvironment of the landing site.

Components containing iron can be detected with simpler methods as well. The Sojourner Rover of Mars Pathfinder was equipped with sheets of different magnetic properties at the front, on which the atmospheric dust settled gradually. This ways are suitable to estimate the rate of dust settling, as well as the share of magnetic particles.

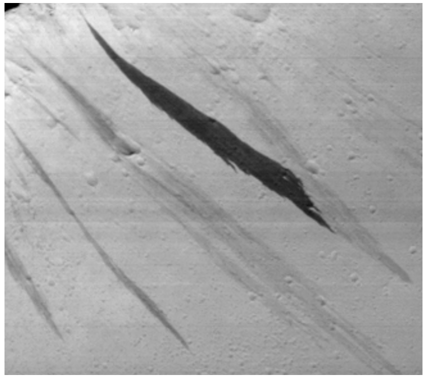
3.3 Transport of debris

The mass movement on slopes and the streaming media are capable of carrying debris. A significant volatile atmosphere is necessary for the latter to work. Water and ice are effective streaming media only on Earth. (Recent explorations indicate that Mars was a wet planet at the initial stage of development, like Earth. One of the most important evidence of this includes the sedimentary stratification carried and deposited by ancient water flows. Subject to proper surface conditions, water can play a role anywhere in transporting debris.) On other planets the determining factors in transporting debris are slump and wind.

In case of movement of large masses of debris the initiating factor is gravitation instead of flow. Such movement, therefore, can occur at any location, where debris accumulates on sloping terrain (valleys, crater walls, volcano sides). A number of basic types of such movements are known:



Euboea Montes on Io: large landslide to the North, and the collapse of large blocks (South). The landslide material is c. 2 km thick, it travelled 130 km from 10 km height to its base.(Schenk et al)



Traces of dust avalanches on Mars

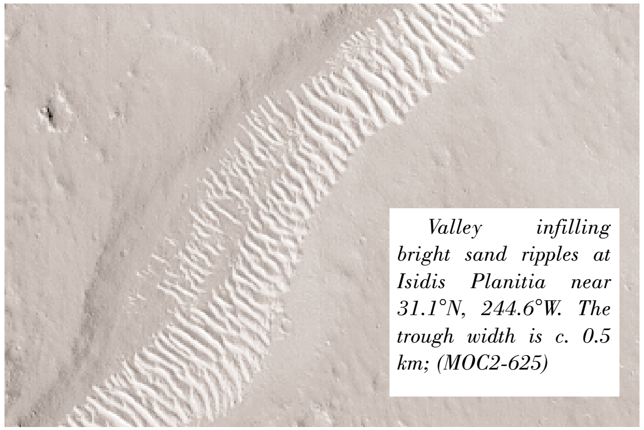
– **collapse**: a suddenly occurring process, where the parts of rock and debris move independently, freely;

– **slide**: a slowly occurring process, where the movement occurs in blocks along a sliding route;

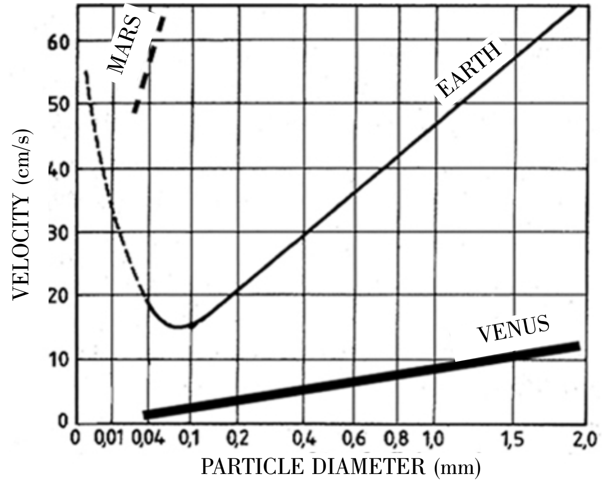
– **creep**: slow but consistent movement of surface material in layers.

Dust avalanches are one of the characteristic mass movements presently observable on Mars. The surface cover consisting of dust settled from the atmosphere starts to move in the direction of slope after losing stability. This initiates a self excitation process, which entrains dust from large areas exposing the generally darker rock below. The forms thus produced could survive for a very long time, because the settling of dust is slow.

The particle size range that can be moved by wind is determined primarily by the wind velocity and the density of air (and the density of the debris is also important factor). A critical starting velocity can be assigned to each particle size. If the wind velocity is below this value, then the debris layer remains in place.

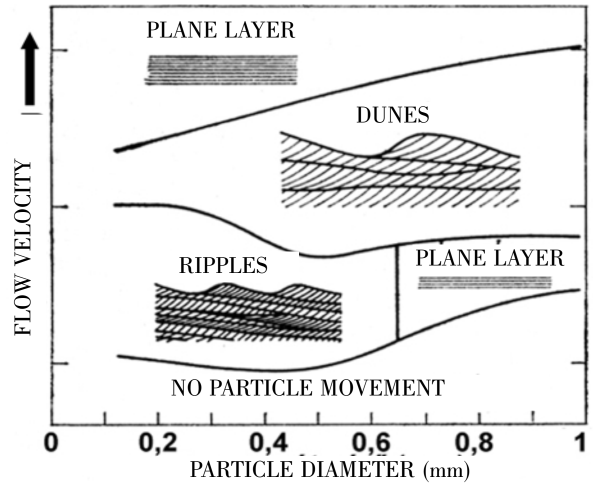


Valley infilling bright sand ripples at Isidis Planitia near 31.1°N, 244.6°W. The trough width is c. 0.5 km; (MOC2-625)

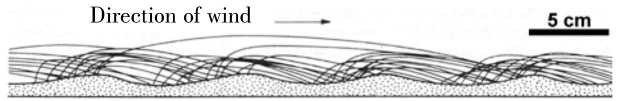


Starting wind velocity vs. particle diameter

Wind is capable of transporting debris particles in three different ways: sliding-rolling in case of large blocks, floating in case of tiny particles, and hopping (saltation) in case of sand particles. Free sand surface becomes rippled as a result of hopping.



Shapes in the function of wind velocity and particle diameter



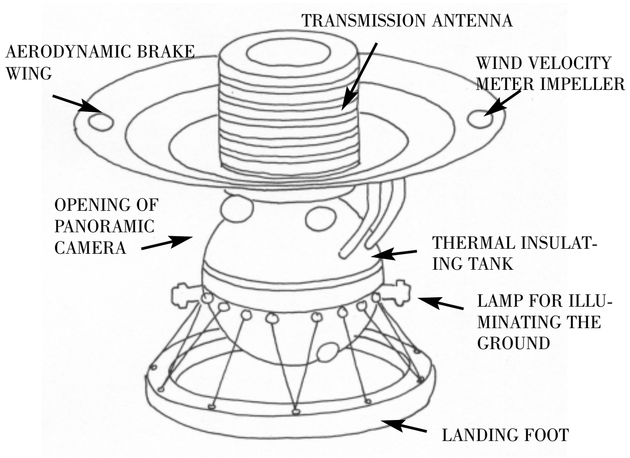
Formation of sand ripples

IV. LANDING ON VENUS

4.1 Rocky desert on Venus

Among the planets the highest numbers of space probes were sent to Venus. Until 2003 the number of space vehicles sent to Venus was 43, from which 15 entered the atmosphere, 11 landed on the surface and only 4 of them have sent pictures from this inferno.

The mass of Venus is about the same as that of the Earth. It has a very dense atmosphere which produces a very high pressure at the surface (90 bar). The atmosphere consists mainly of CO_2, and because of the high pressure, a particularly strong greenhouse effect keeps the surface temperature at around 500 °C. No water is present on the surface of the planet. The small quantity of water is in the atmosphere forming sulphuric acid and sulphurous acid clouds using the sulphur content of the atmosphere. These clouds cover the sky completely everywhere. For this reason, the surface cannot be imaged in the optical wavelenght from space. Mapping the surface is possible only by radar (ground based or spacecrafts: Pioneer Venus 1, Venera 15 and 16, Magellan). Four layers of the clouds can be distinguished in the range of 8 – 55 km. The only difference among the layers is the sizes of drops. It was rather challenging to design space probes for landing on Venus. The early probes got crushed already in the atmosphere because of the large atmospheric pressure. Some of them descended to about 20 km height, but the sensors were "eated off" by the sulphuric acid clouds terminating the mission (Venera 4, 5 and 6, large probe of Pioneer Venus).



Landing unit of Venera 9 and 10

Fig. 1: Black and white panoramic picture made by landing unit of Venera 9. This is the first photograph made from the surface of an alien planet. The landing was on 22 October 1975 at the location 32° latitude and 291° longitude, where the probe worked for 53 minutes. At the landing site the temperature was 457 °C and the pressure was 88 bar. The wind velocity was 0.4-0.7 m/s. Earlier the researchers expected high winds on the surface, including sandy and dusty air, and thought there must be very dark because of the dense atmosphere and closed clouds. For the sake of safety a headlamp was also mounted on the probe. As the picture shows the air was clean in spite of the fact that the picture was taken right after landing. The landscape exhibits the features of a rocky desert. Relatively recent and moderately eroded fractures and surfaces can be observed on the 30-40 cm large boulders. Some of the boulders are sunken into the soil, which means that "soil" (i.e. rock debris) is present.

Equipments were then prepared from other materials and designed for higher pressures, so they could reach the surface. Soviet researchers used to launch two probes simultaneously. Both of them included two cameras in order to take a full panoramic picture. The cap of some cameras did not open, probably because of damage caused by high temperature (one camera of Venera 9 and both cameras of Venera 11 and 12). The probes landed smoothly on the surface, and survived for 20-120 minutes until they overheated and stopped operation (Venera 7, 8, 9, 10, 11, 12, 13 and 14, Vega 1 and 2. The three small probes of Pioneer Venus were not designed to land smoothly).

If there were creatures living on Venus, they could never see the Sun from any place of the planet. It was assumed that light is not enough for taking pictures on the surface, however the light meter of the Soviet Venera 8 detected enough light. The first pictures (in black-and-white) were taken by Venera 9 and 10 after landing. Actually the illumination on the surface is comparable to the Earth surface on a very cloudy day. The shading effect of clouds varies as verified by the pictures taken within 80 minutes interval with the camera of Venera 13 mounted on the boom used for measuring the resistance of the soil. The difference in illumination is caused by the change in the distribution of clouds. During this period the relative position of Sun hardly changes, because Venus makes one rotation around its axis very slowly, only in 243 days.

The pair of probes Venera 13 and 14 already delivered coloured panoramic pictures. The images exhibit interesting light refracting phenomenon. The image is curved strongly as if the observer were standing on a small sphere. This optical illusion is similar to the mirage and caused by the fact that the temperature changes suddenly within 1 m height above the surface. The albedo of the surface is very low as proven by the pictures, it varies between 2 (as measured by Venera 13), and 11 (as measured by Venera 14). The ground is brown in the colour picture that is expected from a grey ground in yellow atmosphere, from which the blue light has been filtered out entirely until the light reaches the ground.

Probes Venera 9, 10, 11, 12, 13, 14 landed in the vicinity of the two huge volcanoes of the Beta Region.

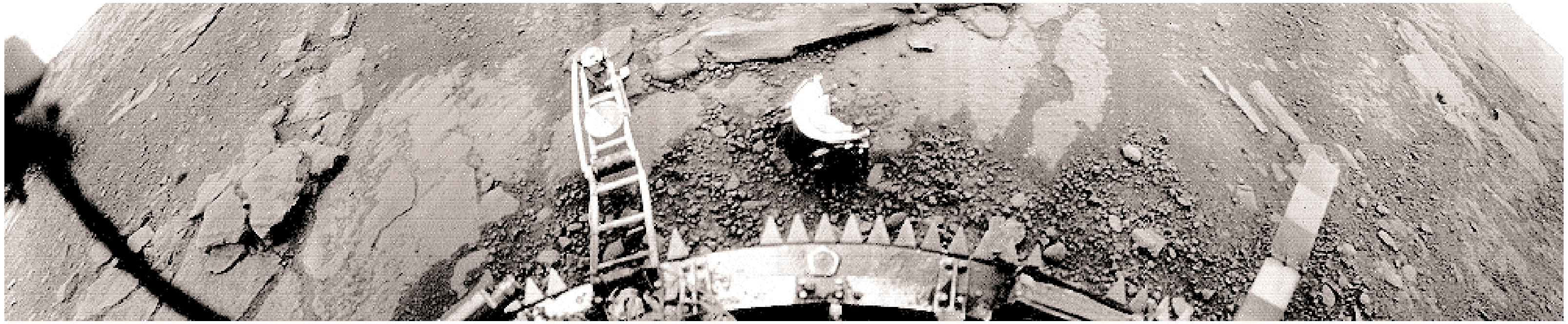


Fig. 2: This panoramic image taken by Venera 13 landing unit was the first colour image from the surface of Venus (the colour version is shown on the cover). Landing took place on 1 March 1982 east of the Phoebe Regio (7.5° latitude, 303° altitude). The probe operated for 127 minutes (instead of the planned 32 minutes) on the surface at a temperature of 457 °C and a pressure of 84 bar. The picture taken with red filter was the clearest, for this reason the surface seems to be reddish (see the image on the cover). Laminar rock can be seen on the picture, the protrusions of which are covered with dark fine particle debris (soil). The results obtained from the soil samples indicate the presence of alkaline gabbro. The investigation of the border of lava flow shows that it is pahoehoe lava.

Venera 13 and 14 were equipped also with UV fluorescent spectrometer and soil sampling boom (1 cm^3 from a depth of 3 cm). Tholeiite basalt was identified by Venera 14, which is very frequent on Earth at ocean floors. Venera 13 found a material similar to alkaline basalt, which occurs on oceanic islands and is rather rare on Earth. Venera 8 used gamma spectrometer to measure the materials that were farther apart, and detected a radiation, which is characteristic of granite like materials.

Radar images indicate that there is no thick dusty regolith layer on Venus. It cannot be excluded, however, that dust is present as a cementing material. Actually, the photograph of Venera 9 shows boulders sunken partially in dust. This verifies the existence of dust on Venus.

The physical conditions on the surface of Venus are fairly constant on a daily or annual time scale. Very low wind (less then 1 m/s) was detected by the probes. Dust was disturbed after the landing of Venera 9 and Pioneer Venus, however, it settled fully within 40 seconds in case of Venera 9. The material of the soot-like dark dust is reminiscent of the properties of basalt. The air is clean close to the ground, dust does not get airborne, but remains on the surface. The erosion is very low on Venus relative to Earth, because the wind is weak, there is no precipitation, and the daily temperature fluctuation is below 1°C.

The only significant process is the reaction between the solid material of the surface and the aggressive gases of the atmosphere. It means that chemical disintegration is at work, which causes the rocks to decompose and pulverise. Dust is being moved downward by gravitation and by the wind which is getting stronger as the height increases. The dust then gets into reaction again with the lower part of the atmosphere. Such product of decomposition can be observed among the boulders in the Venera panoramic images. Their displacement is detectable at the foot of Venera 13, where the distribution of the dust changed gradually during the 100 minutes long operating period.

The panoramic images taken by Venera 14 show large flat stratified rocks, as if volcanic materials have just got cracked after solidification. Similar scenes can be observed at ocean floors on Earth. Rocks are not that sharp at pictures taken by other probes. Here the rocks are somewhat eroded, and dark dust can be seen between them.

If any volcano is active on Venus then it would look very unlike those on Earth, even if the mechanism of operation and the materials involved are the same. Because of the high atmospheric pressure, the eruption of lava takes place in a way that similar to terrestrial ocean-floor volcanism. Volcanic plumes rise only to one third of the height of their terrestrial counterparts, and there is no volcanic ash fall. Exceptionally, such dispersion could occur, if the magma contains abnormally high quantities of volatile material (over 2 % water vapour or 5 % CO_2), or if the atmospheric pressure was lower earlier. At the present atmospheric pressure, the speed of the erupted material is less by 2-4 times assuming the same rate of flow. The spreading/fall of materials takes place in a much smaller area than on Earth.

Lava flows are significantly longer relative to flows on Earth. A number of long lava flows were identified in radar images, the longest reached 6000 km, i.e. longer than Nile. In addition to the high surface temperature other factors also contribute to such long flow. Lava probably contains high amount of salt, which makes it a very low viscosity liquid.

A highly sensitive seismometer was also mounted on Venera 13 and 14, which was capable of detecting microseismic events. Venera 14 detected two events, which may be caused by a displacement of about 10 cm. In terrestrial terms this corresponds to the movement that can be detected at 3000 km distance from a volcano. This was the distance of Venera 14 both from the huge volcanoes Beta and Phoebe. Venus is probably still an active planet as can be concluded from the existence of fresh faults (picture by Venera 14), as well as from these seismic measurements.

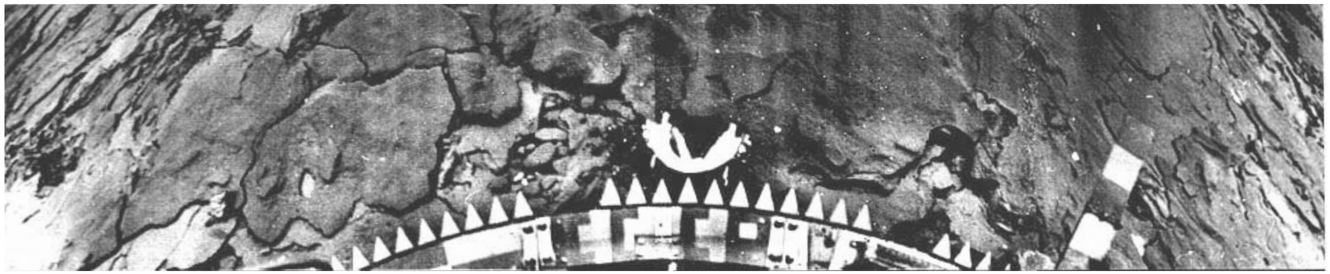


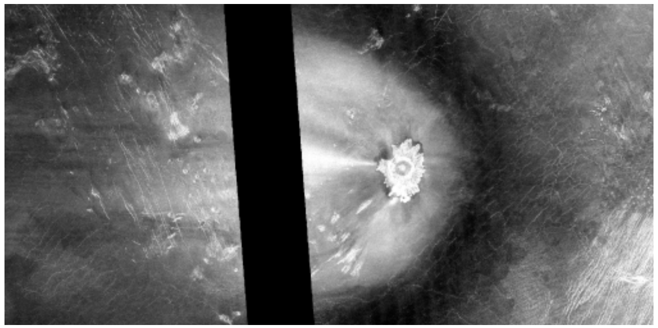
Fig. 3: Panoramic image taken by Venera 14 landing unit. Landing took place on 5 March 1982 on the basalt plain in the vicinity of Phoebe Regio (13.15° latitude, 310° altitude). The probe operated for 57 minutes on the surface at a temperature of 465 °C and an atmospheric pressure of 94 bar. The picture indicates

V. OBSERVATION OF IMPACTS ON THE SURFACE

5.1. Impacts on Venus

About 870 impact craters have been identified on the surface of Venus. It is interesting to note that the craters with diameter below 10-12 km exhibit the evidences of synchronous impacts of more than one bodies. Smaller bodies must have exploded close to the surface after they have been heated up by the friction of the dense atmosphere. The fragments impacted on the surface simultaneously. For this reason the ejecta collided in mid air and fell back to locations deviating from the normal locations of the ejecta coming from a single impact. The ejecta blanket of the larger crater is often asymmetric because of the very dense atmosphere. In case of an inclined impact the turbulent flow of the heated air did not allow the debris to settle in the direction of the trajectory. For this reason a segment of the ejecta blanket is missing here.

Yet another interesting phenomenon occurred in relation to the impacts on Venus because of the high atmospheric density. What happened in case of Tunguz meteor on the Earth, is used to occur very frequently on Venus. The incoming object is heated because of the air drag, and explodes prior to hitting the surface. The shock wave caused by the explosion grinds the particles of the soil to produce fine powder. Such impact locations are very apparent in the radar pictures, because the fine powder reflects radar waves differently than its surroundings. The reflection of radar waves is sensitive to the micro topology of the surface. If the surface roughness is much less than the wavelength, then the radar beam is reflected in a different direction similarly as a flat mirror reflects light. In other directions the surface is shown as dark in the radar image. If the surface features are larger than the wavelength, then the radar beam is scattered in every direction, including the receiver: for this reason such surfaces are brighter in the radar image. That is the reason why the fresh lava flows or mountains are brighter and the plains with no surface features are darker in the radar images.



Crater on Venus (10°N 75°E) (radar image) (the dark stripe is caused by lack of data)

5.2 Vicinity of impact craters on Earth

On planetary surfaces the impact craters are the most characteristic features. Impact craters are very rare on Earth, although the occurrence of impacts were not less frequent. About 160 structures have been identified as possible locations of impact, most of them since the beginning of the Space Age. The impact origin of the craters was verified during the past 50 years also by geological evidences. Earlier the volcanic origin was not excluded because of the morphological features. Additional impact crater structures are revealed in almost every year at locations far from inhabited areas based on aerial and space photographs. About one third of the terrestrial craters no longer exhibit structural evidences on the surface. These craters got buried (Chixulub), or the surface has been equalised by erosion.

The diameter of more than half of the craters on the Earth is below 10 km; the age of the craters vary from several tens of thousand years to several hundred million years (the smaller ones are younger, because they are eliminated more easily by erosion); about 10 craters are older than 1 billion years. The older craters are observable only if the surface itself is older, i.e. on the surface of ancient cratons. The rocks receiving the most frequent impacts at the time of the large meteorite bombardment have been eliminated from the surface by erosion and plate tectonics (subduction of rocks). Such craters, however, can still be seen on the Moon. The young craters which can be seen today have been (also) produced probably by tangentially impacting bodies (Near Earth Objects: Athenes, Apollos).

5.3 Identification of craters

Nowadays the impact origin of craters can be unequivocally verified on the basis of characteristic features. Such features can be studied on the field and in laboratory. It is reasonable to believe that similar features could be observed by studying the geology (i.e. the microtopology) of the impacts structures on other planets. Features of impact origin include:

– Morphology of the landscape (dish shaped depression, rim; on Earth a central uplift appears in case of craters with diameter exceeding 4 km; and central ring is produced in case of craters having diameter of several hundreds km. The existence of rim is an indication of a recent origin on Earth (fast erosion).

– Distribution of rocks (rocks from the deep in the ejecta blanket around the crater, and overturned flap), layers from the deep appear on the surface in steeply skewed orientation.

– Geology of rocks (impact breccias; melts, rocks that have gone through shock metamorphism as a result of high temperature and pressure).

– Morphology of rocks: *in microscopic size*: e.g. changes seen in thin sections, e.g. in quartz; spherules (melted rock that has solidified in the form of spheres or drops); *in macroscopic size:* patterns resembling a horsetail (called shatter cones) generated by shock wave travelling faster than the velocity of sound (pressure cone), which affected the entire rock material (the impacting bodies had a velocity of 12-72 km/s when hitting the Earth). In the Y shaped tracks of the pressure cones the stem of Y is in the direction of the centre of impact, from where the cone of the shock wave had propagated (shown with arrow in the picture).

– Pieces of impactors (meteoroids) (can be found after impact with moderate energy, if the pieces are not vaporised, generally when the crater diameter is less than 1 km). The impactor explodes in the atmosphere, if it cannot withstand the heat and pressure produced by the drag of the atmosphere.

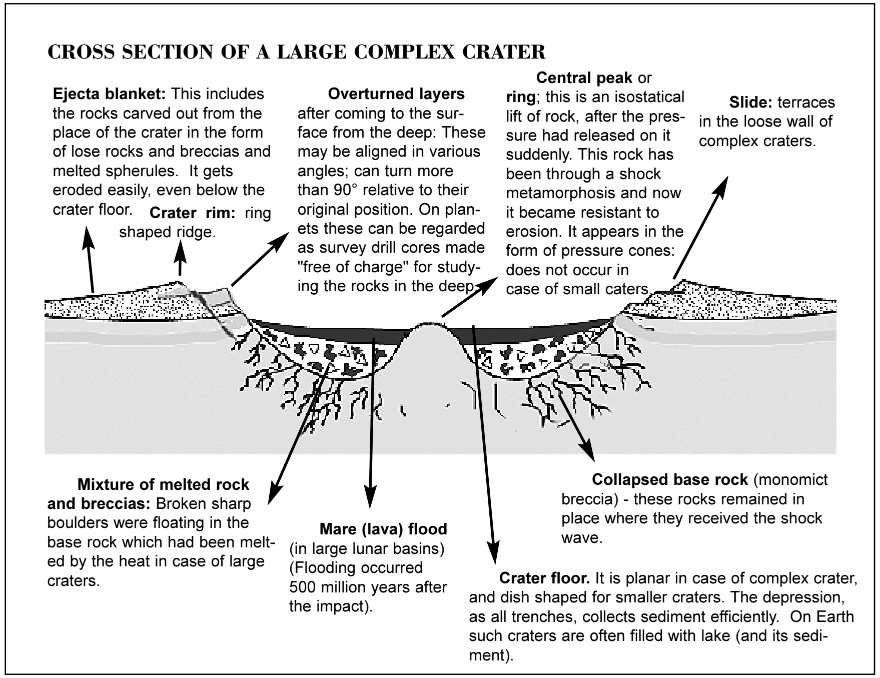
– Geophysical measurement, e.g. gravitational anomalies (negative in case of simple craters because of the lose breccia like sediment, positive at the central uplift in the complex crater because of the shock metamorphosis).

5.4 Erosion of craters

Various parts of the crater have different resistance to erosion.

The rim of the Vredefort crater in South Africa has been completely destroyed (during the last 2 billion years); on the surface of the crater the depth of erosion is several km, for this reason the rock seen on the surface today were at several km depth originally at the central uplift. The reason that these rocks are still visible is that they have become more resistant relative to their environment (particularly relative to the material of the rim consisting of lose sediment) because of the metamorphosis.

On Earth many craters are filled with freshwater or salty lake. On the Canadian craton or in Scandinavia most of the craters can be identified from the lakes, where lose material of the crater rim has been eroded away earlier, for this reason its place is filled with water in a ring shape. Crater lakes were produced on Mars by the inflow of water, which cumulated thick sediment in the craters. A thick series of layers can be found (aged about 180 000 years) in the 200 000 years old Tswaing crater, South Africa, where the pollen of contemporary plants, as well as fossils have been preserved in the sediment of the salty lake, on the basis of which the history of the weather can be reconstructed. The rim usually preserved only for young craters consisting of resistant materials, but such craters' rim heights gradually become eroded as well.



5.6 *Vredefort dome (South Africa)*

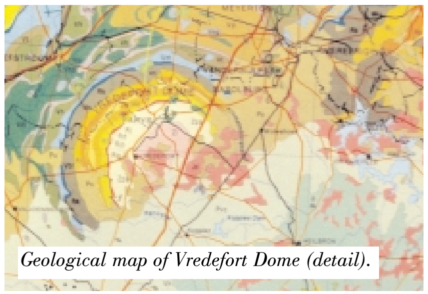
A (half) ring mountain situated in the vicinity of the towns Vredefort and Parys is part of the ring of the impact occurred 2.02 billion years ago; the rest of the crater (e.g. rim) has been eroded completely. This is the largest and at the same time the oldest impact crater on the Earth (evidences of older impact can be detected in rock properties, but the structures do not exist any longer).

The originally 300 km large crater was produced by a 10 km diameter impactor, which penetrated the rocks to several km depths. An associated layer is the light coloured marine sand, which has turned inversed to 100-120°, which had been settled in the ancient ocean existing prior to the impact. A 3.2 billion years old, several km thick granite layer was below this layer, which is now at the surface. This granite melted under the heat of the impact. Fragmented sharp boulders floated in this melt, which are present today as the so called pseudotachylitic breccia, e.g. in the bed of river Vaal.

The location of the impact was covered later by sediments, which again came to the dry surface. The 3.1-3.5 billion years old rocks, which were at a depth of about 17 km at the time of the impact, today are on the surface. The effects of the shook metamorphism can still be seen on these rocks. The present gold deposits of South Africa can be found along the rim of the Vredefort structure. The relationship between the impact and the gold is very probable, e.g. the former lake in the crater might have facilitated the washing out and cumulating of gold.

The Vredefort Dome today consists of two semi-circular shaped mountains chains. The river Vaal, which was larger earlier, carved out the valley between the two mountains. This area is the living place of ostriches and monkeys.

Granite which melted and becoming breccia upon impact in the bed of river Vaal, with a tuff of grass on the top.

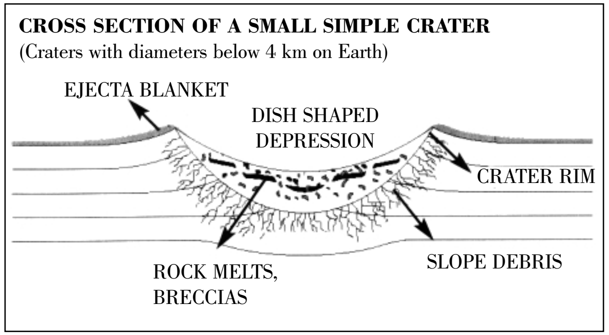


Geological map of Vredefort Dome (detail).

5.5 *Tswaing crater (South Africa)*

This well preserved dish-shaped crater is the result of the impact occurring 200 thousand years ago. The crater wall has been eroded to half of its original height, which has now a height of 60 m relative to the terrain and 119 m above the bottom of the crater. Its diameter is 1.1 km. The impacting chondritic meteorite had a diameter of about 40 m. It destroyed everything, killed all animals within a circle of 30 km diameter. Ejecta had fallen back at a distance of 10 km, where they caused additional damage (secondary craters). The impact origin of the crater could be verified only in the 1990's. A salty lake is present in the crater today (this is why the crater is named Soutpan = salty lake).

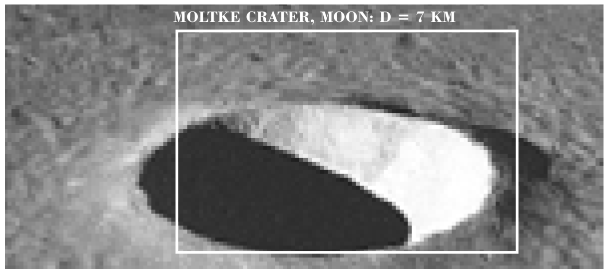
Dense vegetation covers the crater and its vicinity. This crater is located 40 km north of Pretoria at the very middle of the poor region (tin city) inhabited mainly by the ethnic cvána. It is protected by a fence, because it is a natural reserve. The crater rim is the only protruding feature in a large flat environment.



TSWAING CRATER, EARTH D=1,1 KM

In this space photograph a sharp line (in the direction of arrow) represents the border of the vegetation along the fence erected by the road, where the trees are used by the inhabitants of the poor region for their daily needs.

Tswaing crater at sunset. The part of the silhouette of the crater ridge can be seen or sensed behind the trees.



The above picture shows part of Tswaing crater within this frame (this is actually similar to the lunar Molike crater having 7 km diameter)

5.7 SPACE BASE IN A TERRESTRIAL METEORITE CRATER (HAUGHTON)

(Devon Island) (HMP and FMARS)

The surface conditions on Mars and the tasks of future visitors of Mars can be well simulated in certain part of our own world, where similar processes occur, and where similar conditions can be established also for the explorers. The Devon Island in the arctic archipelago of Canada, at the Haughton crater—which is closest to the pole among the terrestrial craters—is one of the places, where the conditions are close to those of Mars. The impact producing the 24 km diameter crater occurred 23 million years ago. The environment of the crater has several parallels to a general Martian landscape in terms of geology, morphology and weather.

Devon Island is not inhabited and it is "suitably" isolated. Here the summer is short (which is much warmer than on Mars, but very cold relative to the temperature usually encountered on Earth), when the snow melts and the debris covered surface becomes exposed. The geology and morphology of the island offers a number of analogies with regard to Mars: in addition to the impact generated shapes the most widely known features include the canyons, the stratified wall of which exhibit protruding rocks. This is similar to the wall of canyons on Mars, which has been found recently, where the tracks of flowing recent water (snow?) can be observed. (On Earth the tracks are surely the result of water.) The similarity is emphasised by the fact that the area is almost free from vegetation (polar bear is an exception regarding similarity). As on Mars, the area is covered by permafrost, i.e. constant ice is in the ground. Ancient traces of life have been preserved in the ground ice, which is also an eventuality on Mars. The vicinity is covered with the ejecta blanket of the impact crater. Traces of lakes existing after the impact have also been found. These sediment layers contain also the history of the climatic changes and biology of the past 23 million years. The ancient remnants found here did not fossilise, but retained their original structure thanks to the dry and cold polar weather. It is very probable that the Martian craters and ancient lake sediments also retain the traces of the former environment for a long time. Erosion is much more extensive on Earth than on Mars; the 23 million years old Haughton crater is more eroded than the 2-3 billion years old Martian counterparts.

The valleys of the island are arranged in a characteristic system. The valleys were carved by the water produced as the ice melted after the ice age, and not by rainwater or groundwater/ice. The morphology of the valleys is similar to that of the network of valleys on Mars. Considering the analogy of Devon Island, it is possible that the Martian valleys were not carved by rainwater in a warmer period.

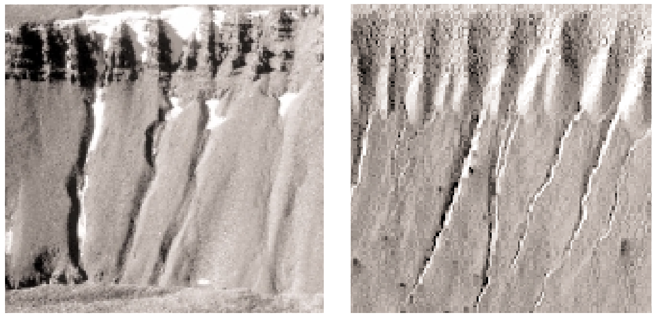
By the exploration conducted about Mars it was possible to detect the traces of an earlier hydrothermal activity in the Haughton crater. The hot water spring were warmed up by the heat of the impact. Similar impact related springs can occur on other planets also, and such springs may facilitate the appearance of life. NASA launched the Haughton-Mars Project (HMP) in 1997 under the nick name Mars on Earth. One year later the Mars Society was founded, and it constructed the first Mars-analogy station in 2000 named Flashline Arctic Mars Explorer Station (FMARS). It was part of the HMP base, and its main objective is to prepare manned landing on Mars (there are overlaps among the participants and research activities of the two projects).

The FMARS station is the living space, laboratory and storage for the crew consisting of 4-6 persons who are the representatives of various fields (geology, astrobiology, physics, engineering, instrumentation). The explorers execute "traditional" geological, microbiological and telecommunication research in addition to the experiments planned for Mars. One of the objectives of the work is to select the most efficient tools; to decide the optimum duration of a field activity; the duration, frequency and distances of Extra Vehicular Activities (EVA), collection and analysis of samples, necessary information and instrumentation for carrying out experiments on the field and at the base far from Earth. What should be the capabilities of a Martian buggy, the space suit to be used for the field activities that withstand the effect of dust? Such questions can be answered only through experiences.

Left: A block of rock expelled upon the meteor impact. The fissures in the rock are occupied by microbes, thus protected from the 24 hours long UV radiation. Right: NASA HMP base camp with the tent City in the foreground. The Mars Society FMARS station can be seen in the background beyond the rock protrusion (Fortress).

At the station of Mars Society the volunteer crew explored the area in space suit, travelled with Martian rover based on a previously prepared program in order to gather experiences. The station worked almost isolated from the outside word (the crew of 4–6 persons were changed on regular basis by 5–10 days). The station worked only during summer, when the ground and bedrocks are exposed after snow melting. The latest addition to the station, the Arthur Clarke Martian Greenhouse, operates during the winter months as well.

Gullies in Devon Island (photo by NASA HMP, P. Lee) (left), and on Mars (70.8 ° L, 355.8° A) (MOC M03-02709, right). The two pictures show the areas of similar sizes (about 0.5 km).



Extra Vehicular Activity (EVA), a simulated Martian walk at Mars Desert Research Station (Utah) in 2004, in a very attractive environment in space suits, – which are rather difficult to put on. At right Ákos Kereszturi, who conducts experiments with a wheeled structure on the canyon wall. This simulation is one of the many preparatory EVA's for a manned flight to Mars. The field scientists test not only field work in space suit, but they live in a station (HAB) planned to be Martian Station : at MDRS, it is a two storey cylindrical building mounted on outriggers and having a diameter of 8 m. Additional inflatable parts may be attached to the outside of this building. They test how can an isolated group solve problems and how can they use their and their environments resources.

5.8 Search for meteorites on Earth

It is not necessary to leave Earth to collect samples from other planets. In the very year of the first lunar landing Japanese researchers found concentration of meteorites on the glacier along the Trans-Antarctic Mountain. Black rocks can be easily found on the white icy background. Researchers visit the site by helicopter each year, where the meteoritic rocks are collected while walking or travelling in snow buggies. Collection in Japan is controlled by the National Institute of Polar Research (NIPR), where sets of polished thin sections were prepared from the meteorites found on Antarctica, for educational purposes. Meteorite collecting expeditions were also organised by USA, Germany, Italy and Great-Britain. Japanese researchers started their work in the Yamato Mountains, while Americans explored first the Allan Hills.

Larger portion of meteorites are from the asteroids, but certain portion of these meteorites were ejected from planets into space by impacts. Meteorites from Mars and the Moon have been identified so far. It is possible that other meteorites came from other planets. The rocks are well preserved in the cold weather, they do not receive contamination, are not eroded, as their counterparts fallen in other climatic zones.

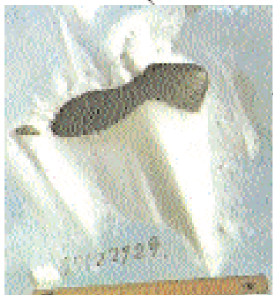
Kezio Yanai assumes that the meteorites fall on the ice within a large area. The snow covers the rocks then the ice or glacier carries them in the direction of slope. The destination of the ice (and the entrained meteorites) is the ocean around Antarctica, but some of the rocks remain on land. If an obstacle is in the way of ice (e.g. mountain), then ice tends to "creep" onto the mountain, its surface evaporates and erodes by the wind, thus decreasing the thickness by 10 cm each year. In this way the rocks tend to be accumulated by the "ice conveyor". The terrestrial ages of the meteorites was found to be over a million years on the basis of the analysis of ice. More than 24 000 meteorites were found here until now. One of the best known finding locations is the Allan Hills (ALH), where the first meteorite from Moon was found in 1981. This is a breccia designated ALH 81005. The first Martian meteorite (SNC) was also found here (ALH 77005). The most well known Martian meteorite is the ALH 84001. Its age is 4.5 billion years, and it was expelled from Mars 15 million years ago, and arrived at the ice of Antarctica 13 000 years ago.

Meteorite on the icy surface

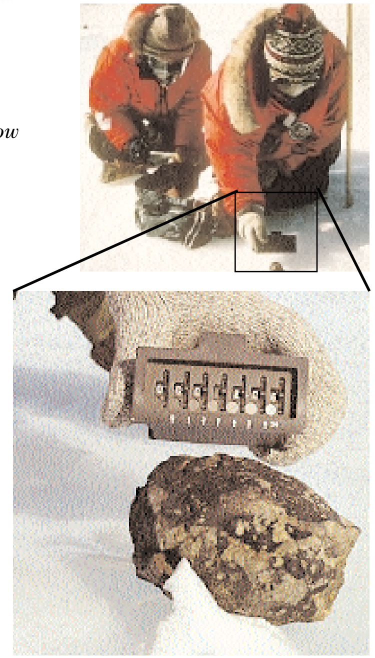
Meteorite frozen in ice

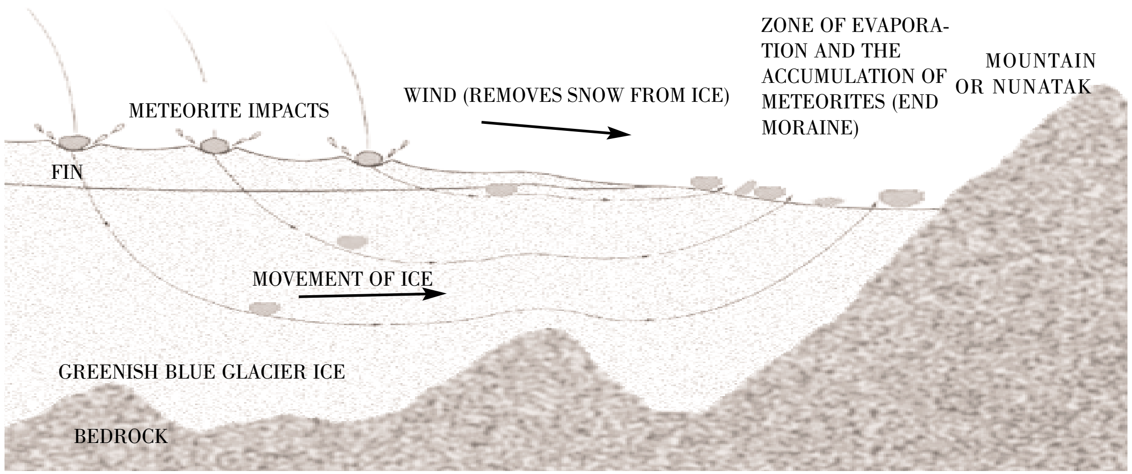
In addition to the ice deserts, meteorite collecting places include real deserts. More than a thousand meteorites have been collected already from deserts, where the meteorites could be easily found because of the lack of erosion, distance of civilisation, lack of vegetation and the light coloured sand. The most significant desert finding locations are in the Sahara desert (Algeria, Libya, Marocco), where meteorites are collected also by private expeditions.

Meteorite findings in the Antarctic



Meteorite with wind streak built from snow in the Antarctic





Allan Hills, one of the first known finding places.

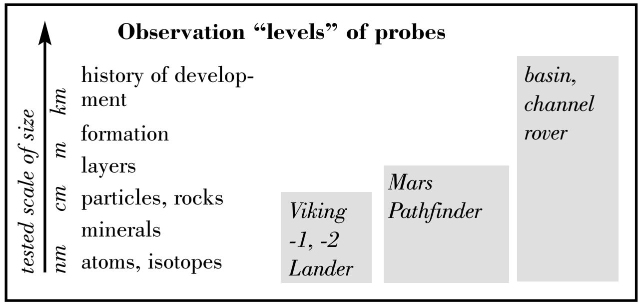
VI. MARTIAN SURFACE SHAPED BY WATER

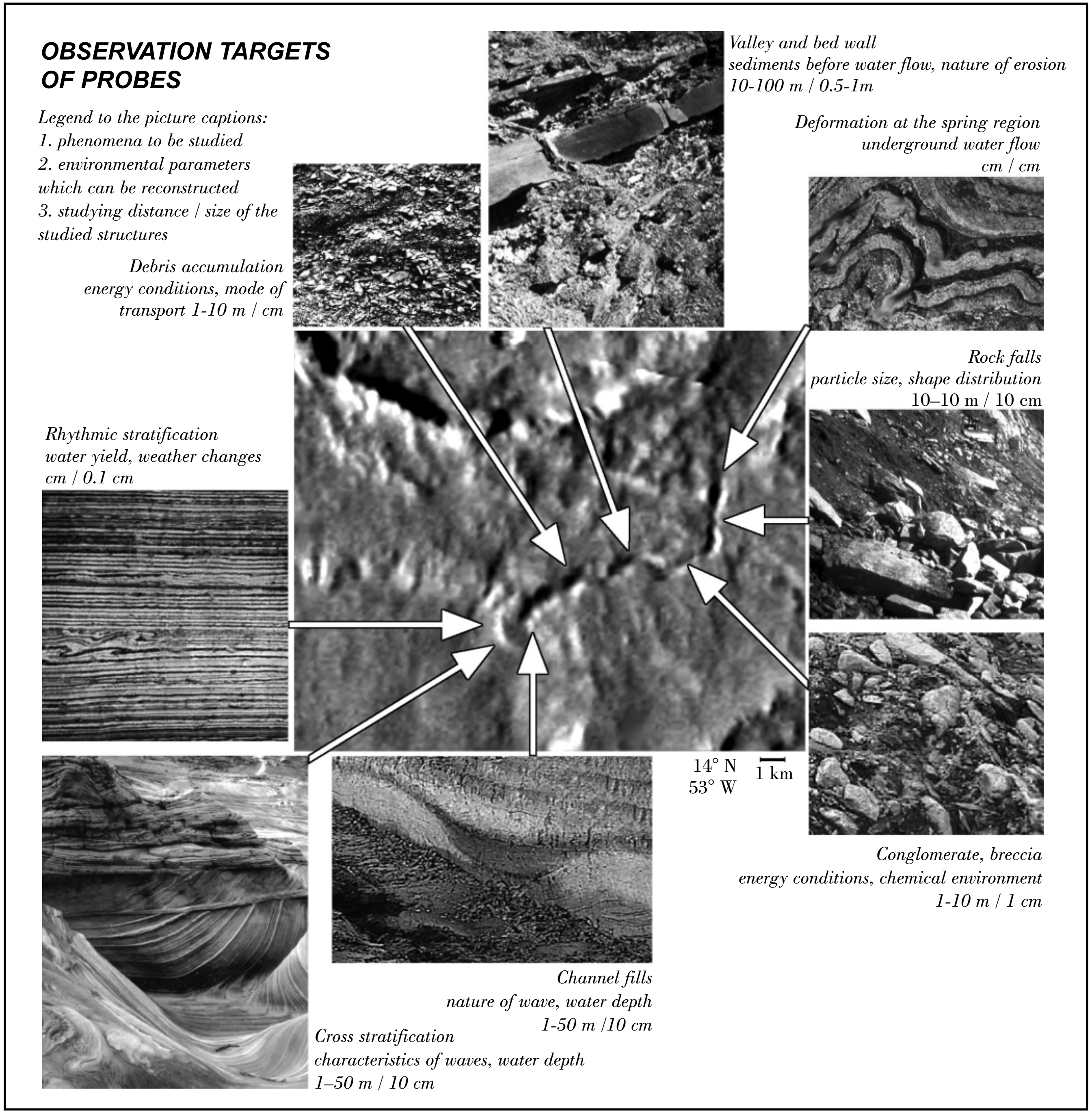
6.1. Observation targets of "Channel Rover"

The two crucial subjects of Mars exploration are the former climate (particularly the presence of water), and the possibility of life. Space probes landing on Mars and the testing of meteorites from Mars have indicated that much more sophisticated methods are necessary to provided reliable results. One of the possible methods is to reconstruct the former environment, where not randomly scattered sampling is used, but areas developing in interaction are being studied. In this way the history of development could be reconstructed more accurately.

The reconstruction of an old riverbed/valley is shown here. Our imaginary space probe is a rover, which is able to travel several km long distances even on rough terrain. Its journey is started at the upper section of a river valley. With its high resolution camera it investigates the stratification at an area of fresh collapses from a distance of 10-100 m, and observes the characteristics of the sediment under its wheel from 1-10 cm distance. If only the visual results are considered, then the phenomena shown on the picture could be observed while travelling along the channel. The microscope of the channel rover is used for observation in the cm to mm size range, and another camera with zoom lenses is used for observation of objects at a distance of several m to several hundred m.

After the estuary we will have enough data for accurately reconstruct the timeline of the water course in three dimensions. The results will show the processes taking place on the surface and under the surface, and will allow the determination of water yield, chemistry of the surface and the paleoclimate.

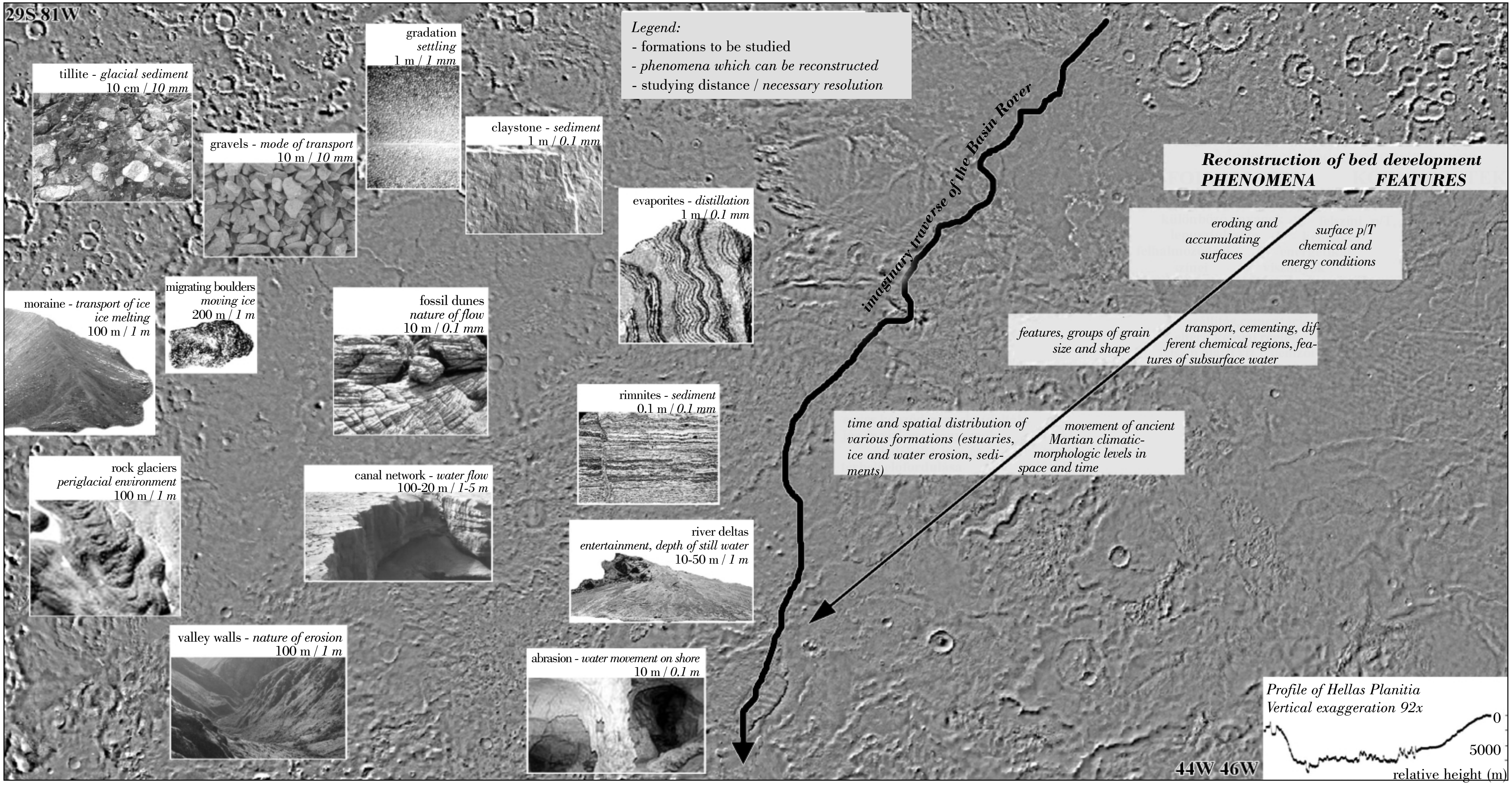




6.2 Observation targets of "Basin Rover"

Surveys performed on the terrestrial basin might be useful also on Mars. The "Basin Rover" adapted for the special Martian conditions can pay special attention to the following features (with detectors optimised to the purpose): requirements for disintegration by acid mists (cell textures on rock surfaces), disintegrating crust and its stratification (climatic changes), fault associated with mass movement in inclined direction (their shapes are related to the consistency, humidity content of the former sediment), fanglomerates and other short lived sediment originating from movement of water. The basin rover introduces a longer period within the development of the surface of the planet within a several 10-100 km distance. Hellas is the largest basin on Mars, the bottom of which is not covered by thick basalt lava. In its route the rover visits various features formed by various activities such as erosion and accumulation by glaciers, floods, network of canals and lakes.

The deepest point of the planet can be found in the Hellas Basin. This is the location where we could get closest to the potential deep water layer. Hot spots can also be observed in this area which is caused by geothermal activity. The following phenomena are utilised in the basin travelling from the rim inwards: 1. the surface formations are getting closer to the subsurface water layers, 2. the transporting distance can be determined from the location of deposits, 3. cementing and chemical environment can be used to determine the nature and behaviours of underground water, 4. the climatic changes can be observed on the sediments of various ages. In the figure the phenomena to be observed are arranged at the left, and the characteristics which can be reconstructed from these phenomena are shown on the right.



VII. MANNED LANDING ON MOON

7.1 The first steps

Armstrong has described the environment he saw and observed right after his famous first sentence after stepping on the Moon:

ARMSTRONG: The surface is fine and powdery. I can pick it up loosely with my toe. It adheres in fine layers like powdered charcoal to the sole and sides of my boots. I only go in a small fraction of an inch, maybe one-eight of an inch, but I can see the footprint of my boots.

7.2 The Lunar regolith

The soil of Moon (rock debris above the base rock) is called regolith. Its top layer has fine particles, but not graded (having variable particle size). On the surface of the Moon this layer is similar to fresh powdery snow, it has high porosity (40-70 %) giving a density of about 1 g/cm^3. It adheres easily to the garment and tools of the astronauts. When the samples were unpacked back in Earth the researches likened them to a greyish powdery slag just taken out of a boiler.

ALDRIN: It is a bit hard to penetrate the crust.
ARMSTRONG: The surface is very soft, but hard ground can be found at some places.
ALDRIN: What a beautiful desert. The surfaces of the rocks are very dusty.

The dusty surface was produced by the fragmenting effect of micrometeorites and particle radiation. Older regolith tends to be thicker, because impacts and micrometeorite bombardment have more chance to excavate the surface. The thickness of regolith at the oldest highlands is 20-30 m, while it is 2-8 m in the younger mares. The regolith layer is only several cm thick on the melted breccia layers within the young craters. The movement of masses on the slopes of crater or valley walls may expose base rock or earlier regolith layers. It is possible that debris is transferred from a farther location to a certain place, but mostly the regolith is the debris of the local base rock. Large particles never cease to exist in regolith, because impacts tend to produce new melt breccia and agglutinates in addition to fragmenting the debris. The proportion of a debris, however, is larger than that of the melt.

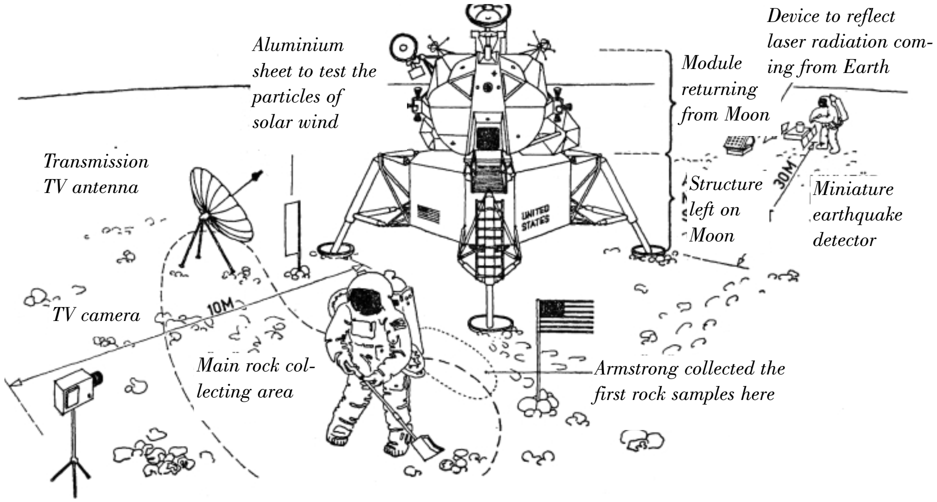
The lunar dust is being pulverised by micrometeorites, but material of a meteorite is seldom found in the dust. Impacts happen generally with a high velocity (15-35 km/s). For this reason the impacting body gets evaporated; part of which escapes the Moon, and the rest is condensed as a film layer on the rock debris. Eventual water in the micrometeorites gets evaporated during the lunar daytime and escapes the Moon (except the polar region which is in the dark constantly).

7.3 Materials of the lunar surface

Glass occurs in the form of independent drops or spherules, or as cementing material of other rocks. It may be formed after an impact from the splashing melts or in volcanic activity. Green spherules were found in the samples collected by the crew of Apollo 15, and orange glass spheres were found by Apollo 17. Most probably, both types of coloured glass originate from volcanic lava fountains (ages 3.6 billion years).

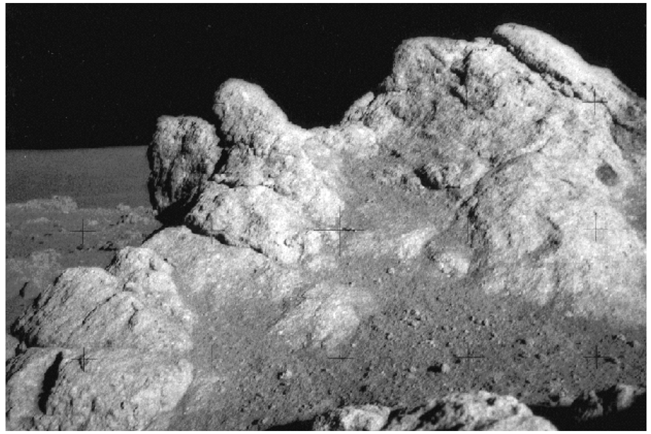
Agglutinate consists of minute melted debris produced by micrometeorite impacts, in which the glass produced by the impact cements the minerals and rock debris of the regolith. In the debris of larger craters the agglutinates are rare; their quantity is proportional to the time during which the surface has been exposed to bombardment by micrometeorites.

Breccias are produced upon impact: the melted rock cements the sharp rock debris orig-

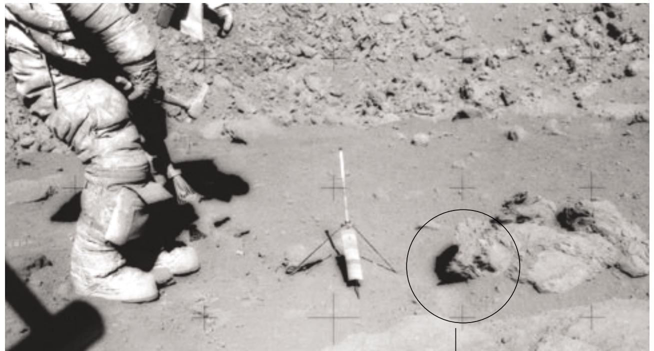


Landing site of Apollo 11 (after P. Hédervári [1970])

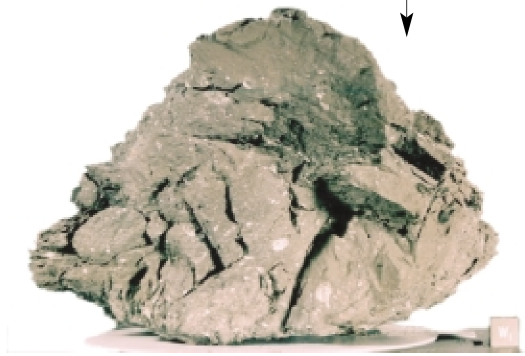
The landing site of Apollo 16 was on an upland area near to crater Descartes. The surface is covered with ejecta of a fresh impact crater.



Landing site of Apollo 14 was on the ejected blanket of the impact which formed the Imbrium Basin. On the essentially flat surface the astronauts found the ejecta (breccia) of impact which produced Imbrium Basin (shown).



4.53 billion year old breccia before and after collection (Apollo 17)



inated from various locations. Breccia-in-breccia structures are frequent, which were formed by series of impacts. The impact breccias are similar to lava, but produced from the rock melted upon impact, and are very good for radiometric dating of the impact. Apollo 16 landed on a highland where many craters are found, and collected very different kinds of breccias. Similarly to the craters, the size of breccias may vary in a wide range from the micro breccias to house-sized boulders.

The **basalt**, which is rich in iron and magnesium, fills the lunar basins and the larger craters. This has come to the surface from deeper layers of the Moon. Old basalt contains high amount of Ti, while the younger ones (3.1 billion years) have low Ti content. The mare basalt flew to the surface several millions years after the formation of large basins. Since their formation lava flows affected basins by a number of times with lava flows which are several hundreds metres thick. During the time between lava flows the regolith was being generated, for this reason thick regolith layers are enclosed within the lava flows, from which significant quantities have been thrown to the surface by impacts.

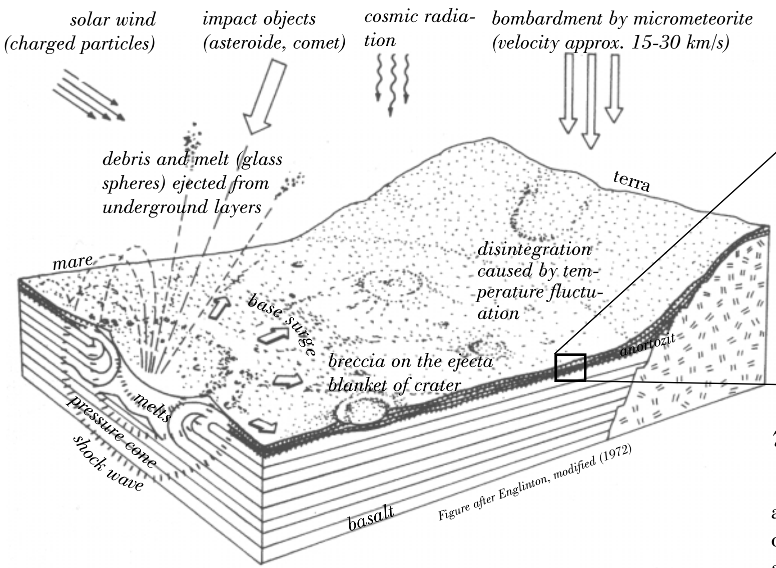
The material of the highlands is the light shaded **anorthosite**, consisting of almost exclusively of plagioclase feldspar (anorthite). Anorthosite is calcium rich feldspar which forms the less dense mineral of the magma ocean generated after the formation of the Moon. Anorthite was "floating" on the surface of the magma ocean.

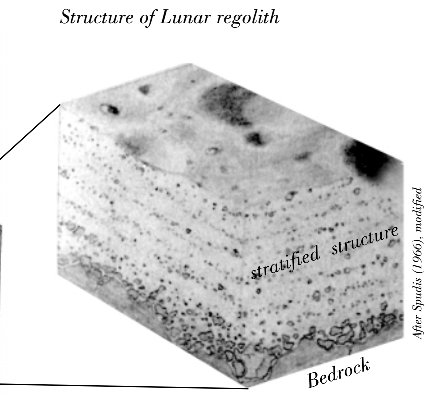
At certain locations the surface is covered with dark crust sediment (glassy ash).

The lunar regolith also takes up small quantities of gases (H, He, N) from the solar wind. The lunar regolith is rich in ^{3}He isotope relative to its terrestrial counterpart. This has accumulated during the past few billion years. In this way the surface and underground lunar regolith layers contain a 3-4 billion years old archive record of the composition of solar wind. It is also a record of supernova explosions in isotopes produced by the cosmic ray, and rocks ejected from Earth by meteorite impacts. From the ratio of the radioactive isotopes produced by cosmic radiation it is possible to calculate the time the rocks have spent on the surface of the Moon.

7.4 *Commercial use of regolith*

Potentially, ^{3}He could be used for power generation if the present efforts to make fusion reactor are successful. It could be obtained primarily from the ilmenite particles, which amount to 0-20 % of regolith, however, the economic extraction is doubtful. Instead of the fuel delivered with substantial cost it might be possible to obtain hydrogen originating from the solar wind by means of heating (as well as oxygen from the rocks, e.g. ilmenite). Yet another utilisation could be the "production" of water. Insulating material could be produced from regolith, and the glass content of the regolith could be used as construction and covering components. Power could be generated by means of solar cells during the 14 days long daytime. The power might be even exported to the Earth.

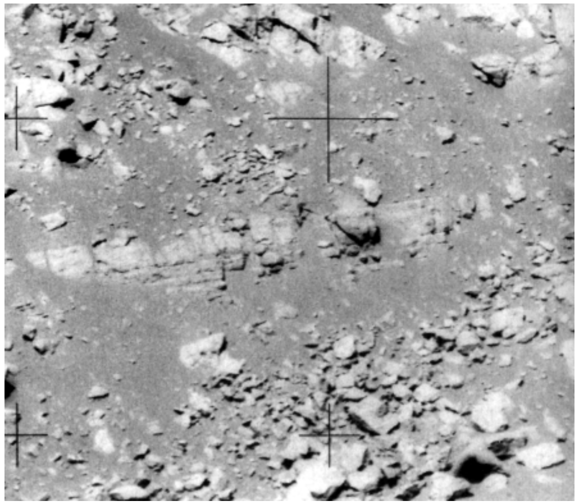


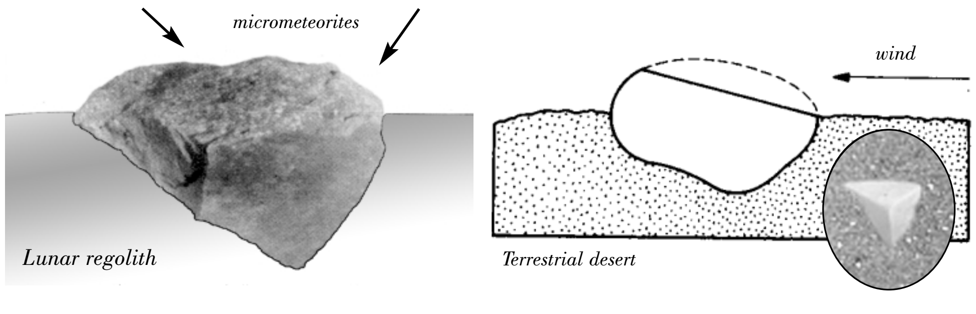


7.5 *Surface processes on the Moon*

The micrometeorite impacts, particle radiation and temperature fluctuation tend to crush and pulverise regolith. This process affects only the top several mm thick layer of regolith, and it is seldom interrupted by larger impacts. Disintegration and crushing by frost do not occur on the Moon, because water is not present even in the structure of rocks. Substantial metamorphism occurs in the base rocks to a great depth because of the high temperature and pressure caused by impacts.

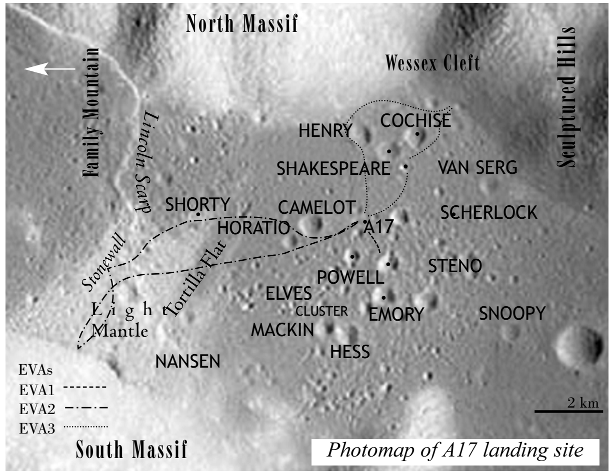
The lunar regolith has a layered structure. The core sample taken by the astronauts of Apollo 15 to a depth of about 2.5 m contained 7 distinguishable paleosoil (regolith) layers. The basalt base rock is 3.3 billion years old, and it starts at a depth of about 5 m below the surface. This is an indication of a very slow regolith generation process. In this particular location the debris from impacts covered the pulverised regolith layer seven times. The fresh debris blanket generally has a light colour, and it becomes dark very slowly during a period exceeding 100 million years. The process (pulverisation, gradual increase of regolith in agglutinates [from the impacts] and in the materials of the solar wind; and the associated darkening) last until the layer is covered by the debris blanket of another impact. Then the pulverisation of the ejected larger debris starts anew.





Above: *Partially buried boulder (sample No. 14310). The protruding part has been smoothed by the micrometeorite bombardment lasting for several millions of years, while the part protected by the Moon dust exhibits the original sharp fractured surface. The result of this phenomenon is opposite to what happens to sharp gravels of terrestrial deserts (to the right), where the sharp edges are polished by windblown quartz sand on the gravels, while the buried parts remain rounded.*
Left: *In Mare Imbrium, located close to the landing place of Apollo 15 the outcrop of basalt base rock protrudes above the regolith in the steep wall of Hadley Valley. Usually the base rock becomes exposed where the cover layer slips off a slope, or where the regolith is cleared by the explosion of an impact (based on Picture 1430 Lunar Sourcebook by Haiken, Vaniman, French.).*

Panoramic photo of A17



Photomap of A17 landing site

7.6. Significance of Apollo landings

The Moon is the only planetary body—in addition to Earth—where geologists were able to collect samples personally. The six landing locations were selected in a way that samples could be collected from as much dissimilar areas as possible. On the basis of the Apollo missions, by studying the microenvironment and testing the samples, it was possible to answer a number of crucial questions regarding planetology:

– Earlier the composition of the lunar surface was unknown. The soil is not a volcanic ash—as was supposed earlier—but ejecta fragments and fine dust produced by impacts.

– Craters are mostly the results of impacts and are not of volcanic origin.

– The age of the surface is 3-4 billion years. This is well over the age estimated prior to the landings. The dating method based on the counting of craters (relative determination) used for other planets has been established using the absolute dating carried out by using the lunar rocks.

7.7 Landing site of Apollo 17

(Taurus-Littrow Valley) (11-19 December 1972)

The last Apollo mission landed on the edge of the Serenitatis basin. The valley was formed 3.9 billion years ago when one of the rock blocks of the ridge of the basin subsided, when an impact produced the Serenitatis Basin. Later, about 3.75 billion years ago, mare basalt erupted to the surface. Before the landing missions, the "halo craters" in the vicinity, which are covered with dark blanket, were thought to have been the vents of volcanic ash cones. The Shorty crater has been investigated to decide whether it is a volcanic vent. "Orange soil" (glass) and black (ilmetite) spherules were found in the vicinity. The glass was formed 3.6 billion years ago from lava fountain coming from a depth of 400 km. This lava fountain is part of the mare activity. On the other hand, the erosion of the young crater is less extensive and it originated from an impact. For this reason there is no connection between the crater and the orange soil. 4.2-4.5 billion years old rocks were also collected, which were formed much earlier relative to the Serenitatis impact. Actually, these rocks were carved out from a deeper part of the Moon's crust by the impact. Some of the samples indicate that the vicinity was affected by a large impact c. 100 million years ago: large boulders rolled down from the hills at that time, from which the samples were taken. The landing location is just at one of the rays of the young Tycho crater. Samples indicate that the Tycho impact occurred about 108 million years ago.

7.8 Advantages of manned landings

Exploration of planets used to cause many surprises for the researchers. All Apollo missions have revealed findings which were not expected earlier by the scientists (e.g. the finding of "orange soil"). Automatic space probes could not be prepared for such events, not even with flexible programming, and the process would also be hindered by the fact that real time connection is impossible to maintain with the space probes because of the time required for electromagnetic (radio) signals to travel long distances. Man can adapt to the environment of the landing location in order to execute the exploration efficiently in various aspects. Astronauts are able to select the most important locations and samples from a large area in the aspect of geology for instance. The flexibility of astronauts cannot be surpassed with machines (e.g. repair of faulty equipment as in the case of A-13). On the other hand, certain events could jeopardise the mission if astronauts are present (e.g. radiation from unexpected solar flare, psychological crisis, illness: crew of Apollo 7 got the flue during flight).

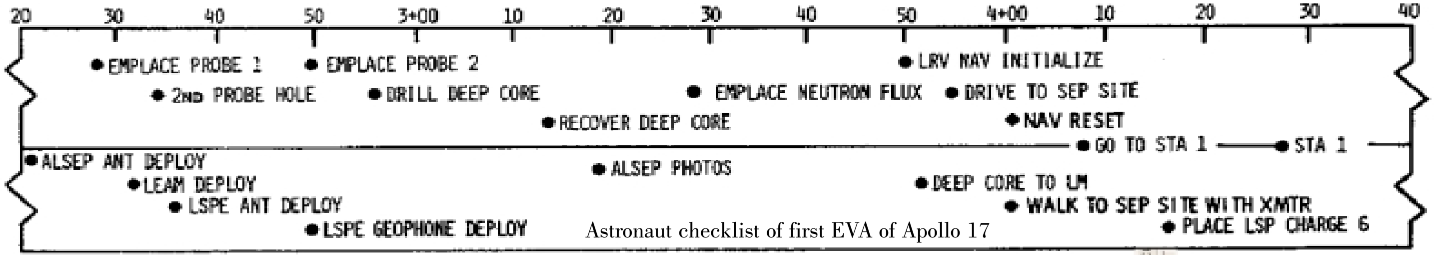
While landing on the Moon with Apollo 11 Armstrong watched the Moon and Aldrin observed the radar. Just before touchdown Armstrong detected that the spacecraft was going to land at the centre of a crater where car sized boulders were present. He switched over to manual control, and flew the Lunar Module farther on where the surface was flat enough. It is possible that the mission would have failed had it been controlled by automatic equipment.

The Apollo mission had a drawback though, i.e. all activities of the crews had been determined in advance. In this way the astronauts were allowed to collect rocks only, and could not make decision of their own, could not engage in "sightseeing", could not go to locations of interest, which normally is an essential mode of operation for geologists. It is also important to track the area a number of times, to discuss the observations, carry out various tests, to use the result for determining additional tests until the mental geological map of the terrain is satisfactorily obtained by the explorers. This could have been done only with a longer stay.

Manned landing on an alien body is an advanced stage in the sequence of operations starting with observation through telescopes, then continued with first fly-by → orbiter reconnaissance → automatic lander/descend probe → rover → soil samples → sample return.

The subsequent stage would be the construction of a permanent base, for which the terrain would be prepared by automatic machines, and the basic supplies necessary for the operation of the base (power, water, food, construction material, radiation protection, fuel) should be obtained from local resources.

In addition to extracting raw materials an eventual lunar base could serve astronomical purposes as well. The lack of atmosphere makes the Moon an ideal place for various activities, such as infrared observations at the permanently shadowed location in the polar region (low temperature is required for such tests), as well as radio astronomy at the far side of the Moon (thus shielding the radio noise from Earth). Smaller craters would provide place for huge parabolic antennas. The possible problems to be handled include the adhering dust and the effects of solar flares.



Astronaut checklist of first EVA of Apollo 17

7.9 Illumination on the Moon

Stars can be seen even during daytime from the Moon because of the lack of atmospheric scatter. From a given point of the near side of the Moon the location of Earth in the sky is always the same as a result of the locked orbiting. The phase varies only. The Sun moves very slowly across the sky because the daytime lasts for 14 days. At zero longitude on the Moon (central region of the visible side) a full Earth can be seen at midnight of the 14 days long night. The lunar terrain is illuminated by a fairly great amount of light from Earth relative to the moonlit night on Earth. As opposed to the 7 % of the light reflected by Moon the proportion of light reflected by Earth is 39 % thanks to the clouds. From the Earth this can be observed as an ash-grey illumination. This phenomenon is the strongest during full Earth (during new Moon as seen from Earth). It has an effect even during the lunar daytime, when the shaded areas would otherwise be completely dark because of the lack of atmospheric scatter. The shaded areas are illuminated by the light from Earth. Astronauts of Apollo 10 flew over areas not illuminated by the Sun a number of times. The details of the lunar surface could be well recognised in the ash-grey illumination, but standing on the suface, it was difficult to accostume to the sharp contrasts.

ARMSTRONG: It's quite dark in the shadow [of the LM] and a little hard for me to see if I have a good footing. ...

ALDRIN: Light is strong, it takes quite a while to accustom to it. But if I stay long enough in the light, it is all right.

Further light sources include the zodiacal light and the post sunset lunar horizon glow of electrostatic charged dust.

All astronauts reported flashes in the eye while their eyes were closed (Visual Light Flash Phenomenon). Two such light strip/points were experienced in one minute generally while resting in the Lunar Module. This phenomenon is caused probably by particles from the cosmic radiation crossing the retina.

7.10 Navigation on the Moon

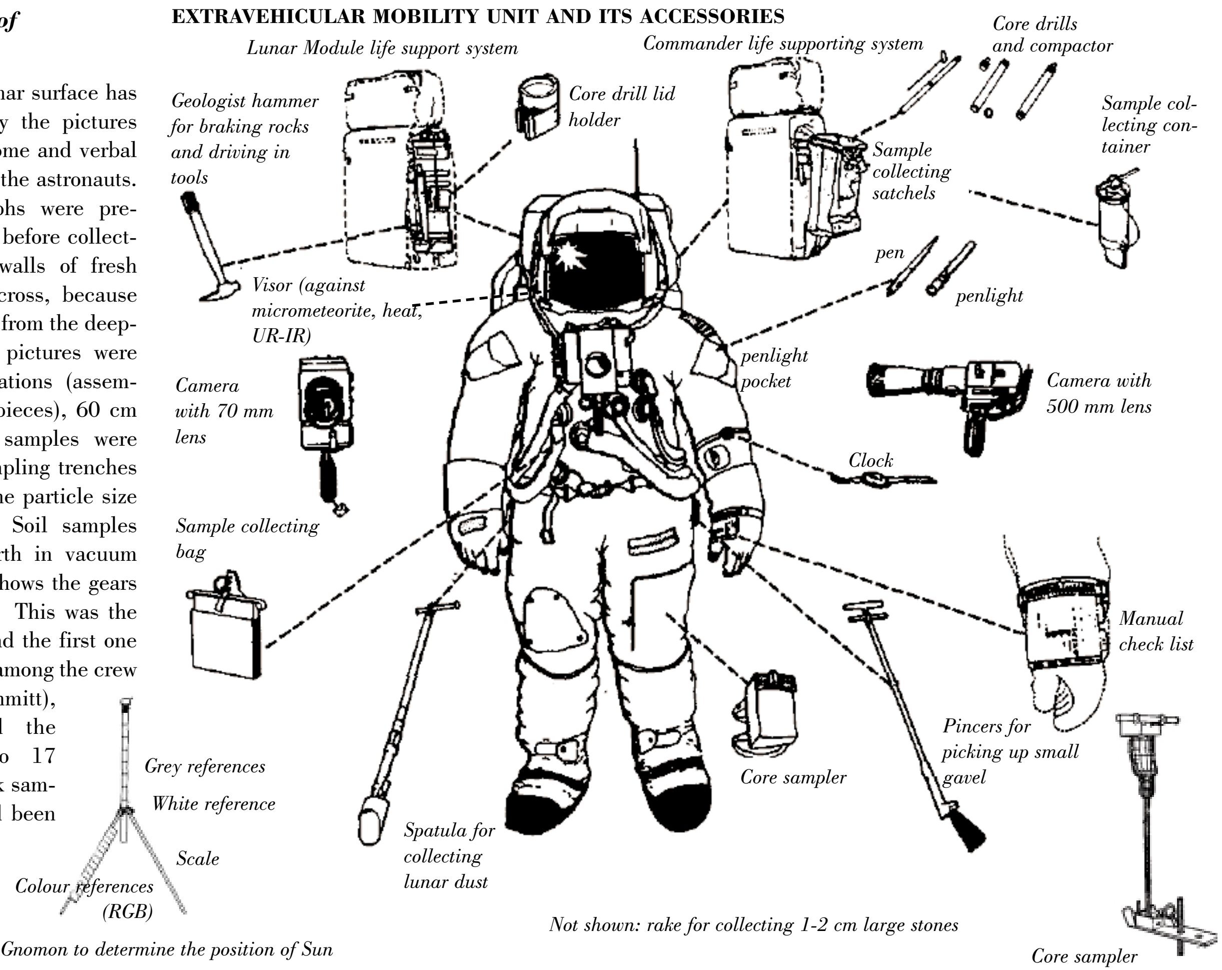
The astronauts of Apollo 14 got lost sometimes when walking on the Moon. It is hard to assess distances because of the crystal clear view in the vacuum, as the Moon has no atmosphere. In this condition everything can be seen equally sharp up to the horizon. The orientation is also difficult because of the lack of familiar objects of terrain (trees, houses, etc.). Except for the boulders of various sizes, there are no objects to help the orientation. The boulders, however, are quite similar and have varying sizes. In the picture below a boulder can be seen behind John Young. This boulder is much larger than it seems: it is as large as a house. The components of the terrain seem to be in close vicinity even if they are several kilometres away. The distance of the horizon cannot be estimated either because of the rolling surface. The astronauts of Apollo 14 could not find the rim of the crater to be sampled in spite of the fact that they were standing on it…

Distances are difficult to estimate on the Moon. How far is the boulder behind astronaut John Young (Apollo 16)? See the text for the answer.

7.11 Work and gears of astronaut geologist

The geology of the lunar surface has been revealed mostly by the pictures took, samples brought home and verbal communication made by the astronauts. Stereo colour photographs were prepared about the samples before collecting them. The ridged walls of fresh craters were sampled across, because this part contained rocks from the deepest location. Panoramic pictures were prepared at various locations (assembled from a number of pieces), 60 cm and 30 cm long core samples were taken, soil (regolith) sampling trenches were excavated, where the particle size was also investigated. Soil samples were taken back to Earth in vacuum packages. The picture shows the gears of Apollo 17 astronauts. This was the last landing on Moon, and the first one in which a geologist was among the crew members (Harrison Schmitt), who also commanded the Lunar Module. Apollo 17 brought back 110 kg rock samples to Earth, which had been collected during a 22 hour long EVA.

EXTRAVEHICULAR MOBILITY UNIT AND ITS ACCESSORIES



Gnomon to determine the position of Sun

VIII. MICROMETEOROLOGICAL MEASUREMENTS ON THE EARTH AND MARS

Mars is the first planet on which meteorological measurements similar to those usually performed on Earth have been done. Micrometeorology—describing the phenomena occurring close to the surface—has become an auxiliary subject of space research. Micrometeorology deals with processes the characteristic size of which are less than 10 km, and having time scale not exceeding one day. Such processes take place in the layer close to the surface, in the so-called Planetary Boundary Layer (PBL), where the surface of the planet provides mechanical and thermal forces.

The study of the surface layer (the lower 10% of the PBL) is particularly important in the exploration, including the determination of the surface energy budget components, studying of various exchange processes (momentum, sensible and latent heat, trace materials) above various surfaces (bare soil, low and tall vegetation, water, ice or artificial surfaces, such as a town). The dynamics and the characteristic phenomena of the PBL are similar on all planets having an atmosphere. The meteorological measurement programme of Viking and Pathfinder probes sent to Mars was designed by American, Danish and German micrometeorologists. This science—at least on the Earth—is closely related to the human activities.

8.1 Structure of the Planetary Boundary Layer

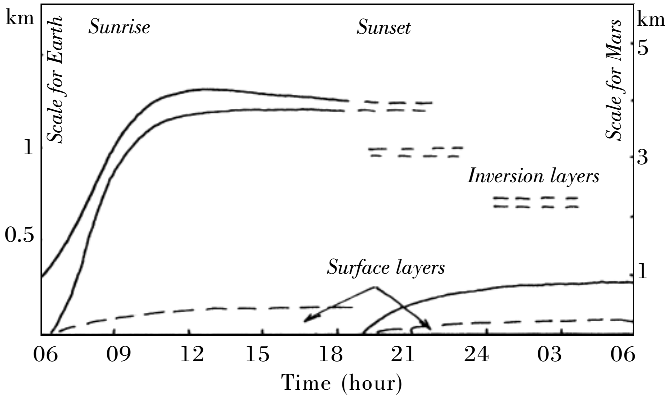
Let us review the structure and wind profiles of the daytime convective and night-time stable boundary layers (for more detailed discussion, see the Atlas of Planetary Atmospheres [Bérczi et al., 2002]) The convective PBL starts to develop very quickly after sunrise by the thermal and mechanical turbulence. Its average height on Earth is 1-1.5 km. This is nearly 5 km on Mars, where the atmosphere is much less dense and the temperature fluctuation is much more intensive. Eddies rising from the warmed surface (thermal turbulence) are larger and more uniform relative to the ones occurring during the night forced by mechanical turbulence. Take the small whirlwinds—or thermals—occurring on Earth and Mars, for example. The PBL is well mixed and the wind speed increases slowly with height.

The surface cools down during the night, and a shallow stable PBL is born. The wind speed increases with height quickly. The inversion layer above the cold surface (temperature decreases with height) is the border of the PBL, where the wind is usually strong.

The development of the PBL is governed by the components of surface energy budget (radiation, sensible heat, evaporation and heat flux into the soil), as well as by the meteorological parameters of the surface and the free atmosphere (wind velocity, temperature, humidity). The components of the surface energy budget are often parameterised on the basis of the cloudiness and the standard meteorological parameters (temperature, humidity, etc.). The formula of the surface energy budget is as follows:

$$Rn = H + LE + G,$$

where Rn is the net radiation, which is the sum of short wave (solar origin in the range 0-4 μm) and long wave (4-100 μm) radiation balance. H is the sensible heat flux of turbulent eddies, LE is the latent heat flux carried by the vapour, G is the heat flux into the soil; the dimension being [W m^{-2}].



Daily variation of the Planetary Boundary Layer (PBL) on Earth and on Mars.

8.2 Micrometeorological measurements – Bugacpuszta, 2003

In addition to the standard meteorological parameters, micrometeorologists measure the surface temperature, as well as the temperature-, humidity- and windprofiles in the surface layer and the components of the radiation and energy budget. They calculate the albedo (ratio of the reflected and incoming short wave or global radiation), record the photosynthetically active (400-700 μm) radiation and the radiation balance.

The heat flux into the soil is determined on the basis of the soil temperature and soil moisture profile measurements. The heat transfer in the deeper soil layer is also measured.

The structure and property transfer of turbulent eddies are measured with high sensitivity instruments with frequency of 10-20 Hz, as the characteristic size of eddies are proportional to the height above the surface, and they pass in front of the instrument within a few seconds. A sonic anemometer is used to measure the actual value of temperature and 3-dimensional wind velocity. The principle of measurement is based on the assessment of sound velocity using the Doppler-effect. The concentration of trace material (e.g. water vapour, carbon dioxide) is measured with laser working in the absorption range of the given gas.

8.3 Micrometeorological station on Mars – Pathfinder, 1997

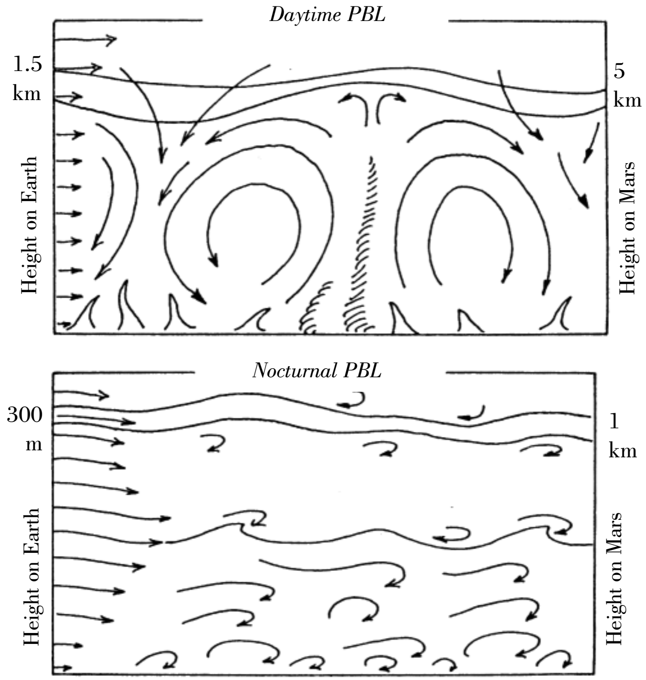
In 1976 two Viking space probes performed measurements on Mars for 1050 and 2245 Martian days. (1 Martian day, or 1 Sol = 24.62 hours, while 1 Martian year = 667 Martian days).

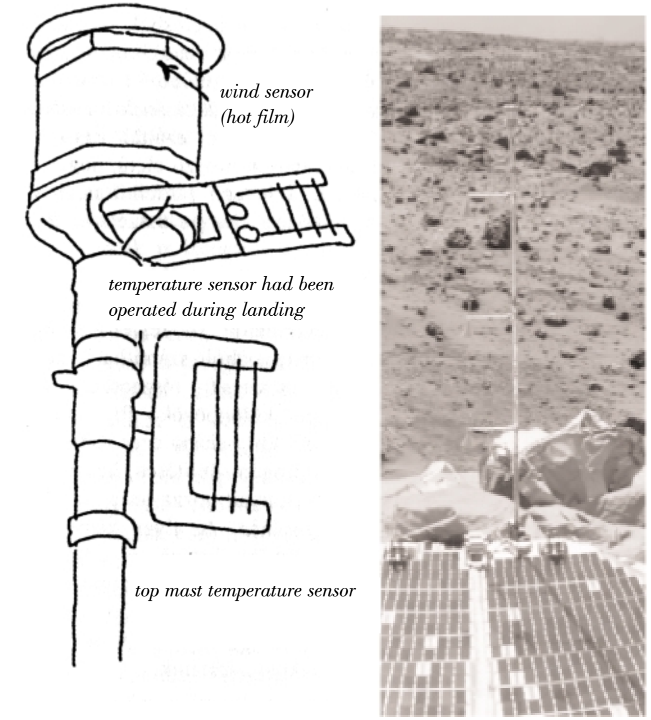
The Pathfinder landed on Mars on 4 July 1997, and provided data for 92 days. The measurements took place in the lower 1-2 m thick near surface layer. An anemometer was used for wind measurement using thermal film sensor. The principle of measurement is very simple. Six thin sheets (films) are kept at a constant temperature above the ambient temperature. The power required to do this is proportional to the wind velocity and direction, i.e. with the heat transfer of the molecules hitting the film. Agro-meteorologists work with similar anemometer working with thermal wires for describing the wind profiles within the vegetation. Cave surveyors also use such instruments to detect small movements of air. The instrument is very sensitive, having an accuracy of cm/s, to provide a measurement with 4 Hz resolution, just like in case of Pathfinder.

Air temperature is also an important meteorological feature, which was measured by sensitive thermocouples that are normally used for terrestrial measurements as well. The actual temperature of the measuring point is provided relative to a reference level. A novel aspect of the project is that the temperature was measured at three different levels (65 cm, 90 cm and 1.4 m). Surface pressure data were also collected.

The momentum and sensible heat transfer of eddies (turbulent fluxes) can be calculated with the so called similarity theory using the temperature gradient and the wind velocity. Roughness length of the surface can also be observed, which was found to be 0.3-3 cm on Mars.

The components of the surface radiation balance have been simulated on the basis of the "transparency" (opacity) of the atmosphere using data provided by Pathfinder and Viking space probes.





Temperature and wind velocity sensors of Pathfinder

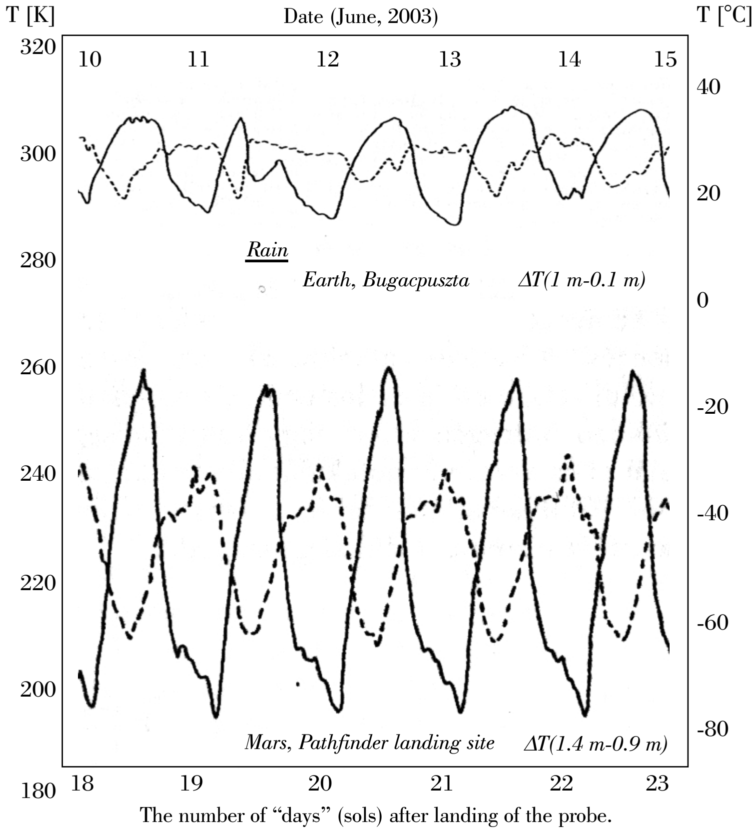
Analogously to the processing of terrestrial measurements the evaluation of Martian data is aimed to find the answers to the following major questions:

– what is the structure of turbulent eddies during daytime and night,
– what is the spectra of wind speed and temperature,
– how can the daily changes of the surface layer be measured and simulated, including the surface radiation and energy budget components,
– how do the daytime and night-time boundary layers develop on Mars,
– how can the one and multi-dimensional PBL models be applied?

8.4 Some characteristics of the surface layer on Earth and Mars

The Martian atmosphere contains 95% CO_2, 2.7% N_2, 1.6% Ar, 0.13% O_2 and 0-0.2 % water vapour. The mean air pressure at ground level of Earth is 1013 hPa, and the density is 1.2 kg/m^3. On Mars these values are less by two orders of magnitude: the surface pressure is 7-8 hPa, the density is 0.015 kg/m^3. The pressure decreases logarithmically with height on both planets. On Earth the sea level pressure varies within a few times 10 hPa interval.

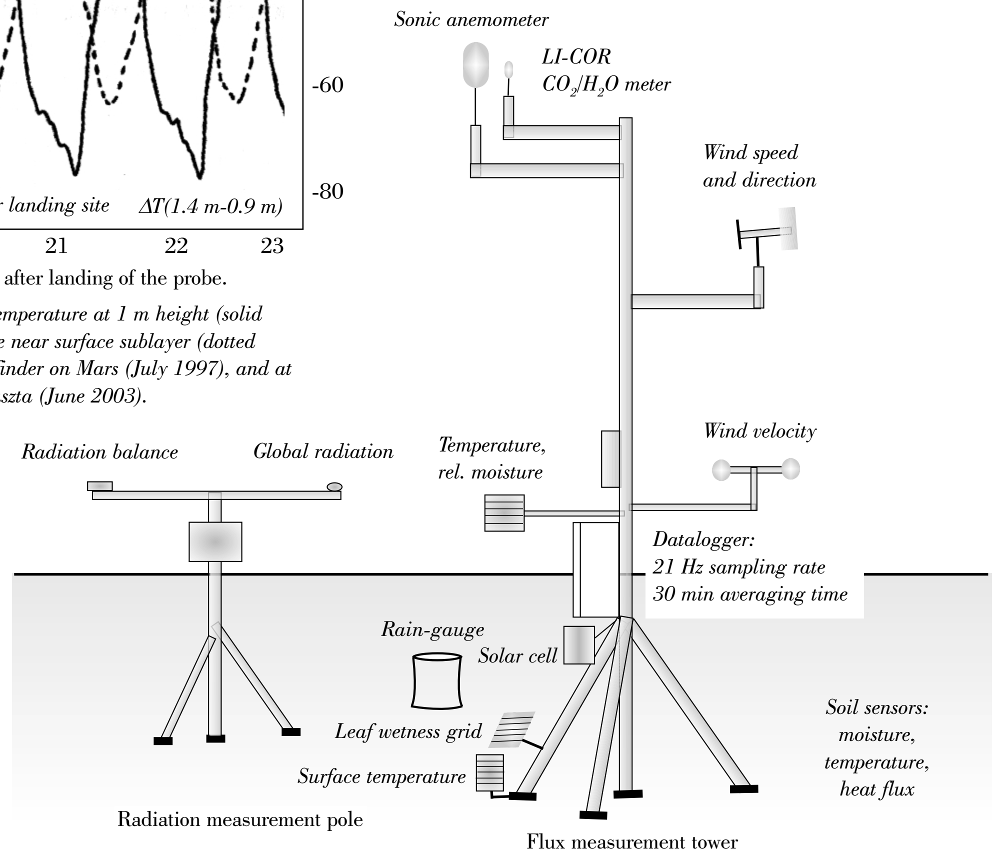
During winter time the temperature at the polar region of Mars reaches the freezing point of the carbon-dioxide due to the large distance from the Sun. Dry ice begins to accumulate, which results in a 10-15% decrease of the atmospheric surface pressure.



Comparision of diurnal variation of temperature at 1 m height (solid line) and temperature difference in the near surface sublayer (dotted line) based on measurements by Pathfinder on Mars (July 1997), and at the meteorological station of Bugacpuszta (June 2003).

Because of the significant eccentricity of the Martian orbit the amount of CO_2 condensed on the South and North Poles and the sublimation occurring after the winter period exhibit very different dynamics. This causes an annual pressure wave. The solar constant of Mars is only 44% of that of Earth. Because of the scarce atmosphere and the lower albedo the Martian radiation balance is comparable to that of Earth. The ground heat flux is larger, and the sensible heat flux is smaller. The evaporation of water carries very little energy. The daily temperature fluctuation, however, is significantly larger on Mars relative to Earth. The wind velocity close to the surface is similar on both planets. The greenhouse effect on Earth is ~33 °C, and on Mars it is ~10 °C. The average temperature on the cold Mars is -50 °C; the temperature varies in the range -125 and +20 °C. At the same time, the average temperature on Earth is 15 °C, and the temperature ranges from -80 to +50 °C. The fluctuation of temperature (deviations from the average value) is significantly higher on Mars. The deeper planetary boundary layer in Mars is a result of the strong thermal turbulence and the scarce atmosphere.

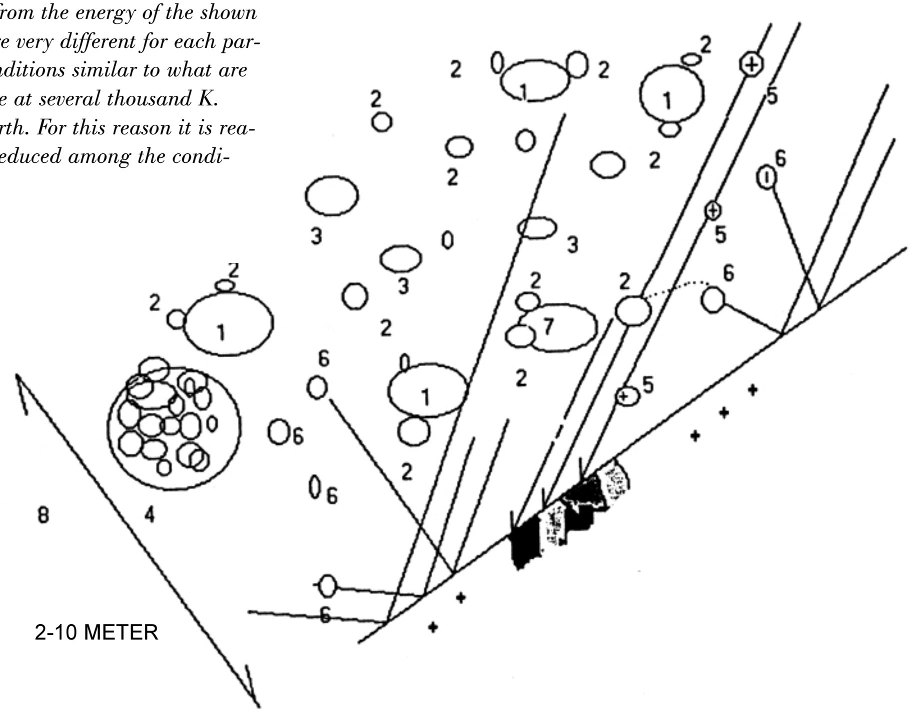
EU5 GREENGRASS program
Location in Hungary: Bugacpuszta
Operated by Szent István University and Eötvös Loránd University
The main objective of the project is to determine the annual balance of the greenhouse gases (CO_2, N_2O, CH_4) above grassland at various climatic zones of Europe: from the rainy Scotland to the drying Hungarian Plain.



IX. ELECTROSTATIC PHENOMENA IN THIN ATMOSPHERE

Space probes arriving at Moon and Mars meet thin atmosphere. The density of lunar atmosphere is below that of the highest vacuum that can be produced on Earth. For this reason the ultraviolet (i.e. high energy) part of the solar radiation has an ionising effect. This ionisation effect appears also on Mars, but to a less extent. First, the case of the Moon is discussed and the model of an instrument is introduced, which might be used for performing the measurements. This is called the FOELDIX-1 measuring instrument, which has been designed for mounting on the university experimental space probe called Hunveyor.

The temperatures that can be calculated from the energy of the shown particles of the lunar quasi atmosphere are very different for each particle. E.g. the solar wind produces the conditions similar to what are experienced in a hydrogen flushed furnace at several thousand K. Such furnace has a reducing effect on Earth. For this reason it is reasonably to state that the rocks are being reduced among the conditions prevailing on the lunar surface.



Model of lunar quasi atmosphere:
1. Oxygen;
2. Hydrogen;
3. Dust particle;
4. Coagulated dust particle (this already contains water molecule);
5. Proton from the solar wind; 6. Electron expelled by UV radiation of Sun from a particle of the dust on the surface;
7. Water molecule;
8. Extent of lunar quasi atmosphere above the ground: this is the range where impacts are still relatively frequent.

9.1 *Levitating dust cloud above the Lunar surface*

A very interesting phenomenon was photographed by Surveyor-5 on the Moon, which was also measured by the LEAM experimental equipment of the Apollo missions. Surveyor-5 photographed a shiny dust cloud above the horizon of the western sky at dusk after the terminator (the borderline of the illuminated and dark areas) has passed over the space probe. The device of Apollo measured the travel of this dust cloud above the instrument deployed on the lunar surface in the same period of the day. The following electric model can be set up to explain the occurrence of the dust cloud.

Lunar surface is covered with fine dust. The energy of the UV radiation of the Sun is high enough to ionise the atoms within the dust particles. The UV photon displaces one of the extreme electrons of the atoms, thus making the remaining dust particle positively charged. The ejected electron does not meet any particle because of the high vacuum, and is extracted from the system. After a certain time the dusty surface gets charged enough to lift the smallest dust particles from the surface. In this way a floating dust cloud is produced above the illuminated lunar surface, and this dust cloud is positively charged and consists of independent particles. This can be seen only during sunset when the background is dark.

9.2 *Effect of solar wind on dusty surface*

The most important particle component of solar wind is the proton. Proton is the nucleus of the hydrogen atom and has a positive charge. It is very probable that protons having energy of several electronvolts (eV) meet free electrons in the vicinity of the lunar surface, and as a consequence a hydrogen atom is produced by the proton combined with one electron. The small mass of the electron does very little in changing the direction of the proton which has a mass about 2000 times that of the electron. The neutral hydrogen atom impacts on the surface. Among the conditions of Earth such kinetic energy produces a temperature of several thousand K in hydrogen charged furnaces. Such furnaces can be used very efficiently for reducing various materials. The same happens on the lunar surface in molecular scale. The incoming hydrogen atom hits an oxygen atom, a water molecule is formed, and it is expelled from the material of the surface. In this way the quasi-atmosphere of the Moon is enriched with water molecules as a result of the solar wind.

9.3 *Water molecules and levitating dust cloud*

The model of the lunar atmosphere described belowhas a very interesting relationship to the development of electron tubes conducted by Bródy and Palócz in the laboratory of the Tungsram Factory, Budapest during the 1930s. During the experiments a mono-molecular water layer was detected on the internal surface of the vacuum tubes (electron tubes) even if high vacuum was applied. This phenomenon was detrimental to the quality of the manufactured electron tubes. The phenomenon was caused by the water molecules which retained the negative electrons for a prolonged time, and thus adhered to the positively charged surface of the glass. What is important in this context is that the negative ions produced by water molecules have very long life span. The water molecules generated close to the lunar surface as described above gets impacted with the electrons produced by the UV radiation of the Sun, thus obtaining a negative charge. The long life negatively charged water ions meet the positive dust particles floating above the surface. As a result of the energy of the impact the water molecules and the dust particles are bonded together, and this is the initial step in a long coagulation process. The size of the coagulated dust particles increases as the process is repeated. This is basically the model of the lunar quasi-atmosphere (Földi, Bérczi, Palásti, 2001).

9.4 *Result of coagulation among Martian conditions*

There is a significant atmosphere on Mars relative to that of the Moon. This atmosphere consists mainly of CO_2 and water vapour. The processes described for the Moon are greatly enhanced by the presence of these two constituents.

The reduction of CO_2 helps the generation of water molecules already in the upper regions of the Martian atmosphere. Very fine dust particles are also present in the Martian atmosphere. For this reason the phenomenon described for the Moon appears already in the upper layers of the Martian atmosphere.

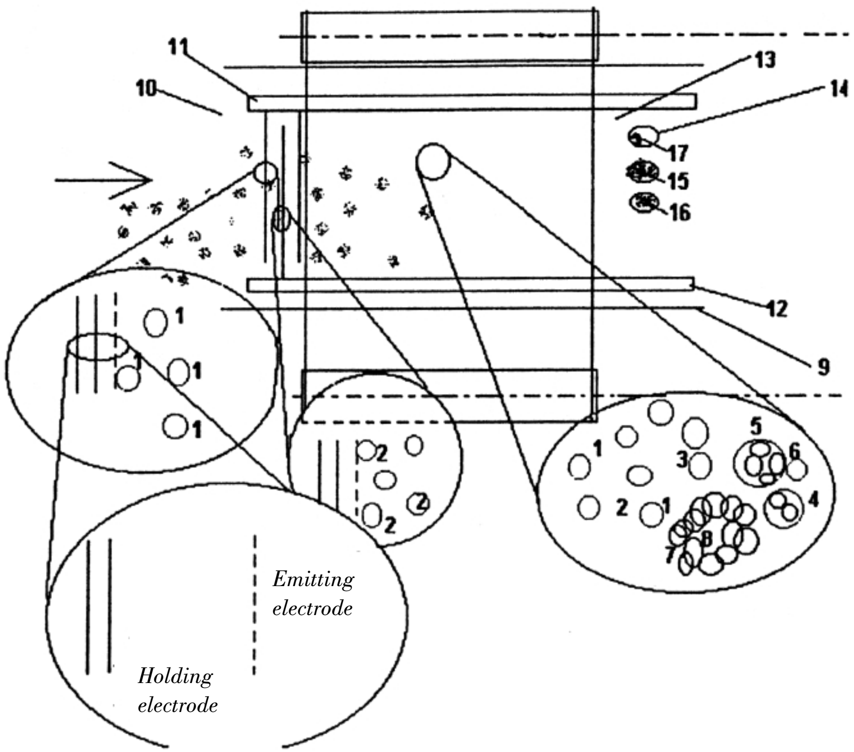
The most important difference, however, is that the coagulation affects of other types of particles as well. If bacteria or spores are also floating in the Martian atmosphere (because the wind moves large masses of the atmosphere), then such particles may be embedded in the compounds of dust particle and water molecule. With such an embedding the floating bacteria might get protection against the UV radiation. The bacteria in these packages might be carried to any point of Mars by the wind. Based on the analysis of the photographs of Mars Global Surveyor, Hungarian researchers have identified potential sources from where the Martian bacteria could come from. Dark Dune Spots (DDS's) can be observed during the end of winter to spring period at around latitudes 60-80° close to the South Pole. The research team thinks that some kind of Martian life could exist beneath that thawing snow-ice cover (Horváth, Gánti, Gesztesi, Bérczi, Szatmáry, 2001). This area could be the preferred landing site of future Mars probes. If a device (FOELDIX-1) could be deployed in this area for collecting coagulated dust, then it would be possible to detect any bacterium.

9.4 Operation of FOELDIX-1

FOELDIX-1 is an electrostatic instrument used for collecting dusts. It is capable of separating dust particles from the gas flowing through the instrument with the use of electrostatic field. A version of this instrument, dimensioned for a space probe, was assembled in 2001. This is an important component of the Hunveyor space probe. The principle of operation is based on the processes described for the lunar atmosphere. As has been indicated above, the water molecules retain the negative charge for a long time in vacuum. FOELDIX-1 is a tube similar to an electron tube, in which rows of cathodes and anodes are arranged alternately. The difference relative to the usual electron tube is that in this instrument the anode emits positive ions also. (In a regular electron tube only the cathode emits electrons.) Anode and cathode electrodes are installed alternately in the tube in the direction of the flow of the rare gas. Equal, but opposite voltages are applied to the electrodes. The wall has a zero potential. Locations of negative and positive electric fields appear alternately within the tube as a result of this configuration. The phenomenon to be utilised by this instrument appear at the interface of the negative and positive fields. Dust particles moving with the flow get a negative, then a positive charge. For this reason they are coagulated at the interface. The mass increase within the tube could be as much as 500 000 fold by changing the charge 19 times started from the nanometre sized dust particles (and the particles containing nanometric bacteria). Except for the applied orientation this process is the same as the one described for the lunar atmosphere. In summary, the tube of the instrument FOELDIX-1 is the functional model of the lunar and Martian quasi atmosphere. As installed in the Hunveyor, it works as an instrument using the observation, detecting and remote signalling functions.

9.5 FOELDIX-1 configured for searching for traces of life

The purpose of FOELDIX-1 device is to collect biological particles on the surface of planets. In extreme environment on Earth we can find living microorganisms, which might also be expected in the Martian environment. Such microorganisms could be collected together with dust particles with the FOELDIX-1 device, e.g. on the ice desert of Antarctica and in the hot desert of Sahara and in the low pressure region of stratosphere. The most efficient use of this device would be at the areas covered with dark dunes in the south polar region of Mars. It is possible that liquid water appears at the lower part of the frozen layer during the spring time thawing. Living bacteria might be present which sustain life with the energy of the sunshine in the dark spots of the dunes. After the sublimation of the frozen layer the dust and the embedded microorganism might be carried away by the wind, which could be collected by the device FOELDIX-1. According to the introduced principle of operation the concentration of the living organisms will be higher within the device, thus improving a chance of their detection. The instruments could also be used at location where the concentration of living organism is expected to be lower, such as close to the equator, in the atmosphere or at the upper border of the Martian atmosphere.



Major components of FOELDIX-1:
1. *Dust (or aerosol) particles with positive charge;*
2. *Dust (or aerosol) particles with negative charge;*
3. *Coagulated dust (or aerosol) particles;*
4. *Coagulated dust (or aerosol) particles with positive charge;*
5 *and 6. Recharged positive coagulated dust (or aerosol) particle (5) meets the positively charged dust (or aerosol) particle;*
7. *Dust (or aerosol) particles after multiple coagulation in bunch-like clusters (with a max. 500 000 fold mass increase), with a packaged nanobacterium inside (8) or virus;*
8. *Bacterium or virus (or other particle with biological information) inside the particle after multiple coagulation of dust (or aerosol); [in such configuration the bacteria are protected from UV radiation of the Sun];*
9. *Wall of the tube;*
10. *Entry gate for atmospheric gases, as well as for invoiced dust and other particles;*
11. *Electrode at positive potential;*
12. *Electrode at negative potential;*
13. *Collecting electrode at zero potential, on which the coagulated particles are precipitated;*
14, *15, 16 and 17. Various culture media for bacteria.*

X. CHEMICAL COMPOSITION OF THE ATMOSPHERE

10.1 *Operation and measurements: the gas chromatograph*

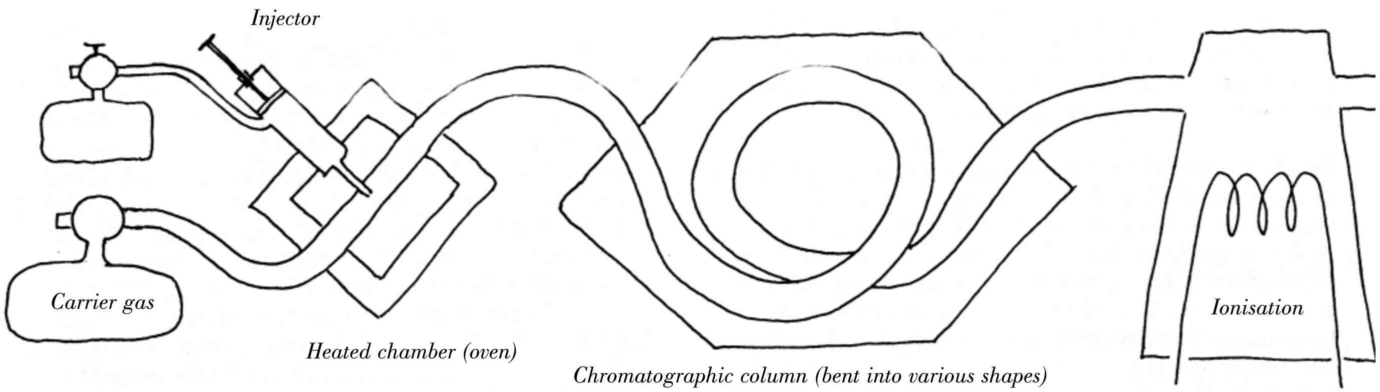
The measurement made with the optical chemical sensor developed by Barna Kovács is similar to the measurements carried out by gas chromatograph. The former is applicable for determining the concentration a substance at a time, while with gas chromatography it is possible to determine more than one substance simultaneously. The components of the vapourized sample are differently trapped by a material (stationary phase). This latter is chemically bounded to the wall of 10-100 m long tube (column), or alternatively filled as a fine granulated material into the tube. There is a constant, so called carrier gas, which would not let the compounds to settle in the trap, but carries it all through the tube. The long layer delays the components of the sample differently, in this way the various compounds can be separated from each other.

Let us now review the kind of materials and the modes of measurement used.

Together with the carrier gas the sample is introduced into a tube (column) having a length of e.g. 30 m. The purpose of the long tube (column) is to provide a long path for the flow of materials. Trapping material (e.g. active carbon, special silicone oil, etc.) are placed on the wall or inside the tube. It will selectively trap the molecules of the introduced sample during the long travel, because the chemical equilibrium between the gas phase and the stationary phase is different for each compound. By this trapping the various compounds are delayed differently while they travel along the tube. A detector is located at the end of the tube to measure the quantities of the delivered materials. For instance this can be a mass spectrometer. Various components arrive at the detector in sequence.

10.2 *Gas chromatographic detectors*

How do we know that a certain compound has come out of the column? In this section we review some types of detectors, and describe the information which can be obtained with their help. The area beneath the signal is proportional to the concentration, but it also depends on the kind of compound and the type of detector. If it is required to know the concentration accurately, then the signal has to be determined as a function of the concentration (plotting the calibration curve). Using internal standard method is also possible. This means, that a known quantity of a compound is added to the sample (internal standard). This should not be a normal constituent of the sample. The ratios of the signal intensity of the sample components and the internal standard are used for the quantitation. Various detectors are available which are sensitive to different groups of compounds.



10.2.1 *Heat transfer detector (TDC)*

The most important component of the detector is a filament (platinum, gold, tungsten, etc.), which is heated with a constant electric power. The temperature of the filament depends on the heat transfer capacity of the gas. In turn, the heat transfer capacity is the function of the size and mobility of gas molecules; the lower the mass of the molecule, the higher the heat transfer capacity. If a larger molecule comes into the detector with the helium or hydrogen carrier gas, then the temperature rises and the resistance of the wire increases. This is the most frequently used detector in the analysis of gases.

10.2.2 *Flame ionisation detector (FID)*

The material coming from the column is introduced into the hydrogen/air flame. The burning head is the cathode and this is surrounded by the cylindrical anode. The radicals produced by combustion get ionised easily. As a result, the space between the cathode and anode becomes conductive. This is the most efficient method for the analysis of combustible organic materials, but it cannot be used for noncombustible materials (water, sulphur dioxide, carbon tetrachloride, nitrogen oxides, etc.).

10.2.3 *Electron capture detector (ECD)*

The operation is based on the principle that materials containing atoms of high electronegativity (halogens, nitrogen) or electron-withdrawing groups are capable of capturing electrons. The gas coming from the column passes between two electrodes, one of which is coated with soft beta radiating isotope (e.g. ^{63}Ni). The emitted electrons ionise the molecules of the carrier gas (e.g. nitrogen), and this produces a constant current. When an electron-capturing compound enters the detector it captures an electron to produce either a negative molecular ion or fragment ion if dissociation accompanies electron-capture. This loss of electrons leads to the decrease of the background current, which is related to concentration.

In addition to this, many other detectors are used which are capable of determining certain compound with high sensitivity, e.g. flame photometry detector (FPD) for determining compounds containing phosphorous or sulphur. It is possible to determine the composition of a planetary atmosphere by means of gas chromatography. The mixture of volatiles evolving on rapid heating from the planetary soil can be analyzed with a gas chromatograph. Searching for organic compounds and certain inorganic volatiles in the surface material at the landing site can provide evidence of life.

"OPERATIONS"	Flow of carrier gas	Injecting the material to be tested	Separation on the column space	Coupling to the detector	detecting and data processing
MATERIALS, CONDITION CHANGE	Carrier gas	Material to be tested + carrier gas	Gases separated with delay	Ionised gas in vacuum	Incoming particles
MEANS, TOOLS ENVIRONMENTAL CONDITION	Gas tank, pipe system	Heated space, injection pumpa	Gas chromatographic column	e.g. ionisation irradiation tube	Particle detector + computer unit

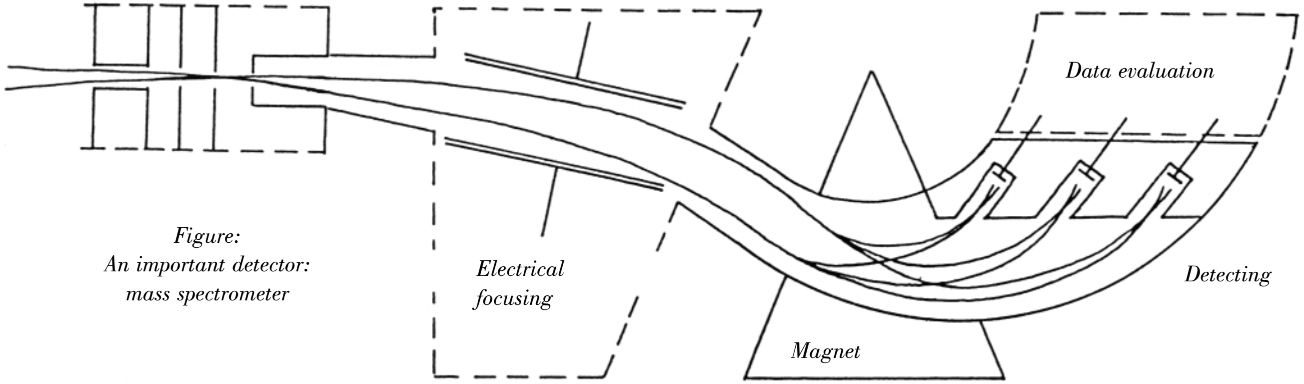


Figure:
An important detector:
mass spectrometer

10.2.4 Mass spectrometer

The mass spectrometer is one of the most frequently used gas chromatographic detectors, which can be also used as an independent instrument or as a component of a configuration. Its major benefit is that the various compounds can be identified, because it allows to determine the exact mass of atoms or molecules flying in the gas. Other detectors allow only relative or indirect identification of compounds.

A mass spectrum is a histogram of the relative abundance of individual ions having different mass-to-charge ratios generated from a sample of neutral molecules. The substance introduced into the mass spectrometer is ionised first, then the ions are accelerated, deflected and detected according to their mass-to-charge ratio (m/z). A low pressure is established within the mass spectrometer. The molecules of the sample are investigated in gas phase. The compounds leaving the gas chromatographic column are in gas phase, so the coupling such columns to a mass spectrometer presents the fewest problem. The molecules of solids and liquids can be also evaporated at elevated temperatures, or using some sophisticated methods (e.g. laser irradiation).

Electron impact ionisation

This is the oldest and simplest mode of generating ions. The electrons emitted from a heated cathode are accelerated depending on the voltage between the anode and cathode. Electrons collid with molecules of the sample, producing ions, if the voltage - and electron energy - exceeds a certain value. Molecular ion (M^+) is produced, which gets fragmented at the weakest points of the molecule depending on the absorbed energy. This process reflects the structure of the molecule. This fragmentation of the molecule can be interpreted as a "fingerprint". Data obtained from the fragments are collected in spectrum libraries. The investigated substance can be identified from the measured spectrum by means of comparison. The fragmentation of the molecules also depends on the energy of the electron used for ionisation. (This is usually 70 eV because the mass spectrum does not change very much above this value.)

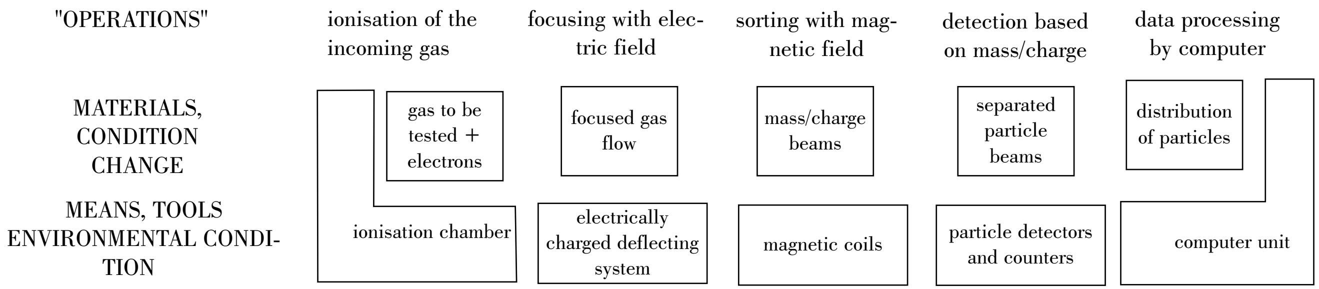
The mass spectrometer unit

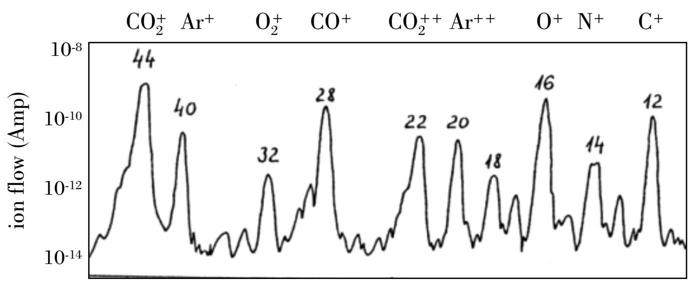
During the measurement made by the mass spectrometer a number of operations are conducted on the gases entering the detector. 1) The gas is expanded to vacuum. 2) The material is ionised, e.g. charging the gas molecules with the electrons emitted by the cathode. 3) The diffused gas is focused during its flow with electric and magnetic fields, then (4) the molecules are separated according to their mass/charge ratio before entering the detector.

Chemical ionisation

It is required to apply a mild ionisation process for compounds having weak bonds, because the molecules could get decomposed before coming into the detector. This disintegration could be so extensive that no useful information could be obtained from the mass spectrometer any more. This method includes an addition of large amount of reagent gas prior to the ionisation. These molecules will be ionised then primarily by the electron beam resulting an ionised plasma. The collisions between the ions of the reagent gas and the sample molecules produce the sample ions. These collisional processes are gentler than electron impact ionization and therefore the fragmentation is reduced. The sensitivity of the measurement is also improved, because large proportion of molecules reaches the detector before the disintegration.

Mass spectrometer is suitable for analysing the composition of planetary atmosphere, and the composition of the soil can be determined as well. The characteristic isotope abundances in the atmosphere or in the soil of the planet are also important informations. This way the source of the meteorite can be identified, if the given fractional isotopic abundance of elements has already been determined in the atmosphere of a planet.



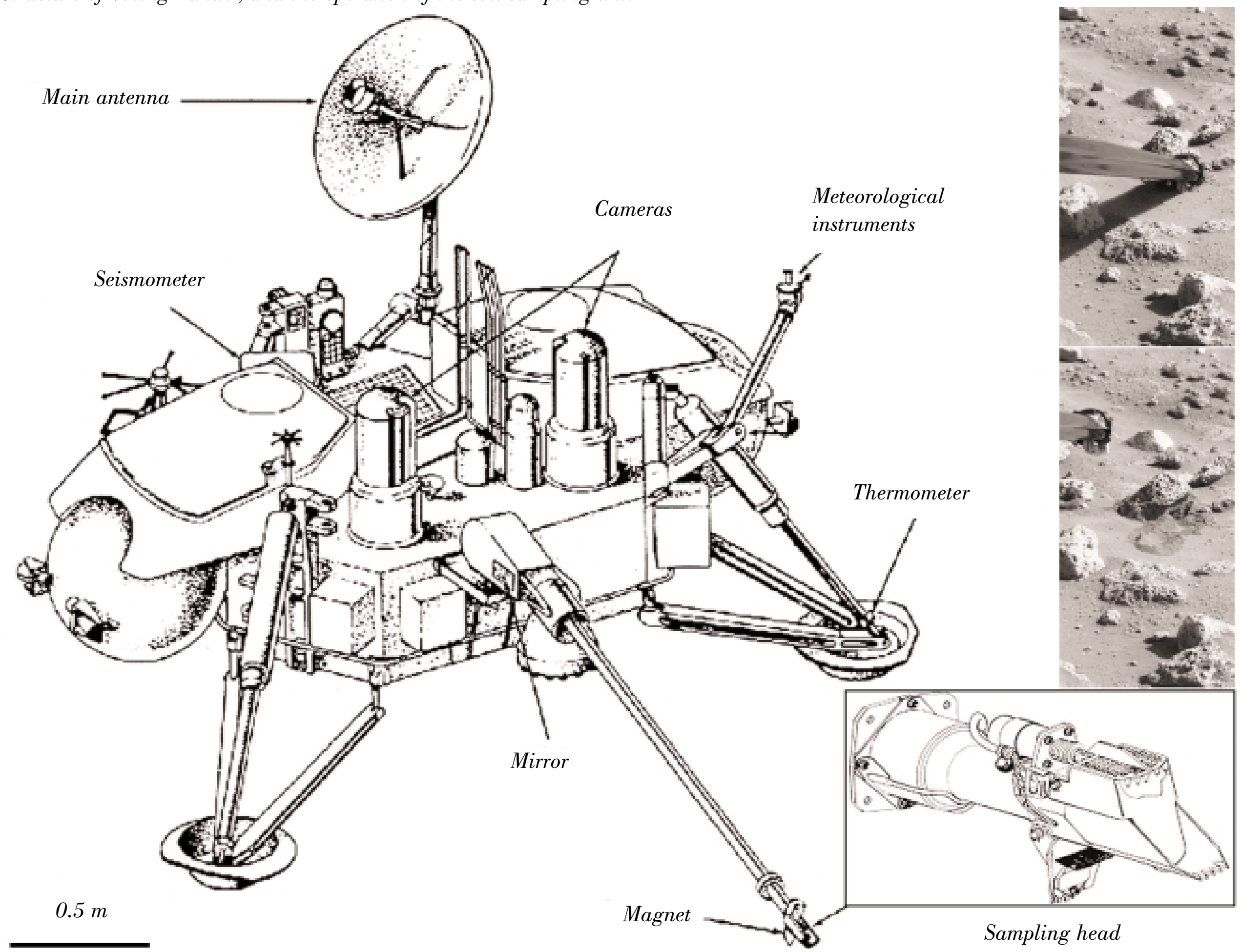


Mass spectrum obtained by Viking -1 landing unit at an altitude of 135 km during landing in the Martian atmosphere on 20 July 1976.

XI. BIOLOGICAL MEASUREMENTS BY THE VIKING SPACE PROBES

One of the most important motivations for the space research is to find extraterrestrial life. This can be done most efficiently with the help of landing units. With the help of advanced space probes it was possible to determine the surface conditions of the nearby planets. During the process, the astrobiological research gradually became focused on Mars. Man-made probes landed on Venus earlier, but the start of research for extraterrestrial life was begun when the pair of Viking probes landed on Mars.

Structure of Viking Lander, and the operation of the soil sampling unit



9.1 *Programme outline*

The NASA researchers intended to gather comprehensive information on Mars, particularly regarding the possible Martian life. Two identical space probes were used for the Viking mission, each consisting of an orbiter and a lander unit. The Viking space probes were launched in summer of 1975 and arrived at Mars in June and august 1976. The lander of Viking-1 touched down within the Chryse Planitia at 23° north of the equator, and the lander of Viking-2 reached the surface on the Utopia Planitia 48° north of the equator. Both landing units operated well beyond the planned 90 days. Viking-1 stopped operating on 11 November 1982, and its counterpart became silent on 11 April 1980. The main tasks of the landing units included to scoop up samples of debris from the surface with robot arms, and to place the samples in to the onboard laboratory for carrying out three different kinds of biological tests.

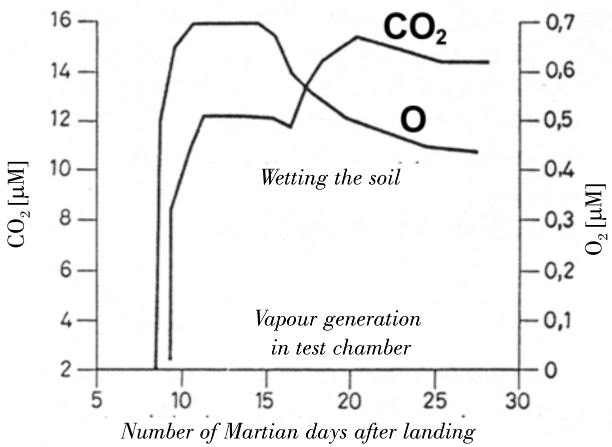
9.2 *Gas exchange experiment*

The objective of this experiment was to detect any gas which might have used or released by potential Martian micro-organisms during their metabolism. The Martian material samples were placed in enclosed chamber, and were mixed with aqueous solution of organic materials (i.e. nutrient), then the generated gas was continuously analysed by means of gas chromatography.

Initially, only a small quantity of nutrient solution was added so that it would not saturate but only moisten the sample. This wetted sample was stored without disturbing for about 7 months.

The test indicated that CO_2 and molecular oxygen were released right after the sample became moist, but this stopped very shortly. The samples in both landers were characterised by quick and short time gas generation.

CO_2 has probably come from the atmosphere after adhering to the debris particles, which has been quickly expelled by the vapour in the mist chamber. The presence of oxygen is not easy to explain, very



few abiogenic processes are known, which produce oxygen. It is assumed that oxygen rich compounds, particularly peroxides, disintegrated upon the influence of vapour, and that was the reason that oxygen was released in the experiment.

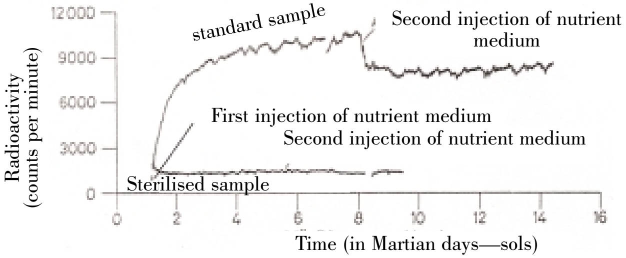
CO_2 was generated for a long time with decreasing intensity, but oxygen disappeared very quickly. CO_2 production is also explained by the process starting earlier, and the absorption by ascorbic acid in the organic nutrient solution might be responsible for the disappearance of oxygen.

It seems that the reactions during the gas exchange reaction happened not as part of biological metabolism, but as a result of interaction between the surface material and the water vapour.

9.3 Nutrient decomposition experiment with radioactive ^{14}C isotope detection

In this experiment the intake of nutrient marked with isotope and the decomposition by metabolism was studied. For this purpose a simple nutrient solution, formic acid was marked with ^{14}C, and glycine. The principle of the experiment includes the assumption that any micro-organism would utilise the nutrient solution, and in the released materials the presence of the radioactive ^{14}C would be detectable.

A quantity of nutrient was added until half of the sample was soaked, and the apace of the chamber was filled with vapour. The results also indicated the generation of CO_2, which was slowed down after a Martian day.



The detected CO_2 was radioactive, i.e. it came from the nutrient solution. It is produced probably from peroxides, as has been assumed from the gas exchange experiment, because the formic acid is quickly oxidized by the hydrogen peroxide, and the reaction result is CO_2 and water (the measured CO_2 was only slightly higher than the quantity expected from the oxidation of the entire quantity of formic acid).

However, no gases without radioactivity had been detected in spite of the fact that such gases were expected from the sample after mixing with water (similarly to the case of gas exchange experiment).

The same sample was mixed with yet another quantity of nutrient solution. The quantity of radioactive CO_2 did not increase, it decreased slightly actually in the chamber. This is congruent with the assumption that the peroxides of the sample have decomposed fully as a result of the first batch of nutrient solution, for this reason further gas emission could not be caused by the new batch. The fall of CO_2 quantity is probably the result of dissolution of a portion of CO_2 in the chamber by the new nutrient solution batch.

The presence of peroxides is also verified by another associated measurement which was conducted for 3 hours with a sample sterilised at 160 °C. In this experiment the above reactions did not occur at all. However, the reaction took place if the materials were heated to only 40 °C, but the quantity of generated gas was reduced to its former half. Some researchers think that organisms were destroyed by the sterilisation, which otherwise released products of metabolism and such products could be detected. On the other hand, this phenomenon can be explained by abiogene processes considering that peroxides are unstable compounds which tend do decompose upon heating.

9.4 $^{14}CO_2$ release experiment with the use of heating

This experiment was conducted according to the true Martian atmospheric and pressure conditions. The absorption of natural CO_2 and CO content of the atmosphere by the sample was tested. Then measurements were carried out to find possible traces of production of organic material (in the former experiments the decomposition products of an eventual life activity was being investigated).

Samples from the surface were placed into the enclosed chamber together with atmospheric gases. CO_2 and CO marked with radioactive ^{14}C isotope was introduced into the chamber, and artificial lighting was applied for five days. Finally, the possible presence of such organic molecules containing ^{14}C was investigated. In two of the nine completed tests such molecules were found! This is the indication of the generation of a very small amount of organic material in the material of the surface. It is important to note that the production of organic material could be detected also in samples closed from light.

9.5 Evaluation of results

The experiments did not give unambiguous results. The NASA researchers think that it was not possible to collect unequivocal evidence of Martian life, or a proof that there is no life on the Red Planet.

9.6 Doubt and certainty

Certain doubts were revealed some years ago regarding the measuring results of Viking landing units. One of the leading researchers of the mission said that the measuring instrument used in 1976 were not sensitive enough to reveal the very small amount of organic material in the samples. In this way the existence of life on Mars cannot be excluded on the basis of the results of the mission.

The tests, however, have indicated that the surface of Mars is extremely oxidative, which would be a great challenge for any life form known on Earth. During the past couple of year extremophile bacterial life was detected in various extreme conditions on Earth, which were thought to be inhabitable before (springs with water temperature exceeding 100 °C, ice layer of Antarctic, lake with extreme pH values, radioactive cooling water of nuclear reactors, ocean floor at several thousand meter depth without light in the vicinity of smokers). It is reasonably to believe that certain life form can survive in the harsh Martian environment. It means that life on Mars cannot be excluded just because the conditions are extreme.

Sure answers regarding life on Mars, however, could be given only by the new landing units arriving at Mars in 2003–2004. It was originally planned to send three landing units to the surface of Mars:

– Beagle-2 lander of Mars Express produced by the European Space Agency, having the major objective of searching for traces of ancient and recent life; (unsucessful)

– Two Mars Exploration rovers of NASA, named Spirit and Opportunity: they performe petrologic and geochemical measurements mostly. These rovers operate at the time of editing.

Close-ups taken by Opportunity at Hematite region (2004). The features of the region are weathered sedimentary rocks that were formed by rippling water. The small spheres found here were also formed in water-rich environment. This is the first time that we obtained chemical evidence from the surface that suggests the presence of fluid water in the past of Mars.

Spirit on the 148th martian day of the rover's mission inside Gusev Crater, on June 2, 2004.

VENUS, EARTH, THE MOON AND MARS: SURFACE CONDITIONS AND LANDERS

	VENUS	EARTH	MOON	MARS
Solar constant [W/m²]	2624 W/m2	1373 W/m²	1373 W/m²	591 W/m²
Apparent diam. of Sun [°]	0,74°	0,53°	0,53°	0,35°
Solar luminosity [magnitudó]	-27.35 (above cloud layer)	-26,7	-26,7	-25,8
Tilt of axis [°]	177,4° (-2,6°)	23,45°	6,7°	25,19°
Diurnal period	116 Earth day = 2802 hours	24 h	29,5 d = 708,7 h	24 h 39 m (1 sol)
Rotational period	243 days = 5832 h, retrograde	23 h 56,1 m	27 d 7 h 43 m = 655,7 h	24 h 37,4 m
Orbital period in Earth days	224,7 Earth days	365,24 Earth days	365,24 Earth days aound Sun, 27,3 days around Earth	686,98 Earth days
Orbital period in local days	1,9 local days	365,24 Earth days	365,24 Earth days aound Sun, 27,3 days around Earth	667 sol (Martian day)
Gravity [g, m/s²]	8,87 m/s2	9,8 m/s², 1g	1.62 m/s², 0,16 g	3,7 m/s²
Surface pressure [hPa]	93219 hPa	1013 hPa	3 x 10-15 bar	6,9-9,1 hPa
Surface temperature [°C]	457 °C	15°C (-69 – +58)	-150 – +130°C	-5 – -75°C (Pathfinder)
Atmopheric constituents	96,4% CO_2, 3,4% N_2	78% N_2, 20,9% O_2		95,3% CO_2, 2,6% N_2
Escape velocity [km/s]	10,36 km/s	11,18 km/s	2,38 km/s	5,02 km/s
Orbital velocity	35 km/s	29,8 km/s	1 km/s (around Earth)	24,1 km/s
Probes that reached the surface of an other planetary body: (date of arrival, site of arrival (name, coordinates and/or local time at landing), total duration of operatoion) **Legend:** no sign: smooth landing, the lander remaied operational after landing † pre-planned impact (the probe remained operatioinal until impact) ‡ planned smooth landing, but it was impacted by accident € planned impact, but radio connection was lost before impact A=impacted after atmospheric measurements TM=soil sample to Earth The table does not list the probes – if radio connection was lost during flight – if the probe missed the target planet or moon – if the probe fell back to Earth – if the probe exploded during launch Soviet (USSR) probes and Mars Express / Beagle 2 were launched from Tyuratam (Baikonur). American probes were launched from Cape Canaveral (Kennedy Space Center).	**Venera 3** ‡ (66.III.1.) **Venera 4** (A, 67.X.18. 19° N 38°E) **Venera 5** (A, 69.V.16. 3° S 18°E) **Venera 6** (A, 69.V.17. 5° S 23°E) **Venera 7** (70. XII. 15. night side, 23m, 5° S 351°E) **Venera 8** (72. VII. 22., terminator, 50 m 10° S 335°E); **Venera 9** (75. X. 22., day side, Guinevere Planitia 32°N 291°E, 53m) **Venera 10** (75. X. 25., day side around local noon, Beta Regio 291°E 16°N, 65m) **Pioneer Venus** † 3 Small Probe (North (59,3°N 4,8°E), Day (31,3°S 317°E) Night (28,7°S, 56,7°E)) and Large (4,4°N 304°E) 78. XII. 9. Bus 37,9°S; 290,9°E **Venera 11** (78. XII. 25., day hemisphere, 14°S 299°E 95m) **Venera 12** (78. XII. 21, 7°S 294°E, 110m) **Venera 13** (82. III. 1., Beta Regio 7,5°S 303°E, 127 m) **Venera 14** (82. III. 5., Beta Regio 13,25°S 310°E, 53 m) **VEGA 1** (85. VI. 11., ‡ Sapas Mons 8,1° N 176,7°E 21 m + balloon 46 hr) **VEGA 2** (85. VI. 15., E-Aphrodite Terra 7,2°S 179,4°E 15 m night hemisphere + 46 h balloon).	Space Centers (launchings): **Tyuratam** (Bajkonur) (since 1957; Kazakhstan 45,6°N 63,4°E) **Cape Canaveral** (Kennedy Space Center) (since 1958; USA, Florida, 28,5°N 81,0°W) **Kourou** (since 1970, France, French Guyana 5,2°N 52,8°W) Mars Society-operated: **Flashline Mars Arctic Research Station FMARS** (Haughton crater, Devon-isl., Canada, since 2001) **Mars Desert Research Station MDRS** (Hanksville, Utah, USA, since 2002) **EuroMARS** (Krafla/Mývatn, North-Izland, planned 2003) **Landers on other planetary bodies:** 433 Eros – **NEAR** (2001. II. 12., 16 days) Planned: Titan – **Huygens** (2004–2005) Merury – **BepiColombo** (2012??)	**Luna 2** † (59.IX.13. Palus Putredinis 29,1°N 0°E) **Ranger 4** ‡ (62.IV.26. 15,5°S 229,3°E) **Ranger 6** € (64.II.2. 9,33°N 21,5°E) **Ranger 7** † (64.VII.31. 10,35°S 20,58°W) **Ranger 8** † (65.II.20.) **Ranger 9** † (65.III.24.) **Luna 5** ‡ (65.V. Mare Nubium) **Luna 7** ‡ (65.X.7. Oceanus Proc.) **Luna 8** ‡ (65.XII.3.) **Luna 9** (66.II.3.) **Surveyor 1** (66.VI.2. 2.45°S 316.79°E-Flamsteed P) **Surveyor 2** ‡(66.IX.22. SE from Copernicus) **Luna 13** (66.XII.24. 18,87N 297,95E, 2 days) **Surveyor 3** (67.IV.20. 2,94°S, 336,66°E Oc. Proc.) **Surveyor 4** € (67.IV.) **Surveyor 5** (67. IX. 11. 1,41°N 23,18°E Mare Tran.) **Surveyor 6** (67. XI. 10 0,46°N 358,63°E Sin. Medii) **Surveyor 7** (68. I. 10. 41,01°S 348,59°E Tycho) **Apollo 11** (69.VII.20. 0,67°N 23,49°E Mare Tranq.) **Apollo 12** (69.XI.19. 2,94°S 23,45°W Oc. Proc.) **Luna 16** (70.IX. 20., Mare Fec. TM) **Luna 17 + Lunokhod 1** lunar rover (1970.XI., 11 months 38,28°N 325°E) **Luna 18** † (71.IX. 1. 3,52°N, 56,5°E) **Apollo 14** (71.II.5. Fra Mauro 3,67°S 17,46°E) **Apollo 15** (71.VII.30. Hadley valley 26,11°N 3,66°E) **Luna 20** (72.II.21. 3,57°N 56.5°E TM) **Apollo 16** (72.IV.20. Descartes 8,6°S 15,31°E) **Apollo 17** (72.XII.11.Taurus-Littrow 20,17°N 30,8°E) **Luna 21 + Lunokhod 2** lunar rover (1973.I. 4 months) **Luna 23** (74.X.31. 12,25°N 62,2°E, TM unsiccessful) **Luna 24** (76.VIII.22. 12,25°N 62,2°E TM) **Lunar Prospector** † (99.VII.31., impacted near south pole 87,7°S 42,35°E)	**Mars 2** ‡(71.XI.27. 45°S, 302°W Hellespontus M.) **Mars 3** (71. XII.2, Terra Sireneum) **Mars 6** € (74.III.12. 23,90° S, 19,42°W Margaritifer Terra) **Viking 1 Lander** (76. VII. 20. – 82. XI. 13., 22.27°N, 47.94°W, Chryse Planitia, 2245 days) **Viking 2 Lander** (76. IX. 3. - 80. IV. 11., 134.01°E (225,8° W), 47.668°N, Utopia Planitia, 1316 days) **Pathfinder – Carl Sagan Memorial Station + Sojourner Rover** (97. VII. 4. - 97. IX. 27. Ares Vallis 19.33°N, 33.55°W) **Mars Polar Lander** (Mars Surveyor '98) ‡(99.XII.3., 76.13°S, 164.66°E.) **Deep Space-2** ‡(99.XII.3. 75.10°S, 163,65°E) **Spirit** (MER-A 2004.I.4., Gusev crater) **Opportunity** (MER-B 2004, Meridiani Planum) **Beagle-2** / Mars Express (2003.XII., Isidis Planitia 10,6°É, 270°Ny) - unsuccessful, reason not known. **Planned:** **Phoenix** (2007, North of Alba-Patera)

Cover photo: Moon: Harrison Schmitt, the only professional geologist, who has been on the surface of the Moon, observing the walls of Shorty crater (Apollo 17). Mars: Landing site of Pathfinder. Earth: View from the center of Vredefort Dome (Vredefort crater), South Africa. Venus: Photo taken by Venera 13. All planetary images are courtesy NASA.

REFERENCES

Basilevsky et al. (1999): Morphology of the APXS Analysed Rocks at the Pathfinder Site. *LPSC XXX*. #1313, LPI, Houston

Bridges N. T., Greeley R., Kuzmin R. O., Laity J. E., (2000): Comparison of Terrestrial Aeolian Rock Textures to those at the Mars Pathfinder Landings Site. *LPSC XXXI*, #2066.

Bridges N. T., Laity J. E. (2001): Rock Abrasion and Ventifact Formation on Mars from Field Analog, Theoretical, and Experimental Studies. *Martian Highlands and Mojave Desert Analogs, Workshop and Field-Trip*. 2001 Oct. #4003.

Horváth A., Gánti T., Gesztesi A., Bérczi Sz., Szathmáry E. (2001): Probable Evidences of Recent Biological Activity on Mars: Appearance and Growing of Dark Dune Spots in the South Polar Region. *LPSC XXXII*, #1543, LPI, Houston

Kaimal, J., C., and Finnigan, J. J. (1994*): Atmospheric Boundary Layer Flows*. New York, Oxford, Oxford University Press.

Larsen, S. E., Jorgensen, H. E., Landberg, L. and Tillman, J. E. (2002): Aspects of the Atmospheric Surface Layes on Mars and Earth. *Boundary-Layer Meteorology* **105**, 451-470.

Savijarvi, H. (1999): A model study of the atmospheric boundary layer in the Mars Pathfinder lander conditions. *Q. J. R. Meteorolol. Soc.* **125**, 483-494.

Murphy J. R., Wilson G. W., Seiffl A., Schofield J. T., Magalhaes J., Larsen S., Haberle R. M., Crisp D., Barnes J. (1998): Meteorological Results from the Mars Pathfinder Lander: An Overview. *LPSC XXIX*. #1824. LPI, Houston

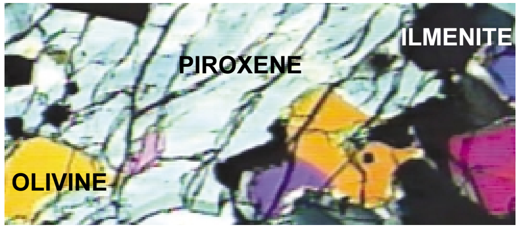
Parker T. J., Moore H. J., Crisp J. A., Golombek M. P. (1998): Petrogenetic Interpretations of Rock Textures at the Pathfinder Landing Site. *LPSC XXIX*. #1829. LPI, Houston

Tuba Z., Haszpra L. Weidinger T., Horváth L., Balogh J., Barcza Z., Czobel Sz., Nagy Z., Pintér K., Tarczay K. (2003): Long-term CO_2 concentration and flux measurements in Hungary. XXVIII General Assembly of the European Geophysical Union, Nice, April 2002, *Geophysical Research Abstract*, **4**, (CD var.)

Tuba Z., Nagy Z., Weidinger T., Csintalan Z., Horváth L., Szerdahelyi T., Nagy J., Engloner A., Juhász A., Balogh J., Pintér K., Fóti Sz., Péli E. (2003): Az 5. EU&D keretprogrambeli gödöllői gyepökológiai kutatásokról. *6. Magyar Ökológus Kongresszus*, Gödöllő, 2003. augusztus 27-29. Szerkesztette Domonkos M. és Lakner K., 266.

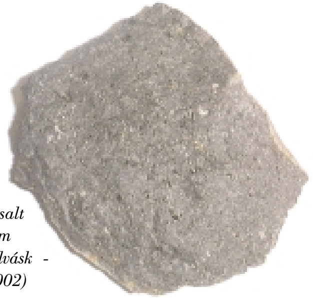
Yanai K. Kojima H. (1987): Photographic Catalog of the Antarctic Meteorites. NIPR, Tokyo

Köszönet: A szerzők köszönetet mondanak Tuba Zoltánnak professzornak (programvezető), Nagy Zoltánnak és Pintér Krisztinának a gödöllői Szent István Egyetem Növénytani és Növényélettani Tanszék munkatársainak, Horváth Lászlónak (OMSZ) valamint Barcza Zoltánnak az ELTE TTK Meteorológiai Tanszék adjunktusának az EU5 GREENGRASS mérési adatok felhasználásáért.

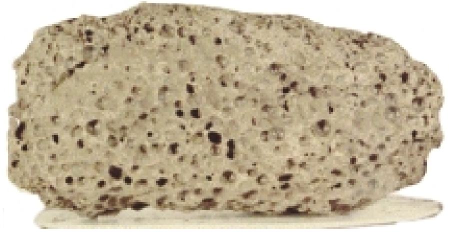


Lunar basalt thin section (Apollo 12, No 12005.)

10049 Apollo 11 basalt

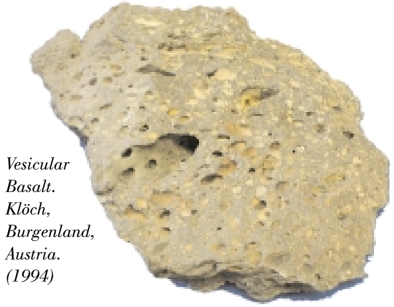


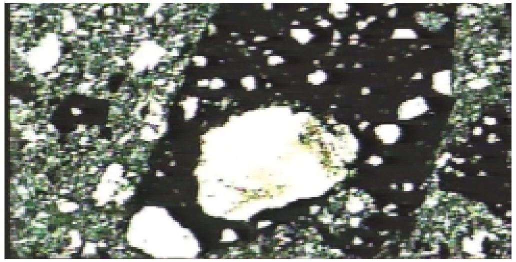
Basalt from Szilvásk - (2002)



15016 Vesicular Lunar mare basalt

Vesicular Basalt. Klöch, Burgenland, Austria. (1994)

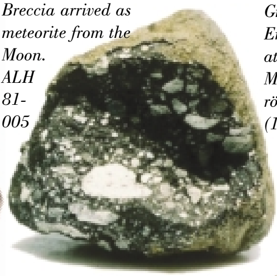




Polimict breccia thin section (Apollo 14, No 14305)

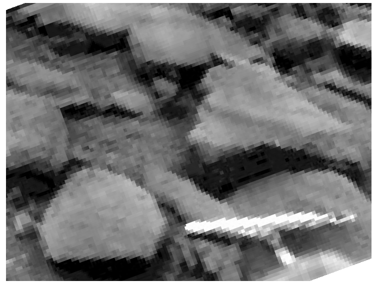
Volcanic breccia(c. 3 Ga old, Barber-ton, S.A.)

Breccia arrived as meteorite from the Moon. ALH 81-005

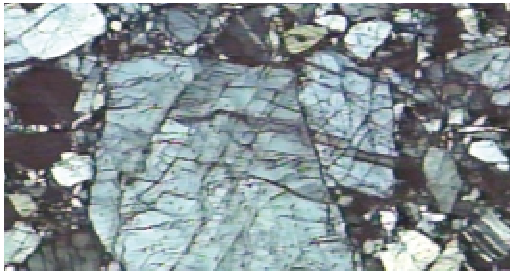


Granite from Erd smecske, at the Mórágyi rög. (1974)

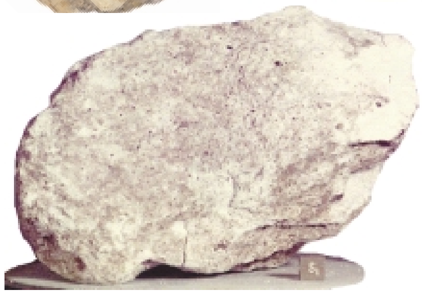
Basaltes on the sandy surface of Mars (Pathfinder)



Basaltes on the surface of Venus (Venera 9)



Anortosite (plagioclase) thin section (Apollo 16, No 60025)



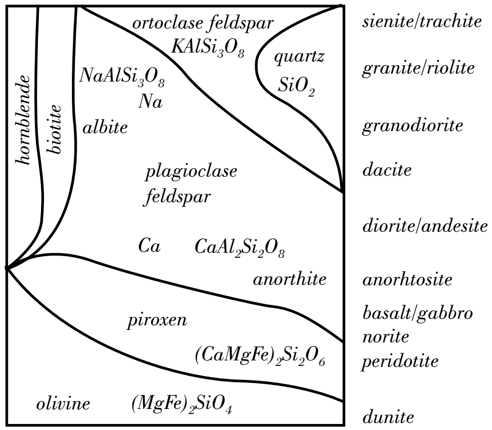
4,19 Ga old Lunar Anorthosie (Apollo 16)

2 Ga old impact partly melted and brecciated gran-ite from Vredefort (S. Africa) (2003)

Peridotite from basalt tuff from Szenték-kálla. (Bérczi Sz. 1982., KAVÜCS)

Terrestrial soil (Piliscsaba, 2003)

Lunar regolith (Apollo 11, 1969)



Hammer / Apollo 15

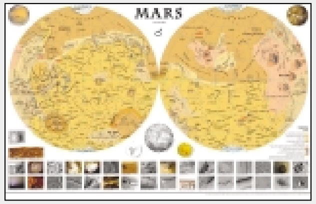
Tongs / Apollo 16

Rake / Apollo 16

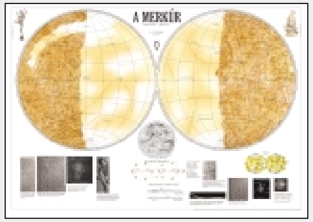
Scoop / Apollo 17

Sampling Bag / Apollo 16

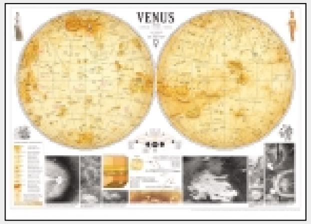
Also related



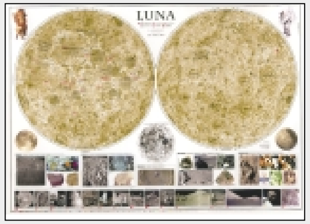
Multilingual Map of Mars



Bilingual Map of Mercury

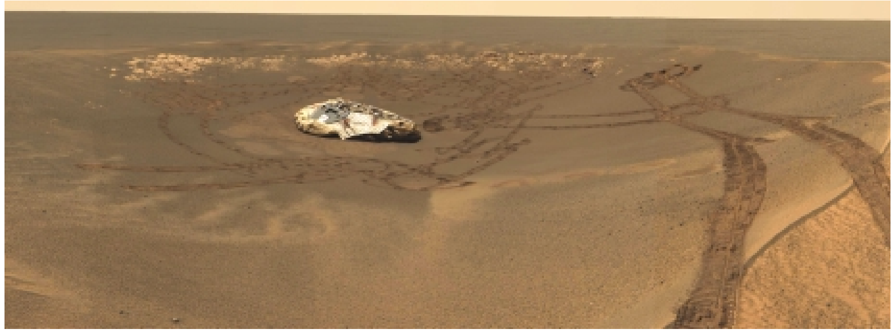


Multilingual Map of Venus

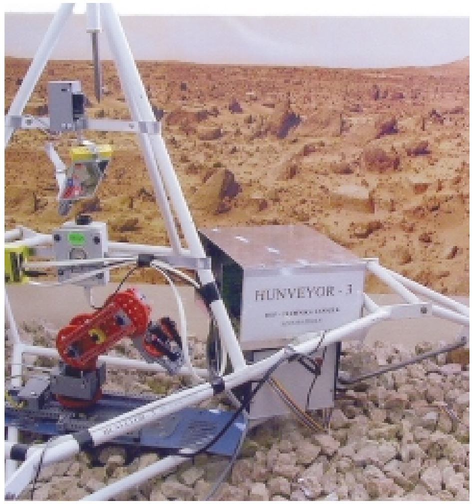


Multilingual Map of the Moon

The multilingual map series is made in cooperation with Moscow State University for Geodesy and Cartography (MIIGAiK) and are supported by the Commission on Planetary Cartography of the International Cartographic Association and the Hungarian Space Office.

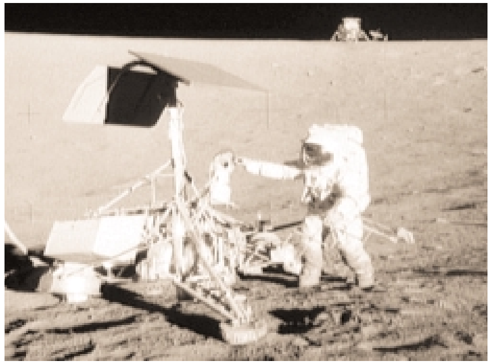


The Opportunity in Eagle crater, at the Hematite region of Meridiani Planum, Mars.



The Hunveyor experimental space probe in front of a photograph of a Martian landscape (BDF, Szombathely)

Hunveyor on the artificial Martian terrain model.

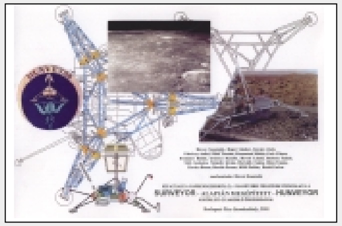


Surveyor III with Pete Conrad, the astronaut of Apollo 12, with A12 in the background

Hunveyor with its constructors (ELTE, Department of General Technology)

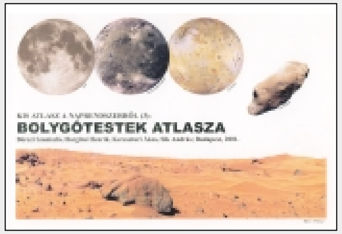
CONCISE ATLAS OF THE SOLAR SYSTEM
TEXTBOOK SERIES FROM THE COSMIC MATERIALS SPACE RESEARCH GROUP, EÖTVÖS LORÁND UNIVERSITY, BUDAPEST

Also in the series



From Surveyor to Hunveyor
How we constructed an experimental educational planetary lander model.
In English and in Hungarian 2001-2.

Planetary and material maps:
Lunar Rocks, Meteorites
In Hungarian, 2000.

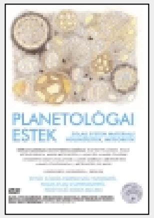


Atlas of Planetary Bodies
In Hungarian. 2001.

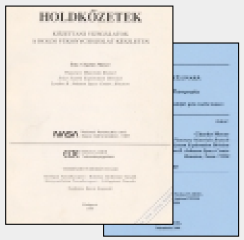
Atlas of Planetary Atmospheres
In Hungarian. 2002.

These titles are available from the Cosmic Materials Space Research Group of Eötvös Loránd University, Bérczi Szaniszló, 1117 Budapest, Pázmány P. st. 1/A, Hungary
E-mail: bercziszani@ludens.elte.hu
Web: http://planetologia.elte.hu

Space Research and Geomety
In Hungarian. 2002.



Planetary Science
educational DVD
Video; 2004. in English and Hung.



Lunar Petrography (NASA)
Available in Hungarian and Romanian languages

EÖTVÖS LORÁND UNIVERSITY
COSMIC MATERIALS
SPACE RESEARCH GROUP
HTTP://PLANETOLOGIA.ELTE.HU