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THE MOON AND ITS NATURE

- USSR -

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THE MOOD AND ITS NATURE

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What We Know About Our "Perpetual Sputnik" -- Mountains, Craters, Seas -- A Gaseous Envelope Around the Moon? -- The Solid-Color Surface Cover: Dust or Foam? -- From 140°C Heat to 150°C Cold.

The Moon as a cosmic body and as a world has become a center of attention to modern science. From an object whose study once occupied a small circle of astronomers-selenographers, it has become the subject of numerous studies and lively discussions. All this is a consequence of the brilliant feats of Soviet science which we are witnessing.

In the two years which have elapsed since 4 October 1957 -- the date of the launching of the first artificial Earth satellite, which ushered in a new era of science and technology and laid the foundation for the practical conquest of outer space by Man, we made such accomplishments as the firing of three outer-space rockets, the establishment of an automatic interplanetary station which had transmitted to the Earth by telemetry the results of its observations, two-way radio communication with that station over distances of hundreds of thousands of kilometers away from the Earth, the powering of the equipment of the artificial Earth satellites and the automatic station by means of solar batteries, etc.

Such prodigious advances place in the forefront the solving of the problem of the reaching and colonization of the Moon by man in the not distant future. The study of the nature of the lunar surface is thus becoming a quite pressing matter. It may be said that the investigations in the field of the physics of the Moon are being transformed from a special section of astronomical sciences into a painstaking exploration of that "territory", which shall soon be mastered by man.

In the present sketch our purpose will be to provide a brief survey of all the information on the Moon available to us, on outlining basically, the new facts established by science in the past decade.

Let us begin by recalling the basic general information which we owe to the era of "classical" astronomy.

The Moon is a spherically shaped body with a diameter of 3,476 km. Its mass amounts to 1/82 of the Earth's mass, or 7.33×10^{25} grams, whence it follows that its mean density equals 3.33 grams per cm^3 , which is much less than the mean density of the Earth (5.5 grams per cm^3). The Moon's gravity is one-sixth of the Earth's gravity, and the "escape velocity" or the "second cosmic velocity" for the Moon amounts to only 2.4 km per second (compared with 11.2 km per second for the Earth).

The mean distance of the Moon from the Earth is 384,400 km, but because of the ellipticity of the lunar orbit it varies from 363,300 km (at the perigee) to 405,500 km (at the apogee). The Moon completes its path around the Earth in 27 days, seven hours, 43 minutes and 11.5 seconds--a period termed the stellar or sidereal month. The length of a day on the Moon equals the period during which the change in the lunar phases ends before the eyes of the Earth-based observer, i.e., 29 days, 12 hours, 44 minutes and 2.8 seconds (synodic months).

The Moon's Relief

The study of lunar topography is an old problem. To a certain extent it could be plied even in the era preceding the invention of the telescope, because the outlines of dark spots on the lunar disk and certain other details are clearly discernible even to the naked eye. In the Middle Ages the invariant character of the drawings then composed gave birth to the strange hypothesis that the Moon is a mirror world in which we always see a reflection of the face of our Earth. Another more natural hypothesis to be advanced was that the dark areas on the Moon were water-filled basins and the light areas -- land masses.

To be sure, the very first telescopic observations of Galileo had led to the rejection of that standpoint too: even at a small magnification folds, wrinkles, and other forms of a soft relief which cannot exist on the surface of a fluid could be clearly seen on the relatively smooth and low surface of the dark areas. Thus, these areas could not be any open-water reservoirs but merely lowland plains blanketed by some dark-colored substance. Nonetheless, selenography -- the science describing the Moon from the same standpoints as the ones used by geography to describe the terrestrial globe -- has retained the nominal ancient terminology: the dark plains are termed "seas", their branches -- "bays", the individual small spots -- "lakes", and the largest dark area in the eastern (left-hand) half of the lunar disk -- "Ocean of Storms". Each "sea" or "bay" has its own name ("Sea of Showers", "Sea of Brightness", etc), and the light background on which they are seen is termed a "continent".

Galileo had also established the cause of the fixity of the solar disk: this is because the period of the rotation of the Moon about its axis is exactly equal to the period of its revolution about the Earth. Because of this exceptional circumstance, only one-half of the lunar sphere invariably facing our planet is accessible to our vision, while the other half had until very recently remained totally unknown to us.

To be sure, there existed no foundations for expecting that that reverse half differs from the visible one in any principal sense. Nonetheless, it is important to a high degree to obtain even only a general idea about its topography, and therefore the periodicals concerned with the problems of astronautics have published many projects and suggestions regarding the study of the unexplored part of the lunar surface through the sending of a rocket around the Moon.

Success in carrying this out was achieved by the USSR in October 1959. The launching of the third outer-space rocket, which had executed history's first circumlunar flight and had carried aboard an especially equipped cosmic station, made it possible to photograph the side of the lunar sphere not visible from the Earth and to transmit the obtained images to the Earth by methods of television engineering.

One of the photographs thus obtained is reproduced on the Insert. As we can see, the reverse side of the Moon coincides with the previously studied side in that it also has "seas", "continents", and "craters". At the same time, it is distinguished by the fact that the part of its area occupied by seas is much smaller.

While only the first steps have been taken in the study of the reverse side of the Moon, that half of the lunar sphere facing the Earth has been investigated in considerable detail. Numerous maps and atlases of that hemisphere have been compiled, the latitudes, longitudes and altitudes of a great number of formations on the lunar surface have been determined, and detailed descriptions, drawings and photographs of individual regions of the lunar world have been published.

The modern telescope makes it possible reliably to distinguish between formations upwards of one kilometer in size on the lunar surface; under particularly favorable conditions individual objects measuring only 200 to 500 meters can be distinguished. At an oblique illumination, when even small irregularities have sharp shadows (which occurs in the vicinity of the so-called terminator, i.e., the boundary line between the day and night hemispheres of the Moon), it is possible to discern elevations and ledges only a few dozen meters high.

The morphology of the lunar surface is widely known, and here we will merely remind the reader of its most important elements. The seas are constituted by lowlands or troughs whose floors always lie below the surface of the adjacent continents. As noted previously, their relatively smooth surface, when obliquely illuminated, displays clearly soft relief formed by rolling elevations resembling low walls and folds. On the other hand, the edges of these seas are in many cases very steep, so that the boundary line between a continent and a sea resembles a rampart. Many of the seas are ringed by veritable mountain ranges whose slopes tumble steeply seaward and gently toward the continent.

The surface of the continents is characteristically mountainous. Their mountains are arranged in the distinctive lunar ring-like formations which are conventionally termed craters and circuses. A circus is constituted by a mountain range closed in the form of a regular circular ring. Inside the ring extends a plain which not infrequently is dark-

colored, like the "seas", and termed the floor of the circus. A crater differs from a circus in that an isolated cone-shaped mountain massif termed "central peak" rises up from its center. There is not any doubt that the annular "wall" of the crater and its central peak constitute a system related by a common origin.

The number of mountain rings on the Moon is very large. In many places the surface of continents is densely pocked by craters and circuses which literally pile up on each other. Individual craters also exist on the surface of the seas. The latter is also characterized by peaks -- light-colored jagged mountain tops rising solitarily from the centers of dark plains.

The ring-like mountain formations involve blankets of a light-colored substance forming crowns or halos of short light-colored streaks radiating from a crater and individual narrow streaks of rays extending hundreds and thousands of kilometers outward along the arcs of great circles. The largest such system of bright rays is the one around the Tycho Crater, located in the southern half of the lunar disk; certain of its rays extend as far as 90 degrees of an arc.

Let us further note the fissures and rills -- narrow, tortuous slit-like depressions with steep, precipitous edges. In structure they resemble our steppe gullies, magnified hundreds of times.

The Origin of Lunar Mountains

It is natural to pose the question of how such an enormous number of ring-like mountain systems originated and why they are so abundant on the Moon and absent on the Earth. Unfortunately, only various hypotheses can be offered in reply.

Quite a number of theories advanced to account for the formation of the lunar craters, circuses and circularly contoured seas have been published. It is simply impossible to examine them within the scope of the present article. Let us merely observe that in general these theories can be classified into two groups: endogenic and exogenic.

The endogenic theories consider the relief of lunar surface as a result of the action of internal forces -- volcanism and tectonic phenomena in the lunar crust. The circular outlines of the ring-like mountain systems are usually compared with the structure of the terrestrial volcanos, although, it must be admitted, there is virtually no similarity. The geologist A.V. Khabakov attaches major importance to faultings of the lunar sphere, the alternation of which he uses as the basis for his opinions. Of interest is the idea of Academician A.N. Zavaritskiy, who cites the parallel between the lunar craters and the terrestrial calderas -- circular depressions of volcanic origin forming as a result of the collapse of the cone of a volcano.

The authors of exogenic theories consider the circuses and craters to be a result of the impacts of huge meteorites against the lunar surface. A meteorite reaching the lunar surface at a cosmic velocity amounting to dozens of kilometers per second is suddenly brought to a stop as a result of collision. Under such conditions the kinetic energy of motion instantaneously converts itself into heat, so enormous as to convert not only the body of the meteorite itself but also a major part of the lunar rocks at the site of impact into a vapor of a very high temperature. In other words, there occurs an explosion of a power equal to that of an atomic bomb. The absence of an atmosphere and hence also the absence of weathering has resulted in the conservation for hundreds of millions of years of the ring-like mountain systems arising as a result of the destructive effect of such explosions, whereas on the Earth they would have been demolished with time under the action of water and air. The tremendous number of craters which we now see on the lunar disk has accumulated during the lengthy period that has elapsed since the formation of the lunar crust.

The meteoritic theory is justified by analogies with the shape of the funnels created by exploding aerial bombs of various weight, and also by comparisons with the craters forming on the Earth as a result of the impact of individual large meteorites. In our country this theory has been supported by the calculations of Professor V.V. Fedynskiy and Professor K.P. Stanyukovich and also by a great number of experiments with the artificial creation of craters on models, conducted by P.F. Sabaneyev.

The Moon's Atmosphere

It has long been known that the Moon lacks a gaseous envelope of any considerable density. This is proved by a large number of reliably established facts.

Thus, on the boundary between the day and night hemispheres of the Moon, i.e., on the line of the lunar terminator, there exist no signs of that gradual transition from light to darkness which is created by the scattering of solar rays in the upper layers of an atmosphere and constitutes the commonly known phenomena of dawn and twilight. The shadows of the mountains on the Moon are totally black, which could not be the case in the presence of an atmosphere, because parts of surface protected from direct solar rays by elevations would then be illuminated by the scattered light of the firmament and the Earth-based observer would then have seen also the brightening effect of the bluish air haze created by the scattering of solar rays in the gas layers overlying the shadowy mountain crests.

Of great importance also are the observations of the eclipsing of stars by the lunar disk. In its movement around the Earth, the Moon from time to time obscures our vision of such a star, and in this connection, at the instant when the star vanishes behind or appears from

behind the rim of the lunar disk, its rays pass through the entire thickness of the atmosphere tangentially to the surface of the lunar sphere. In these conditions, even a strongly rarefied atmosphere would manifest itself by the gradual fading of the star prior to its disappearance. But this has never been observed: in such cases a star always disappears and reappears suddenly, without any change in its shine.

This is in accord with the results of certain theoretical calculations. As is known, not just any celestial body is capable of sustaining a gaseous envelope. This ability hinges primarily on the magnitude of the so-called second cosmic velocity (escape velocity) at which a body moving in a definite direction completely leaves a given planet.

Inasmuch as for the little Moon this velocity amounts to only 2.4 km per second, the molecules of light gases -- hydrogen, nitrogen, oxygen -- will escape from the Moon comparatively quickly, which constitutes the process of the so-called dissipation of the atmosphere, i.e., the scattering of its gases in interplanetary space. Known odds for remaining close to the lunar surface exist only for the gases with a very high molecular weight, primarily krypton and xenon and partly also, perhaps, carbon dioxide.

Thus, viewed from the theoretical standpoint, in principle an atmosphere resembling the terrestrial one cannot exist on the Moon, but a strongly rarefied gaseous envelope consisting of heavy gases perhaps might.

But does any such rarefied envelope actually exist on the Moon?

To answer this question, new studies have been undertaken to detect various signs of a lunar atmosphere. As a rule, they have yielded negative results, and therefore they could merely indicate the upper limit of the density of that atmosphere. Thus, Academician V.G. Fesenkov searched for the signs of polarization created by crepuscular light on the terminator line in the disk's center and, having found no such signs, arrived at the conclusion that the mass of the lunar atmosphere (above an area unit of the surface) should be at least a million times smaller than the mass of terrestrial atmosphere. The French astronomer Dyul'fysy [Dolfus?] employed the same method, but with more sensitive equipment, and found that the density of gas near the lunar surface should be at least one hundred million times less than in the ground layers of [terrestrial] air.

The most sensitive method of detecting traces of a lunar atmosphere consists in radio-astronomical observations. Moving on the background of constellations the Moon sometimes eclipses the cosmic sources of radiowaves located in the depth of the Galaxies, such as, e.g., the well-known Crab Nebula in the Constellation Taurus. As in the case of light rays at the moments of the covering and uncovering of stars, the radio waves at such moments glide along the surface of the lunar sphere, traversing the longest path through the lowest layers of gas. But that gas, being ionized, would have exerted a strong refracting effect on the radio waves if it were dense gas. Il'smur and Uaytfil'd [Whitfield],

who conducted in Cambridge observations of the eclipsing of the Crab Nebula and other objects by the Moon, by means of a large radio telescope, found that the density of gas at the Moon's surface should be at least one million millions (10^{12}) times less than the density of [terrestrial] ground air. However, as it were, certain signs of the deflection of the radio waves are noticeable and hence these investigators calculated that the density of the lunar atmosphere, under normal conditions, is 2×10^{-3} times lower than the density of air. A gas of such a low density differs little from an airless medium. It creates neither support for nor resistance to flying probes, exerts no effect on the movement of even the finest fractions of micrometeors, and provides no protection against ultraviolet radiation from the Sun, roentgen and gamma rays, and cosmic radiation.

The fact of the existence of an extremely rarefied gaseous envelope of the type of a distinctive ionosphere around the Moon has been corroborated by the observations executed as a result of the launching of the second Soviet outer-space rocket on 12 September 1959. The recording of the currents created by the particles of ionized gas in the ambient medium which were trapped in gadgets mounted in the container separated from the rocket, revealed that with approach to the Moon, at a distance of the order of 10,000 km, the recorded currents and hence also the number of trapped particles increase.

The Glow of Rocks

A new problem to selenophysics is that of the luminescence of montane rocks on the Moon. It is known that many types of minerals when exposed to short-wave radiation emit a fairly intense radiance -- the phenomenon of fluorescence or photo-luminescence -- in the visible portion of the spectrum. Thus, the mineral fluorite, when properly exposed, emits a very bright green light, which also has given birth to the term "fluorescence" itself.

Inasmuch as the lunar surface is not protected by an atmospheric layer, extreme ultraviolet radiation, and all other forms of cosmical radiation, reaches that surface without hindrance and may cause thereon the glowing of various minerals.

The astronomical press has frequently announced observations of the luminescence of individual formations on the night side of the lunar surface, i.e., on the side not illuminated by the Sun's rays. Sometimes this phenomenon was ascribed to the action of solar corpuscles penetrating into the night hemisphere as a result of the warping of their trajectories by the Moon's magnetic field, analogously to what happens on the Earth during the polar auroras. However, measurements conducted during the movement of the container with scientific equipment which had separated from the second Soviet outer-space rocket, revealed no appreciable magnetic field on the Moon, and the cases of luminescence on the Moon's dark side have remained unconfirmed.

More definite results were obtained by the Czechoslovakian scientist F. Link. The observation of the weak light of the luminescences on the light side of the lunar disk is hindered by the considerable brightness of the reflected solar rays. More favorable conditions arise during lunar eclipses. On the parts of the lunar surface which are traversed by the boundary line between the Earth's umbra and penumbra at a given instant, i.e., on the parts on which the solar disk is ready to conceal itself completely behind the Earth's disk or just begins to appear from behind it, the light of the direct solar rays is weakened hundreds of times (because a major part of the solar disk is covered by the Earth), but inasmuch as the rim itself of that disk is not yet covered, therefore the ultraviolet radiation emitted by the chromosphere and corona is still sufficiently intensive. As a result, the brightness created by fluorescence will no longer be so small in relation to the brightness of the reflected rays, and it will be possible to detect it. On comparing the results of the photometric observations of lunar eclipses with theoretical calculations, Link detected, in the majority of cases, in the zone adjacent to the boundary line of the umbra, an excess of brightness, which he ascribed to the effect of the luminescence of the lunar surface. Unfortunately, the photometric theory of lunar eclipses is extremely complex and therefore the formulas used to compute brightness for comparison with the results of measurements are merely approximate, so that the reliability of Link's conclusion has as yet to be further verified.

Another method of detecting luminescence on the Moon is based on the fact that the light of the luminescence is free of Fraunhofer lines, i.e., lines of absorption of solar spectrum. Inasmuch as that light complements the reflected solar rays on portions of the continuous spectrum and on the wavelengths of Fraunhofer lines, such rays then will be less black or, to use the spectroscopic terminology, less deep than in the spectrum of direct solar rays, as can be verified by a careful comparison of the spectra.

Such a comparison was carried out by Professor N.A. Kozyrev. The expected difference in the blackness of lines was detected only for one of the spectrograms of the Aristarchus Crater. The French scientist Dyubua [Dubois?] obtained similar results for several sectors of the solar disk.

It is possible that luminescence also lies behind the phenomenon observed by N.A. Kozyrev on the night between 2 and 3 November 1957. This concerns the bright emission spectrum detected on one of the spectrograms of the central peak of the Alphonse Crater. N.A. Kozyrev ascribes this phenomenon to a cloud of gas ejected from that peak and glowing brightly under the action of some radiation.

The Color of the Lunar Landscape

In connection with the problem of man's reaching the Moon, the question of the composition and structure of the outer blanket forming the Moon's surface visible from the Earth becomes a timely question.

At one time, the students of the Moon held widely to the opinion that the lunar surface is composed of bare rocks with a composition analogous to the terrestrial magmatic rocks. This opinion was based on the consideration that inasmuch as neither an atmosphere nor an hydrosphere had ever existed on the Moon, therefore such processes as weathering, erosion by water, and other disintegration processes, did not take place at all and hence the rocks forming upon the cooling of the magma should retain their original shape. All variants of blankets on the Moon were regarded as the product of the activity of endogenic forces alone -- volcanic eruptions, extensive outpourings of lava and various tectonic processes. Had it been so, the study of the optical properties of various areas on the Moon could have yielded essential indications as to the presence of such rocks.

Of course, a genuine investigation of the chemical composition of even the matter forming the outer blanket is not feasible, because the method of spectral analysis is not, generally speaking, applicable to non-selfluminous materials which provide light only by reflecting the solar rays incident on them from the outside. However, if we adopt the hypothesis that the types of rocks widespread on the Moon are the same as those on the Earth, and that the identical types of rocks both there and here are characterized by identical colors, then such simple forms of observation as the measurement of luminosity (albedo), color and polarization can be utilized for determining the rocks which may compose the visible surface of the Moon in various places. Thus, a frequently advanced opinion is that the bright mountainous surface of the continents should be composed of viscous effusive rocks of an acidic composition, e.g., of liparite, or even of intrusive rocks of the granite type, while the dark surface of the seas may consist of basic rocks approximating basalts. However, judgments of this kind can be justified only to the extent to which it can be certain that the surface of lunar rocks lacks even a fine film of some sort of material of a later origin. But is that really so?

The Observatory of Leningrad University has conducted extremely detailed comparisons of the albedo and color of various formations on the Moon with the average characteristics of coloring of the various types of terrestrial rocks, both magmatic and others (metamorphic, sedimentary), and meteorites as well. It was found that, from the standpoint of the average characteristics of optical parameters (but, of course, not according to data for isolated samples), not one type of terrestrial rock displays similarity with the lunar surface. The point is that the reflectivity of the lunar surface is exceptionally low; its reflection coefficient ranges from five to 15 percent, averaging seven

percent. Even the darkest types of terrestrial rocks are, on the average, much brighter; thus, the mean value of the albedo for basalts is 14 percent, which is twice as high as for the Moon. Moreover, the Moon is distinguished by the exceptionally small differences in its color. This long-known peculiarity differentiates it sharply from the visible surface of planets and from such rocks as granites, limestones, sandstones, clays, which are characterized by motley coloring.

Spectrophotometric observations of the lunar surface indicate that within the limits of the visible part of the spectrum, for all the formations on the lunar surface, the curve of the spectral albedo (i.e., the coefficient of reflection of monochromatic rays of individual portions of the spectrum) increases uniformly and identically from the violet to the red ends of the spectrum without revealing any absorption bands or other notable features. This is completely in accord with what is seen when observing the Moon's disk through a telescope: the entire Moon is of a single color, and only barely noticeable differences in that color are observable in a few places. Considering all this and taking into account the general low level of its albedo, it can be stated that the Moon is completely pigmented by uniform dark-brown color which is somewhat darker on the seas and brighter on the continents. If we could place a lump of the Moon-blanketing material on a table, among ordinary objects, it would prove to be of a color resembling a piece of chocolate or the crust of a bread loaf, or to borrow an example from mineralogy, resembling the dark varieties of limonite.

If that is so, then why does the lunar disk at night seem to us to be, as it were, white or even silvery and, when viewed through a telescope, produce the impression of a snow-white surface? It was not entirely without cause that at one time, when the Moon's albedo was not yet established with sufficient reliability, certain investigators advanced the conjecture that the entire Moon is covered with snow and ice. Actually, all this comes from illumination. At night it is dark here while the Moon is brightly illuminated by solar rays. Compared with the surrounding darkness, the surface of the Moon, dark-colored but exposed to very intense light, thus seems white to our sight, and hence the reason for this is purely physiological. True enough, it is possible to see the Moon in the daytime also, occasionally, and then it also looks white. But here the reason is different. What happens is that under daytime conditions the bright blue sky superimposes itself on the Moon's disk. The combination of the dark-brown color of the lunar disk with the blue color of the clear sky results in a whitish color.

The above-described results suggest that the actual rocks of the Moon's crust are always hidden from our sight by some dark single-color blanket of a later origin. The recent deeper investigations of the physical properties of lunar matter definitely corroborate this conclusion.

Temperature

The measurements of temperature in various regions of its surface and at various times are of major importance to exploring the nature of the lunar world. For these purposes, the astronomers are provided with the quite reliable method of thermoelectric measurements.

The junction of a very sensitive thermocouple is placed in the focus of a large telescope-reflector, and the images of various parts of the lunar disk are successively projected thereon. The radiant energy flux coming from these parts heats up somewhat the junction so that, as a result, an electric current, measurable by a galvanometer, arises in the thermocouple's circuit. However, the radiant energy measured in this manner cannot as yet provide any information on temperature, because fundamentally it represents the solar rays reflected from the lunar surface containing but a minute admixture of that radiant heat which is emitted by the heated surface itself of the lunar soil. The problem consists in isolating that weak natural heat radiation of the Moon, and it can be solved because the reflected and the natural rays belong to different portions of the spectrum. As is known, in the solar spectrum the intensity maximum lies in the visible portion and is located approximately in the green-color zone; that zone also encloses the energy maximum in the spectrum of the solar rays reflected from the Moon, because the process of reflection causes only insignificant modifications. As for the natural heat radiation of the Moon, the circumstances are different. Under the not high temperatures of the order of 0 to 100°C which can be logically expected here, the radiation energy will be concentrated in the distant infrared portion of the spectrum, in the zone of approximately 10 microns, which makes it possible to separate that energy from the reflected energy by means of a color filter that is transparent to the rays of the visible portion of the spectrum and absorbent to the energy in the distant infrared portion of the spectrum. Such properties are displayed by water, glycerine and glass. If the measurements are done twice -- one without a color filter and once with it, then the difference in the obtained results will yield the energy flux emitted by the lunar surface itself. However, the relationship between radiation intensity and temperature is known: it is expressed by the Stefan-Boltzmann radiation law and by Kirchhoff's law. It is this that makes it possible to determine the temperature of the various parts of the Moon.

Naturally, the foregoing is only a generalized exposition. In practice the determination of temperature is much more complicated, because a large number of various corrections have to be introduced into both calculations and measurements. But inasmuch as these corrections are known, therefore the ultimately determined temperature values prove to be quite reliable.

The results of the observations of Nicholson and Pettit, conducted with the 100-inch reflector of the Mount Wilson Observatory in the United States, can be reduced to the following. In the central areas of the disk of the full Moon, i.e., where the Sun stands at the zenith,

the temperature of the lunar surface reaches 130-140°C, and at the midpoint between the center and the rim it amounts to about 120°C, while at the very rim of the disk it is 60-70°C. At sunset the temperature plummets and reaches a minimum of the order of minus 150°C and perhaps even lower. The curve of this diurnal course of temperature coincides with the change in solar exposure without any lag, so that the temperature maximum coincides with the greatest height of the Sun.

Analogous results are yielded by the measurements conducted during solar eclipses, i.e., under conditions when a total eclipse of the Sun occurs on the Moon and exposure to the Sun declines from its normal value to zero within a comparatively short time. In this case, the surface temperature also coincides with the course of insolation (solar exposure) without any appreciable lag, so that the temperature values corresponding to a given level of insolation are reached almost instantaneously. This result proves that the fluctuations in temperature encompass only a very thin surface layer of lunar matter, which is possible only at a very low heat conduction of the matter.

The natural heat radiation emitted by the Moon could be successfully detected also in the range of wavelengths observable by the methods of radio astronomy. In the zone of wavelengths of from 14 microns to one millimeter, the terrestrial atmosphere is nontransparent to radio waves, but in the zone of from one millimeter to one meter observations are feasible. Various investigators have conducted successful observations on wavelengths of 1.4 millimeter, eight millimeters, 1.25 centimeter, 33 centimeters, and certain others, and obtained corresponding temperature values. The most interesting results of these investigations consists in that the greater the wavelength the greater the lag of the temperature maximum compared with the radiation maximum, and the lower the fluctuation amplitude of temperature. Thus, for the centimeter waves [microwaves] the temperature maximum lags behind by 3.7 days, while the amplitude amounts to only 100°C, i.e., to 0.4 of that obtained by thermoelectric observations on the spectrum portion of approximately 10 microns; on the wavelength of 33 centimeters the monthly temperature fluctuations are in general inconsiderable, like the changes accompanying lunar eclipses.

The above-described phenomena are to be explained by the circumstance that the material of the outer blanket of the lunar surface, while completely nontransparent to radiations with a wavelength of an order of 10 microns, is semi-transparent to radio waves, in which connection its transparency increases with increasing wavelength. Therefore, thermoelectric measurements inform us about the temperature course of the outer surface, and radio measurements -- about the effective temperature of a certain layer beneath that surface; this layer increases in depth the greater the wavelength employed for observations. From the foregoing it follows that the temperature fluctuations caused by the shift from day to night on the Moon extend to only very shallow depths.

In view of such results, it is necessary to abandon the concept of the lunar surface as a compact rock area; it is necessary to assume that the lunar surface is all of its parts is covered with some special homogeneous layer which, because of its very pronounced porosity, displays an exceptionally low heat conductivity. One hypothesis to be advanced was that such properties would be displayed by a layer of fine dust whose heat conductivity should be extremely low under the conditions of a total absence of an atmosphere, because then heat transfer will occur only through heat conduction at the point of contact between dust particles of a very minute size, and through radiation in the space between dust particles as well. Regrettably, it does not seem possible to verify this important fact experimentally, because it is not within present possibility to create a vacuum corresponding to the conditions of the medium at the lunar surface.

The Structure of the Lunar Surface

In connection with the foregoing, at present the hypothesis of the English astronomer Gold is being widely discussed among Moon researchers. He pointed out that the montane formations on the Moon which could more or less reliably be said to be the most ancient always prove to be lower and smoother than the more recent objects of the same type. This provides a foundation for assuming that an erosion mechanism exists on the Moon, as on the Earth, and that it gradually wears away the matter of lunar rocks, converting it into fine dark dust which subsequently drifts from the elevations down onto the plains. According to Gold's estimate, the speed of this process is such that in one million years it disintegrates a layer of rock one kilometer thick, which drifts downward [as dust particles].

Thus, in all of its parts, the visible surface of the Moon consists of a layer of extremely fine dust displaying a distinctive fluidity, and hence gradually drifting onto the deepest surface depressions and accumulating there. The lunar seas constitute, according to Gold's views, deep basins filled with layers of dust several kilometers thick.

Gold's hypothesis has encountered many different objections. It was pointed out that the mechanism itself of the erosion of montane rocks and transport of dust over considerable distances remains insufficiently clarified. Inasmuch as the surface of the seas is reppled in many places, it has to be assumed that the movement of the dust, which Gold likens to the flow of a fluid, can occur not only from elevations to plains but also from the bottom up. The dark coloring of dust and, together with it, the surface of lunar seas which it composes, remain unexplained. Under the conditions of terrestrial rocks and artificial experiment, erosion, as a rule, leads to an increase and not a decrease in reflectivity.

The hardest blow to Gold's theory (and to all "dust" hypotheses in general) was struck by the results of the most recent photometric studies of the lunar surface. The well-known work on lunar photometry published by Academician of the Academy of Sciences Ukrainian SSR N.P. Barabashov and Professor A.V. Markov has shown that the reflection of solar rays from the lunar surface occurs very distinctively and completely unlike the reflection from a smooth matt surface. For example, the edges of the disk of a full Moon display the same brightness as its central parts, although in the center the rays fall perpendicularly while on the edges they encounter the spherically shaped surface of the Moon at very large angles. Moreover, to the Earth-based observer, the maximal brightness of any part of the lunar disk occurs not when the Sun stands at the zenith and thus provides maximum illumination but when the observer regards that part from the Sun's side -- when, at full moon, all parts of the Moon are maximally bright. All these facts can be explained only by presuming that the surface of the Moon consists not only of the mountains and irregularities visible through a telescope but also of a micro-relief whose elevations and depressions spread uniformly over both the surface of mountainous areas and the plains of the lunar seas.

The question of the structure of the lunar surface was investigated in detail by the Leningrad astronomer N.S. Orlova, who explained that the reflection of light from both the bright and the dark areas of the lunar surface occurs so that a major part of the light flux is thrown back toward the Sun, analogously to the process occurring in the reflectors-cataphotes mounted on bicycles, automobiles, and road signs.

A reflection of this type can be given only by an intensely furrowed surface whose minute irregularities have steep or even sheerly vertical walls and sharp, jagged edges. A granular material such as sand, volcanic ash or dust is in no way capable of forming irregularities of this kind. This is because the limiting angle of repose for granular matter usually amounts to 20-40 degrees. Therefore, the relief of a locality completely covered by dust cannot include surfaces with an inclination greater than such angles. This explains why a layer of pulverulent material smoothes out the irregularities of soil, as exemplified by the snow blanket in winter.

Analogous conclusions were reached by the French astronomer Dol'fyus, who pointed out that granular material could not maintain itself on the very steep slopes and vertical precipices of the lunar mountains, e.g., on the plane of the so-called "straight wall", and on the slopes of rills and fissures. In this case, such slopes would constitute the outcroppings of bare rocks and hence would have to differ sharply in coloring and in nature of polarization from the surrounding less steep forms of relief, which actually is not the case.

But if the lunar surface visible to us does not consist of smooth rocks nor of a pulverulent soil such as dust or volcanic ash, then what does it consist of? A reply to this question is furnished by a theory developed by Professor N.N. Sytinskaya and known under the appellation of the meteor-slag hypothesis.

A type of matter in which an extremely low heat conduction is combined with a strength sufficient to form jagged types of relief is constituted by a very porous, spongy material as exemplified by many types of slag, both artificial (industrial) and natural such as the slag of volcanic origin. Slags of this kind form on the surface of molten masses releasing many gaseous products. Constituting, as it were, a cooled stone foam forming on the surface of a lava flow, such slag has a bubbly structure consisting of individual empty cells with very thin walls. As a result, the heat flux transmitted through these cell walls is very weak. Under lunar conditions, the cells cannot, of course, retain their gas, so that heat transfer by gaseous convection, i.e., by the movement and mingling of gases is also excluded. What remains is the transfer of energy inside the cells because of radiation, which can assure only a very small heat flux. Thus, the heat conduction of a material with such a structure will be very low -- possibly even lower than that of a layer of loose dust. At the same time, the cells located on the upper boundary, being open to the outside, form, as it were, a blanket with jagged edges which causes the distinctive reflection of light on the Moon.

If this view on the structure of the matter blanketing the lunar surface is adopted, it still remains necessary to answer the question of how such a blanket has formed, and why it is so darkly colored.

N.N. Sytinskaya assumes that this matter, which externally resembles volcanic slag, has formed in a totally different way, to wit, as a result of the continuous belaboring of the lunar surface by the explosions accompanying the impacts of meteorites. As noted before, calculations have shown the impact of a meteorite vaporizes a mass of lunar surface hundreds and even thousands of times greater than the mass of the impacting meteorite. This result pertains not only to the impacts of those rare giant meteorites which, it may be, had created the lunar craters and circuses but also to the small and even minute meteorites termed micrometeorites, whose number is very large. Thus, according to the data of the observations conducted in the United States during the ascents of meteorological rockets, the frequency of collisions with micrometeorites amounts to one impact per square centimeter per minute. The mass of such a particle is very small but, because of the enormous cosmic velocity, the energy liberated at the impact suffices to create a small explosion and to form an appreciable indentation on the surface of the receiving metal plate. Clearly, the effect of the micrometeorites alone is sufficient to alter completely the appearance of any part of the lunar surface within a short time. While, parallel to this, other processes of formation of the outer layer are active

on the Moon, e.g., the processes of the release of lava, deposition of volcanic ash or treatment of the rocky surface by cosmic or other radiation, their action cannot yield any decisive results because of their slowness: meteoritic impacts rapidly re-work any neo-formation of the lava blanket type should it arise on the Moon. This explains satisfactorily the astonishing uniformity of the blanket on all parts of the lunar disk, which causes the operation of an absolutely identical law of reflection literally throughout that area. It is striking that the careful telescopic observations of the lunar surface conducted since Galileo, i.e., for approximately 350 years, could not detect on the Moon even one small spot whose contrast with the surrounding background would vary appreciably over a month as a result of an essential difference in the law of reflection of solar rays. This, in particular, prevents the adoption of the opinion once offered that slag-covered areas are encountered together with dust blankets and bare rock outcroppings on the Moon.

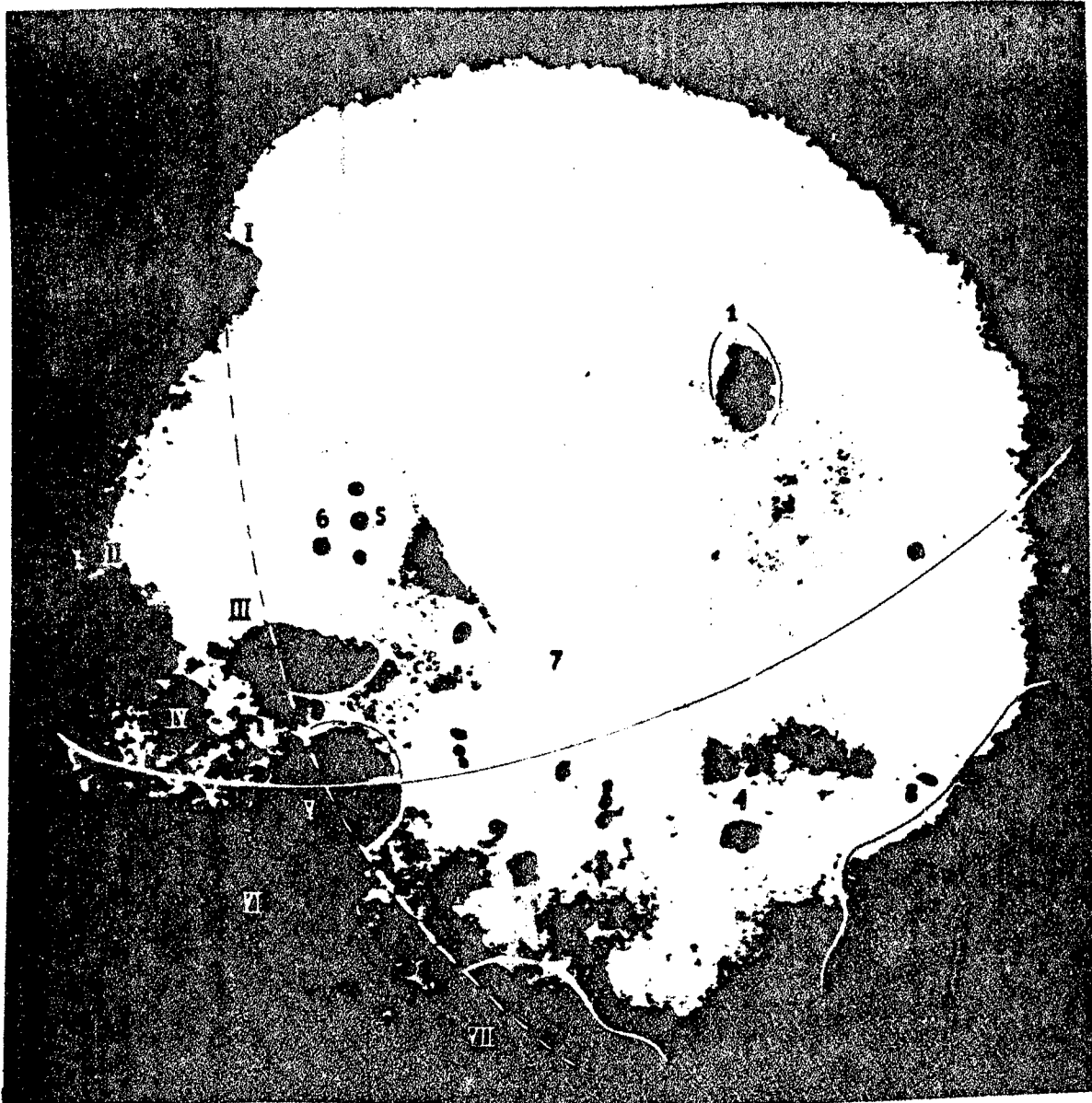
The dark coloring of the slag blanket can be easily explained if it is assumed that the original rocks from which this slag has formed had belonged to the basic or ultra-basic class and, in particular, had contained a large amount of olivine ($\sqrt{\text{Fe, Mg}}_2 \text{SiO}_4$) and other iron-rich silicates. At a high temperature, such minerals, and their enclosing rocks, usually melt into a material with a dark coloring, as exemplified by the black melting crust forming on meteorites when they pass through the Earth's atmosphere. As shown by the investigations of I.A. Yudin, this black coloring is a result of the decomposition of the molecules of silicates and release of black-colored oxides of iron (ilmenite, magnetite, and others). It is natural to assume that on the Moon the product of the decomposition of olivine-containing rocks, as caused by meteoritic bombardment, acquires its brownish-black coloring also because of the release of iron oxides, and its spongy structure because the vapor arising as a result of the high temperature of meteoritic explosion cools rapidly and settles on the surface, where it forms a crust with a bubbly structure.

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We are living at a time when the study of the matter forming the lunar surface by direct methods of chemistry and petrography is becoming a matter of the relatively near future. The time will come when, at last, the first samples of the lunar blanket will be brought to the Earth. Then it will be possible to state definitely the extent to which the representations expounded above are correct. However, it is indisputable that the complex whole of the information about the nature of the lunar world now at our disposal can be successfully utilized for continuing the studies of our satellite by means of the continually improved techniques.



Photograph of the Visible Part of the Moon, Made on the Earth by Means of a Powerful Telescope.



Caption on page 18b.

Distribution of Objects on the Moon's Side Invisible From the Earth,
Revealed by the Preliminary Processing of the Photographs Transmitted
by the Automatic Interplanetary Station ["Lunik"]

1. A large crater sea with a diameter of 300 km -- the Moscow Sea;
2. The Bay of Astronauts in the Moscow Sea;
3. Continuation of the Southern Sea on the Obverse Side of the Moon;
4. Crater with a central peak -- Tsiol'kovskiy Crater
5. Crater with a central peak -- Lomonosov Crater
6. Joliot-Curie Crater
7. Sovetskiy Range
8. Dream Sea.

The solid line bisecting the scheme is the lunar equator, and the broken line -- the boundary between the visible and invisible -- from the Earth -- parts of the Moon. The solid-line circles ring the objects reliably established by preliminary processing, and the broken-line circles -- the objects whose classification needs further revision; the dots ring the objects whose classification needs further revision; as for the remainder -- the processing of the obtained photographic material is being continued. The Roman numerals denote objects on the visible part of the Moon: I -- Humboldt Sea; II -- Sea of Crises; III -- Boundary Sea, which continues on the invisible part of the Moon; IV -- Sea of Waves; V -- Smith Sea, which continues on the invisible part of the Moon; VI -- Sea of Fecundity; VII -- Southern Sea, which continues on the invisible part of the Moon.

END