THE SURFACE OF THE MOON

OBSERVATIONS BY THE COMMITTEE ON STUDY OF THE SURFACE FEATURES OF THE MOON

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THE Carnegie Institution of Washington was founded by Andrew Carnegie to advance knowledge in different fields of science through research work. In the early days of the Institution careful surveys of certain branches of sciences were made by special committees of experts to ascertain the particular problems in each field that were strategically important and could be attacked by scientists working together but approaching each problem from different standpoints. The value of diversified but coordinated attack on a problem is well recognized in the military services (tactics) and is equally important in science.

The committees, after study of the different fields, recommended certain problems for consideration. Of these a limited number were adopted and small groups of research men were brought together and given opportunity to work on them. These groups were gradually organized into the departments and laboratories of the Institution. A number of these units have now been operating for more than thirty years, and have made extremely important contributions to science. In addition to support of the work of the departments, the Institution has aided many individual investigators (research associates) on specific problems related to work of the Institution.

During the first twenty years of their existence the departments were so occupied with their own problems that each one functioned as an independent unit with little knowledge of the work and personnel of the other groups. This situation was recognized by Dr. Merriam when he became President of the Institution in 1921. On his initiative, steps were taken to bring the several departments into closer touch with one another and to a better understanding of the purposes and functions of the Institution itself.

At the same time he realized the desirability of more effective contact with the public in order that the work of the Institution might be better known and of greater service. He felt that the public had the right to know of the work of a semipublic institution, like the Carnegie Institution, operating under special congressional charter and devoting its energies entirely to research work in science. To meet this responsibility several steps were taken. At the time of the Trustees' annual meeting greater emphasis was placed on the public exhibition of the results of current work of the Institution; the number of public lectures by members of the Institution was increased; and many of the lectures were published. The annual exhibition and the annual series of Institution lectures have been successful and have attracted wide attention. Under Dr. Merriam's guidance, the Editor of the Institution has prepared a series of bulletins for distribution to newspapers (news releases), to schools and other organizations (news bulletins), and to staff members of the Institution (staff edition of news bulletins). The purpose of these bulletins is to present, in easily readable form, brief statements on some of the investigations by the Institution; serious effort is made to have the bulletin articles correct and authoritative. The large demand by the public for these bulletins is evidence that they are meeting a need and are appreciated.

Dr. Merriam has also encouraged greater cooperation between Institution departments by appointing interdepartmental committees for study of problems in fields peripheral to those of two or more departments. A good example of a committee of this kind is the Committee on Study of the Surface Features of the Moon.

Realizing how little definite information was available on the nature of the materials exposed at the moon's surface and on the mode of their distribution, Dr. Merriam organized the Moon Committee and appointed to it certain members of the staff of Mount Wilson Observatory (Drs. W. S. Adams, F. G. Pease, E. Pettit) and of the Geophysical Laboratory (Drs. A. L. Day and F. E. Wright, Chairman), and from the group of Research Associates (Drs. J. P. Buwalda, P. S. Epstein, and H. N. Russell). The Committee consisted of four astrophysicists, one mathematical physicist, one volcanologist, and two geologists. With the exception of

Dr. Pease, who for many years had been enthusiastic over the possibilities of research work on lunar surface features, none of the members had made special study of the problem. They were given no specific instructions, other than that implied in the name of the Committee, but were afforded opportunity, as time permitted, to survey the problem and, with the unusual instrumental facilities available within the Institution, to investigate any phase of it that might seem promising.

The Committee has now been at work for a number of years gathering definite data of measurement on the nature of the surface materials, on their distribution, and on the characteristics of the surface features themselves. Throughout this period the members have cooperated effectively and given generously of their time.

Early in the attack on the problem it was realized that precise data of measurement are needed rather than suggestions regarding possible modes of formation of the different lunar surface features. Before the origin of these features can be adequately discussed, knowledge of the nature of the materials exposed at the surface of the moon is essential; also information on the conditions that exist at the lunar surface. A photographic map consisting of a series of photographs of the moon at different phases and with the plane of mean libration as its plane of projection is needed; also a topographic map of the central part of the moon's disk. Information is desired regarding the exterior ballistics of projectiles as represented by ejectamenta from volcanoes or from craters produced by impact of large meteorites or of swarms of meteorites. Statistical information on the frequency of lunar craters of various sizes is required.

Work on these and related problems has been in progress for some years and the results obtained have increased our knowledge of lunar surface features. Some of these results we shall now consider briefly.

Nature of Lunar Surface Materials

In study of rocks and geologic formations on the earth the geologist examines their occurrence and relations to other formations in the field, and procures samples of each type of rock for further tests in his laboratory. He prepares thin sections of the rocks and examines them under the petrographic microscope; he makes chemical tests and, if necessary, may make a complete chemical analysis of an important sample. Under the microscope he determines each mineral by the effects it produces on polarized light on transmission through the thin mineral sections. These effects are many; in general, they are easy of measurement, so that quite accurate and satisfactory determinations of the minerals composing a rock are possible.

In the study of lunar surface materials the geologist cannot visit the moon and collect samples; he must be satisfied with measurements at the long-range distance of about 240,000 miles. The rays of the sun after reflection by the moon reach the earth as moonbeams 3 seconds later; they serve as lunar messengers and carry signals in code from its surface. It is our task to receive and decipher these signals if we are to ascertain the kinds of substances that are exposed at its surface.

The moon shines by reflected sunlight. The sun's rays impinging on its surface undergo, on diffuse reflection, changes that can be measured. These changes are of three kinds: (*a*) a large part of the energy of the incident sunlight penetrates a short distance into the surface and is absorbed, thereby heating the surface materials; the heated surface in turn radiates the absorbed energy into space as heat waves (planetary heat); (*b*) different wave lengths or colors of the incident sunlight may be absorbed in different proportions, whereupon their relative intensities are altered slightly, thus coloring the scattered light (selective absorption); (*c*) a certain amount of plane polarization is introduced on scattering and reflection; the amount depends on the character of the material and on its surface. In general, dark-colored opaque substances polarize the light much more than do non-opaque substances into which the incident light may enter and be returned in part by internal reflections.

Detailed observation of these changes and comparison of the results with those obtained on terrestrial materials under similar conditions of illumination enable the observer to ascertain the general nature of lunar surface materials. The problem is analogous to that of the determination of minerals with the aid of the petrographic microscope. In the one case the changes produced in light on diffuse reflection are analyzed; in the second case, those resulting from transmission through mineral sections and grains are determined. With lunar substances, unfortunately, the changes are relatively few and cannot be measured with the degree of accuracy possible in polarization phenomena of light transmitted through mineral plates. In lunar observations it is not feasible to apply the methods of transmitted light; the observer has no choice but to infer the nature of the surface materials of the moon from the slight changes they induce in sun's rays on reflection. If satisfactory conclusions are to be drawn, it is essential that the measurements be made with high accuracy by independent methods and through several complete lunations for each method. It is for this reason primarily that the task is time-consuming and difficult.

The proportion of plane polarization in a beam of moonlight can be ascertained by several methods based on various types of receivers, such as the human eye (visual), the photoelectric cell, the thermoelement, or the photographic plate in a polarization spectrograph. These methods cover different parts of the spectrum, but their spectral ranges overlap sufficiently so that the results obtained by one method can be checked by those obtained by other methods.

Polarization eyepiece. Visual determinations of the percentage amounts of plane polarization in light from different parts of the moon at different phases of the moon have been made by the Moon Committee during eleven lunations. As a result, the changes in amount of polarization with change in lunar phase angle are now known with a fair degree of accuracy for the light received from twenty-four selected areas on the moon's surface and also for the integrated light from the entire visible lunar surface. Study has been made of the factors that influence the accuracy of the results, especially the depolarizing effect of dust particles and of water vapor (thin clouds) in the earth's atmosphere.

Similar visual measurements have been made of the amounts of plane polarization in sun's rays after reflection by terrestrial materials of different kinds. The amount of plane polarization thus introduced depends not only on the phase angle or angle between the incident beam and the line of sight to the observer, but on the refractive and absorption indices of the material and on the nature of the surface that scatters the light, whether it is a surface of fracture, a rough or finely ground surface, or a coarse or fine powder surface. The factors that enter into the problem are many; their influence can be determined only by adequate numbers of measurements on each material under test.

The phenomena observed are chiefly those of scattered (diffracted) light combined with absorption and internal and external effects of reflection; under these conditions the character of the surfaces that scatter the light plays an extremely important part and gives rise to phenomena that cannot be explained on the basis of reflection and refraction alone. When the angle between the incident and the radiated beam is small, at some value between 10° and 30° depending on the substance and its surface, the amount of polarized light in the scattered beam is zero. For still smaller phase angles the scattered beam is again partially polarized, but the plane of vibration of the polarized component is in the plane of incidence rather than normal thereto.

Lyot, who was the first to observe this phenomenon in moonlight, called it negative polarization. It appears in moonlight about two days before full moon and continues for an equal period after full moon. Terrestrial materials exhibit the same phenomenon and approximately the same range of variation. The percentage amount of negative polarization rarely exceeds one per cent and may be less. In terrestrial materials it varies with the substance and with the character of the scattering surface. As a diagnostic feature negative polarization is of little value. It is, however, an important element in the theory of scattering of light and is being investigated further.

The visual measurements have been made with a special eyepiece consisting of a tilting-plate compensator together with a detector for ascertaining the point of exact compensation. The field of the eyepiece is a divided photometric field in which two factors, equality of illumination and exact alignment of Savart fringes, are the two criteria used in making a measurement; it is the combination of these two factors that renders the method so accurate. With this eyepiece the percentage amount of polarization can be determined with an accuracy of 0.2 per cent. The plate of the compensator can be tilted up to 70°; for this angle of tilt the percentage amount of polarization introduced by a single thin plate of glass or celluloid of refractive index 1.505 is approximately 26 per cent; at a 60° angle of tilt it is about 18 per cent; with a compensator consisting of two plates mounted in parallel and tilted at 60°, the percentage amount is increased to 30 per cent; with 4 plates, to 46 per cent; with 6 plates, to 56 per cent; and with 12 plates, to 71 per cent.

For observations on the moon the single-plate compensator suffices; the maximal polarization in moonlight from the dark areas or Mare is approximately 17 per cent, and from the bright lunar mountain areas it rarely exceeds 8 per cent. For observations on terrestrial materials more than one tilting plate is needed to compensate the much higher amounts, exceeding 60 per cent, of plane polarization produced by dark-colored rocks, such as basalts and peridotites.

With the aid of the polarization eyepiece, equipped with tilting compensators of one, two, and six plates, polarization measurements have been made on fifty selected terrestrial substances illuminated by sunlight incident at different angles and viewed from different directions.

The results of visual measurements of polarization in light scattered by the moon's surface and by terrestrial materials have been plotted on graphs and are now being assembled, preparatory to a report on this part of the determinative work.

Thermoelement. Many measurements have been made of the amount of plane polarization in a beam of light with the aid of the vacuum thermoelement together with a special rotatable Wollaston prism of quartz and a lens system of fused silica. The sensitivity of the thermoelement is not sufficiently high to be satisfactory for this purpose, but it extends over the entire spectrum and is useful as a check on measurements by other methods.

Polarization spectrograph. A spectrograph consisting of optical parts of fused silica and a Wollaston prism of quartz in a sliding mount has been used for polarization measurements and many spectrograms have been taken. In the parallel beam between the collimator and the first prism of the spectrograph the Wollaston prism can be inserted and two spectra obtained, the one with vibrations in the plane of incidence and the second with vibrations perpendicular thereto. With this arrangement each spectrogram has imprinted upon it three spectra, one above the other; of these the two outer spectra are the polarization spectra, and the central one is the spectrum of the entire beam. The polarization spectra are imprinted by a second exposure after insertion of the Wollaston prism. Difficulty was experienced in this arrangement with the calibration of the negative film in translating densities of the negative into intensities of incident light. To avoid this situation a tilting plate of thin mounted celluloid was built into the instrument. With it any definite percentage amount of polarization light can be introduced into the beam of incident light and the resulting changes in intensity measured on the spectra thus obtained, thus converting the method into a null method. The sensitivity of this method is not high but the spectrograms yield information both on the percentage polarization for any given wave length and on the relative intensities for different wave lengths. The polarization spectrograph covers a wide range of wave lengths, through the ultraviolet into the near infrared of the spectrum. Measurements with this method are being continued.

Photoelectric cell. Two different methods with the photoelectric cell as receiver have been employed. The first is based on the use of direct current and the second on alternating current. In the first attachment a large Wollaston prism of quartz in a rotatable mount is placed in front of a vacuum potassium Kunz photocell of fused quartz, the current from which is passed to the special amplifying circuit of DuBridge and Brown as adapted and improved by Dr. J. Stebbins. This method has been tested on a number of rock samples but has not yet been applied in series of routine measurements. The second method utilizes a mounted polarization prism that is rotated about its axis five times a second. If the incident beam of light contains a certain amount of polarized light, the intensity of the transmitted light will be a maximum whenever its plane of vibration coincides with that of the rotating polarizing prism, thus giving rise to an alternating current of 10 cycles per second in the photocell. A special high-gain amplifier for use with this arrangement has been devised by Mr. Ellis Johnson, of the Department of Terrestrial Magnetism; through the courtesy of Dr. J. A. Fleming the amplifier was built in the shop of that Department. The attachment has been thoroughly tested recently, but has not yet been employed in routine measurements. It gives promise of high sensitivity, but will require some modification before it is entirely satisfactory.

The foregoing methods have now been tested and their suitability for the task ascertained. Series of routine measurements with their aid are still outstanding.

The results of the visual measurements of the amount of plane polarization in sunlight reflected by lunar and terrestrial materials indicate that the substances exposed at the surface of the moon are of the nature of volcanic ashes and pumice high in silica. The changes in the amount of polarization in the reflected light for different angles between incident and reflected rays prove that the lunar surface is rough and not smooth. The changes in the intensity of light from different areas on the moon point to the same conclusion. It is true that the observations are restricted to materials at the actual surface of the moon and that in certain regions the cover of ashes and pumice may be quite thin and, like a light snowfall, may serve to blanket and conceal whatever is underneath. For this reason efforts have been made to measure the amount of plane polarization in sunlight reflected from steep lunar mountain slopes and inner crater walls that may not be coated with an insulating layer. These measurements are being continued with more powerful equipment.

Further evidence on the nature of lunar surface materials was obtained by Drs. Pettit and Nicholson during the lunar eclipses of June 14, 1927 and of November 26, 1928. Their measurements were made with the aid of a vacuum thermoelement and of screens of fluorite, glass, and a water cell mounted on a large reflecting telescope. The results showed that during an eclipse, when the moon enters the earth's shadow and is cut off from the sun's radiation, its surface chills so rapidly that, in the course of an hour or two, its temperature drops from +120° C. to approximately −100° C. From the data of measurement thus obtained Dr. P. Epstein has shown that the actual surface layer, which absorbs and radiates heat, is very thin; in other words, that lunar surface substances are good heat insulators, resembling, in thermal behavior, volcanic ash and pumice, or other highly porous substances. Large uncovered areas of massive rocks, such as granite, when heated to the boiling temperature of water and then set in a cool place require a long time to cool; they are thus precluded. If massive rocks occur near the moon's surface they are now covered by pumiceous material and well protected from the disintegrating effect of the alternations of extreme heat and cold to which the lunar surface is exposed.

Photographic Map of the Moon

Study of the surface features of the moon has emphasized the need for a lunar map that is free from the personal factors that have entered heretofore into the construction of maps of the moon. Of maps there are two kinds, the plan or base map and the topographic. Thus far only the first kind has been attempted for the moon. It represents the moon's surface projected on a definite plane and shows the features somewhat as the astronomer sees them through his telescope. These maps have been drawn by astronomers untrained in the principles of map making, with the the result that existing maps are unsatisfactory in several respects: the balance between map scale and amount of detail shown is not realized and some of the maps are not easily legible; several lunar maps have been prepared by men who were good observers but not good draughtsmen and unable adequately to portray what they saw. In other words the existing maps suffer from the personal equations of the men who prepared them. Comparison of a lunar map made a century ago with one drawn recently shows marked differences in the appearance of certain features; on the basis of such a comparison it has been concluded that changes have taken place here and there on the moon. But astronomers do not agree on the validity of any single change and the bulk of the available evidence goes to show that there has been no appreciable change on the moon's surface within the past century.

It seemed, therefore, to the Moon Committee that a lunar map should be prepared which is free from the personal equation and not dependent on the skill of the observer to depict correctly what he sees on the surface of the moon. The positions of approximately 4000 points on the moon's surface have been accurately measured by Saunders, Franz, and others and expressed in terms of selenographic longitude and latitude. With the aid of these data on position it is possible to ascertain the amount and direction of libration in each photograph of the moon. If each photograph could be transformed so that its plane would coincide with the plane of mean libration, namely, the plane on which all lunar maps are projected, the transformed photograph would form part of a lunar map and at the same time be free from the personal equation of the one who prepares the map.

To prepare a photographic map of the moon it is necessary to transform photographs taken with the aid of the 100-inch telescope at Mount Wilson so that the plane of projection is the same for all photographs. A map is a projection on a definite plane; the type of projection and the plane of projection must be quite definite if the map is to be satisfactory. For the transformation of the photographs a special moon house has been built at Mount Wilson. It is an insulated structure with double walls, corrugated sheet iron on the outside and paper on the inside with ventilation between the walls so that they quickly respond to temperature changes outside. The floor is covered with a layer of sawdust 6 inches thick to prevent radiation from the ground. As a result, the temperature distribution within the 150-foot building is remarkably uniform and seeing conditions are good so long as the temperature outside is not changing rapidly and there is no appreciable wind.

To transform a given moon photograph taken at the Cassegrain focus of the 100-inch telescope (focal length 135 feet), the moon positive, 15 inches in diameter, is mounted in front of a powerful beam of light reflected by an Army searchlight mirror 3 feet in diameter; the light passes through the positive to a parabolic silvered mirror of 67.5 feet focal length and 135 feet distant and thence back to a carefully turned globe of bronze, 15 inches in diameter and coated with magnesia powder. This coating furnishes a white diffuse reflecting surface. The image of the moon formed on it is in all respects similar to the moon in the relations of the surface features one to another; in other words, it is a miniature moon which can be photographed from any direction. For this purpose a second reflecting mirror, also of 67.5 feet focal length, is placed at such a position that it views the moon from the direction of mean libration and casts an image of it on a photographic plate mounted in a compartment beside the illuminated globe. The photographs thus produced are actually projections on the plane of mean libration; they fulfill the requirements of a map on a given scale. In order to complete the series of maps showing the moon at different phases, photographs of the moon, taken in July 1938 with the 100-inch telescope at the Newtonian focus, are to be transformed so that the plane of projection is that of mean libration for each negative. The series of maps made by this method will be free from the personal factor and of more value a century hence than at present.

Topographic map. A simple method was developed several years ago for ascertaining, from photographs of the moon, the slopes, shapes, and dimensions of its surface features. The moon is so nearly spherical in shape that, for all local measurements, it may be considered to be a sphere. A photograph of the moon is a projection of its spherical surface on a diametral plane normal to the line of sight. With the aid of an accurate lunar perspective polar projection of the same diameter as that of the lunar image on the photographic plate, it is possible, by superposing the projection on the photograph, to ascertain the angle which the incident sun's rays include with the normal to the moon's surface at any given point. If, for example, the inner slope of a crater is greater than the angle of elevation of the illuminating sun's rays, it will cast a shadow; if the slope angle is less, the surface will be illuminated; when slope angle and angle of elevation are equal, grazing incidence is observed.

From a series of photographs taken at different times during a lunation it is possible to observe the changes in character of illumination of any given slope and to ascertain its angle. In 1929 a series of motion pictures was taken of the moon with the 100-inch telescope on films in a motion picture camera. In July 1938 more than 400 photographs of the moon were taken at the Newtonian focus of the 100-inch telescope. A new 3-element zero corrector lens, designed by Dr. F. E. Ross, was used and found to be excellent for the spectral range between 5000 and 6000 Ångström units. This set of photographs will afford the basis for a better physiographic study of the moon than has heretofore been possible and will make possible the preparation of a rough topographic map of the central part of the moon's disk. The dimensions of a crater, for example, are read off directly on the superposed projection chart in terms of latitude and longitude angles or of polar distance and azimuth angles; these are, in turn, reduced to linear distances by use of a conversion table. With the aid of the Nautical Almanac it is possible to ascertain the phase angle (angle at the moon's center between the lines of sight to the centers of the sun and earth respectively) for the instant of time at which a given photograph was taken. With the aid of the projection the angle of elevation of the sun's rays at any given point on the moon's surface and for any given phase angle can be read off directly without computation. By this method the observer is in position with a sufficiently complete set of photographs to reconstruct the shapes, both in plan and section, of lunar surface feature within 45° of the center of the moon's disk and to draw therefrom a rough topographic map. Work on the preparation of this map will be started as soon as prints from the negatives have been made. Preliminary measurements of slope angles on negatives taken at the Cassegrain focus of the 100-inch telescope prove that the inner slopes of small craters (craterlets) are greater than those of the larger craters and walled plains. The slope angle of the inner wall of some of the smaller craters ranges from 50° to 55°.

Photograph of Moon on Globe

The projection of a moon positive on the magnesia-coated bronze globe in the moon house gives an extremely beautiful and realistic presentation of the moon's surface. The undistorted appearance of the craters and other features near the edge of the moon's disk is helpful in the visualization of the surface relationships. In order to make this globular relationship more accessible, a glass globe coated on the outside with photographic emulsion was substituted for the magnesia-coated bronze globe and the moon negative projected on it, thus producing a moon transparency which is angle true. The globe is frosted on the inside and illuminated by an electric lamp. The coating with photographic emulsion was done, through the courtesy of Dr. C. E. K. Mees, by the Research Laboratory of the Eastman Kodak Company, and represents an advance in photographic technique. A number of these globes have been prepared and will be useful to the Moon Committee in its physiographic studies later; they serve also as exhibits of miniature moons, 13.5 inches in diameter, and show the aspect of the moon at different phases.

Lunar Surface Features

Although the Moon Committee has thus far devoted the major part of its available time to polarization measurements in the effort to ascertain the nature of the materials exposed at the moon's surface, it has made many observations on the surface features themselves and has sought to interpret some of the extraordinary features in terms of the conditions known to exist at the lunar surface, such as absence of atmosphere, of water and water vapor, and of the effects of ordinary erosion by running water; gravity one-sixth of that of the earth; rapid changes in temperature from +120° C. at noon to less than −100° C. at midnight. It has made a detailed study of the trajectories of materials hurled out of lunar craters and found that they are from 20 to 50 times longer than those of materials ejected at the same initial velocity and angle of elevation on the earth.

Under such conditions materials ejected from a lunar crater are scattered far and wide, whereas on the earth the greater part of the ejected rock fragments fall near and into the crater orifice. Lunar craters are cleaned out, as a rule, and are of the nature of immense deep holes in the ground with the floor of the crater below the level of the surrounding country; the floors of terrestrial craters, on the other hand, are near the top of the crater and high above the level of the adjacent country. On the moon, few, if any, typical lava flows have been observed. The floors of the latest craters are commonly whiter and brighter than older craters; this is especially true of the craterlets and of the "rays" from many craters. The structural features follow in many areas definite patterns; along many structural lines rows of craterlets are observed, as also craterlets in the central hills of larger craters. These relationships occur in too many regions on the moon to be ascribed to mere chance and indicate strongly that many of the craterlets are of volcanic rather than meteorite impact origin. On the other hand, the translational energy of a meteorite impinging unimpeded on the moon with a velocity of 20 to 40 kilometers a second and penetrating into its surface for some distance is able not only to produce the crater form but, on transformation of its residual kinetic energy into heat, to melt and even to volatilize the invaded rock and thus to give rise to actions that in their effects closely resemble volcanic phenomena.

Study of the "rays" radiating from craters, such as Tycho, has shown that they do not project as ridges above the land they traverse; they cast no appreciable shadows when near the terminator; they reflect the light more strongly than do the materials of the surfaces over which they reach. It was suggested many years ago by different observers that the rays from a crater are streaks of fine dust or ashes blown out from its top or sides, and carried along by the jets of hot escaping gases from which they gradually settled out along the paths followed by the streaming gases. This explanation of the origin of the rays seems to accord well with the observed facts. The rays, like many of the craterlets, are younger than the land on which they occur. Observations by the Committee indicate clearly that the floors of younger craters are whiter and brighter than those of older craters and that, as a general rule, the degree of whiteness of a crater floor is an indication of its relative age; it appears that the younger craters have brought to the surface white fresh materials that have not yet been darkened by the staining action of slowly acting weathering agencies and by the gradual accumulation of a thin mantle of cosmic dust.

A preliminary study has been made of the relative frequency of lunar craters of different diameters, as listed in the publication entitled *Named Lunar Formations* by M. A. Blagg and K. Mueller of the International Astronomical Union, 1935. The total number of craters for which the diameters are given is approximately 3950. The analysis shows that the distribution curve is remarkably smooth and approximately exponential in character. No satisfactory explanation has been found for the type of the frequency curve.

Program for Future Work

The work of the Committee on Study of the Surface Features of the Moon has progressed relatively slowly. Each member of the committee has had but little time to give to it; the Committee realized early in the task that, before physiographic studies of value could be attempted, more definite information was needed regarding the nature and environment of the lunar surface materials; also that a topographic map or a simple method for ascertaining the shapes and spatial relationships of the various surface elements was desirable. These tasks had of necessity to be undertaken not by the whole Committee but by one or two of its members, working at Mount Wilson Observatory for a month or so each year and calling upon the other members for advice whenever needed. This deliberate approach to the problem has had the advantage that it has enabled the Committee to plan the attack well and to carry it out with relatively small cost, even though the work is spread over a number of years.

The Committee has developed new methods that are yielding results of measurement of known accuracy, thus providing a firm foundation for the critical analysis of the data obtained. At the present rate of progress several years will be required to finish the measurements on polarization by the different independent methods and to complete the topographic map and the series of photographic maps. It will then be possible for the committee to proceed to the problem of physiographic description and interpretation of the surface elements of the moon with the assurance that the available data are reliable and can be trusted within definitely determined limits.

The policy of assigning to an interdepartmental committee a problem of large scope is in keeping with the general policy of the Carnegie Institution of supporting organized efforts in fields of science too large for one man to encompass. Each department of the Institution is essentially a group of cooperating scientists, each member of which is engaged partly in researches of his own and partly in the attack on larger problems in cooperation with other members. This group method of facing each problem from all standpoints and of determining the best means for solving it has, in recent years, been extended by Dr. Merriam to cooperative work between the several groups within the Institution and between the Institution and outside groups.

The dividends accruing from cooperative work of this type, in terms of scientific results obtained for a given sum of money, are large, chiefly because of the facilities and background of experience within the several groups. Emphasis by Dr. Merriam on the unity of the Institution in its approach to new problems in science and in its relations with the public has been an extremely important factor in increasing the effectiveness of its work, and in stimulating the interest of each staff member in fields of research other than his own. This shift in attitude has led to better appreciation of the meaning and value of cooperation in research in science.