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A COMPARISON OF THE FEATURES OF THE EARTH AND THE MOON

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GEORGE P. MERRILL,

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ADVERTISEMENT.

For more than twelve years past I have been preparing the material for the publication of a work, on the part of the Smithsonian Institution, which it was hoped would consist essentially of photographic views of the moon, so complete and, it was expected (with the advance of photography), so minute, that the features of our satellite might be studied in them by the geologist and the selenographer, nearly as well as by the astronomer at the telescope. This hope has only been partially fulfilled, for photography, which has made such eminent advances in the reproduction of nebulae and like celestial features, has indeed progressed in lunar work, but not to the same extent as in other fields. The expectation that such a complete work could be advantageously published for this purpose has, then, been laid aside for the present.

It has been decided to draw from the material prepared for this larger work, some photographs taken at the Lick Observatory and the Paris Observatory, and particularly some recently obtained by Professor Ritchey at the Yerkes Observatory, for which I have to express the thanks of the Institution. These illustrations are attached to the present paper by Professor Shaler, and may, then, be considered to be a separate contribution by the Institution to the study of selenography.

Professor Shaler's memoir gives the results of personal studies carried on for a third of a century. He has devoted about one hundred nights to telescopic study of the moon with the Mertz equatorial of Harvard College Observatory, his later researches having been chiefly by means of photographs at Harvard University, with which he has so long been connected.

In accordance with the rule adopted by the Smithsonian Institution, the memoir has been submitted for examination to a committee consisting of Dr. George P. Merrill, Head Curator of Geology in the U. S. National Museum, and Mr. C. G. Abbot of the Smithsonian Astrophysical Observatory.

S. P. LANGLEY,

SECRETARY.

Smithsonian Institution,
Washington, December, 1903.

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A COMPARISON OF THE FEATURES OF THE EARTH AND THE MOON.

BY N. S. SHALER.

PRELIMINARY NOTE.

The object of this paper is to set forth the general results of certain studies concerning the form and structure of the lunar surface with reference to various terrestrial problems.

These studies were begun in 1867 with the Mertz equatorial of the Harvard College Observatory, at the time when my lamented friend and colleague, Joseph Winlock, was director, and have been continued in a desultory manner, from time to time, for a third of a century. Between 1867 and 1872 about one hundred nights were devoted to telescopic work; since that time what has been done has been almost altogether by means of photographs, which have of recent years become much more convenient and for my purpose more serviceable than the opportunities afforded by an instrument even if it were as good as the Harvard Mertz.

It should be observed that so far as possible my task has been kept apart from problems of selenology or selenography strictly so called. The ends sought have been those alone which had distinct reference to geology. Certain questions, as, for instance, that concerning the antiquity of the lunar surface, necessarily touch upon matters which relate to the history of the moon as an individual sphere. In fact almost all the questions brought up by studies on the satellite are more or less entangled with those relating to the evolution of the planet, so that except for the detailed account of the features of either body they must needs be considered together. These features may be compared by types, and in the main the following essay consists of such comparisons.

If other duties permit I hope to present the matters discussed in the following pages in a more extended form, one in which it will be possible to illustrate the facts here set forth, as well as to discuss the conclusions attained in an ampler manner. Almost all the points I have endeavored to make clear demand this

more extended treatment. As many of them are debatable, some of them, indeed, requiring more observations and comparisons than I have been able to give, I may hope that the criticism this paper may receive will enable me to better the work which it describes.

GENERAL DESCRIPTION OF THE MOON.

Although the moon has been the most studied of all celestial objects, few persons, except astronomers, have a clear idea of even the general results which have been derived from the vast body of observations that have been made upon it. On this account it appears desirable to preface the account of the special inquiries which are set forth in the following pages by a statement of what is known concerning this nearest neighbor of our earth. This account will necessarily be limited to the facts which can be set forth in other than mathematical form; fortunately, these include all that the reader needs to have in mind in order to obtain a fairly clear understanding of the questions which are to be discussed.

The history of primitive astronomy shows that the moon, of all celestial objects, from the beginning of man's intellectual development has been the most closely observed. Although the sun was doubtless recognized by the lowliest man as the most important feature of the heavens, as the giver of life, the conditions under which it is seen, especially its blinding light, long made any extended study of it impossible. So, except for the very evident changes of its course across the sky and the consequent succession of the seasons, little was known of the solar center two hundred years ago, and, save its approximate distance from the earth, its mass, and its general relations to the planets, not much knowledge was gained until the last century. On the other hand, the moon, because of its nearness, being only about one four-hundredth part as remote from the earth as the sun, has in a noteworthy way entered into the records of men. Its relatively short period of change and the very pronounced character of its alterations made it the first index of time beyond the round of the day. It is evident, indeed, that as soon as men began to reckon time they used the lunar month to make their tally, rather than that of the solar year. Moreover, the surface of the moon reveals much to the naked eye, not clearly, but sufficiently well to afford the basis for speculation and to tempt the imagination to create there a world like our own. It is therefore not surprising that a host of myths concerning the nature of our satellite grew up in the days before the telescope. It is interesting to note the fact that many of these myths have not only become fixed in the minds of uninstructed people, but they have had a remarkable influence upon the minds of modern astronomers, limiting their capacity to interpret what their instruments clearly reveal to them. At every stage in the advance of selenography we note the curious persistency of the endeavor not only to interpret the lunar features by the terrestrial, but to warp the observed facts into accord with those seen on the earth. There is perhaps no better instance of the extent to which prepossessions and prejudices may affect the judgment of the most conscientious observer, blinding him to evident truth, than the history of lunar inquiries affords.

The story of the physical conditions of the moon had best be begun by noting that the relation of our satellite to a larger sphere is not exceptional, but the most characteristic of all the relations of one stellar body to another. Of the planets in the solar system, all save the two nearest to the sun, Mercury and Venus, have one or more smaller spheres circling about them. The relation of the sun to the several planets in a larger way repeats this plan of grouping lesser about greater orbs.

It is generally believed by astronomers that the celestial spheres have been formed by a process of condensation, due to gravitation, of matter which was originally widely diffused; that our solar system, before it was organized into the sun and lesser bodies, was in the form of a diffused nebulous mass of spheroidal form which extended beyond the orbit of the outermost planet. As this matter gathered towards the center, the material now in each of the planets and its satellites parted from the parent body, probably at first in the form of a nebulous ring, or spiral, which in time broke and gathered into a spheroidal mass. In that detached portion of the parent nebula the process of concentration was repeated, with the result that satellites, or, as we may term them, secondary planets, were formed substantially as the greater spheres were set off from the sun. There are many questions and doubts concerning the details of this nebular theory, but that the evolution of our solar system and probably of all stellar systems took place in substantially the manner indicated appears to be eminently probable; it is, indeed, fairly well established by what we know of the distant nebulae and by the rings of Saturn, which apparently contain the material which normally should have formed one or more of its satellites, but which for some unknown reason have remained unbroken.

It is not certain at just what stage in the concentration of a nebula a planet or a satellite may be set off from the parent body; nor can the present distance of the satellite from the main sphere be assumed as that at which the parting took place. It is possible that the concentration of the parent body had gone so far that the diffused or nebulous stage of its materials had been passed by and the more advanced stage of igneous fluidity entered on. It is, however, more likely that in all cases the separation occurred while the particles of matter were divided as they are in a gas or vapor. As soon as the two spheres are separated from one another, and so long as they remain in any measure fluid, the difference in their gravitative attraction on the nearer and more remote part of their masses induces tides, and the effect of these tidal movements, as has been shown by Professor George Darwin, is necessarily to impel the two bodies farther apart. It seems certain that before the earth and the moon became essentially rigid, as they now are, the effect of these tides in driving them apart must have been great enough to account for a considerable part of the interval which now separates them.

In the present condition of the moon, it is a sphere having a computed diameter of 2159.6 miles and its mean distance from the earth 238,818 miles. So far as has been determined, the moon exhibits no trace of flattening at the poles

such as characterizes the earth, unless, as is possible, there are irregularities of figure on the unseen part of the sphere. It is essentially globular in form. The fact that the moon is not flattened at its poles probably indicates that if it once rotated in the manner of the planet it ceased to do so before it became solid.

The measure of density of the moon—i. e., the proportion of its weight to its bulk—is only about six-tenths that of the earth. While the earth's mean density is nearly 5.7 times that of water, that of the moon is about 3.5 times as great. Thus the total gravitative force of the lunar mass is to be reckoned as only about $\frac{1}{8}$ that of our planet.

As the moon revolves on its polar axis but once in about a month, and at a rate that tends to keep the same part of its surface turned towards the earth, we should, but for the phenomenon of librations, see no more than one-half of its superficial area. Owing, however, to this feature, which is due to certain complications of the moon's exceedingly varied movements, the satellite in effect sways in relation to the earth so that at certain times we see farther to the east and at others farther to the west of its center, and in the succession of these movements we are able to behold somewhat more than one-half the total area, in fact about six-tenths of it. It is impossible to set forth in this writing the reasons for the librations of the moon, as the matter cannot be explained without giving in mathematical form a full account of the motion of our satellite, which is one of the most complicated of astronomical problems. An excellent non-mathematical presentation of the question, which affords a sufficient idea of it, may be found in *The Moon*, by Richard A. Proctor, pp. 117 *et seq.*, D. Appleton & Co., New York, 1878.

As noted below, there is some accessible information going to show that even beyond the extreme field revealed by the librations the surface of the moon has the same character as that which is visible. Thus we find that up to the limits of the visible part there is no sign of change in the nature of the surface. It is therefore reasonable to conclude that the same characteristics extend for some distance beyond the limits of vision. We also note on the verge of the unseen field the hither margins of certain ring-shaped structures, evidently of large size, the so-called volcanoes, so that it is fair to conclude that these features are continued on the unseen part. Moreover, there are some light-colored bands, such as on this side of the moon always radiate from crater-like pits, which apparently come over from such centers on the unseen part. These several facts, taken together, make it eminently probable that the unseen four-tenths of the lunar surface in no essential way differs from that we observe. It is, indeed, altogether likely that we see every type of structure that exists on the moon, and that a view of its whole area would add nothing essentially new to our knowledge of the sphere.

Seen by persons of ordinarily good vision, even at a distance of about 240,000 miles, the moon reveals much of its surface shape, structure, and color; it is evident that the color varies greatly from very bright areas to those which are relatively dark, that the latter are somewhat less in total extent than the former

and that they are disposed in a general way across the northern hemisphere.¹ (See plates I. to VII. inclusive.) Persons of more than usually good vision may, under favorable conditions, see on the edge of the illuminated area the ragged line of the sunlight, which indicates that the surface is very irregular, the high points coming into the day before the lower are illuminated. Such persons at time of full moon can also note, though faintly, some of the bright bands which, radiating from certain crater-like pits, extend for great distances over the surface. So, too, they may see at the first stage of the new and the last of the old moon, the light from the sunlit earth slightly illuminating the dark part of the lunar sphere, or, as it is often termed, the old moon in the arms of the new.

With the best modern telescopes under the most suitable conditions of observation, the moon is seen as it would be by the unaided eye if it were not more than about forty miles from the observer. The conditions of this seeing are much more favorable than those under which we behold a range of terrestrial mountains at that distance, for the reason that the air, and especially the moisture, in our atmosphere hinders and confuses the light, and there is several times as much of this obstruction encountered in a distance of forty miles along the earth's surface as there is in looking vertically upwards.

Seen with the greater telescopes, the surface of the moon may reveal to able observers, in the rare moments of the best seeing, circular objects, such as pits, which are perhaps not more than five hundred feet in diameter. Elevations of much less height may be detected by their shadows, which, because there is no trace of an atmosphere on the moon, are extraordinarily sharp, the line between the dark and light being as distinct as though drawn by a ruler. Elongate objects, such as rifts or crevices in the surface, because of their length, may be visible even when they are only a few score feet in width, for the same reason that while a black dot on a wall may not make any impression on the eye, a line no wider than the dot can be readily perceived. Owing to these conditions, the surface of the moon has revealed many of its features to us, perhaps about as well as we could discern them by the naked eye if the sphere were no more than twenty miles away.

Separated from all theories and prepossessions, the most important points which have been ascertained as to the condition of the moon's surface are as follows :

The surface differs from that of the earth in the fact that it lacks the envelopes of air and water. That there is no air is indicated by the feature above noted, that there is no diffusion of the sunlight, the shadows being absolutely black and with perfectly clean-cut edges. It is also shown by the fact that when a star is occulted or shut out by the disc of the moon it disappears suddenly without its light being displaced, as it would be by refraction if there were any sensible

¹ It is well to note the fact that in a celestial telescope objects are seen in reverse position, or "upside down." For convenience they are usually so depicted on maps and pictures of the moon; the north pole at the bottom, and the east where it is customary to place the west on terrestrial maps.

amount of air in the line of its rays. This evidence affords proof that if there is any air at all on the moon's surface it is probably less in amount than remains in the nearest approach to a vacuum we can produce by means of an air-pump. Like proof of the airless nature of the moon is afforded by the spectroscope applied to the study of the light of an occulting star or that of the sun as it is becoming eclipsed by the moon. In fact a great body of evidence goes to show that there is no air whatever on the lunar surface.

The evidence of lack of water at the present time on the surface of the moon appears to be as complete as that which shows the lack of an atmosphere. In the first place, there are evidently no seas or even lakes of discernible size. There are clearly no rivers. If such features existed, the reflection of the sun from their surfaces would make them exceedingly conspicuous on the dark background of the moon, which for all its apparent brightness is really as dark as the more somber-hued rocks of the earth's surface when lit by the sun. Moreover, even were water present, without an atmosphere there could be no such circulation as takes place on the earth, upward to clouds and thence downward by the rain and streams to the ocean. Clouds cannot exist unless there be an atmosphere in which they can float, and even if there be an air of exceeding tenuity on the moon, it is surely insufficient to support a trace of clouds. Some distinguished astronomers have thought to discern something floating of a cloud-like nature, but these observations, though exceedingly interesting, are not sufficiently verified to have much weight against the body of well-observed facts that shows the moon to be essentially waterless.

The well-established absence of both air and water in any such quantities as are necessary to maintain organic life appears to exclude the possibility of there being any such life as that of plants and animals on the lunar surface. The reader will find below a further discussion of this question, and it may therefore here be passed with the statement that very few astronomers are now inclined to believe that the moon can possibly be the abode of living forms.

Being without an effective atmosphere, for the possible but unproved remnant that may exist there would be quite ineffective, the moon lacks the defense against radiation of heat which the air affords the earth. Therefore in the long lunar night the outflow of heat must bring the temperature of the darkened part to near that of the celestial spaces, certainly to some hundred degrees below Fahrenheit zero. Even in the long day this lack of air and consequent easy radiation must prevent any considerable warming of the surface. The temperature of the moon has been made the matter of numerous experiments. These, for various reasons, have not proved very effective. The most trustworthy, the series undertaken by S. P. Langley, indicate that at no time does the heat attain to that of melting ice.

Turning now to the shape and structure of the moon's crust, we observe that it differs much from that of the earth. Considering first the more general features, we note that there are none of those broad ridges and furrows,—the continents and the sea basins. A portion of the surface, mainly in the northern hemisphere,

is occupied by broad plains which in their general shape are more nearly level than any equally extensive areas of the land, or, so far as we know, of the ocean floor of the earth, though they are beset with very many slight irregularities. These areas of rough, dark-hued plains are the seas or *maria* of selenographers, so termed because of old they were, from their relatively level nature, supposed to be areas of water. These maria occupy about one-third of the visible surface. Their height is somewhat less than that of the crust outside of their area. The remaining portion of the moon is extremely rugged. It is evident that the average declivity of the slopes is far greater than on the earth. This is apparent in all the features made visible by the telescope, and it likely extends to others too minute to be seen by the most powerful instruments. Zöllner, by a very ingenious computation based on the amount of sunlight reflected, estimates that the average angle of the lunar surface to its horizon is fifty-two degrees. Though we have no such basis for reckoning the average slope of the lands and sea bottoms of the earth, it is eminently probable that it does not amount to more than a tenth of that declivity. This difference, as well as many others, is probably due to the lack on the moon of the work of water, which so effectively breaks down the steeps of the earth, tending ever to bring the surface to a uniform level.

The most notable feature on the lunar surface is the existence of exceedingly numerous pits, generally with ring-like walls about them, which slope very steeply to a central cavity and more gently towards the surrounding country. These pits vary greatly in size; the largest are more than a hundred miles in diameter, while the smallest discernible are less than a half-mile across. The number increases as the size diminishes; there are many thousands of them, so small that they are revealed only when sought for with the most powerful telescopes and with the best seeing. In all these pits, except those of the smallest size, and possibly in these also, there is within the ring-wall and at a considerable though variable depth below its summit a nearly flat floor, which often has a central pit of small size or in its place a steep rude cone. When this plain is more than twenty miles in diameter, and with increasing numbers as the floor is wider, there are generally other irregularly scattered pits and cones. Thus in the case of Plato, a ring about sixty miles in diameter, there are some scores of these lesser pits. On the interior of the ring-walls of the pits over ten miles in diameter there are usually more or less distinct terraces, which suggest, if they do not clearly indicate, that the material now forming the solid floors they enclose was once fluid and stood at greater heights in the pit than that at which it became permanently frozen. It is, indeed, tolerably certain that the last movement of this material of the floors was one of interrupted subsidence from an originally greater elevation on the outside of the ring-wall, which is commonly of irregular height with many peaks. There are sometimes tongues or protrusions of the substance which forms the ring, as if it had flowed a short distance and then had cooled with steep slopes.

The foregoing account of the pits on the lunar surface suggests to the

reader that these features are volcanoes. That view of their nature was taken by the astronomers who first saw them with the telescope and has been generally held by their successors. That they are in some way, and rather nearly, related to the volcanic vents of the earth appears certain. The nature of this relation is discussed below. We have now to note the following peculiar conditions of these pits. First, that they exist in varying proportion, with no evident law of distribution, all over the visible area of the moon. Next, that in many instances they intersect each other, showing that they were not all formed at the same time but in succession; that the larger of them are not found on the maria but on the upland and apparently the older parts of the surface; and that the evidence from the intersections clearly shows that the greater of these structures are pre-eminently the elder and that in general the smallest were the latest formed. In other words, whatever was the nature of the action involved in the production of these curious structures, its energy diminished with time, until in the end it could no longer break the crust.

All over the surface of the moon, outside of the maria, in the regions not occupied by the volcano-like structures, we find an exceedingly irregular surface, consisting usually of rude excrescences with no distinct arrangement, which may attain the height of many thousand feet. These, when large, have been termed mountains, though they are very unlike any on the earth in their lack of the features due to erosion, as well as in the general absence of order in their association. Elevations of this steep, lumpy form are common on all parts of the moon. Outside of the maria they are seen at their best in the region near the north pole, where a large field thus beset is termed the Alps. From the largest of these elevations a series of like forms can be made of smaller and smaller size until they become too minute to be revealed by the telescope; as they decrease in height they tend to become more regular in shape, very often taking on a dome-like aspect. The only terrestrial elevations at all resembling these lunar reliefs are certain rarely occurring masses of trachytic lava, which appear to have been spewed out through crevices in a semi-fluid state, and to have been so rapidly hardened in cooling that the slopes of the solidified rock remained very steep. As noted in more detail below, the only reliefs on the moon's surface that remind the geologist of true mountains are certain low ridges on the surfaces of the maria.

The surface of the moon exhibits a very great number of fissures or rents, which when widely open are termed valleys, and when narrow, rills. Both these names were given because these grooves were supposed to have been the result of erosion due to flowing water. The valleys are frequently broad, in the case of that known as the Alpine valley, at certain places several miles in width: they are steep-walled and sometimes a mile or more in depth; their bottoms, when distinctly visible, are seen to be beset with crater-like pits, and show in no instance a trace of water work which necessarily excavates smooth descending floors such as we find in terrestrial valleys. The rills are narrow crevices, often so narrow that their bottoms cannot be seen; they frequently branch and in some

instances are continued as branching cracks for a hundred miles or more. The characteristic rills are far more abundant than the valleys, there being many scores already described; the slighter are evidently the more numerous; a catalogue of those visible in the best telescopes would probably amount to several thousand. (See plates XII, XXI, and XXII.)

It is a noteworthy fact that in the case of the rills and in great measure also in the valleys the two sides of the fissure correspond so that if brought together the rent would be closed. This indicates that they are essentially cracks which have opened by their walls drawing apart. Curiously enough, as compared with rents in the earth's crust there is little trace of a change of level of the two sides of these rills—only in one instance is there such a displacement well made out, that known as the Strait Wall, where one side of the break is several hundred feet above the other. (See plate XXI.)

In the region outside of the maria much of the general surface of the moon between the numerous crater-like openings appears in the best seeing with powerful telescopes to be beset with minute pits, often so close together that their limits are so far confused that it appears as honeycombed, or rather as a mass of furnace slag full of holes if greatly magnified, through which the gases developed in melting the mass escaped. (See plates IX, XIII.)

Perhaps the most exceptional feature of the lunar surface, as compared with that of the earth, is found in the numerous systems of radiating light bands, in all about thirty in number, which diverge from patches of the same hue about certain of the crater-like pits. These bands of light-colored material are generally narrow, not more than a few miles in width; they extend for great distances, certain of them being over a thousand miles in length, one of them attaining to one thousand seven hundred miles in linear extent. In one instance at least, in the crater named Saussure, a band which intersects the pit may be seen crossing its floor, and less distinctly, yet clearly enough, it appears on the steep inside walls of the cavity. In no well-observed case do these radiating streaks of light-colored material coincide with the before-mentioned splits or rifts. Yet the assemblage of facts, though the observations and the theories based upon them are very discrepant, lead us to believe that they are in the nature of stains or sheets of matter on the surface of the sphere, or perhaps in the mass of the crust. At some points the rays of one system cross those of another in a manner that indicates that the one is of later formation than the other. (See plates VI, XVI, and XIX.)

Perhaps the most puzzling feature of the radiating streaks, where everything is perplexing, is found in the way they come into view and disappear in each lunar period. When the surface is illuminated by the very oblique rays of the sun they are quite invisible; as the lunar day advances they become faintly discernible, but are only seen in perfect clearness near the full moon. The reason for this peculiar appearance of these light bands under a high sun has been a matter of much conjecture; it is the subject of discussion in a later chapter of this memoir, where it is shown that inasmuch as these bands appear

when the earth light falls upon the moon at a high angle, the effect must be due to the angle of incidence of the rays on the shining surfaces. It should be noted that the light bands in most instances diverge from more or less broad fields of light color about the crater-like pits, fields which have the same habit of glowing under a high illumination; in fact, a large part of the surface of the moon, perhaps near one-tenth of its visible area, becomes thus brilliant at full moon, though it lacks that quality at the earlier and later stages of the lunar day.

In the above considered statement concerning the visible phenomena of the moon no account is taken of a great variety of obscure features which, though easily seen with fairly good instruments, have received slight attention from selenographers. As can readily be imagined, observers find it difficult to discern obscure features which cannot be classed in any group of terrestrial objects. Whosoever will narrowly inspect any part of the lunar surface, noting everything that meets his eye, will find that he observes much that cannot be explained by what is seen on the earth. It is evident, indeed, that while in the earlier stages of development this satellite in good part followed the series of changes undergone by its planet, there came a stage in which it ceased to continue the process of evolution that the parent body has undergone; the reason for this arrest in development appears to have been the essential if not complete absence of an atmosphere and of water.

The difference in height between the lowest and highest points on the lunar surface is not determined. To the most accented reliefs, those of the higher crater walls, elevations of more than twenty-five thousand feet have been assigned; it is, however, to be noted that all these determinations are made from the length of the shadows cast by the eminences, with no effective means of correcting for certain errors incidental to this method. It may be assumed as tolerably certain that a number of these elevations have their summits at least twenty thousand feet above their bases and that a few are yet higher. We do not know how much lower than the ground about these elevations are the lowest parts of the moon. My own observations incline me to the opinion that the difference may well amount to as much as ten thousand feet, so that the total relief of the moon may amount to somewhere between thirty and forty thousand feet. That of the earth from the deepest part of the oceans to the highest mountain summits is probably between fifty-five and sixty thousand feet; so that notwithstanding the lack of erosion and sedimentation which in the earth continually tends to diminish the difference between the sea-floor and land areas, the surface of the satellite has a much less range of elevation than the planet. If the forces which have built the mountains and continents of the earth had operated without the erosive action of water there is little doubt that the difference in height between the highest and lowest parts would now be many times as great as it is on the moon.

AGE OF THE EXISTING LUNAR SURFACE.

Several of the most important problems to be considered in this writing intimately depend on a determination of the age of the moon's surface. If we

accept the commonly adopted view as to the nature of the prevailing topographical features of that sphere and regard them as essentially volcanic, *i. e.*, as due mainly to the expulsion of heated vapors or gases from the interior of the sphere, we have a basis on which to found a determination of that age sufficiently accurate to serve our immediate purpose.

It appears eminently probable that the lunar surface must have attained to something like its present condition long before the earth came to the state in which its igneously fluid mass was crusted over. And this for the following reasons: At the time when the material of the moon and earth separated from the previously united mass we have to believe that the amount of heat they severally contained was in general proportionate to the mass of each body. Now the mass of the moon is to that of the earth as one to eighty, and its diameter about as one to four. From this, by the well-known law of cooling bodies, it follows that the moon must have acquired a permanent rigid crust, if indeed it did not become entirely frozen, long before the earth ceased to have a molten surface. There are too many doubtful elements in the computation to make any seemingly accurate reckoning trustworthy, but it appears altogether likely that the moon cooled far beyond the point where volcanic action was possible ages before the earth's surface could have frozen or perhaps have passed from the gaseous to the fluid state.

At present all the volcanic action of the earth is apparently limited to the sea-floor or regions within three hundred miles of the shore; effectively to regions where the central heat is brought upwards into strata containing water laid in them when they were deposited; the rise of the heat being due to the slow conductivity of the imposed beds. There is reason to believe that since the earliest recorded ages the earth has mainly, if not altogether, depended on such action for the volcanic outbreaks which have occurred upon it. While there may in this particular matter be some reason for doubt, there is none as to the fact that if the so-called lunar volcanoes are due to the central heat of that sphere, they must have been shaped before the crust of the earth was formed, or long before the earliest geological records. It has, however, been suggested by G. K. Gilbert¹ and others that what appear to be volcanoes on the moon are not really such, but are, in effect, punctures caused by the falling of large meteorites or bolides. This interesting suggestion commends itself at first sight as a possible explanation of the pits on the moon, structures which differ in many regards from those due to terrestrial volcanic action, in that they are often of much greater diameter, have relatively much smaller encircling cones, and show little, if any, clear evidence of lava flows, or ash showers, proceeding from them. As I propose further on in this paper to discuss the question of their nature in more detail, I shall now give only in brief the reasons why, as it seems to me, the hypothesis that they were caused by bodies falling from the sky is not verified.

It is to be noted that these so-called volcanoes of the moon, vulcanoids, as I shall term them, have generally very steep walls around their crater-like pits;

¹ See *Bull. Phil. Soc. of Washington*, vol. 12, p. 241, *et seq.*

the average outer slope, according to my estimates, exceeding forty degrees, the inner slope being generally somewhat steeper. On this hypothesis this inner slope must mark the path of the impinging bolide, and the cone that surrounds it be the result of the outthrusting action of that body, such as we note when a pebble is thrown into soft clay or a shot from a cannon enters an armor plate. We have under Gilbert's hypothesis to suppose that the impinging bodies came into contact with the moon at something like planetary velocity. Such bodies having a diameter of even a mile—and some of them must, on this hypothesis, have been of fifty or more miles diameter—would, by the conversion of their momentum into heat, have served to melt a wide field of the crust about their points of contact.¹ As there is no trace of any such bolides in the bottoms of these craters, but commonly a floor, as of hardened lava, we have to suppose that they penetrated to a great depth and that the lava flowed up after their entrance. But the necessary effect of the entrance of a mass sufficiently large to have punctured these openings would, if they had penetrated to a molten zone, have been to send up a quantity of lava far more than sufficient to fill the opening they made, while in fact with few, if any, exceptions, this lava appears at no time to have risen to the general level of the surrounding rampart. Furthermore, if the cones about the craters were due to outthrusts caused by such impacts on material stiff enough to maintain the steep walls of the crater, then we should have evidence of radial cracking in the form of open rents, such as would inevitably be developed under the assumed conditions, but have evidently not produced in far the greater number of the vulcanoids.

There is another and, taken alone, conclusive argument against the supposition that the lunar craters are due to the impact of bolides; this is found in the facts presented in the series which may be traced in the sizes and distribution of the fractures which it seeks to explain. As regards their sizes, the pits grade from the smallest that can be discerned by the most powerful telescope, probably not over five hundred feet in diameter, to rings that are one hundred miles across. The steepness of the inner slopes of these cavities does not perceptibly differ, nor is there more evidence of lava having been poured out from the larger than from the smaller craters. Moreover, there is no better evidence of radiating fractures in the case of the larger than in the smaller pits. Furthermore, there is no such relation in the masses of material composing the enveloping cones or rings as we would expect to find if they were due to the impact of bodies varying in size as we have to suppose. In many instances the walls of a pit scores of miles in diameter are no thicker or higher than in the case of other pits less than a mile across.

As regards their distribution, the craters of the moon are generally placed in such apparent lack of order as to give some warrant for the hypothesis that

¹ Assuming that the impinging body came upon the surface of the moon at planetary velocity, and that all the resulting heat was applied to its mass, the resulting temperature would exceed, according to my reckoning, 150,000 degrees. A bolide fifty miles in diameter would be likely to melt an area many times its diameter.

they must owe their origin to other than volcanic action, for on the earth we find volcanoes very generally disposed along lines which, in most if not all cases, appear to be determined by faults. In many instances, however, the lunar vulcanoids have a linear arrangement.

The vulcanoids of larger size which are arranged in linear order are not numerous. Among these may be cited the train extending from Herschel through Ptolemæus, and Alphonsus to Arzachel; that from Thibet to Stofler; that from Atlas to Franklin; and that from Vendalinus to Casatus, near the limb in the third quadrant. (See plates I and XXI.) In all these instances there are four or more pits in fairly true alignment: in alignment and in number they appear to exclude the supposition that their order is due to chance. Passing from the examples in which the greater vulcanoids are grouped in trains and taking the pits of smaller size, we find the instances of such arrangement becoming more numerous as the structures are of smaller diameter. It is, however, in but few of the pits over ten miles in diameter that there are more than three or four so placed in relation to one another that they can be said to be linearly arranged.

When, in following down the series of vulcanoids as regards size, we come to the pits less than a mile in diameter, those commonly termed craterlets, we note that the linear order, hitherto exceptional, becomes so common that the exceptions are rather to be found in the departures from it. The observations of W. H. Pickering and others, as will be noted below, make it evident that there is a causal relation between the smaller visible pits and the cracks that form on the surface of the moon. There can be no question that there are thousands of these smaller of the craterlets which are thus disposed in lines, some of the series extending for hundreds of miles. (See plate xx.)

It may be taken as evident, that in the time when the larger vulcanoids were in process of formation the conditions of strain in the moon's crust were not such as to determine that the points of outbreak should to any great extent be linearly arranged and that when thus arranged they tended to follow the meridians, rather than the parallels. In the later stages of the surface when the smaller openings were made they obviously tended to a linear order, but the direction of the lines was exceedingly varied, some of them being radially disposed with the greater vulcanoids as centers, others along lines of weakness which lie in extremely diverse positions.

Reckoning great and small, there are some hundreds of these lines of pits, a number sufficient to make it evident that they cannot be accounted for by chance. It is evident that to explain this linear order of vulcanoids by the hypothesis we are considering is difficult if not impossible, for that would require us to suppose the bolides to have been thus arranged during their movements through space. It is also to be noted that in very many instances there are pits within the larger cavities so centrally placed that they cannot be explained by the chance in-falling of bolides. Therefore, while the relation of lunar volcanoes to those of the earth is a perplexing question, there seem on the face of the facts to be

sufficient reasons for rejecting the suggestion that they are due to the impact of falling bodies.

In addition to the features of the lunar volcanoes there is another though more remote reason why such falls of celestial bodies on the moon's surface have not occurred. Of these we may here mention two; these are as follows: It is evident that these vulcanoids were formed at successive times, and under somewhat diverse conditions. So far as I have been able to determine, the largest were, at least in a general way, first produced, and the smaller, approximately, in the order of diminishing size, the smallest in most instances being formed last. Now, as will be more particularly noted hereafter, the light bands which radiate from certain craters and which are clearly mere strips of material which at full moon reflect the sun's light more intensely than the general surface have evidently not been covered by deposits of ordinary meteoric matter, such as falls on the earth in considerable quantity. It thus appears that for some reason the moon, provided its surface has anything like the antiquity it appears necessary to assign to it, has not been the seat of such deposits; for the accumulation of a small amount of meteoric matter would mask such stains. We would thus, according to the Gilbert hypothesis, have to suppose a succession of showers, each sending bolides of smaller size than the preceding, and with them no considerable amount of ordinary finely divided meteoric material such as comes to the earth.

It is also to be noted that since the earth's surface came to its present state there is good reason to believe that no such falls of large bodies as are supposed by the bolide hypothesis to have fallen upon the satellite have ever come to the planet. There are no traces of like craters, for even the greatest calderas, such as that which holds Lago Bolsena or Kilauea, are evidently volcanic and in no way related to meteoric action. Moreover, the fall of a bolide of even ten miles in diameter would, by the inevitable development of heat due to its arrest, have been sufficient to destroy the organic life of the earth, yet this life has evidently been continued without interruption since before the Cambrian time. The point to be last noted is that so far as I have been able to determine from an extended inspection of lunar craters, including several hundred of the more determinable, they all have the axes of their pits at right angles to the surface. Now if these pits had been formed by bolides encountering the moon in their movement, that movement necessarily being at planetary velocity, it does not seem possible that they could all have come upon the sphere in a path normal to its surface. Even with the resistance of the earth's atmosphere, which is far denser than that of the moon ever could have been, the small meteors which enter it mostly come at high angles to the surface of the planet, although its attractive power is more than eighty times as great as that of the satellite. It seems, indeed, incredible that if the lunar vulcanoids were due to bolides they should not have fallen in somewhat greater numbers on the earth because of its greater gravitative attraction. The number received would probably be nearly in proportion to the area of the two spheres, with a slight preponderance in the number falling on the earth because of its greater mass and consequently the greater effect of its gravity. It

is, however, as before remarked, evident that no such falls as have formed the hundreds of pits over ten miles in diameter which exist on the moon's surface have occurred on the earth since the Cambrian age.

The foregoing considerations justify us in rejecting the hypothesis of falling bolides as a means of accounting for the so-called craters on the moon. There are, however, certain other features of lunar surface which may be explicable by the impact of large bodies falling from space. These we will now proceed to consider.

MARIA OR SEAS.

A large part of the surface of the moon is occupied by the so-called *maria* or seas. These are extensive irregular, indistinctly circular areas of relatively level nature and of a perceptibly darker hue than the other more rugged fields. This dark hue is shared by the floors of a number of the craters which lie near the seas, as for instance by that of Plato, and more rarely by craters which lie remote from their margins. Though vulcanoids exist on the maria of the moon they are of relatively small size, none, in my opinion, which have clearly been formed since the material of which the maria are composed came to its present level position, exceeding ten or fifteen miles in diameter. So far as I have been able to reckon, the proportion of these pits on the seas does not exceed one-fifth that we find on the other part of the lunar surface. The average discernible inclination of the surface of the maria is relatively so small they are more nearly true plains than any equally extensive land areas on the earth.

It is a noteworthy fact that the maria, though they occupy about one-third of the visible part of the moon, *i. e.*, including what is shown by the librations, rarely, if at all, lie on the margin, in positions enabling us to infer that they are parts of like areas on the unseen portion of the lunar surface. On the western limb of the sphere the so-called mare Australis is generally mapped as extending around the margin, as it in fact does at certain stages of the libration, but under the most favorable conditions the ordinary rough surface of the satellite appears to me to be visible beyond this small mare, so that the statement as to none of these seas crossing the limb apparently does not admit of exception. The ill-named mare Humboldtianum is evidently a vulcanoid. It therefore appears probable that if such maria exist on the unseen portion they are less extensive than on the part of the orb which we see.

The most interesting feature of the maria is found in their contact with the higher, rougher surface areas which bound them. Whenever I have been able to observe this contact in a sufficiently exact manner there appears to be good evidence that the material of which their surfaces are formed flowed in against or upon the rough ground as very liquid lava would do. In a general way this fact had been often noted. It fills in the lower ground forming numerous bays. In many instances, as, for example, in the case of Doppelmeyer, it distinctly appears to have melted down the side of the crater's wall next to it, and to have filled the cavity to its own level. Whoever will inspect these lines of contact of

the maria with the higher parts of the moon throughout the several thousand miles of their extent will probably come to the conclusion that they were formed by the once fluid matter of the sea inundating firm land. Assuming, as I shall do, that these maria are made up of vast bodies of lava, which came upon the surface after the greater vulcanoids were made and, as we shall hereafter see, after some of the radiating light streaks were formed, how shall we account for the production of such bodies of igneous material? The quantity of this matter was evidently very great and in each of the seas it seems to have appeared all at once, there being no mark of successive flows such as compose the extensive lava fields of the earth. So far I have not been able clearly to trace any signs of contact or over-lapping of the lava of the several maria. The search is, however, difficult; no more has been ascertained than that the material must have been extremely fluid, far beyond what is seen in ordinary terrestrial flows. This is shown by the fact that although gravitative attraction is only one-sixth what it is on the earth, there is no steep face at the front of the fields, such as occurs from cooling of an ordinary stream of lava.

As for the origin of the lava of the maria there are few facts on which to base an hypothesis. What have been gathered may be briefly set forth. First, it is to be noted that none of the vulcanoids of the moon give forth freely flowing lava streams; it is, indeed, doubtful if any true lava flows have come from them. The features which suggest such streams are rare and rather inconclusive; they justify the statement that even the greatest, in general the earliest of the craters, and therefore those which should have had the largest amount of molten rock beneath them, show little or no signs of a tendency to extrude free flowing lava at the time when they were formed. Nor do any of the numerous fissures or faults of the lunar surface, some of which evidently penetrate deeply, distinctly give rise to lava flows. And we shall see when we come to consider the conditions of these volcano-like openings they appear always to have retained their lavas within or near their vents. Clearly these vulcanoid openings do not indicate any tendency of lava to pass up to the surface in large quantities.

It is an important point that there is no evidence in any of the maria that the lava comes from a central pipe or from an elongate fissure; their general form would seem to indicate that if the fluid came from within it should have emerged as from a terrestrial volcanic pipe, for if it came from fissures these should have been of elongate shape. But if it came either from fissured or from pipe-like openings there should be a grade to the flow extending from the center of the field to its margin; owing to the slight value of gravitation this grade should be steep. There seems to be no trace of such a slope; on the contrary, the curve of the terminator or margin of the illumination shows that they are essentially horizontal. It is difficult to believe that lava flowing from an opening for hundreds of miles could have this absence of slope. When it flows from a terrestrial crater the course is always short and very steep.

In view of all the facts, I am disposed to hold with Gilbert and other inquirers that the maria are the result of large masses falling upon the surface of

that sphere. All the facts indicate that these vast sheets of lava did not come from the interior, and that the interior at the time when they were formed was not in a condition to yield any such masses of liquid rock. We are therefore fairly driven to this working hypothesis. In its favor we may adduce the following considerations :

The fall of a considerable body or bodies competent by the conversion of its momentum into heat to produce an extensive melting of the lunar surface, would be likely to develop melted lava under conditions quite different from that which is exuded from volcanoes. Assuming that the bolide came upon the surface at planetary velocity and that it was some miles in diameter, the heat due to the arrest of its movement would, we may fairly suppose, convert the whole of the body into a liquid if not into a gaseous state. A like result would occur in the part of the sphere which received the blow. Moreover, for some distance beyond the seat of impact the shearing strains would probably be sufficient to convert much of the material of the surface into the fluid state, with the result that a mass of lava at very high temperature, equal at least to the bulk of the invading body, and probably several times as great, would be sent at the speed determined by the gravitative value of the sphere radially from the point where the impact took place. It seems also, perhaps, a fair supposition that a great collision of this nature would temporarily form a heated atmosphere enveloping the moon, which would serve to delay the cooling of the molten rock until it had time to find its level. Yet the absence of any deposits of these temporarily volatilized materials is indicated by the fact that the light streaks are not obscured.

In favor of the hypothesis above suggested, it may also be said that the evidence of melting effected by the material which forms the plains of the maria is considerable at several points, notably in the case of the vulcanoids on the margins of the seas. It seems quite certain that the walls of these craters next the sea have been in some manner effaced by contact with the material which came against it. Again, as in Flamsteed in the *Oceanus Procellarum*, the crater wall has been almost melted down, but still rises slightly above the surface of the apparent inundation. At many points the material forming the mare comes against extended steep-faced cliffs, which have the same general character as the inner slopes of the great craters, where the form of the declivity pretty certainly has been determined by the melting action of the lava at the base. Furthermore, where there are depressions in the area on the borders of the maria, the material of which they are composed flows into them as a fluid would have done.

It is also to be noted that at many points where the maria come against gently inclined slopes the material of which they are composed appears to have at first flowed over these low but now unsubmerged areas and then retreated from them, leaving them in a measure smoothed as if by the in-filling of their cavities or perhaps by a partial melting of their projecting features. If such apparent inundation really occurred, it may have been brought about by the frontal wave of the lava which mounted, after the manner of those produced by earthquakes in the sea, for some distance above the permanent level of the inundation.

It may further be said in favor of this hypothesis as to the origin of the maria, that the material of which they are composed appears to have had throughout the whole extent of the several areas a singularly uniform fluidity. As before remarked, there are no signs of successive flows such as have always characterized the accumulation of the relatively much less extensive lava deposits on the surface of the earth. In this connection it should again be noted that none of the vulcanoids show any tendency to send forth extended flows, and the matter which appears to have been ejected to form the cones has evidently consolidated on very steep slopes. Thus, if the material of the maria was fluid when it came to rest, of which there seems no reason to doubt, it cannot have been poured forth from the interior in the manner of volcanic effusions.

The fact that the surfaces of the maria are of a distinctly darker color than the other and higher extended areas of the moon has some value as evidence that they have a peculiar origin, one not connected with the interior of the sphere. Certain of the crater floors have, it is true, about the same tint; this is conspicuously the case with Plato. In this, as in certain other instances, the likeness may be due to the penetration by subterranean passages of the material of the neighboring mare into the cavities of the craters. There are, however, examples, as, for instance, the great vulcanoid Grimaldi, where the resemblance cannot be thus explained. Although these exceptions weaken the value of this evidence derived from the color of the maria, the uniformity of a tint which is evident in all of them and the seldomness of the exceptions tend to support the hypothesis that the rocks of which they are composed have not come from the interior of the sphere. This point will be further discussed below.

We turn now to consider the objections which may be made to the hypothesis that the maria were formed by molten rock produced by the impact of large bodies falling upon the surface of the moon. Of these objections, the first and, in many regards, the strongest is derived from the general consideration that like bodies competent to generate a great deal of heat have not fallen upon the earth's surface in the time which has elapsed since the beginning of the geological periods. There is indeed no geological reason for supposing that they have ever so fallen upon the planet.

Against the above-noted objection that the geological record of our sphere affords no trace of evidence of any such falling-in upon its surface of bodies of sufficient mass to produce widespread melting, and the proof that no cataclysms of this nature have occurred since the development of organic life, we may set the following considerations: first, that the moon's surface probably took its shape long before the beginning of our geological record; and, second, that even in this late stage in the evolution of our solar system there remain bodies in that system in order of size such as would in falling upon the surface of the larger spheres produce the effect which we observe in the maria. Thus the group of asteroids which lie between Mars and Jupiter, though generally of far greater mass than would be required by impact to melt the larger of the mare fields, probably contains many bodies which, in case of collision with our satellite,

would bring about the consequences we note. At least one such mass of matter, Eros, apparently not to be classed either with planets or satellites, has recently been discovered at no great distance from the earth. It is possible that in the relatively ancient state of the solar system, when the surface of the moon acquired its crust, these detached masses of matter were more abundant than they are at present. The tendency would be for those near the greater spheres to be drawn in upon them, with the result that they would become rarer near the planets and the larger satellites.

As for the origin of detached bodies of the bolide type, we have no basis for more than conjecture; we may, however, fairly suppose that the explosive action, which is of not infrequent occurrence in the fixed stars, may have happened in the case of our sun or even of the planets, with the result that masses of matter, perhaps originally gaseous or possibly in the molten state, were flung so far away that they acquired independent orbits.

Although the direct evidence going to prove that the maria are the result of the in-falling of large meteoric bodies is not complete, the hypothesis appears to me to have distinct value for the reason that the cause is sufficient to produce that evidently sudden development of large bodies of very fluid matter, which, for reasons before given, cannot fairly be supposed to have come from the interior of the lunar sphere. It is, in a word, the only working hypothesis that I have been able to find which in any way serves to explain these remarkable features of the lunar surface.

In considering the details of the maria it is to be noted that it is not necessary to account for all of them by supposing a single falling body brought about the melting. In several instances, especially in the case of the Mare Australis, and sundry other indistinct patches of the mare quality, the hypothesis can best be applied by assuming that a number of such bodies fell at about the same time and relatively near together. In this way we can account for the fact that in place of normal, rudely circular fields of melting, as in the case of the M. Crisium, we find an irregular, somewhat ragged field of this nature; in some instances with a periphery that suggests that there were several centers of dispersion of the fluid. Gilbert has maintained that the connected seas were formed by the in-falling of a mass upon the region occupied by the M. Imbrium. This view seems to me to be contradicted by the fact that in the passages between the connected maria there is no evidence of scouring action such as would have been brought about by the swift movement of great masses of lava.

It may also be said that the evidence of melting down of the pre-existent topography on the margin of the maria varies much. It appears most clearly in the case of the large, distinctly circular field of the Mare Crisium, and is least indicated in the irregular areas. Such are the conditions we should expect to find brought about by the fairly supposable variations in the size and number of the masses in any one fall. Thus, so far as my examination of the problem has gone, the supposition that the maria have been formed by sudden melting of colliding bodies and of the lunar surface about the point of collision appears to be

warranted as a working hypothesis, though it has, perhaps, not been established as a theory.

To the suggestion that the surface of the maria is in general lower than that of the regions surrounding them, and that this fact is inconsistent with the addition to the quantity of matter in the area they occupy, such as would be brought about by the falling in of a bolide, the following answer may be made. In the first place, it is to be noted that the outer part of the moon is, except in the maria and in the crater floors, evidently characterized by a very open structure. It is prevailingly much occupied by volcanic openings, greatly rifted and probably composed of scoriaceous materials. If any such section as that about the Apennines were completely fused to the depth of some miles, it is likely that we would have a subsidence of the surface quite as great as that exhibited by the maria. In the second place, the bulk of the material brought by the bolide to the lunar surface would be small as compared with the volume of matter which would be melted by its impact. The proportion would probably be less than one to ten; so that the contribution from the impinging body would be so small that it would not be likely much to affect the general level of the melted area. The nature of the lunar surface in the maria and on the other more extensive regions will be further considered in the section on volcanic action.

As before noted, there is no series connecting the ordinary craters, however large they may be, with the maria. That this is the case is well indicated by the fact that selenographers have in only a few instances been in doubt into which group individual examples of these two species of lunar forms should be placed. The fields classed as seas, with the evidently related embayments thereof, termed sinuses or paludines, have always been regarded as readily distinguishable from the craters. This decision has not been made on the basis of well-described categories, but on the immediately evident differences between the two groups of forms. It is recognized that while nearly all the vulcanoids are essentially circular, or with only moderate distortions of that outline, the seas are as generally irregular in outline. So, too, it is patent that the vulcanoids, at least those of large size, have in all cases a fairly well-marked external slope or cone. None of the seas are thus characterized except where their periphery in part corresponds to some antecedent feature, such as the wall of a large pit which they have invaded, as in the case of Fracastorius, on the margin of the Mare Humorum, or where it encounters an elevation such as the Hæmus Mountains, on the southern border of the Mare Nectano. (See plate xxv.) This general acceptance of an essential difference between the vulcanoid floors and the seas, and the very slight doubt as to the classification of the level surfaces in one or the other, is excellent evidence as to their difference in nature.

The only areas of a level surface on the moon which may not be on mere inspection classed as maria or vulcanoid floors are a few large crater-form depressions situated near the eastern limb of the moon, of which the most important and doubtful is Schickard. Even a slight examination of this feature shows that it has a distinct continuous wall, and that the irregularities of its outline are

due to the melting down of the borders of other craters as its area was extended in the manner which we shall hereafter see to have been common in the development of the larger crater-form pits. In other instances, as in Ptolemæus, the irregularity of the crater's shape may lead to doubt as to its classification, yet it is regarded by Elger as one of the most characteristic walled plains, its rampart being exceptionally good. A further analysis of the instances which at first sight appear to lead to some doubt as to the existence of a sharp line parting the maria from the vulcanoid floor leads to the same conclusion as the facts previously set forth, that these groups of level areas are, as structures, completely separated from one another, and therefore cannot have had like histories. In the one there has been a long-continued local volcanic-like action leading to the formation of an external rampart; in the other, a swift production of an igneous fluid, which has swept away until it found its level and shaped its margin by melting down the pre-existing reliefs.

Although in general the material which forms the floors of the several maria appears to be confluent, *i. e.*, to show no marks of overlapping at the lines of junction, there is reason to believe in the opinion of many observers that there is some diversity in the level of their floors. Thus the Mare Nectaris is supposed to be decidedly deeper than the others. This is not inconsistent with the view that they were all formed at nearly the same time. The greater depth of the last-named mare may be explained by the supposition that the absorption of the fluid matter into the ancient crust was relatively greater there than elsewhere.

While the surfaces of the maria are, as compared with the general surface of the moon, decidedly plain-like, they are, in fact, the seat of many irregularities. Of these the more important are a multitude of more or less continuous low-arched ridges, probably in no instance more than two thousand feet high, but uniformly of relatively great width, often several miles in transverse section. The nature of these ridges will be hereafter discussed. There are also on the maria numerous craters, none of them approaching in magnitude those on the old, more elevated portions of the crust. The ratio of craters on the maria is only about one-fifth as great as on equal areas of the original surface, and their average size is in about the same proportion. It is also to be noted that rifts or open cracks are apparently rarer on the maria than on the high lands and that the light bands and patches are of relatively seldom occurrence.

CLASSIFICATION OF VULCANOIDS.

In considering the so-called volcanoes of the moon (I shall term them vulcanoids), the first step should be a classification of their features. Selenologists have generally agreed to distribute them in seven categories termed as follows: walled plains, mountain rings, ring plains, craters, crater-cones, craterlets, crater pits. Besides these groups they recognize the existence of a less characteristic group to which they give the ill-defined name of depressions. Under the term

walled plains, those who use this classification include the greater pits with the ring of high land about them. Elger selects Ptolemæus as the type of this group. He states that it is the distinguishing characteristic of this group that there is "no great difference in level between the outside and the inside of the walled plain"; he proceeds to cite notable exceptions to the rule, accepting Schmidt's term of transitional forms for them. These many exceptions range from Gassendi, where the interior plain lies at about two thousand feet above the floor of the Mare Humorum, which three-fourths surrounds it, to Clavius, where the interior is some three thousand feet below the general level of the area in which it lies; such variations are so numerous that they include practically all the differences in the altitude of the enclosed plain which we find in any of the groups. Nor are the other criteria of this category more characteristic. The irregularities in the walls, the clefts, breaches, and greater breaks, are, in proportion to the length of the encircling ridges, hardly more frequent than in the mountain rings or ringed plains. So, too, with the minor craters, cones, and ridges on the floors and rims; they are abundant, as inspection proves roughly, in proportion to the area and the age of the structure. A careful examination of this group of walled plains will satisfy the observer that they are essentially like the mountain rings except for certain accidents which have befallen the members of the last-named group.

Nearly all the so-called *mountain rings*, all, indeed, that I have been able to group in this category, lie in the maria. They appear, as has been considered by several selenologists, notably by Elger, to be the more or less ruined remnants of what were originally to be classed as walled plains. From their position in the maria and even more from their topographic features, they are fairly to be regarded as akin to the first-named group in origin and general history, save that at the time when the maria were in igneous fusion their rings were in part melted down and it may be in part breached by the tides of lava which surged against them. In some instances these mountain rings appear to have been suffused by the lava when it stood at its highest level, and afterwards bared as the surface of the fluid was lowered. The maria of the second and third quadrant particularly abound in these structures, in every stage of assault and demolition, from those which stood so high above the flood of lava that their exterior slopes show only slight signs of attack, to the intermediate stage of the broken ring immediately north of Flamsteed, and thence to sundry unnamed and scarcely recognizable fragments of rings in other fields of the maria. There seems, indeed, hardly any room for doubt that to establish this group we shall have to accept the principle that the state of obliteration of lunar formations affords fit basis for their classification. It appears to me that for my purpose this group must be rejected.

In the group of *ring plains* selenographers have grouped all the strongly walled vulcanoid pits of the lunar surface; they find the criteria for separating them from the walled plains in the more continuous nature of their ramparts and the steep declivity of their inner walls. They note also that there are often

terrace-like structures on these walls such as would be produced by the successive stages of descent of the lava of the crater. Here again by the use of the method of series we may intimately connect the vulcanoids of this group with those of the two preceding groups. None of the students of this classification whose writings are known to me has failed to observe that there exist examples which may be classed as wall plains quite as well as ring plains. There is no doubt that these ring plains have in general better defined, more volcano-like cones than the wall plains, and that the contact phenomena of the lava of the floor with the inner slope of the rampart are more characteristic of volcanic action as we know it on the earth, yet these differences seem to me so to graduate together in the two groups as to afford no basis for distinct classification.

In the group of *craters* selenographers have placed so far the greater number of the vulcanoid pits. They have included in them nearly all the distinct pits from about fifteen to about three miles in diameter. So far as I have found, they suggest no definite criteria for the members of this group, save that they are widely distributed, occurring even on the walls of the large structures, and that on this and other accounts they appear to be newer than the wall plains or the ring plains. Inspection shows that there is no structural difference between the vulcanoids of this and the preceding groups, their relatively smaller size and apparent newness of formation affording no good basis for instituting a category in which to place them.

Following down in the order of size, the next accepted group is that of *crater-cones*. The objects included in this category are all of small size. Elger compares them to the parasitic cones of *Ætna*, which seems to me not a happy comparison, for their origin is in no wise related to the *Ætna* "parasites." As the pits are generally less than a mile in diameter it is difficult to determine the shape of their bottoms. My own observations agree with those of the selenographers, that these pits are usually in the form of inverted cones, terminating downward obtusely, *i. e.*, with no very distinct floors, and further that they are occasionally found with rounded, saucer-shaped bottoms, as if there had been lava in the cups, which had withdrawn with the cessation of activity into the deeper part of the crust. There is enough of this obscure flooring to connect by series the crater-cones with the craters, showing clearly that the difference between the two is one of dimensions alone and does not indicate any essential difference in the nature of the constructive actions. As regards the distribution of the crater-cones and craterlets, it is to be noted that they in certain instances appear to be associated with the light streaks; of this feature we shall take account hereafter.

The smallest of the observable pits on the surface of the moon are termed *craterlets*, or *crater pits*. These features are extremely numerous, the actual number on the visible part of the sphere, which might under favorable conditions be counted, amounting to many thousands. In the most characteristic specimens of this group there is no distinct wall or cone surrounding the pit, the opening often being abrupt, as if it were brought about by a mere subsidence of the area

in which it lies. Yet here, too, there is a gradation, for in sundry instances there is trace of a ring wall as if some material had been extruded. In many instances these pits are not circular, but with irregular outlines, which further suggest that in certain cases there was no explosive discharge, but an in-falling of the covering of a pre-existing cavity. It is further to be noted that these craterlets often, perhaps oftenest, lie upon ridges, either the walls of the larger vulcanoids or the numerous elongate elevations which occur in great numbers on various parts of the surface and appear not to be connected with any large vents. In general it may be said that the craterlets are the smallest observable members of the series which has for its largest term the ring plains, and that they are among the newer features of the lunar topography.

Looking upon the variety of form of the vulcanoids of the moon in the light of our knowledge concerning the shape of terrestrial volcanoes, it may be said that the range in form is not very much greater in the case of the satellite than in that of the planet. Between the great caldera craters, such as those of the Sandwich Islands or the Bolsena group of Italy on the one hand, and the smaller cones on the flanks of *Ætna* on the other, we have a range in width of cup less considerable but approaching what is found on the moon; or, comparing the nearly coneless craters of the Eifel, the products of a single eruption, with the peaks of the Teneriffe type or those of the Andes, we note a difference in the ratio of the enveloping cone to the interior which is also comparable to that exhibited by the lunar vulcanoids. It is evident that the series of lunar craters has much ampler range in diameter than those of the earth, but the correspondences are sufficiently evident to justify us in including all such features of our satellite in one group, assuming that the conditions of their formation were probably as near alike as in the several varieties of terrestrial volcanoes. An inspection of the lunar vulcanoids shows us that the most important features which separate them from those of the earth are to be found in the amount and nature of their extrusions; the order, or lack of it, in their positions on the surface; and the influences which have served to deform or to destroy their features. These peculiarities will be considered below.

The presence of a level surface of frozen lava in all of the lunar vulcanoids save perhaps the very smallest is, as compared with the volcanoes of the earth, their most conspicuous feature. This clearly indicates the relatively languid nature of the eruptions from those craters. There are, it is true, a number of terrestrial volcanoes where such a floor exists, but in all cases the facts justify us in supposing that the last eruptive action was of the milder type, as in the case of Kilauea in the Sandwich Islands. Eruptions of even slight intensity measured by terrestrial standards result in blowing out all of the fluid rock. Thus we are justified in regarding the level interiors of these vulcanoids as evidence that the normal lunar crater did not discharge explosively in true volcanic fashion. If such violent discharges took place at any stage of the history of our satellite they appear to be unrecorded in its existing features.

Not only is the presence of lava shaped on a floor in all the hundreds if not

thousands of distinctly observable lunar pits proof of the non-explosive nature of their eruptions, but we have other evidence to the same effect in the lack of all signs of ejected masses and of dust-showers, such as are the most striking phenomena of terrestrial outbreaks. If we select any of the vulcanoids situated in a region of much accidented topography, which evidently existed before the vent was formed, and examine the surface about the opening, we readily note that it is not masked as it would be in case it had been subjected to a succession of ash showers such as come from a normal terrestrial volcano. In many instances I have observed that there was no trace of such ash-covering up to the very foot of the ring wall. Like evidence of a more affirmative nature is to be had in the very numerous instances in which one vulcanoid cuts another. So far as I have been able to note the details of these instances, the earlier existing crater, except where its walls have been deformed by the encroachment of its neighbor, never suffers from any distinct obliteration. Its ring wall—craterlets, vents, terraces, and other slighter features, which should be hidden or distinctly changed in aspect by an accumulation of even a few score feet of ash—remains, so far as can be discerned, unaltered. When we remember that there has evidently been no erosive action on the moon such as has normally washed away thousands of feet in thickness of ash about *Ætna* and other large terrestrial volcanoes, we see how clear is this evidence that the lunar vulcanoids have not been the seat of ordinary volcanic explosions.

The lack of considerable lava flows on the moon appears to be almost as well established as the absence of ash; in but a few instances have structures which can possibly be classed as flows of really fluid matter proceeding from craters been reasonably suspected, and these on inspection appear to be more than doubtful. As will be noted below, the material in the craters appears not to have had a high order of fluidity, so that it quickly consolidated on very steep slopes—according to my observations generally exceeding 20° of declivity—as soon as it passed out of the cup. None of the rills or other fractures appear to have afforded passage to the interior fluid material; they seem, indeed, to have been formed long after the larger vulcanoids had ceased to be active.

DISTRIBUTION OF VULCANOIDS.

In considering the distribution of the lunar vulcanoids it is first to be noted that, unlike those of the earth, they are scattered over the whole of its visible surface. The fact that here and there all around the limb we may trace the hither borders of great ringed plains fairly leads to the supposition that like structures exist on the unseen portion of the sphere. Except that on the maria there are no large vulcanoids formed since those great plains were produced,—probably none as much as ten miles in diameter that postdate their fluid period,—there is little to be said concerning the distribution of these features on their surfaces. There are, it is true, considerable areas of the lunar surface outside of the maria where the only vulcanoids are the craterlets. With slight exceptions

these are the regions of so-called mountains, or in fields where there exist very many low dome-like elevations, often circular in outline but occasionally somewhat elongate. Of those regions where vulcanoids of considerable size are rare, the most noteworthy are the field of the Hæmus Mountains, the region on the west side of the Mare Fœcunditatis, and that to the northwest of the Caucasus Mountains, though there are many others of about the same extent. (See plate XVIII.) Several of these regions are of more than fifteen thousand square miles in area. It should be understood, however, that none of these fields entirely lacks vulcanoids; it is indeed doubtful if there is any part of the moon's surface, except it may be some portions of the maria, where craters of large or small size may not be found in every circle of twenty miles in diameter.

In many accounts of the distribution of the lunar vulcanoids it is stated that the greater of them exhibit a distinct train-like arrangement. As before noted, I have been unable to find any satisfactory evidence of such order being at all common. Here and there, as in the group of Ptolemæus, Alphonsus, and Arzachel, there is a trace of linear order, but a study of the facts shows that so far as the larger structures are concerned there is no reason to believe that there is any prevailing definite order in their placement. There is, however, good reason to believe that the smaller vulcanoids, commonly termed craterlets, are not infrequently arranged in linear order. This is not true of all of them, but is clearly so in the case of those which are in some way related to the rills or other crevices, and to the light rays of this point I shall have more to say below.

As regards the order of distribution in time of the lunar vulcanoids, it may be said that all the facts point to the conclusion, if they do not establish it, that the largest of them commonly were formed first. This is shown by the fact that in only a few instances does a large ring plain cut a decidedly smaller structure of the same nature, while the instances in which the smaller have intersected the larger are very numerous. So far as I have been able to apply this method of determining the relative age of the rings, it establishes the fact that the greater number, if not all, of the vulcanoids of say over fifty miles in diameter were completely formed before the most, if not all, of those say twenty miles in diameter were built, and further that very many of the craterlets were opened after the greater structures were completed. Still further it appears likely, though not certain, that before the greater vulcanoids were formed the so-called mountain districts and the general surface of the moon had acquired the topography we now find them to have, at least as regards the larger features of the surface. In very many of the great vulcanoids we find evidence that the neighboring country has had its surface somewhat distorted by the intruding structure. In a word, there appears to have been an ancient surface antedating the distinct ring plains, though it is possible that this surface was itself largely made up of such rings which have been obliterated by the agents of decay, which have in many instances partly demolished structures which are still recognizable, though often but faintly. The number of these faint rings too indistinct to be named, and rarely affording more than the merest traces of their original form, is so great as to warrant the conjecture that

those now existing are but the last of a long series which has been formed and destroyed. Close attention to these features in the moments of good seeing, which occasionally reward the observer, will reveal a series connecting such still distinct though extensively demolished rings with other more numerous fragments of circles which would not be interpretable save for the connecting links.

It may here be said that the phenomena of dilapidation exhibited by the relicts of ring walls in the fields of the maria differ essentially from what we find on the outlying surface of the moon. In the last-named areas, the ruining of the ancient ramparts has evidently been in large measure brought about by the encroachment and possibly by some shearing pressure of later-formed vulcanoids, which actions have broken down and shoved about the fragments of the once complete circumvallations. In addition to these processes of burial and displacement, there have apparently been at work some influences which have slowly broken down the rings, so that they have lost the original steepness of their profiles. In and on the borders of the maria we find evidence that the destruction was brought about by the immediate and swift assault of the originally fluid material that now forms these plains of frozen lava. The rings are not deformed but more or less broken down, in part breached, by the stroke of a tide of fluid rock, as in the case of Doppelmeyer and Hippalus on the shores of the Mare Humorum, or simply overflowed and melted down, as is the case with the great unnamed ring north of Flamsteed, the more effaced ring between that structure and Damoiseau, or the many other like instances in other maria.

As we pass from the largest rings downward in the series towards the smallest craters which have distinct floors, we note a progressive increase in the freshness and finish of these structures. The departures from the original form become less frequent, the walls are less breached, and the slopes of the ramparts steeper and more even. The interference of rings of like size becomes rare, so that with those less than five miles in diameter it does not appear to occur. All these facts point to the conclusion which finds expression in the writings of many selenographers, that in general the larger the rings the greater their age.

PHYSICAL HISTORY OF THE VULCANOIDS.

Comparing the lunar vulcanoids with the terrestrial volcanoes and adding to the considerations no more than a reasonable amount of conjecture, it seems to me that we may interpret the phenomena as set forth below. In this explanation care has been taken to introduce into the interpretation nothing in the way of action that does not appear to be warranted by the processes of our own sphere.

It is, in the first place, evident that while the lunar vents indicate some process of eruption it cannot be regarded as in its nature identical with that of ordinary terrestrial volcanoes. These last-named craters are, while they remain active, with rare and questionable exceptions, on sea-floors or near their shores. What we observe in their action and their distribution leads us to believe that

they are—mainly if not altogether—the points of discharge of water-vapor or of its dissociated gases, and that this water has been buried by aqueous sedimentation. The result is that when heated to a high temperature the fluid commonly explodes with a great tension, scattering large amounts of morcellated rock to great distances from the place of escape. On the other hand, in the lunar vulcanoids, the evidence goes to show that there were no explosions competent to drive fragments in extended trajectories. It is evident, indeed, that the movement of the lava in the pits was almost exclusively up and down in the cavities, often with successive haltings on a particular level, followed by a sinking to a considerable depth. In these stationary periods, the terraces of the frozen fluid on the inner slopes of the ramparts apparently were formed. That the position of the lava was not in all instances determined by a common interior deep level of the fluid seems to be shown by the fact that in some of the rings its surface is several thousand feet below the surrounding area, while in the case of Wargentín, just south of Schickard, the floor apparently lies high above the surface of the surrounding country.

That there was some kind of boiling or up-welling action in these crater lavas is well shown by the fact that in a number of instances, more numerous than the records show, the surface of the floor is flexed upward, so that the center is some hundred feet above the rim of the sheet, as if the final much weakened impulse was sufficient to arch the frozen crust but not great enough to rend it from its adhesions to the shore. Such tumefying action is also shown by the numerous instances in which a mountainous mass of lava has been forced up in the central part of the crater floor. These medial heaps of lava are so common in the vulcanoids of middle size as to be the rule rather than the exception in these structures. In many instances they are replaced by central craters, or now and then, as in the case of Theophilus, there is a mass spewed up, as are some terrestrial trachytic cones, with only a faint trace of crater pipes leading downward into the interior. (See plate xvii.)

Finding as we do evidence of some swelling and sinking process competent to lift and lower the lava in the craters of the vulcanoids, and seeing at the same time that this action did not take place with anything like the energy of terrestrial eruptions, the question arises as to the nature of this eruptive force which has operated on the crust of the moon. The only hypothesis which has suggested itself is some kind of boiling, such as will take place in any fluid mass which is heated below and cooled on the surface, as in molten iron, where substances in the vaporous state, though they exist, are not present in sufficient quantities greatly to affect the movement, or there is a circulation mainly impelled by the escape of imprisoned vapors. Mere convection of heat in an igneous fluid does not seem to be sufficient to account for the rise and fall of the lava in the craters, especially as in the case of Wargentín, for there the lava floor lies at a height of some thousands of feet above the general level of the surface. We will therefore consider the possibility of there being materials vaporized by heat in the lava, not enough to produce the type of terrestrial explosions, but sufficient

to lift the lava to the tops of the existing rings and to produce a circulation sufficient to keep the material for a long time in a molten state. On this point we have some direct evidence from the fact that many types of lavas that form dykes, such as granites, are violently forced into rocks of the earth's crust without there being any evidence of vaporous or gaseous materials impelling them; it is more likely, however, that what we see in the way of eruptions on the moon are the results of extrusions brought about by the pressure of gases originally contained in the fluid mass of the sphere.

It is commonly assumed that for a long time after any celestial sphere has entered on its fluid state, in passing from its nebulous or fragmentary previous condition, the process of separation of its materials volatilizable at the temperature established by the concentration must necessarily go on with the result that some such vulcanoid phenomena as appear on the lunar surface will be likely to occur. It is a fair working hypothesis that every crater-like opening on the moon was formed by the relatively mild outbreak of vapor such as keeps open the terrestrial craters of the Kilauea type; in such vents there may be vapor enough to induce some movement of the lava, but not enough to cause very great ejections of the fluid.

It may be assumed that the lava of the moon far more than that of the earth would tend to retain its gases and to form the viscid, slow-moving material known as pumice, which even when near a melting temperature is of a wax-like stiffness. The reason why the blebs of vapor could not separate from the lunar lava as readily as from the fluid rock of our planet is to be found in the relatively slight value of gravitation, which on the surface of the moon is only a little more than one-sixth what it is on the earth. The tendency of bubbles to separate from a fluid depends in large measure on the difference between the weight of the contained vapor and that of the mass in which they lie; so that it may well be that the lavas of the satellite were on account of their contained vesicles of vapor less fluid and more like pumice than those we have a chance to observe in volcanic action.

When the lavas were lifted to the edge of the encircling rampart it is evident that they flowed out. That they were in the periods of activity so lifted and discharged is plain from the height of the terraces in many lunar craters, and from the elevation at which the lava floor has remained in the case of Wargentín. The normal well-preserved vulcanoid of sufficient size to permit a study of its features shows, in most instances, buttress-like ridges extending not more than a few miles outwardly from its rim; these are fairly to be taken as flows which have passed over that rim or through breaches in it. It is to be noted that all of these buttresses have very steep slopes, both in the radial direction from the crater and laterally from the center of the ridge. To those accustomed to the gradual slope of lava streams, such as break forth from the base of volcanic cones where the angle of declivity is often not more than two or three degrees, the twenty to thirty degrees of inclination of these supposed lunar flows may seem to negative the hypothesis that they can be lava streams. Lyall and

others have, however, shown that lavas may, flowing over the edges of terrestrial craters, consolidate in slopes of eighteen degrees of declivity. Now the angle at which the stream comes to rest will, other things being equal, be determined by the value of gravity; reckoning this as before at one-sixth that of the earth's surface, we see that a very much increased slope may well be allowed in the case of the lunar discharges.

The conception thus formed of the process by which a lunar vulcanoid of the larger size was produced, a conception founded on an extended study of their phenomena, is as follows: the first stage of the action probably consisted in the production of a slight dome-shaped elevation such as abound on the lunar surface, being, indeed, the commonest of the smaller features on many parts of the areas outside of the maria. These dome-like elevations appear to be due to some accumulation of vapors beneath the superficial layer, formed perhaps when the whole crust was still partly softened by heat. At a certain stage of the process this arch fell in, or was broken to pieces and thrown outwardly, leaving a pit with lava in it. When in its oscillations of height this lava overflowed the edge of the pit, the material so passing from the heated interior quickly consolidated and began the formation of a ring-shaped rampart. With the continuance of this action the lava would tend to melt down the interior faces of the rampart, gradually extending the diameter of the opening, destroying and remaking the wall as the process of enlargement went on. Finally, as the supply of melted rock was by unknown causes reduced, the lava fell to its lowest depth and gradually froze; the last stage in the activity being usually marked by a small central crater, a low dome, or by a spewed-out cone, such as so commonly occupies the central part of the floors of the greater rings. It is to be noted that the present position of the lava in the vulcanoids is not to be taken as its average height, for practically all of the craters which preserve what seems to be a fair semblance of their original form show the remains of terraces that indicate higher levels of their floors.

The objection may be made that the summits of the ramparts abound in peaks which rise far above the general level of the rings. It is evident that these salient points present serious difficulties; in some instances they may be accounted for on the supposition that the parts of the ridge now much lower have been broken down by lava which has poured over its crest. In other cases we may find the explanation in the fact that there is an obvious tendency to form small craters on the crust of the ring wall, there being many such that are plainly visible. Now, as we see elsewhere, particularly in the center of the vulcanoids of middle size, sharp, irregularly shaped masses of extruded lava, sometimes, as in Theophilus, many thousand feet high, often take the place of small craters. (See plate xvii.) Thus these isolated peaks may be masses of lava which have been spewed up to a great height. The origin of the small vulcanoids on the ramparts of the greater is a difficult matter to explain; it may perhaps be accounted for by reference to terrestrial volcanoes, where we find some evidence of a like tendency to form secondary craters around the margins

of a plug of frozen lava which fills the cup. If we suppose a ring widening by the process of melting and rebuilding its walls, we may conceive that the fluid is likely to extend at points beneath the ramparts, so that when, after a period of repose, in which the lava was frozen and had shrunk, activity was resumed, the easiest way upward for the vapors would be by passages leading vertically through the wall.

The curious fact may here be noted, that in no observed instance is there distinct evidence of any lava flow which has broken under and through the rampart or cone surrounding a vulcanoid. When we consider that practically all the lava streams from terrestrial volcanoes break out through the base of their cinder cones, this condition of affairs on the moon demands an explanation. This may, like many other of the lunar events, be explained by the fact that the weight of the fluid, which is the impelling agent of its flowing, is only one-sixth that of terrestrial lavas, while the cohesion of the rocks may be, and most likely is, quite as great as on the earth; certainly these cones, which apparently are far more firmly built than the ash heaps of volcanoes, must have resisted the relatively slight hydrostatic pressure of the lavas they enclose far better than the like structures of the earth.

We may here turn aside for a moment to consider the hypothesis that the evident and often probably repeated up-and-down movement of the lava in the vulcanoids was due to tidal action effected by the earth. While it cannot be doubted that the effect of the earth's attraction, at present six times as great on the moon as is that exercised by that body on our sphere, and may of old have been yet greater, would be competent to lift any internal united mass of fluid to a considerable height, there are reasons why it cannot well have served to pump the lava up to the elevations it attained in the lunar craters. To be operative, we have to suppose that the terrestrial attraction took effect in a central mass of igneous fluid, the surrounding crust being essentially rigid, not flexing to any great extent with the pull, which seems to be an unwarranted assumption. Under these conditions the lava would mount and descend in each lunar day, which, before the moon ceased to have a diurnal rotation, may have been of almost any length less than what exists at present which we have a fancy to reckon. It is, however, to be observed that the lavas of the vulcanoids, from time to time, froze at exceedingly varied levels, there being a range of several thousand feet in altitude in craters which are near to one another. These stations of repose, long enough to permit the freezing, are not to be explained on the hypothesis of incessant tidal pumping; nor have I been able to account for the facts by any warrantable subsidiary hypothesis. Moreover, the smaller vulcanoids, the craterlets, which are evidently in the same series as the greater, having little or no lava in their bases, cannot be thus explained. Furthermore, the central cones of many of the larger vulcanoids, the formation of which was evidently in some way connected with the actions which built the whole structures, apparently cannot be brought under this explanation.

The most reasonable view as to the interior condition of the moon when its

vulcanoids were in activity is that it was in a state of essential fluidity with a relatively thin crust. This fluidity may not have been that of terrestrial lavas; it may have been, and apparently was, more viscous or pumiceous. That such was the case is suggested by the behavior of the extruded lavas; it is further supported by the form of those other extrusions which occur in the so-called mountains, as will be further noted in the study of those structures. Thus the crust, despite its being of greater weight than the interior lavas, may have attained a considerable thickness; it may have had a depth of some miles. Yet it is hard to believe that it would have formed a sufficiently rigid enclosure of the interior fluid to have caused the sphere to remain undeformed by the earth's attraction to the extent necessary to bring about a great up-and-down play of the lava in the passages leading to the surface. It is furthermore to be noted that no trace of tidal action has been observed in terrestrial volcanoes—though this fact may be accounted for by the difference in the nature of their origin.

I have already, in preparation for the study of the maria, considered the arguments against the supposition that the vulcanoids are due to the in-falling of meteoric bodies, the main point being that they fail to exhibit any trace of the great melting due to the collision of bolides of sufficient size to make such pits. The maria being, according to my view, due to such in-fallings, showing all the evidences of a vast and sudden development of very fluid material of high temperatures, it follows on this hypothesis that the vulcanoids cannot be due to like action. The objection to this explanation in the case of all the crateriform openings seems to me to be so insuperable that it may not be further discussed.

It is important to consider the group of vulcanoids which have been formed on the surface of the maria since the lavas of the maria were produced. We note, at the outset, that these openings are all of relatively small size. Leaving out many doubtful cases, where it is not easy to determine whether the structure was in age antecedent to the maria in which it lies or no, these vulcanoids, so far as I have observed, never exceed ten miles in diameter, and even those of such width lie in positions where the covering of lava proper to the mare may be thin. It is therefore possible that they are due to actions occurring beneath this marial sheet which have manifested themselves on the new surface. The only vulcanoids which may be with some confidence regarded as having their origin in the lavas of the maria are the numerous small craters and craterlets, those in general of less than a mile in diameter, which are abundantly found scattered over their fields, though they are there less numerous than on certain other parts of the lunar surface.

It may here be noted once again that in certain instances the likeness of color and the relation of height of the lavas of the maria and those of large nearby craters leans to the suggestion that the igneous fluid from the neighboring mare passed under the ring wall, or through clefts since effaced, into the area it encloses. This view is most distinctly suggested in the case of Plato and Grimaldi, but there are other instances to which it would be applicable. Such a passage of lavas by underground ways is made doubtful by the fact before adverted to, that in no

instance has the molten rock contained within a ring been observed to discharge itself through the rampart, as is often the case in terrestrial volcanoes. It is perhaps more likely that any communication with the maria was by fissures in the walls which have since been closed, or, if remaining, are so narrow as to escape observation. It may be said, however, that the great heat of the marial lavas and their evident high fluidity would have enabled them to burrow through passages not permeable to the viscous lavas of the vulcanoids.

The evident fact that the order of succession in time of the vulcanoids is, in a general way at least, in the order of succession of their size, the larger being the more ancient, enables us approximately to determine at what stage in the lunar surface the maria were formed. All of these several areas which have originated independently one of another appear to have about the same sizes of minor vulcanoids on their surfaces. The small craters apparently originated after the greater rings had been formed, but certainly before the discharge of materials from the interior had ceased. It is possible, however, that all the vulcanoids in the maria, except those which were situated on such elevated ground that they were not suffused by their lavas, owe their origin to boiling action within the liquefied zone of the seas themselves. In this case it is possible that the time when these fields were formed was after vulcanoids ceased to be produced on other areas of the lunar surface. The general sharpness of these structures on the maria is in favor of their relatively recent origin, though it affords no data for a precise determination of their age.

I have, in considering the origin of the maria, referred to what appears to me to be evidence that the fluid of which they were originally composed had extended upward along portions of and perhaps all of their shores, so as to produce a smudged effect on parts of the relatively low-lying ground. So far as I have observed, this apparent effect is most evident on the southern shores of the Mare Nubium and the Mare Humorum. (See plate XXI.) My observations suggest that these apparently inundated fields lack craterlets, such as occur on the areas of the distinct maria. If this observation should be confirmed, it would make it likely that the seas were formed after the activity of the moon, as a whole, had ceased, and that the craterlets of the maria were due, as just above suggested, to boiling within their masses, and not to the internal fluid of the sphere. A careful reckoning of the number of very minute craterlets on the maria, as compared with those on other parts of the moon, will probably show that they are on the average more numerous on them than on some other fields of higher ground, and also that they are of prevaiingly smaller size. As a group they appear to me to grade less distinctly into the flat-bottomed craters than do those of the highlands. My observation on these points are, however, not sufficient to more than suggest these possibilities. Anything like a determination of them demands better seeing than is to be had at the Harvard College Observatory and better sight than is now mine. Should these variations really exist, they would tend to show that the maria had developed their vulcanoids from their own materials. In further inquiries concerning these pits on the maria, it will be well to

have them compared with like structures in the lava floors of the larger ring plains. My inspection shows them to be very similar in aspect, as they may be in origin, probably being both alike due to actions taking place within a moderate distance from the surface.

MOUNTAINOUS RELIEFS OF THE MOON.

Next in topographic importance to the vulcanoids come the reliefs, which have received the general name of mountains. In this group we find at least three distinct categories, which probably are due to as many separate causes. First and most important of these species of salient forms come those which have generally been named after terrestrial ranges or orogenic systems, as, for instance, the Alps, Apennines, Caucasus, etc. Although these groups of elevations have a considerable local diversity in character, varying in elevation from two or three thousand to twenty-six thousand feet or more, and in shape of their individual peaks from seldom nearly conical forms to much extended ridges, they in general have the character of elongate masses rudely elliptical in horizontal section, the several units of each field showing a tendency to a rude parallelism of their axes. These units are rarely distinct from one another, but connected at their bases, so that the field they occupy is by their confluence considerably raised above the general surface of the country in which they lie.

The number of these fields of mountains which have been named by sel-nographers is about twenty-five. There are, however, probably at least twice as many areas which exhibit this type of structure in a tolerably clear manner. One of the most important of these is the area between Schröter on the south and Marco Polo on the north, the area in part forming an isthmus-like barrier between the Mare Nubium and the Sinus Æstuum. The facts go to show that while the tendency to form this type of topography is more evident in the northern than in the southern hemisphere, it has existed in some measure on all parts of the moon except those now occupied by the maria; in these fields, though there appear to be ill-preserved remains of such structures, they are very imperfect. It may also be said that structures of this nature seem to be more frequently developed near the limb than elsewhere, but this may be due to errors in classification, consequent on the difficulty of determining whether elevations in that part of the surface are the borders of vulcanoids or mountain ridges.

In considering the relation of the mountains of the moon to the vulcanoids, it is important first of all to note the fact that where they are extensively developed there is a prevailing absence of larger crater-form structures, and that in certain instances we may at least suspect that they have broken up such structures. At a number of points involved in these tangles of ridges there are features which look very much like fragments of the rampart of ringed plains which had been involved in the apparently tumultuous movements attending the building of the mountainous reliefs. Instances of this nature occur in nearly all the larger mountainous areas; good examples exist in the Hæmus Mountains

and in the unnamed district between the Lacus Somniorum and the Mare Crisium. As it is the habit of the ridges to be rather straight, the occurrence of curved fragments, varying from those of a few degrees of arc to half circular, appears to warrant the hypothesis that antecedently existing vulcanoids have been broken up in this peculiar constructive work.

In some instances vulcanoids which were evidently once fairly perfect, as such structures necessarily are at the time of their formation, have been apparently invaded by the mountain ridges. This is the case in Marco Polo, just above mentioned. Here an originally normal ring plain has been broken into on its northern versant, and thereby so deformed that its original nature is not readily perceived on casual observation. The great walled plain of Hipparchus appears to have been in large measure destroyed by the development of mountain ridges, which traverse its walls and in part the enclosed plain. Many other instances could be cited to show that these mountain-building actions, whatever their nature may be, have been very effective in deforming if not in destroying the vulcanoids of large area. Even the generally well-preserved Plato appears to me to exhibit in its wall evident traces of dislocation arising from the disturbance of the moderately accidented region about it.

There is no evidence sufficient to determine the stage when the building of lunar mountains ceased. There is, however, reason to suspect that they were not formed after the maria came into existence. There are, it is true, a number of groups of such structures which lie within the boundaries of the seas, but there is some reason to believe that these are the survivals from an antecedent time, being parts of systems which were not entirely buried by these widespread lava fields, though they show to my eye distinct evidence of having been effected by the inundations of liquid rock. If this judgment as to the history of the intramarian ranges be accepted, then we may safely conclude that the mountain-building period was passed before the seas were formed. There is some reason to suppose that this stage of the lunar development did not extend down to the time when the smaller vulcanoids, at least those which lie outside of the ring plains, were produced. In no instance have I observed any of the mountainous folds breaking in upon craters less than ten miles in diameter, though my observations are not sufficient to completely exclude such occurrences. In many instances, however, very well-shaped craters of several miles in diameter occur in mountain-built areas. They often are so well preserved that we have to exclude the supposition that they were formed before the ridges were developed.

The second group of prominences which may be termed mountains has for its type the isolated masses which often occur in the central parts of lava floors of the greater vulcanoids, and more rarely in excentric positions on those floors. These reliefs were evidently produced by some action connected with the formation of small craters which they appear to replace. Such craters on the floors of the vulcanoids are, as is well known, extremely common; in many instances there are more than a dozen within the ring, and in the Stadius Schmidt says he counted fifty, and forty-one have been delineated. Commonly there is either a

considerable pit or a mountain in the center of the ring, the probability of this central feature occurring being greater with the decrease of the size of the vulcanoid, until the diameter of the plain becomes less than about ten miles, when it tends to disappear. The facts indicate that the central pit and mountain of the vulcanoid floor are interchangeable features. In some cases the peak has a more or less distinct craterlet upon its summit, or, as is shown in the central compound structure of Theophilus, there may be traces of a crater masked in the extruded heap.

The third group of reliefs on the lunar surface is typified by the long, low, apparently continuous ridges which are found on all the maria, but which are particularly well developed on the Mare Imbrium, the Mare Serenitatis, and the Mare Nectaris. (See plates XVIII and XXIV.) The characteristic features of these ridges are their prevailingly low-arched forms, their slight height, and their remarkable continuity; they very often attain a length of one hundred miles, and in some cases of twice or thrice that extent, while the greatest elevation assigned to them is less than two thousand feet. As their flanks grade rather indistinctly into the general surface of the maria, their precise width cannot be stated; it is evidently variable, with a probable maximum of five to ten miles. So far as I have been able to ascertain, well developed continuous ridges are limited altogether to the maria and practically so to the larger fields of this nature; in the small maria they are much less distinct, though there are instances of slight undulations which may belong in the same category of structures. In fact all the extended plains, even those of the greater vulcanoids, exhibit more or less wrinkled surfaces, when seen with powerful telescopes under very oblique illumination, such as serves to bring out irregularities only a few score feet in height.

The distribution of the continuous ridges indicates that they belong to two distinct groups which may be due to diverse causes, or at least to different methods of action of some general cause. The most evident of them are often nearly rectilinear, or with broad curves, which have no evident relations to the outlines of the shore of the mare in which they lie. Of these, the great examples extending from near Lambert in the Mare Imbrium, or those of the Mare Serenitatis lying between Posidonius and the promontory of Acherusia, may be taken as types. Another group, well indicated on the borders of many of the maria and some of their embayments, has the folds following the shores and seems to be limited to a somewhat distinct field lying near those shore lines. Elger suggests that in the case of Mare Nectaris these shore-following ridges are due to the settlement of the lava in the central part of the basin. It is undoubtedly the fact that the lava has been lowered in the Mare Crisium since the surface has frozen, as it probably has in all the maria; traces of like action seem to me to be more than conjecturable in the floors of the larger vulcanoids as well; but it is not to me clear that these shore-following wrinkles are, as Elger suggests, caving-in steps, such as those formed on the edges of a frozen pool or stream as the water in the basin subsides. If they are, as some of my sketches indicate, arranged in the manner of a carpet on a stairway, as monoclinical folds of terres-

trial rocks, we have reason to suppose that they are due to faults which skirt the shores and which occurred in the basement rocks while the lava sheet was still in a plastic state. This supposition has its difficulties, for there is no evident reason why such faultings should occur; faults with vertical displacement are very rare on the surface of the moon, and in no case are they found in any such order as we need to have them to account for the shore wrinkles like those curving around the borders of the maria.

Less distinct than the typical continuous ridges, but probably to be connected with them, as lesser phenomena of the same order, we have, as before noted, on all the maria and on some of the greater vulcanoids' floors, faint wrinkles of great linear extent. The relation of these to the larger ridges appears to be confirmed by a series in which it is impossible to determine any break. I am therefore disposed to place all the elongate wrinkles in one group, regarding the typical examples hundreds of miles in length as structurally related to the slight, relatively short foldings which are barely revealed by the telescope. On close examination of the more characteristic elongate ridges it appears likely that they are not, as they appear at first sight to be, even arches, but in some instances at least are compounded of smaller wrinkles arranged in a more or less parallel order. As these minute features are discernible only by their shadows, it is as yet undetermined whether they are subordinate ridges forming a kind of chain or fractured blocks. I am inclined to think it probable that they are of the last-named nature, for the reason that analogy with terrestrial lavas would indicate that solidified superficial lava would fracture and not fold into arches. Some of these ridges appear to have craterlets on their summits.

It is also to be noted that, while the systems of low elevation which we are considering have great continuity, there is an evident tendency to break the continuity, so that the chain is composed of separate links, each parted from the other, as in terrestrial mountain chains. Here and there these units are arranged in an echelon order, as is the case in many terrestrial mountain chains such as the Alleghanies. This arrangement makes the likeness of these lunar elevations to terrestrial mountains more evident than any other of its reliefs.

A third group of lunar elevations, possibly akin to the long ridges above described, is found in the domes which abound in many parts of the surface; they are, according to my observations, commonest on those parts where vulcanoids are rare. I have suggested that certain, or perhaps all of them, may be incipient craters. These domes are found on the maria, though here they are of prevaillingly smaller size, as well as on the older, more elevated surfaces; in number they rival the crateriform structures. Following the plan of grouping the lunar features, when possible, into series, I have endeavored so to connect the domes with the elongate arches before described. There are many examples of domes which are somewhat elongate, say with the major axis near twice the extent of the minor, but I have not been able to unite the two groups by any complete series of transitional steps and therefore am led to consider them as possibly distinct.

ORIGIN OF LUNAR MOUNTAINOUS RELIEFS.

As regards the origin of the first-described groups of lunar reliefs, those which form the massive elevated mountains, it may be said that they cannot be placed in the category of terrestrial structures due to folding and faulting combined with aqueous erosion. If there be any one certain fact concerning lunar topography it is that it nowhere exhibits the results of water erosion. If orogenic action such as operates on the earth has acted on the moon, as it may have done in the case of the elongate ridges of the maria, it could give us no more than arches and the fractures incident on their formation. It could not possibly have developed the steep, lofty, and extremely serrate structures such as are found in the greater fields of the so-called mountains. So far as geology enables us to interpret them, these elevations must be due to the ejection of exceedingly viscous lavas, forming heaps such as we have in certain masses of trachytic rocks on the earth. That such ejections do occur on the moon is well shown by the very numerous and often high peaks which have evidently been thrust up in the central part of the lava field enclosed by the greater vulcanoids. In character of summits and slopes these tumefactions of the ring plains are to my seeing essentially like the so-called mountains. They often attain to near the average height of the peaks in the Alps or the Apennines or other lunar fields of crowded elevations. The facts have led me to the following considerations and to a working hypothesis based on them:

Noting that the peaks formed in the central part of the lava floors of the greater vulcanoids clearly indicate that, after a period when tolerably fluid lavas existed beneath the crust, there came a time when these lavas were so viscous that while they might be extruded they would not flow, but retained the shape in which they were spewed out; noting also that the evidence from the invasion of the vulcanoids by mountain ridges indicates that these elevations were among the more recently formed structures of the maria, we are led to the suggestion that they represent a stage of the eruption when the ejected materials were so viscous that they could no longer form vulcanoids, but poured forth masses which not only did not flow but heaped up near the vent, just as they evidently did in the central field of many craters. It is true that small craters are here and there, though rarely, found amid these mountainous elevations; they may represent the localized remnants of the once general fluid state, remnants sufficient to produce slight eruptions of the earlier type.

I have already called attention to the fact that the distribution of the exceedingly numerous small bleb-like domes on the lunar surface suggests that they are the first stage in the development of craters, the imprisoned vapors serving to lift the surface although it was not broken through. It appears to me likely that it is in such elevations that we have also the beginnings of the other group of vulcanoids, the ejected peaks. In several parts of the moon, notably in the region where mountainous elevations occur, these domes abound. In some cases small craters occur in the same field, which suggests, as before noted,

that these bleb-like elevations may have been the first stage of such vents; in other cases the cones appear to pass by a series of transitions into the mountainous form. I have not been able to verify this passage from the dome to the peak, but the indications of it appear to me to be noteworthy. In this connection it may be remarked that the structures in the centers of the middle-sized vulcanoids lend support to the view that a dome-shaped elevation may, by further development, pass into a peak. When these prominences are low and small they often have a rather evenly arched form, but when they are of considerable magnitude they take on a complicated shape with serrate crests substantially like the structures classed as mountains, the only evident difference being that the masses are not so commonly elongate in horizontal section, as the individual mountainous ridges commonly are.

The observed facts concerning the mountainous protuberances of the lunar surface lead me to the opinion that they are classifiable in one group, of which the simplest and most interpretable examples are found in such peaks on vulcanoid lava plains as that of Theophilus, where we have a mass of ejected materials which shows no trace of flowing for it has very steep walls. (See plate xvii.) This great viscid ejection covers an area of more than three hundred square miles, and rises to a height of six or seven thousand feet above the floor of the crater; it is particularly interesting for the reason that while it is essentially a group of peaks it retains traces of what seems to be a volcanic type, as it has an indistinct crater on the summit of the mass. Other instances could be cited to show this passage from the conditions of a crateriform structure to a rugged cone. In fact the series appears to be sufficiently fairly complete to establish the point that the last stage of activity in the craters of the vulcanoids was that in which the interior lavas, primarily hot enough to flow in the manner necessary to form very level surfaces, had become so viscous that they would maintain themselves at angles of sixty degrees or more to the horizontal.

As for the ejections of viscous lava which took place outside of the craters, forming mountain-like elevations, the evidence appears to warrant the conclusion that they represent, as do the craterless cones within the rings, a survival of a tendency to eruptions after the time when the lava was liquid enough to produce the normal vulcanoid structures. In these later eruptions, because of this exceeding viscosity of the ejected material, there could be no ring wall or interior lava plain formed. All the material which would have gone to such constructions was heaped in the viscid mass which was forced out of the opening. The natural result of these conditions is that the mountainous elevations, while less in diameter than the larger vulcanoids and having no more material than goes to the formation of an ordinary lunar cone and lava plain, present normally very elevated peaks.

It may seem that if the craters and the mountains are the result of essentially the same expulsive energy, with no other difference in the conditions than the suggested variation in the fluidity of the lavas, we should find a series of intermediate forms between the crater and the peak. Such intermediate

stages are, as I have noted, to be found in the central structures of the normal vulcanoids. I have here and there suspected like transitional shapes among the mountains, but can cite none that is conclusive. There are, however, in the region of the Alps and other fields in the northern hemisphere of the moon various instances which may be of this nature. My eyes are no longer fit for such difficult observations, so I must leave this point, along with many others, unverified. It is well, however, to note that the passage from the state in which the lava of the moon's interior was sufficiently fluid to bring about the formation of the ordinary vulcanoids, to that in which peaks only would be formed, does not involve any great change of temperature. In terrestrial conditions, a lowering of a few degrees in heat at the critical point in a progressive cooling would be sufficient to bring about the change in the nature of the eruption.

The frequently elongate shape of an individual mountain seems at first sight to be, and perhaps really is, an objection to the above-described theory of their origin. It is, however, to be remarked that a large part of these elevations have rudely circular bases, and that where they depart from this figure they do not take the shape of long, continuous ridges, the major axis rarely exceeding the minor in the ratio of more than two to one; moreover, some of the mountains of the crater floors show the same tendency to elongation. Later on in this writing I shall note that the phenomena of "rills" and other rifts show that the surface of the moon was very generally in a state of contractile tension, and this before the formation of the smaller vulcanoids was arrested, and further that the axis of the mountains often coincides with the direction of the rill-splitting. If this be the case, then the extrusion of somewhat rigid materials such as formed these cones would naturally tend to rend the crust as with a wedge, so that an elongated opening would be formed for the extruded mass and the shape of such opening would determine the outline of the elevation.

There is yet another class of reliefs on the lunar surface, those which are typified by the great escarpment of the Altai Mountains in the fourth quadrant. (See plate xvi.) In this Altai relief we find in the southeast a slight and gentle rise of a field, which has few very noteworthy features, for a hundred miles or more to the edge of the steep, and then a sudden fall to the northwest, the descent being on the average at least six thousand feet. The crest of this declivity is much varied; one peak, at least, is said to attain the height of thirteen thousand feet above its base. It appears likely that the northwest face of the Hæmus Mountains and the southeast face of the somewhat similar district lying between Eratosthenes and Mt. Hadley, facing the Mare Imbrium, are structures of a related nature. The most warrantable hypothesis, from the point of view of the geologist, is that these reliefs are due to faulting on a large scale, accompanied by a considerable amount of extrusion of the type that forms lunar peaks. In two of the three evident examples of this group, those last named, the lava of the *maria* has extended to the base of the declivity; in the case of the Altai steep, the igneous matter of the Mare Crisium, though it once extended much beyond its present limits, did not attain the base of the escarpment. There are divers other steeps

which may be allied to those above described; of these perhaps the most interesting is that which forms the border of the Sinus Iridum and of the Mare Imbrium, to the northwest and southeast of that remarkable bay; nearly the whole eastern shore of the Sinus Roris and of the Oceanus Procellarum may be of this nature. Though the last-named escarpment does not rise suddenly to any great height above the mare plain, the straightness of the line suggests that it was originally of greater vertical extent and was formed by faulting.

The principal objection to the hypothesis above stated, that the above-described features are due to faulting, is found in the fact that clear instances of such action are rare on the lunar surface. The most conspicuous fault, where there can be no doubt as to the nature of the conditions, is that commonly known as the Strait Wall on the surface of the mare between Birt and Thibet. (See plate XXI.) Here the break has a length of at least sixty-five miles and is quite as rectilinear as any terrestrial fault. The vertical dislocation is at least five hundred feet and may be much greater. It is evident that this is relatively a modern feature, having been formed after the time when the mare had cooled. It is not unlikely that in the earlier ages, when the moon was parting more freely with its heat, the resulting faults were of far greater extent than is shown in the Strait Wall. It is to be noted that the break of the Strait Wall did not lead to the extrusion of any considerable amount of igneous matter. Elger has observed craterlets and mounds upon the crest of the escarpment, but it is not clear that these are genetically connected with the break, for such features abound in the Mare Nubium as in other seas. Thus, though there is no basis for certainty, I am disposed to regard the Altai group of escarpments as due to faulting.

As to the age of the great escarpments above described, it may be said that they certainly antedate the maria, which have their margins to some extent determined by them. They seem also to antedate some of the larger vulcanoids, for Piccolomini, which is about sixty miles in diameter, being in size among the score of greatest structures, was formed after the Altai escarpment. Plato also, though less clearly, appears to have been formed after the steep which bounded the Alps on the south, now somewhat effaced by the Mare Imbrium, was developed. If this hypothesis, which seeks to account for the steep faces of highlands by faulting, be correct, we must regard these features as among the most ancient, perhaps the very oldest, reliefs on the lunar surface. They are now to a great extent masked by the maria, which have found in them their natural shores, they being, it would appear, bordered by them for near half their total coast line. Further reference to these features will be made in the discussion of orogenic action.

VALLEYS, RIFTS, AND RILLS.

In addition to the above-described positive reliefs of the moon, the surface of that body presents a multitude of minor depressions which demand consideration; of these the most notable are the cavities which have received the obscurely

defined name of valleys. The most conspicuous depression ordinarily classed in this group is the great Alpine valley which traverses the mountainous ranges of that name, extending in a northeast direction from near the Mare Frigoris to the Mare Imbrium, a distance of about eighty miles. (See plate XXIII.) In width it varies from four to six miles, but at its southern extremity for about one-fourth of its length it is somewhat narrower, being reduced at one point to about two miles in cross-section, and at the mouth it is beset with what seem to be extruded masses, so that it debouches by several narrow clefts into the neighboring sea. The walls of this valley are generally nearly vertical; from my own comparisons with other measured objects, they appear to average more than a mile in height and to be for the greater part of their extent almost rectilinear. The floor of the depression is approximately level, though with some obscure pits, and by its color as well as its form is evidently covered by an extension of the Mare Imbrium. The Ukert valley, on the east side of the crater of that name, is longer than the Alpine and has about the same width with less depth. The fracture by which it was formed appears to be continued in an obscure cleft, which extends from its northern end to the vicinity of the vulcanoid called Marco Polo, the whole constituting what seems to be one structure nearly two hundred miles in length. A similar valley with a length of about eighty miles lies on the west side of Herschel. It has a width of at least ten miles and is rather straight-walled. Yet another notable feature of this group is that lying on the eastern side of Rheita, which is about one hundred miles in length and about twelve miles in diameter. Last of all we may cite the great valley on the southwest side of Reichenbach, which extends in a rather tortuous course for about one hundred miles and has a width of ten or twelve miles. There are many other similar, though smaller, valleys, varying from a maximum width of ten or twelve miles downwards, until they grade in dimensions into the group of clefts. A full list of these structures is lacking, but they probably number several score.

As regards the distribution of the fault valleys, it is noteworthy that all the distinct examples of the group lie outside of the maria. It is true that on those fields there are depressions which have been classed with the vales, but, so far as I have been able to determine, they all fail to exhibit the essential features of this group—*i. e.*, they lack the steep walls and the generally rather level floors characteristic of the true valleys. They seem to my eye to be in their nature synclines, or downward foldings, the counterparts of the continuous ridges which are so characteristic of the maria, though they are not found in any definite relations to those up-folds. As to the time of the formation of the valleys, it appears to have been relatively late, posterior to the formation of the mountains, though before the production of the lavas of the maria. It is not certain that any larger vulcanoids than the craterlets were formed at a later stage in the evolution of the surface, for only very small structures of this group appear to have been produced in their cavities. It is also to be noted that these fault valleys are most developed in the regions where the larger vulcanoids are not very abundant, though it must be said that they are not lacking in the fields where these features are well developed.

CRATER VALLEYS.

In this group may be placed a number of curious though unnoted structures in which one or more craters have been in some way deformed so as to make a broad valley. The range of this action is great and the features to which it gives rise rather obscure. The changes of shape, arising from this deforming action, become very difficult to observe in all the vulcanoids at any distance from the central field of the lunar surface, for the actual elongation is confused with the apparent lengthening of the basins brought about by the obliquity of the view.

A fair sample of the crater-valley type is found in Hypatia, in the north-central part of the fourth quadrant. (See plate xvii.) Here the crater is so far deformed that its major axis, extending in a S. W.—N. E. direction, is about twice as long as its minor axis; moreover, this depression is vaguely continued as a valley for some distance beyond the walls of the crater. There are other like depressions in this neighborhood. Gutenberg in the same quadrant passes on the south into a broad, extensive, ill-defined valley. Palitzsch, near the western limb, is a yet more characteristic sample, having, according to Elger, whose reckonings appear always to be accurate, a length of sixty miles and a width of only twenty miles. Capella also exhibits this passage into a valley, and there are, according to my notes, six other like instances in this part of the field. It would be possible to collect not fewer than one hundred instances of the deformation of craters into elongate valleys, or their extension into broad vales, which are in some way evidently connected with them. As I am not undertaking a list of lunar features I cite only such as are needed for illustration of this point.

Besides these numerous cases, in which the craters have been so far deformed that they have had the character of valleys imposed upon them, there are about as numerous instances in which the greater vulcanoids have been but slightly deformed—so little changed, indeed, that the alteration has escaped observation. In these cases, which include a large part of the pits over twenty miles in diameter, the northern and southern walls show a distinct, though often slight, change of form, indicating an elongation in that axis. I find that in my rough notes of observations I have termed this the “spooning” of the crater in that meridional direction. This feature may be best noted in the vulcanoids of the central part of the lunar surface. It is distinct in Hipparchus and Albatagnius which approach being crater valleys. Alphonsus and Davy show the same feature, and it may be noted in perhaps one-third of the greater vulcanoids which are so placed as to make it possible to discern this feature in its slightest expression. (See plate xviii.) Without at present undertaking to discuss the condition which has brought about the evident warping of these greater vulcanoids on the meridional line, it may be said that its aspect suggests that they have been involved in certain movements, tending to produce considerable synclines. I have sought for, but failed to find, clear evidence of anticlinal folds corresponding to these troughs, yet the inquiry has not been carried far enough to insure that they do not exist.

CLEFTS AND RILLS.

The clefts and rills of the lunar surface are features which seem to me to belong in one group, though they may reasonably be separated from one another by certain differences. Among the clefts we may class the very numerous rifts which intersect the walls of the vulcanoids, particularly those of larger size, which often extend for considerable distances beyond the limits of the ramparts in which they occur. In the characteristic examples of this group, the features radiate from the crater, and are thus shown to be in some way connected with its conditions. They closely correspond in appearance with the Val del Bove on the eastern versant of *Ætna* and many like structures on other terrestrial volcanoes. In some cases they appear to be essentially akin to the terrestrial *Graben* or multiple fault depressions, as for instance the Alpine valley, in that the ground between two fractures has been lowered. They may, indeed, be regarded as a variety of that class of depressions determined by the strains originating in a vulcanoid. There are very many examples of the group, ranging from those which produce broad breaches in the crater walls to such as are shown on the flank of Tycho, where the two parallel light streaks, which appear to follow the path of faults, have the ground between them apparently somewhat lowered, in the manner of a rather gentle syncline, without any evident displacement.

Related to the several fault groups of depressions in that they are alike the results of fracturing of the crust are the remarkable features known as rills. In this group we have a single fracture with a space separating the walls, but no distinct indications of a floor between them. Perhaps the most characteristic example of the group is that known as the Sirsalis Rill, so named because the Sirsalis vulcanoid lies near to it. Elger's description of this structure — he evidently knows it well — is as follows : "Commencing at a minute crater on the north of it [= Sirsalis], it grazes the foot of the Glacis, then passing a pair of small overlapping craters (resembling Sirsalis and its companion in miniature), it runs through a very rugged country to a ring plain east of De Vico [De Vico *a*] which it traverses, and still following a southerly course, extends toward Byrgius, in the neighborhood of which it is apparently lost at a ridge, though Schmidt and Gandilot have traced it still farther in the same direction. It is at least three hundred miles in length and varies much in width and character, consisting in places of distinct crater rows." It has been suggested, according to Elger, who does not state by whom, that the rills are not in fact breaks but a series of small craters so near to one another that the effect on the eye is that of a continuous crevice. This view, according to my observations with the excellent fifteen-inch Mertz refractor of Harvard University, is not maintainable; while craterlets are often present along the line of the rill, their nature as fractures, when clearly seen, appears certain. The breaks are ragged, as if torn through a row of craterlets, not usually more than half a mile in diameter and often narrowing at one or both ends, so that their terminations cannot be determined; but that they are in their essence rents seems to me beyond doubt.

As regards the number of the rill fissures on the visible part of the moon we have no good evidence. They are probably to be numbered by thousands, and as the fainter seem to be the more plentiful, more effective instruments may reveal many thousands of them. As regards their distribution there are many noteworthy features. First we observe that those which have been mapped show an obvious tendency to be arranged in groups, and in these groups the individual breaks show here and there a tendency to intersect one another, though they are more often arranged in a parallel relation. The next point is that those which are in appearance sufficiently conspicuous to be mapped lie mostly in the central part of the visible surface between the parallels of 30° north and south of the moon's equator, and within 30° east and 50° west of the central meridian. They are thus remarkably rare in high latitudes and apparently seldom near the east and west margins of the visible part of the sphere. This apparent feature of distribution may be due to the oblique view of those marginal fields. It is also to be noted that all the important fractures are situated on or near the maria, or on the floors of the greater vulcanoids. Of about seventeen examples mapped by Elger, twelve intersect the shores of maria, and none of them lies altogether more than one hundred miles from those lines. The great southern upland has no mapped examples and the central parts of the larger maria are also without them. I am aware that the floors of the greater vulcanoids abound in rills all of small size. I am also aware of the fact that somewhere about a thousand of these rill fractures have already been noted and that their distribution is much wider than that indicated where only the more important are plotted, yet there is probably some significance in the grouping of these greater specimens of the class in or near the maria.

As to the time of the formation of the rills, it may confidently be said that they appear to be, with the possible exception of some of the craterlets, the most recent structural features of the moon. If narrower scrutiny than has yet been given to the matter shows that craterlets have developed in the cracks, then the later structures, of course, postdate the rills. If, however, as it seems to me quite possible, the rills have merely followed lines of incipient fracture, such as joint planes would afford, in some instances going around the pits instead of cutting through them, the rills may be the very last of the considerable lunar accidents. Such, indeed, they seem to me to be.

OROGENIC ACTION.—CAUSES OF DISLOCATIONS.

We turn now to consider the possible causes of the dislocations on the lunar surface which are represented by the various kinds of valleys, clefts, rills, and ridges which have been briefly described above. First, as to the valleys of the Alpine type, it may be said that they appear to correspond to the *Graben* type of terrestrial down-faultings, where there are two or more approximately parallel faults, the included area having been lowered. As to the origin of geological *Graben*, we have as yet no evidence of value and naturally no consensus of opinion.

It appears, however, most probable that they are due to the orogenic strains which enter into the complex of actions involved in mountain building, combined with some withdrawal of support ordinarily afforded by the materials of the under earth, as would be brought about by the migration of matter seeking volcanic vents. In the simpler and more applicable case of these down-faulted blocks of the crust, such as occasionally occur about terrestrial volcanoes, we may fairly assume that the sinking was due to the ejections which had made the under earth unable to support the load. That such deficiencies of support would have locally resulted from the lunar eruptions is highly probable. To this action then, with fair probability of its truth, we may for the present refer the valleys of the Alpine type. The minor cleft valleys radiating from the vulcanoids are evidently to be most reasonably explained on the same hypothesis. They are, indeed, so far as I can see, comparable to the Val del Bove of *Ætna*.

The rills, where we have relatively narrow crevices, which seem to extend indefinitely downward, with no distinct floors, may be regarded as due to the secular refrigeration of the superficial parts of the lunar sphere at a time so late that they found their way to no bodies of lava. They are evidently contraction cracks formed on a very extensive scale. Where they are limited, as is often the case with the smaller of them, to the lava field of a large vulcanoid, they may represent no more than the contraction of that body of lava. When, however, they are on the maria, an indefinitely extended sheet of the frozen material may find relief in the fracture. The predominance of the greater rills on and about the maria may be due to the fact that, whatever was the origin of those vast bodies of once igneously fluid rock, the consequence of their appearance on the moon's surface was, when they cooled, a great necessity for contraction. Not only were the lavas of the maria originally at a high temperature, but they must have communicated this heat to their shores and to the high country near them, with the result that new and extensive readjustments due to cooling would be required in those portions of the crust which had been thus affected. Thus the rills and the Alpine valleys appear to be distinctly diverse in origin, the former being due to loss of temperature of the crust in general, the latter to more complicated action.

As regards the rare instances of true displacement faults such as the Strait Wall, they appear to be due to ordinary faulting such as so abundantly occurs on the earth. They may in their first stage have been rills where there was some lack of support which caused the rocks on one side of the fracture to change their level with reference to those on the other. The only peculiar feature about them, from the point of view of geology, is that they are so rare and apparently so unconnected with compressive strains. If the surface of the earth as it has been affected by faulting, but without the effects of erosion, could be examined under the conditions in which we behold the moon, the fault dislocations would appear by the hundred thousand and with vertical displacements of miles in height. Nothing, indeed, so well illustrates the very great difference in the history of these two neighboring spheres, the moon and the

earth, as the diversity in the development of this group of structures which they exhibit.

The next question is as to the group of lunar reliefs to which the continuous ridges of the maria belong. It seems clear that, whatever be the detailed structure of these ridges, they indicate compressive actions of the terrestrial mountain-building type. The great linear extent of these compression ruptures shows that they are due to no local strains but are the result of stresses which pervaded wide fields of the maria. Their narrowness and lack of considerable height may be taken as evidence that they are the result not of deep stresses but of such as resided in the superficial parts of the crust, probably within the lava of which these fields are composed. As to their age they of course post-date the formation of the maria and apparently the larger vulcanoids — none, indeed, of great extent — which have developed on their plains. It is obviously important to determine the time of their uplifting in relation to that when the rills were formed. This I have been unable to do in a satisfactory manner. I have no notes of good examples in which either of these groups of structures are found in intersection; nor does my limited acquaintance with the literature of the subject supply such instances. It appears, however, likely from the fresh aspect of both groups of dislocations that they are not of very diverse age, but that the rills are the newer.

The problem presented to us is the existence in the same field of the rills which indicate the shrinkage of the material of which the maria are composed, together with that of the continuous ridges which even as clearly show that this portion of the moon's surface has been in a state of compression that compelled the rocks to buckle upwards and, if we have rightly interpreted the structures, brought about the formation of corresponding synclinal forms, the shallow troughs which exist on these plains. If it is proved, as seems likely to be the case, that the rills on the maria were formed after the continuous ridges, then we might conceive that the cooling of the interior of the moon brought about a compressive strain on the already cold outer crust, and that the limited diameter of those wrinkles was due to the fact that there was still some measure of viscosity in the lower part of the lavas of the maria which made it possible for the hard upper part of the sheet to act independently of the subjacent portions of the section, so that this upper part of the sheet as a whole received the compressive stress as a thrust from the shores against which it lay.

There is another way in which we may consider this problem of associated compression and shrinkage in the maria. It is to be noted that the most distinct examples of each action lie in fields remote from each other, the rills near the shores and the continuous ridges remote from them, the one in fields where the lava is presumably rather shallow, the others where it is deep. With this difference in conditions it might come about that contraction of the deeper parts of the marial sheet in the process of cooling would be sufficiently strong to fold the surface, while in the quickly-cooling shallow parts of the maria the only effect would be the formation of shrinkage cracks. It is to be noted that

something like these diversities of action is to be seen in terrestrial lava fields, though it is not certain that they are due to like causes. On any frozen expanse of lava we are apt to find at once ridges which cannot well be attributed to the *roping* of the solidified crust, along with cracks which are evidently due to superficial cooling. There are other possible explanations of these contracted dislocations of the maria, but I shall here take leave of the subject, for it is one on which I have not been able to form a satisfactory opinion.

ADJUSTMENTS OF THE SURFACE TO CONTRACTION.

Looking over the whole of the lunar structures, the geologist is naturally surprised to find so little in the way of adjustment of the crust of the sphere to a nucleus diminished by the loss of heat. On the earth he sees in the ample folds of the sea-basins and of the continents, as well as in very many folded mountain chains, what he takes to be evidence of a long-continued accommodation of an anciently cooled crust to a central mass which is ever losing heat. On the moon he finds what, in proportion to the size of that sphere, is surely not the hundredth part of such action. The folding of the marial ridges and furrows is trifling and is probably due to action set up in the lavas of those fields. The features of the crater valleys and the deformed vulcanoids appear to indicate some small measure of folding, but that may have been brought about by the loss of the moon's rotation through tidal action, and the consequent disappearance of an equatorial bulging due to that rotation. In any event it does not appear to represent any considerable readjustment of the crust to the interior. It is true that the moon has only one-fourth the earth's diameter, and the folding caused by shrinkage should only be in about that ratio to like action on the earth. Yet on the satellite the process of cooling is probably at an end, while in the case of the earth, reckoning from the time when the crust was formed, it cannot well be more than half accomplished. What then is the meaning of this startling diversity in the orogenic history of the two spheres?

In considering the difficult problem which has been just above suggested, the first question that comes before us is as to the value of the evidence concerning the antiquity of the general surface of the moon. We may ask whether the original sphere may not have cooled in its time to a low temperature, making in the process the necessary adjustments of its outer crust to the diminished interior, and whether after that was all done the mass may not have been added to by the in-falling of meteoric bodies, such as has been hypothesized to account for the maria. By such in-fallings a general outer coating of lava might have been formed, only a few-score miles in thickness, and to this may be due all the vulcanoid phenomena down to the time when the later coming of other such bodies formed the maria. On the basis of this conjecture we would not have to look for any extensive marks of readjustment of crust to central mass. It cannot be denied that the body of any celestial sphere is liable to be added to by in-falling masses, at least until it has cleared its path of them; and the fact that it has

been found necessary to account for the maria by such action lends a certain countenance to this view. Yet it seems to me safer to suppose that the moon has, as a whole, had essentially the same experience in space as our earth. As before noted, the earth, since its organic life, at least in the present series of forms, began to exist, has evidently had no such impacts of foreign bodies as formed the maria. It is, of course, among the possibilities that the earth has been subjected to invasions of large meteoric bodies, as the moon appears to have been, and that an ancient organic period was not only destroyed but the records of its existence entirely effaced. There is, however, no other known evidence on which to found such a conjecture, except what we find on the moon.

As regards the failure of the moon to exhibit the marks of adjustment of its crust, which first hardened, to an interior diminished by the loss of heat, it may at first appear that as the value of gravity is only about one-sixth what it is on the surface of the earth the stress which would impel the superficially cooled section to accommodate itself to the lessened bulk of the interior would be proportionately smaller, so that the outer shell might remain unsupported while the inner portion shrunk away from it. This view seems inadmissible, for the reason that in the case of the earth, as has been well reckoned, a shell less than a mile thick would, if unsupported, crush and fall in of its own weight, so that in the moon the crust would in a like manner crush at less than six miles of depth. It is thus evidently necessary to form some other hypothesis which will account for the lack of adjustment. I have essayed several of these, which I will now briefly set forth with the reasons why they seem adequate or otherwise.

At first it seemed possible that the aggregate wrinkling and crushing exhibited in the larger ridges and furrows, as well as in the host of small ridges which are seen with the greater telescopes, might have been sufficient to provide for the necessary contraction through the buckling and shoving of the crust. Yet on carefully examining selected areas of the crust where these features are best shown it does not seem possible that the accommodation or "take up" thus effected can amount to many miles of length. Moreover, the phenomena are not those which would be produced by the folding of a thick crust, as it sank upon a diminished nucleus, but only such as superficial strains would induce on a thin outer layer. It appeared conceivable that for some reason an accommodative folding might have taken place on the portion of the moon which is never seen, but this supposition is supported by no evidence whatever; all we see on the extreme margin of the visible surface leads to the conclusion that the hidden side is essentially like that we behold. Again, it appeared possible that the whole mass of the satellite remained in the boiling condition until it had been brought to a state where the cooling quickly induced rigidity throughout the sphere, all parts down to the center having attained somewhere near the same temperature. In this way we could explain the small amount of internal contraction which has apparently occurred since the most ancient features on the lunar surface, the larger vulcanoids, were formed.

Although in a general way we know the law of cooling bodies, we are not

yet certain as to their application to celestial spheres. It is, however, evident that the earth did not cool down to anything like an equal temperature throughout this sphere before a crust was formed. But in the lighter mass of the moon, when gravity tended less to promote interior solidity than it has probably done in the case of the earth, it is possible that boiling went on so long and effectively that when it ceased the whole was at a temperature not much above the heat of lava, so that the further cooling would be uniform, and the undiminished crust would not have in any considerable measure to conform to the diminished interior. There are difficulties with this hypothesis, as with the others which have been suggested. If we could suppose that the moon had been during its cooling stage deeply wrapped with a vaporous envelope, as was probably the case with our earth at the corresponding stage of its development, it would be easier to conceive a process of slow cooling which would permit the exterior part to attain about the same temperature as the central portion, so that they would solidify at the same time. But it is likely, for reasons given below, that through its whole history as a sphere it has lacked such a covering and has been exposed to the temperature of space. Yet for all these objections it appears probable that the hypothesis last above suggested is the most tenable, and that the greater part or possibly the whole mass of our satellite became solidified at nearly the same time and at nearly the same temperature.

To the geologist, the action of the lunar surface under the limited compressive stresses to which it appears to have been subjected is of especial interest, because it shows clearly that rocks, which certainly are not stratified, apparently may warp into rather sharp up-and-down folds. The student of the earth has come to recognize that, in a limited way, foldings may take place in crystalline rocks where there is no stratification on which the separate parts of the mass may slip, nor even schistose planes that may facilitate such action, but that such extensive and far-reaching movements as are apparently shown in the continuous ridges and furrows of the maria or in the crater valleys may occur, has not been appreciated. So, too, the lunar phenomena suggest to the geologist that the variations in the action of a sphere under conditions other than those now existing on this planet may be exceedingly great.

DIVERSITIES IN HUE ON THE LUNAR SURFACE.

Under this head I shall consider the differences in the amount of light and its color which the surface of the moon sends to us, taking first the permanent hue of its several parts and then the variations which occur in the various angles of illumination. Beginning with the observations of Sir John Herschel at the Cape of Good Hope, there have been a number of studies on the light of the moon. Herschel, by comparing the color of the moon with that of the face of Table Mountain, came to the conclusion that the hue of the satellite did not perceptibly differ from that of weathered sandstone; that it was rather a dark than a bright object. It is easy to make an equivalent observation when the old moon is seen

in the day-lit sky. The evidence, in a word, goes to show that the surface of the moon is, as a whole, quite as dark as the average lavas of the earth's surface when they are lit by a vertical sun.

Although the moon's surface, taken as a whole, must, according to Zöllner, be regarded as nearer black than white, there is little doubt that parts of it under certain conditions of illumination are as white as any portions of the earth's surface; as white as the chalk cliffs of Dover, probably; or as white as new-fallen snow would appear to an observer looking upon it from the moon. Although the range in the scale of tint between black and white is probably nearly as great on the moon as upon the earth, it is most noteworthy that there is no distinct trace of the other colors so abundantly exhibited in the terrestrial minerals and rocks. There are no greens or yellows, and it may be doubted if there is any trace of red. Schröter, whose scale of hues ranges from the black shadows to the whitest illuminated objects in the moon, selects ten gradations in that scale, but makes no provision for the prismatic colors; he evidently did not find them. I have a fair sense of color and have only to confirm this judgment. The geological importance of this point is considerable, for it clearly indicates uniformity in the lithological composition of the moon, or at least in the aspect of its rocks, which differs widely from that we have on the earth. It appears to me that the value of this uniformity in the color scale of our satellite may fairly be set forth as follows:

It is a reasonable supposition that the chemical elements of which the moon is composed are essentially like those of the earth, for such identities are indicated by the spectroscope in the sun and the remoter stars. It is, indeed, altogether likely that all the elements of the terrestrial rocks would be found in those upon the lunar surface. Is there any reason why they should not present us with a like range of color? It seems not improbable that this difference may be due to the lack of water or air on the satellite. In the terrestrial rocks almost all the prismatic colors are due to processes of oxidation which water brings about. Those which are thrown out by volcanoes commonly are without such hues, and only exhibit them when they have been subjected to oxidation on the surface. So subjected, they acquire, by that process acting on various substances, particularly on the iron they contain, a considerable variety of tint, including yellows, blues, and reds. Thus it seems to me the lack of color range on the moon confirms the supposition that there neither is nor has been water or free oxygen on its surface.

Within the range of tints recognizable on the moon we have room for something like as ample a scope of petrographic variation as may be supposed in the varied volcanic rocks of the earth if they were precluded of oxidation. According to Proctor, the darker parts of the lunar surface are of the tint which would be reflected by dark syenite. The whiter are probably as bright as the lightest of our volcanic rocks or the encrustations formed by solfataric action. In a word, there is no reason to suppose that the lunar volcanic rocks are any less varied than are those that come from the depths of the earth. As before noted, how-

ever, there is a striking difference in the behavior of lunar and terrestrial lavas ; the lunar, except in the maria, where the evidence of high and continued liquidity seems to me plain, appear to have become stiff almost as soon as they escaped from their craters, a fact which may be accounted for by their viscosity or perhaps by the swift cooling to which they were exposed on the airless sphere.

It is noteworthy that the most important differences of hue on the lunar surface are found in the maria and certain of the greater vulcanoids. The maria are without exception much darker than the higher ground. The lavas within the craters are likewise rather dark, but less conspicuously so ; but in the case of certain of the great rings near the eastern limb, notably Grimaldi, they are quite as somber hued as any of the seas. In the neighboring vulcanoid, Riccoli, there is a patch on the floor which is perhaps the darkest-colored of any part of the lunar surface. If these dark lavas were altogether peculiar to the maria, it would be easy to account for their color by the supposition that the material imported by the bolides, which I have supposed to have caused their formation, was of a different constitution from the materials of which the general surface of the moon is composed. The frequent incoming to the earth of considerable meteoric masses, composed in large part of iron, would warrant the hypothesis that the bolides which produced the lavas of the maria were largely made up of this metal. Even if not the tenth part of the lavas were of this foreign material, it might serve to effect the darkening of the resulting sheet. The occurrence of a like hue in lavas which lie on the central floors of distinct vulcanoids appears to negative this supposition.

Although for the reasons given above I cannot at present strongly maintain the hypothesis that the hue of the seas is due to the color-producing action of the bolides which produced them, it is perhaps hasty to dismiss the view without some consideration. It may be urged that the in-falling bodies were probably of varied sizes. Thus the mass or masses which I have supposed to have produced the isolated Mare Crisium were probably smaller than the mass or masses which brought about the formation of the great system of connected maria. It is fairly supposable that a fragment large enough to have given the lava of Grimaldi its peculiar hue fell within that vulcanoid, and that a small fragment likewise affected a part of the floor of Riccoli. So numerous and crowded are these great vulcanoids near the eastern limb of the moon that there is more than an even chance that two such falls would both lodge within some of them and not in the intervening country. As before noted, Plato and other less conspicuous vulcanoids situated near the maria have dark floors, but in these cases there is a fair chance that the external bodies of lava may, while fluid, have penetrated into their enclosures ; its evident exceeding fluidity would probably enable it to burrow its way in, though the more viscid lavas of the craters in no case appear to have been able to flow out through the cones.

Thus while the facts do not warrant us in concluding that the color of the lavas in the maria is due to mineral peculiarities imported by bolides which formed them, it strongly suggests that explanation. Progress towards an interpretation

of this point may possibly be made by a careful study of sundry parts of the lunar surface where outside of the vulcanoids there are features which may have to be accounted for on the hypothesis of meteoric falls—of masses great enough to produce some local melting but not sufficient to create distinct maria.

AREAS OF VARIABLE HUE.

Of all the diversities of hue observable in the lunar surface, those which vary from time to time are the most curious and the most baffling to the inquiry. The objects of this class may conveniently be divided into two groups, of which the first should include the irregular patches of light generally capping the flanks and ramparts of the vulcanoids and the cones they enclose, together with the bands of light color which in most instances radiate from vulcanoids or originate near them. It is characteristic of the objects in this group that they are invisible or nearly so when the sun is just rising on them, that they commonly are not noticeable, indeed, until the sun is high, and that they disappear when the illumination becomes again very oblique. The other group contains sundry examples where the fields are lighter colored in low than in high illumination, in this regard reversing the conditions of the first named series. There are no features on the moon's surface which have been the subject of more inquiry, though mostly of a discursive kind, than the first-named group of colored areas. The hypotheses and speculations concerning them have been numerous, but have led to no accepted judgment concerning them. It appears to me that the best way to approach the problem they afford is that indicated below.

First let us note that by far the greater area of the fields, which suddenly become very white as the lunar day advances, lies on the higher part of the vulcanoids, on their slopes and the summits of their enclosed cones. It is evident, therefore, that the whiteness is most likely due to some quality of the surface imparted by the vulcanoid action to which these regions have been exposed, a quality which is developed only under a rather high sun. Under these conditions the measure of whiteness is roughly proportional to the approach of the illumination to verticality, perhaps not absolutely so, for it is held by most observers that probably the brightest point on the moon's surface is the central peak of Aristarchus which lies about twenty-three degrees south of the equator. I am inclined, however, to believe that the apparent extreme brightness of this object is due to the contrast afforded by the dusky fields of the mare in which it lies, and that the fields of extremest lucency are all nearer the central part of the moon.

That the brightness of the very shiny parts of the moon, the patches and the rays alike, is not due to any change in their constitution brought about by the action of the sun during the monthly fourteen days of illumination, is proved by the fact that these features distinctly appear on the moon's surface when, in its newest stage, it is receiving a like vertical earth-light. I noted this fact many years ago, though I did not then perceive its full significance. I am now assured that my observations were trustworthy for the reason that negatives of the dark

part of the new moon taken in the earth-light clearly show these differences of hue; they are, indeed, plain enough to enable one to map the more brilliant rays of the Tycho system. We may therefore dismiss the idea that these features are evolved in the progress of one lunar day to be reconstructed in the next, and regard them as permanencies made visible when they may reflect to us the light which comes to them at a high angle.

As to the conditions which bring about the large amount of reflection under a high sun from those parts of the moon which appear very white when it is full, the experience of geologists suggests the following working hypothesis: First, that the bright area may be covered by an incrustation of a smooth nature such as ice or other material which forms a sheet. It cannot be frozen water, but various volcanic emanations may be conceived as forming like surfaces of glassy smoothness. Or we may suppose that some part of the material which came forth during eruptions was distributed as vapor to become crystallized on the surface. Such solfataric action is common enough in terrestrial volcanic districts; it would often be sufficient to cover extensive fields were it not for the erosive agents which scour the surface. It appears to me, however, that the suggestion of a smooth surface, such as an incrustation, is insufficient to meet the facts, for the reason that such coating could not be formed save of frozen water or of materials laid down by fluid water. With the low temperature of the moon's crust and the lack of an atmosphere, the idea of a quick crystallization of mineral substances from a vaporous state seems more consonant with the known facts.

It is possible that the sudden-coming brilliancy of the bright patches and streaks is due to the fact that these shining areas are covered with crystals which have their planes so arranged that they are prevaillingly parallel with the surface on which they lie, so that they reflect their light toward the earth only when the sun is high. This hypothesis has some support in the appearance of certain steep slopes, as those of the cones in the greater vulcanoids, where the face of the cliffs may be observed to shine brightly, when the sun's rays strike them, some time before the adjacent nearly horizontal surfaces gain the intensity of light which they afterwards acquire. A close study of this matter may afford data for a determination as to the nature of the action. So far I have been able to do no more than prove that the brilliancy is due mainly to the angle of illumination, by noting that it appears in earth-shine as well as sunshine, though the brilliance of the glow on the margins of the moon suggests that there is also an element of fluorescence or other action in the phenomenon.

Although light rays distinctly appear to be connected by series with the light patches, there are certain peculiarities about the former which demand explanation. Their exceeding length and their generally slight width make them very puzzling features. It has been frequently suggested that they are due to certain dust-like emanations from the craters which have been blown by the wind which bore them and lodged in crevices or in the lee of projecting points. The current of air which bore them is conceived as produced by the gaseous emanations from the crater. This view appears to me to be ill-founded, because the volume of

emitted gases required to produce a sufficient current even in a vacuum would have to be impossibly great to make such a wind at the distance of hundreds (in one instance 1700) of miles from the vent. Moreover, as W. H. Pickering has well shown, these bands do not, in all cases, point to any large crater, but in the case of the most remarkable group — that of Tycho — appear to originate not in the main vent but in certain small craterlets somewhat on one side of that opening. Moreover, as well observed by Pickering, these bands are not definitely continuous but made up of relatively short strips of bright-colored surface, each of which appears to originate in a craterlet and to fade as it extends to another in the same line, and that this arrangement probably continues to the end of each streak.

It is also to be noted that in some instances the bright rays of the moon show a tendency to be parallel, or approximately so, to one another, they being in some way causally related to rows of small vulcanoids. I have already called attention to the existence of such near approach to parallelisms in the case of the two striking examples in the Tycho system. There is another equally good example in the case of Messier, where the two streaks of this system, though slightly divergent, show an evident departure from the normal radial order. Many other instances could be cited to show that, while these bands of lighter color obviously tend to be placed in radial position with reference to a vulcanoid, they are here and there affected by some conditions which warp them from that position and force them to become parallel. This later condition is much more common in the numerous faint streaks which cannot be referred to any group radiating from a large vulcanoid. To my eye, this tendency to parallelism affects a considerable part of the rays which appear to be of the older origin.

It is obviously important to determine whether the rays of bright color on the lunar surface are due to superficial conditions alone, or whether they are the result of some action affecting the crust beneath the surface. On this point we have little information but that of a highly indicative kind. A glance at these features when they are best presented shows the observer that they extend across the irregularities of the broken country they traverse. In at least one instance, a ray emanating from the Tycho center crosses the lava plain in the bottom of another crater (Saussure) and apparently traverses the steep slopes of its wall, while another ray of this group seems to have been deflected from its normal course by the ramparts of this vulcanoid. I have personally verified the observations on the passage of this streak over the lava plain of Saussure and have, though imperfectly, traced its passage up the inner wall of the rampart. Other more skilled observers appear to have no doubt that it exists.

The facts just above noted make it evident that the light rays are not purely superficial features, but are in some way connected with the structure of the crust; from the point of view of the geologist, they have to be accounted for by supposing that they are the superficial expression of an action essentially solfataric in its nature, wherein vapors of some crystallizable substance, or substances, have passed through crevices of joint-like nature from the deeper parts

of the sphere, either to form a coating on the surface about a vulcanoid, or to stain a belt of rocks on either side of the rift, so that a strip of country, perhaps a mile or more in width, extending to the top of the crust, was impregnated with the material—the deposit being perhaps more extensively accumulated on the surface.

As already noted, there is reason to suspect that, besides the large reflecting power which the materials of the largest rays possess when the sun is high, these materials have a certain fluorescent property, which causes them in some measure to store up light which is given out after the sun has passed the angle at which they begin to shine. That such is the case is indicated by the fact that the rays are visible on the limb of the moon when the sun's light is considerably more oblique than it is when they become very bright. Such a property is known to exist in many species of minerals. A close study of fluorescence may, indeed, serve to indicate the nature of the substance which sends us the light from the very shiny parts of our satellite,—that of the diffused patches as well as that of the rays.

If we accept the hypothesis that the bright parts of the moon are due to the deposition of some highly reflecting and perhaps fluorescent materials, we may proceed to derive certain important corollaries from the proposition. It is at first sight evident, from the extent of the shining fields on and about the ramparts of the greater vulcanoids, that the egress of the light-reflecting materials was there by so many paths that the resulting stains were confluent, and that the rays marked its passage in fields where the channels were rarer, though related to the same centers of vulcanoid action. It is also evident that, while these passages for vapors from within cut a few of the crater floors of lava and occasionally extend on to the maria, they appear never to originate in those areas. Moreover, the great extent of these rays, some of them exceeding one thousand miles in length, and the way in which they radiate from their several centers, are problems of no small importance.

As to the common origin of the blotches of light material on and about the vulcanoids and the rays, the series of facts leaves no good reason for doubt. The blotches generally pass outwardly by gradations into rays, the most of which are short, perhaps less than a score attaining a length of one thousand miles or more. As to the deep-seated origin of these structures, it is fairly proved by the fact that they cross irregularities of the surface, as well as by the fact that they occur along lines of craterlets. There is some reason for believing that these, the smallest of the vulcanoids, were formed along the lines of the rills, presumably before those clefts were opened. Their existence along the light rays is of itself evidence that there is some incipient breakage along their courses. It is a reasonable supposition that vapors were forcing themselves out on those lines, and that sometimes they did so with explosive energy.

The existence of incipient crevices, such as jointings arranged in a general radial order with reference to the greater vulcanoid centers and extending for very great distances, is a feature which from the point of view of the geologist is surprising. While in the case of terrestrial volcanoes it is common to find traces

of a tendency of the crust to split radially so as to permit the entrance of dike-making lavas, these fractures are not known to extend for more than at most a score of miles from the vent to which they center; nor is there any observed tendency of the crust about volcanoes to become penetrated with joint-planes, having the position of those which the before-noted facts lead us to suppose exist on the moon. Before this evident lack of likeness between the two spheres is weighed, it is well to note that, while in the case of the earth all the extensive jointing of the rocks is apparent, brought about by strains due to mountain-building action, even when the beds have not been visibly dislocated it is evident that they have been jointed by the stresses; so that the fracture systems of the earth may be said to depend on an action which does not appear to have been to any considerable extent effective on the satellite.

Given a sphere in which there are no extensive strains due to the contraction of its central part and a consequent readjustment of the crust to the nucleus, which appears to be the case with the moon, it is not unlikely that a series of ruptures such as we find indicated by the rays would be formed. In such an orb, the last stage of its cooling would necessarily lead to the contraction of its outer part. Such was evidently the case in the moon, as is shown by the late formation of its valleys and rills. After this strain had become so slight that it was no longer competent to open distinct fissures, it might still have been sufficient to produce the incipient tension cracks required for the escape of vapors such as are needed to account for the light rays.

The most difficult point to explain is the radial distribution of most of the rays and the evident relation of nearly all of them to the greater vulcanoids or to craterlets situated on their flanks. This, it seems to me, may be accounted for in the way set forth below. Let us suppose that in the last stage of the expulsion of the vapors of the lunar sphere, when the formation of vulcanoids of more than about a mile in diameter was no longer possible, the crust was by its cooling brought into a state of contractile tension so that it had a tendency to break. We may then fairly assume that this tendency would be greatest in the ancient uplands, and least in the relatively new maria and in the lava floors of the vulcanoids. These fractures, or lines of weakness, for they do not seem to have been defined openings of measurable extent, would naturally—indeed necessarily—be made as radii to the large pits of the crust which plentifully occur in the higher parts of the moon. We may have visible evidence of their necessity by watching how shrinking clay splits in relation to holes made in its surface. Beginning in the field about a vulcanoid, a fissure would extend radially for a certain distance, far enough to satisfy the strain which led to its formation; if it afterwards happened, as W. H. Pickering has noted, that a body of vapor broke its way to the surface, forming a craterlet at the point remotest from its origin, then the rupture might be continued on the same line, attended by the formation of another craterlet, until the strain was again satisfied; and this process might be again and again repeated until the greatest observed extension of the ray was brought about.

Supposing rays be formed by successive developments and reliefs of cooling strains in the manner just above suggested, we find a reason for the peculiar shape of these features which Pickering has well observed. He finds that the longest of them are not strictly continuous, but that originating at a craterlet they extend for a variable distance, widening and becoming dimmer the farther from the place of origin; then at another craterlet they again begin narrow and bright, to fade and widen once more as they become remote from the opening. According to my view, the first craterlet started the fracture; near it the fissure was most passable to the vapors in question, so there the streak is narrow and bright; farther away the fissure was less open, so that the effusion had to force its way through the country rock, and so made a wider and fainter deposit of the shining material. The second craterlet developed an extension of the fracture with the same features as the first, and so on to the end of the colored belt. According to this hypothesis, we need not suppose any such mighty accident as required by the view that the ray system of Tycho was formed at once; it may have been geologic ages in developing; the end of a great ray may, indeed, have been formed very long after its beginning.

To those who are unfamiliar with the movements of homogeneous materials in the process of shrinking, it may seem unlikely that the outer part of the moon in cooling equally would tend to fracture in systems of joints arranged in radial order. A little observation on drying clay will show that slight accidents determine in very uniform materials the direction of the fractures due to strains which lead to cracking. When the pull is equal in every direction and when there are depressions on the surface, the tendency is to make these pits the center of radiating fractures. In this way, by cracks running from many centers, the general tendency to rupture is satisfied. On the visible surface of the moon there are near two-score recognizable ray systems, differing much in the distinctness and extent of their light streaks. As these systems are widely scattered, they are perhaps sufficient to have satisfied all the shrinkage strains of the crust during the time when there were still vapors seeking to pass to the surface.

As to the age when the rays were formed, it appears evident that they were not all made at or near the same time. Those of certain systems appear to cut those of other systems. Thus, according to Nicoll as quoted by R. A. Proctor, the rays of Copernicus, Aristarchus, and Kepler cut one another in an order indicating that they were formed in the succession in which they are here named. It also appears possible that the greater part of the ray systems were formed before the maria were produced, for relatively but few extend over their fields, though it may be that their general failure to traverse these bodies of lava and also those contained in the craters of the greater vulcanoids is due to some condition of the material which diminishes the shrinkage tension existing on other and older parts of the moon. That the light rays antedate certain of the rills, and perhaps all of them, is shown by the fact that they are cut by these fissures. It should, however, be noted that Trouvelot, who had a very keen eye, noted that certain of these open crevices are continued beyond

the point where they are distinctly gaping by slender streaks of shining material, which appear, from his description, to be like the rays. It may be that vapors ascending through open clefts would not be sufficiently concentrated to produce a distinct band of color on their margins, while such would be the case when they mounted through an incipient fissure, as I have supposed to be the fact with the radiating streaks.

In considering the succession of the ray systems, it should be noted that, beside those which are definitely to be observed, there are evidently others in part destroyed by later developed groups. In the best conditions of seeing, these faintly indicated and evidently ancient sets of rays may be seen in all stages of obsolescence, down to the state where they are conjectured rather than observed. This, together with the phenomena of interference of one set of rays with another, suggests that the process of their formation may have been continued for a very considerable time, though the development of the larger bands appears to have been brought about only in the later state of the surface, yet, as remarked above, not to the very latest time of activity.

It is evident that the distribution of the several ray systems is not equal on all parts of the moon. Thus the first quadrant has thirteen recognized groups, while the fourth, just south of it, has but six. The second quadrant has eleven and the third eight. Thus the eastern and western halves of the surface together have the same number, but the northern hemisphere has twenty-four and the southern fourteen systems of rays. Moreover, the greater number of the groups are situated on that half of the visible surface wherein lie by far the greater part of the maria, and on the surfaces of those lava fields none of the distinct centers of radiation are found. This predominance of the rays in the regions of high country near the maria may possibly be due to the extensive heating of the northern half of the moon by the lavas which formed them, and to the consequent refrigeration which would tend to develop crevices and thus lead to the production of rays.¹

THE PRESERVATION OF THE RAY SYSTEMS.

The facts already set forth clearly show that the ray systems are fairly to be regarded as features which have been somewhat gradually developed, and are, as a whole, of ancient origin. It is, indeed, difficult to escape the conclusion that they are, when measured in terms of geological ages, all exceedingly old. They

¹ In the earlier years of my work on the moon, the results of which are here set forth, I noted certain very faint rays which appeared to point to centers of radiation on the unseen side of the moon. I have been unable to find the note-book in which these observations were recorded, and my eyes, damaged by studies on that brilliant surface, no longer enable me to trace them. According to my memory, these streaks, as are all others near the limb, were faintly though distinctly traceable, in the course of some years' observation, to the number of about a score, indicating about half a dozen such invisible centers. The impression left upon my mind is that the very best vision and opportunity might prove the existence of at least a dozen of these groups where the rays converged to a point in the invisible field. The studies needed to determine this matter will be difficult to make, for the reason that all these rays are faint in the regions near the limb.

must be judged to be the result of actions essentially like those termed by geologists solfataric, *i. e.*, due to the escape of vapors from a heated sphere, which have colored or coated the surface on which they lie. The considerations which lead us to believe that this internal heat of the moon vanished long before the earth's surface became frozen over are very strong. Accepting the view that the light streaks on the moon are of exceeding antiquity, the question arises as to why they have not been obscured by the fall of meteoric matter upon the surface of that sphere. It is a well-known fact that some hundred thousand, if not some million, meteoric bodies come upon the earth each day. It is true that nearly all of these bodies are so small that they are burned by their friction in the atmosphere, and are added to our planet only as dust that descends in the rain or as gases contributed to the air; but on the lunar surface, which, apparently, should receive, per unit of area, quite as many of these fragments as the earth, there is not, and probably never has been, an atmosphere sufficient to decompose these wanderers so that they should have attained its surface unchanged.

Estimating the average diameter of the meteorites that come into our atmosphere at only a millimeter, which, in view of the light they afford, is probably too small, it is evident that even in a hundred thousand years they would, if gathered on the surface of an airless sphere, be sufficient to form a coating such as would give a common hue to all its features, and in a geologically brief time the mass would attain a considerable depth. Yet we have evidence in the ample gradations of light reflected from the moon that very ancient features of color are as undimmed by foreign matter as newly fallen snow. In other words, we seem to be compelled to the opinion, either that there has been no such in-falling of meteoric matter on the moon as has of late taken place on the earth, or that the whole scheme of coloring on the lunar surface has been formed within a few thousand years. That the latter of these suggestions is not true is clearly indicated by sundry considerations. It is, in the first place, to be noted that there is much to show the absence of any accumulation of fragmental matter since the oldest of the lunar features were formed. A meteoric rain such as comes upon the earth for even a million years would have masked a host of objects which, though presumably very old, are still manifestly unaffected by any such sheet of dust as would have enwrapped the lunar sphere. Thus the exemption from meteoric contributions appears to have been from a very remote time. Moreover, as before noted, the rays of different systems are of diverse ages, yet there is no indication that the newer are very much brighter than the older.

As for the other possible explanation, *i. e.*, that the moon has not long received meteoric material in the manner in which it now comes upon the earth, there appear to be at first sight but two diverse ways that may have brought about this condition. In the first place, the earth and moon alike may, until very recent times, have been exempt from such contributions. In the second place, it may be that the matter which falls on the earth is in whole or in large part limited to materials which have been ejected from the planet by volcanic action. The first of these suppositions must be regarded as possible, though

rather improbable. While there is no recorded instance of any meteorite having been found in ancient geological deposits or elsewhere, save upon the surface of the earth, the rarity of falls sufficiently large to escape burning in the air makes it unlikely that they would be discovered in a fossil state, or, if found, that they would be recognized as of meteoric origin, so that this consideration has not much weight. On the other hand, if, as seems likely, the supply of carbonic dioxide in the air depends in any considerable measure on the burning in it of carbon meteorites, the presence of this material in something like its existing quantity, certainly neither much greater nor much less, from the early geologic ages, is evidence that meteoric falls, at least those containing carbon and of the smaller size, have during that time been at about the same rate as at present. So far as I can discern the astronomic conditions, it seems very improbable that the earth should now be encountering a multitude of small bodies such as had not come to it until within a few thousand years.

The suggestion that the meteoric matter which comes upon the earth may have been expelled from it, though possible, does not seem to me to afford a way of escape from our difficulty. It appears not improbable that volcanic action may be sufficiently violent to impel bodies beyond the control of the earth's attraction. The shining clouds which were observed for some years after the eruption of Krakatoa in 1883, and which went upward until they appeared to escape from the atmosphere, may be instances of this nature. Moreover, large fragments, which have been hurled forth by great eruptions, have been known to fall at such distances from the point of ejection as to make it likely that they had an initial velocity near to that which would be necessary to send them into space and to make them independent of the earth; but, if I conceive the problem rightly, such ejections would either in very rare instances fall upon the moon or proceed to move in elliptical orbits, one focus of which would be the sun and the other the place in space where the earth was at the time they separated from it. It is eminently probable that in time these fragments would be apt to return to the earth, but it seems evident that they would be about as likely to fall upon the moon.

If we had any evidence that the moon had been surrounded with a fairly dense atmosphere down to the present geological period, we might account for the absence of meteoric dust upon its surface by the supposition that the smaller bodies had been burned in its air as they are in that of the earth, but all the facts at hand, which will be discussed below, are distinctly against this supposition and in favor of the view that the low gravitative value of the sphere allows the gases which do not become solid at the low temperature which prevails there by kinetic action to move off into space; so that the development of an aërial envelope has been impossible.

I have but recently come upon the difficulties we have to face in this problem concerning the preservation of the surface of the moon from meteoric matter, and am therefore not well prepared to discuss them. As they now appear to me, they may be met by any one of the following described hypotheses: (*a*) That the

meteors which burn in our atmosphere are so minute that falling at their present rate they would not have formed a dust coating had they accumulated on the surface of the earth for all recorded geologic time, and that the larger masses, such as now attain the ground, have been so rare that they would not of themselves form a coating. (*b*) That the earth and moon, as members of the solar system, and sharing in its motion through space, are now in a field where meteors are prevalent in a measure that was not the case in earlier ages, so that the moon's surface, though very ancient, has not been long enough exposed to such in-fallings to have acquired a coating of them. (*c*) That we have entirely misjudged the antiquity of the moon, and that our reckonings, based on the law of cooling bodies and on the supposition that the planet and satellite were differentiated from a common nebulous mass, are altogether erroneous. Of these suppositions, that designated as *b* seems the least objectionable, though as before noted it presents sundry difficulties.

In considering the effects arising from the fall of bodies from the celestial spaces upon the surface of the moon, we should take into account the fact that in the present airless state of that sphere they would come upon its surface at a very much greater velocity than when they break through the atmosphere of the earth. Owing to the resistance of the aerial envelope of our planet, it is doubtful if even the heavier meteorites have at the moment when they touch the ground an average velocity above a thousand feet a second. Computations which assign them a higher speed at the moment of contact are made doubtful by the slight amount of their penetration into the soil. On the other hand, the meteors which fall upon the moon must be moving at the average rate of at least twenty miles a second, or about one hundred times as rapidly. Where they impinge on the advancing side of the moon the rate would be much greater than where they come upon it from the other or following side.

The effect due to the great speed at which meteorites would usually fall upon the moon cannot be accurately determined; certain of them can, however, within limits, fairly be conjectured. It is in the first place evident that so far as the penetration of mass into the crust was concerned it should be very much greater than on the earth. On the assumption which has been above made as to the comparative velocities, it should often be about a hundred-fold as great as on the earth. It is, however, to be noted that the increase in velocity would lead to a proportionate increase in the evolution of heat due to the friction of the penetrating mass in its passage through the materials it encountered and to the shearing of its particles on one another. Assuming the rocks of the lunar surface to have the average resistance of pumice, it seems evident that any meteoric body such as we know to fall upon the earth would not only penetrate to a great depth, but would probably be volatilized by the very high temperature it would attain. We see that a certain amount of this action occurs even in the relatively slight resistance which a meteorite encounters in passing through the air. With a resistance sufficient to produce an effective shearing movement in a meteor, such as would be encountered on entering matter of the solidity of

pumice, we may fairly assume that the mass would, in effect, explode, the gaseous products being cast forth from the opening it made. The temperature produced by the arrest of the movement at a rate of twenty miles a second would vaporize the mass.

It is also evident that on a surface in the present airless condition of the moon all meteoric bodies, even the smallest, would come in contact with its rocks. As is well known, by far the greater part of the meteors which enter upon the earth are burnt in the upper air, and pass into the gaseous state or fall to the ground gently in a purely divided condition. Such bodies, however minute, would enter the moon's crust at the same speed as the larger masses. Owing, however, to their smaller bulk, they would be more quickly dissipated by the engendered heat. If this view as to the volatilization of meteors by the conversion of the energy due to their motion into heat is true, then the effect of any such meteoric fall as takes place on the earth in, say, a hundred thousand years would be to produce a mass of gaseous and dust-like material which should be somewhat widely scattered from the point of impact of each meteorite, and this for the reason that the gases evolved by the heat would enter into what is essentially a vacuum and would be radially distributed at high speed, quickly to fall upon the ground as their temperature lowered. The effect of such action would evidently be to give the lunar surface a uniform color, determined by the average light-reflecting quality of the resulting deposits of condensed vapors and dust. If, on the other hand, we assume that the material bodies penetrated into the moon without being volatilized, then the result of the first falls would be merely to pit the surface, the color being destroyed for the area of each pit, but when the successively formed pits became so numerous that they occupied the whole of the original area the color would disappear. The effect can be better realized by firing successive charges of shot at a white plank. As the number of penetrations increases to a point where the total amount of lead is equal to a continuous layer, the original material becomes, in effect, covered with the metal and takes its hue.

The considerations just above set forth make it appear eminently probable that in either of the conditions in which we can imagine meteoric matter to have come upon the moon, that in which it was vaporized or that in which it remained solid, a period in a geological sense brief would suffice to obliterate the diversities of hue such as we find in the dark maria, the light streaks and patches, and in its general surface. Thus the best interpretation which we can give to the facts clearly leads to the supposition that our satellite has not in recent ages shared with us in anything approaching like measure the falls of detached masses from the celestial spaces.

On my first consideration of this matter I was inclined to believe that the curiously pitted or honeycombed character of the lunar surface, which becomes more and more clear as the magnifying power of the telescope is increased or the seeing more favorable, might possibly be explained by the supposition that the cavities were produced by the in-fall of meteorites of considerable size.

Many of these pits which may be seen in advantageous conditions are not more than four or five hundred feet in diameter, and seem to have the general shape that would probably be given them by the sudden effectively explosive development of gases which we have seen reason to suppose would be brought about by the penetration of large materials into the crust. Yet as there is no indication of a peculiar coloration of the fields about those pits, such as would be produced by the precipitation of the condensed vapors, this interpretation must be regarded as unverified, though it remains possible. Taking into account the fact that the best instances of the honeycomb type of pits occur in tolerably clear relation with the larger vulcanoids, it seems most likely that this group of depressions owes its origin to the escape of indigenous vapors from the depths of the lunar sphere.

The question as to the possibility of any of the distinct vulcanoids owing their formation to the impact of large meteoric bodies is elsewhere discussed. It is therefore only necessary here to note that, as the size of the in-falling body increased, the heat evolved would be augmented, so that a mass a few hundred feet in diameter would inevitably bring about such a general melting of the crust where it fell that a cavity would not be formed, but in its place a level blotch caused by the frozen lava, substantially what we find in the maria. There are, indeed, sundry patches on the lunar surface which may have this origin, but so far I have not been able to find any criteria sufficient to warrant this interpretation of them.

The eminent probability that the fall of meteoric bodies on the lunar surface should lead to the temporary production of a high temperature, suggests that it might be possible by photographic if not by eye observations to detect these collisions, if they occur with anything like the frequency per unit of area with which they come to the earth. It is possible, though not likely, that these observations might be practicable on the illuminated surface of the satellite, for the reason, elsewhere noted, that as a whole it is more nearly black than white, and even a small meteor would at its contact with the surface be likely to produce a flash sufficiently brilliant to make an impression on a sensitive plate. On the dark part of the sphere or even in a lunar eclipse it would probably be easier to make the photographic observation. It is, however, to be noted that, as meteors enter the crust at high speed and there is no atmosphere to give the train of light such as is exhibited by those of small bulk which fall upon the earth, the flash might be of very brief duration—so brief, indeed, that it might escape the eye and the camera alike.

It may well be observed that, supposing the moon's surface to have received extensive contributions of meteoric matter, we might thereby possibly explain the apparent degradation of some of its older features. On the supposition that the in-falling bodies penetrated deeply and were converted into the gaseous state so that they produced explosions, we would have an agency competent to break down reliefs in the manner in which many of the ancient features seem to have been mined. Yet when we note the exceeding sharpness of outline retained by

many structures, such as the cracks, displaced faults, and the smaller vulcanoids, all of which must, on any apparently valid supposition as to the moon's history, be many million years old, we are led to believe this view inadmissible.

In this connection attention is due also to the fact that on the unilluminated part of the moon various observers have, from time to time, noted patches of light which they have believed to indicate volcanoes in activity. I have elsewhere suggested (see p. 53) that these objects may have been highly reflecting parts of the lunar surface illuminated by the earth-shine. It is barely possible, however, that in some instances they can be explained on the supposition that considerable meteorites had recently fallen at the point where the light was noted. So also it seems possible that the vapors which W. H. Pickering and others have thought they observed floating in the manner of clouds on the illuminated area may be in this way accounted for: a large meteorite penetrating deeply into the crust might give rise to vapors which would continue to pour forth for months or years after it fell. The difficulty with this hypothesis is to see how vapors could *float* and remain in the form of a cloud in the conditions of essential vacuum which exist on the surface of the moon. Granting the possibility of such action, which in the present state of our knowledge seems improbable, I should much prefer to account for these vapors by meteoric action than to seek their explanation in true volcanic activity.

EROSIVE ACTION ON THE LUNAR SURFACE.

Those who are familiar with the lunar surface as it is exhibited by a good telescope, cannot help acquiring the impression that there is some agent which has operated on the moon in a way partly to break down the more ancient topographical features. There is an evident difference of aspect between the walls of the older vulcanoids and those of newer formation. Apart from the distortions of the ancient structures and the breaches of their ramparts, which may be fairly accounted for in other ways, there are a rounding of their steeps and a general appearance of having been smoothed over by some erosive agency which are evident in proportion to their antiquity. It is indeed a general fact which has been remarked by many observers, that the newer vulcanoids have an appearance of freshness that is never found in the earliest formed. It is therefore important to discover, if we may, what are the actions by which such changes may be brought about.

On the surface of the earth there are four agents of erosion, all of which, coöperating with gravitation, serve to bring about more or less considerable changes. These are chemical alterations, which loosen the structure of rocks; the direct action of the wind, which removes their lighter particles when they are not protected by vegetation; the action of moving water by waves, streams, and glaciers; and last, and by far the least, the expansion and contraction of materials arising from changes of temperature. The essential effect of all these agents is to deliver fragments of rocks to the more or less free action of gravitation. They

all act to send divided matter from higher to lower positions. Except the first and the last, they incidentally provide means of carriage by which the fragments may be conveyed to indefinite distances; chemical decay and the increase and decrease in bulk due to variable heat acting by themselves do no more than give the separated bits a chance to move down declivities of considerable slope.

It is evident that all the chemical change which occurs on the earth depends on the presence of an atmosphere containing water. This condition apparently, I think surely, does not now exist on the moon and probably, as I shall hereafter give reasons for believing, has never existed there; for this reason we may set aside this agent as a possible source of changes of lunar topography. From the same facts we are led to dismiss the possibility of wind action. The only suggestion of such work has been to explain the radial light bands on the supposition that the vapors emanating from the craters by their rapid diffusion caused winds that blew the material which forms the rays to the places it occupies. We have seen that this hypothesis does not account for the facts, and that they are apparently explained by a much simpler view of the matter.

The idea of water having been at some time in the past an agent of erosion on the moon is so persistently recurring that it is worth while to set forth, in some detail, the results of my studies of the matter. I gave over fifty nights of observing with the Harvard College Mertz refractor, which has an excellent glass, to the question of a possible aqueous history of the several divisions of the lunar field. The result was to convince me that no part of that surface, new or old, has ever been shaped by aqueous erosion, and this for the following reasons: Aqueous erosion by river action has one characteristic effect: it, in all cases, except where *pot holes* are formed by waterfalls, brings about a system of continuous down-grades from the heights to the lower ground. My inspection of the moon's surface, which, from this point of view, was carefully made, satisfied me that the streams had never done their inevitable work on that sphere; for I was unable to find a single case of a depression of considerable length having a continuous down-grade, or an instance where it might be supposed that a valley, so shaped, had been subsequently deformed. None of the rills which have been supposed to be stream-like in shape are in the least so to an eye trained in terrestrial topography. They have no gathering grounds, no trace of that digitated system of valleys which must have been formed if they had been water channels; moreover, they have a perverse habit of branching the wrong way, when they branch at all. Most selenographers have quite abandoned the idea that any of the features of the moon are due to water action, though some of them adhere to the notion that there may be some slight trace of water vapor in a supposed remnant of an atmosphere lying very near the surface.

The same arguments that exclude river action on the moon will *a fortiori* exclude glaciers. Both these forms of water require extensive evaporation areas and the machinery of an atmosphere for their maintenance. Now that it is generally accepted that the maria are not and never could have been seas, but are

evidently lava fields, save in origin, essentially like those within the larger vulcanoids, there is evidently no place where waters in a sufficient extent to supply rainfall could have been stored. In this connection it is worth while to note that on the earth, with two-thirds of the surface covered with water and with air currents to carry moisture, large areas are practically unsupplied with water. Without the oceans it is evident that rainfall would cease. The little which is evaporated from the land would readily be stored in the air, perhaps to fall as dew. So that lunar rains or snows would be impossible without a system of great reservoirs, such as we cannot believe to have existed in any recorded stage of the moon's history.

There remains but one agent of erosion which can have acted on the moon, *i. e.*, that arising from the expansion and contraction of rocks in the changes of temperature which there occur. On the surface of the earth, where the average annual variation of heat on rock faces does not exceed about twenty degrees Centigrade, and where the maximum variation is probably not more than fifty degrees Centigrade, the effect of the variations is evident. Excluding, as far as we may, the concomitant influence of freezing water, we find that the expansion of rock is competent to produce cracks and to urge detached masses of rock down the slope on which they lie. Thus the concentric structure which develops near the surface in certain crystalline rocks, as granite, is due to the expansion of summer heat, which often causes the slabs of stone sensibly to lift from their beds. On the surface of the moon, according to Langley's observations, the range of temperature is probably not less than two hundred degrees Centigrade, so that the measure of expansion and contraction should be fourfold what it is on the earth. Moreover, these alterations of temperature are repeated each month. During the fourteen days' insolation, the heat should effectively penetrate for some meters of depth. Though it is doubtful if the melting point of water is ever attained, the range is as effective in promoting motion as if it occurred above that point.

The effect of the great alterations of temperature in the superficial materials of the moon is probably twofold; in the firmly imbedded rocks it must institute successive strains and releases which should be competent to produce certain effects not recognizable on this planet. Supposing that at a depth of three meters the range of temperature was one hundred degrees Centigrade, the horizontal thrust induced, if the rock had the modulus of expansion of ordinary granite, would be sufficient to produce in a sheet fifty miles in diameter an extension of some hundred feet. From what we see of like action on the surface of the earth, we are justified in supposing that sheets of great width would on the declivities of the moon become separated from the subjacent materials and move over them in the alternations of volume. So, too, we may suppose an interminable series of varying adjustments which would, from time to time, bring about alterations in the direction and energy of the thrusts which were thus induced. These changes may have continued throughout a period as long as recorded geologic time, and they may be in process of development to-day.

Another consequence of the variation in bulk of rocks in the changes of

temperature of the lunar day is that fragments lying on steep slopes would slowly move down the declivities. Such detached blocks would, where they expanded and in proportion to the efficiency of the gravitative impulse, press more vigorously against the obstructions below them than on those above; they would thus gain a chance to creep farther downward when they were again expanded. This process would somewhat resemble what takes place where a talus slope is knit together by a sheet of snow ice, when we may note a creeping of the united mass due to the changes of temperature it undergoes. I have frequently observed taluses where this process has extruded the deposit, as in the manner of a glacier, far beyond the limits to which masses falling from the cliffs whence they came ever attain. This process is yet more nearly alike to that which takes place in the lead covering of roofs, where the metal has been observed slowly to work down the slopes on which it lies in a movement evidently due to alternating expansions and contractions.

At first sight it may seem that the relatively small value of gravity on the surface of the moon would limit the movement of fragments due to expansion and contraction so that the angle of repose in the taluses they formed would be very high; but on consideration it appears to me that this angle may be even lower than in terrestrial conditions, for the lessened weight of a given volume of rock would greatly diminish the amount of the friction, and the value of the adhesions which tended to resist its movements would, owing to the absence of water and chemical decay, be so slight that I see no reason why, given time enough, the talus material should not be brought to a nearly level attitude. The coefficient of expansion is likely to be the same in lunar materials as in the igneous rocks on the earth, while the resistances to such motion, both in the horizontal flakes of great width and in the detritus on steep slopes, would be but one-sixth what it is in our sphere. Therefore we may reckon on this agent of change being of greater value on the satellite than on its planet, and find in it an explanation of the worn character of the ancient topography which is not evident in the newer formations. As we shall see below, this view as to the expansion of rocks may be of value in accounting for certain possibly recurrent as well as accidental recent changes in the shape of structural features on the lunar surface which certain observations appear to indicate.

There is one rather obscure group of features on the lunar surface which may be immediately due to the expansion of the superficial materials of the crust. These are the numerous slight ridges which intersect the ground and which are fairly visible near the terminator; these ridges seem to me to be very low, perhaps not more than a score or two feet in height. They are generally rather straight-lined and so placed that they reticulate the level fields in which they lie, dividing them into irregular blocks of very variable area, rarely more than fifty miles across. I have seen what seems the miniature equivalent of this structure, where a sheet of ice on a lakelet has been affected by great changes of temperature, all below the freezing point of water, and has been broken by the expanding process into blocks which, at their contacts, are crushed up into rude little anticlinals, formed

of ruptured bits of ice. These ridges of ice-fields retain their shape during the contractions of the sheet in which they lie, as the blocks of stone in the moon may do when they have found an adjustment. These lunar features deserve careful study, though the conditions make an inquiry into their nature very difficult. I have rarely been able to discern them clearly, and then for only a brief time.

ON THE POSSIBILITIES OF A LUNAR ATMOSPHERE.

The apparent arguments in favor of the existence of an atmosphere on the moon, if not now, then in some former age of that sphere, are so strong that selenologists are hardly to be undeceived by the evident facts that militate against this view. These facts are, in brief, as before noted, as follows: There is no trace of clouds on the moon; there is no difference in the clearness of the seeing as between the lowest ground and that which is about six miles higher; there is not the faintest sign of diffusion of light on the line between day and night; the effect is that which would take place in what we term a vacuum, but not in the most attenuated part of the atmosphere that lies about our earth. Moreover, the course of the light of a star which goes behind the moon's disc shows clearly that at a mile above the lowest part of the lunar surface the air, if such there be, has less than the thousandth part of the density of that belonging to the earth at the same height. So, if there be any atmosphere at all on the moon, it is in volume, at least, quite unlike that of our planet, and very like the nearest approach to a vacuum which we can in any way produce. There is, indeed, no other valid reason for supposing that any kind of gas or vapor exists about the moon save that it is deemed necessary to have it in order to explain certain changes of color which are deemed to be evidences of organic life. The value of this evidence I shall consider below.

There is reason to believe that the moon has had upon its surface ample material derived from the vulcanoids out of which to form an atmosphere. Regarding the lunar sphere as the offspring of the terrestrial, we may fairly suppose that it received its share of the lighter elements of the original common mass when the separation took place. If we regard the atmosphere of a celestial body as the gaseous remnant remaining on its surface after the more readily solidified elements have consolidated, then the moon should have had an original covering of this kind on a scale proportionate to its total mass, *i. e.*, it should have had an atmosphere equivalent in weight to some inches of mercury. Throughout its recorded history there has evidently been a great efflux of vaporous or gaseous materials from below the crust, in total amount probably enough to have provided an envelope in quantity as great as now lies upon the surface of this planet, yet no trace of it remains. We cannot believe that the materials which should have formed as air on the moon have been largely taken into the crust by chemical action, as is the case on this planet, for there are good reasons to suppose that there is no such action going on there, nor can we accept the suggestion that the air-making gases have been frozen, for while the temperature is at times very low

it is for a part of each month probably high enough to permit all the elements which form our atmosphere to return to the vaporous or gaseous state. What, then, is the condition which makes the moon an airless realm?

It appears to me that there is a possible explanation of the lack of an atmosphere on the moon, one that has not been subjected to the inquiry which it deserves; this is, in brief, that the kinetic movement of gases causes their atoms to fly away from the surface into space as rapidly as they are parted from the solid sphere. I understand that this hypothesis has been adduced to account for the separation of certain gases from our atmosphere which are held in that of the sun; an extension of the same view may serve to explain the failure of the moon to retain the gaseous materials which have evidently come to its surface but which the gravitative attraction has not been sufficient to retain against the diffusive effect of the kinetic movement.

THE EXISTING CONDITION OF THE MOON.

The idea that the moon should be the seat of some activities such as operate on the earth is most natural. Again and again observers with much imagination and with poor telescopes have seen what they took to be evidence of volcanic action or of organic life on the surface. With the advance of selenography, these views as to changes on the moon have been by better observations limited to two groups of events. First, changes of form of certain craters, either those of a cataclysmic and permanent nature, such as that which appears to have occurred in the shape of the vulcanoid Linné, and the serial changes in certain other vulcanoids, where the structures return to their original form; second, the lightening or darkening of color of certain patches of the surface as the lunar day advances. There are also some assertions of minor alterations which need to be separately considered.

Of all the observations which point to the conclusion that changes are still going on upon the moon, those which relate to the supposed sudden alteration of Linné are the most important. This vulcanoid lies in the Mare Serenitatis, and was mapped and described by several observers as having a crater about six miles wide and with distinct steep walls. In 1866 it was believed that the structure did not answer to the descriptions for in place of a crater there was found to be a white spot of nearly twice its recorded diameter, and in the center of this field a minute craterlet. Subsequent observations, however, have thrown doubt on this conclusion, and led some selenologists to the opinion that Linné is a structure that varies much under diversities of illumination, and that its variations of aspect, combined, perhaps, with some original bad mapping and servile copying, may account for the seeming change. Other instances, which appear to indicate the sudden appearance of craterlets where none were observed by skilled selenographers, are easily accounted for by the same difficulties arising from the conditions under which we behold the lunar surface. Thus it has been claimed that the lava flow of the vulcanoid Mersenius, which on close scrutiny is seen not

to be flat or slightly concave, as is usual in such structures, but quite convex, indicates a change, for it must have been originally level as Schröter, as well as Baer and Mädler, so represents it. A study of this feature will convince any competent observer of the moon, who has had experience with his own work and that of his fellows, that the peculiarity might easily have been overlooked. So, too, with the craterlets on the southwest side of Copernicus, which have not found a place on Baer and Mädler's map, and the continuation of the same craters and a honeycombed appearance of the ground towards Eratosthenes, which Schröter failed to notice. An inspection of the field with a better instrument than those used by the above-mentioned selenographers will show that they may well have searched it a score of times without having a chance to note these rarely visible features. On the whole, the evidence for and against the sudden appearance and disappearance of craters and craterlets, or of features in their structures considered without reference to the probabilities of such changes based on the moon's history, leaves us in a state of doubt as to the occurrence of such accidents. I am inclined to think that the case of Linné is the strongest and that the walls of that vulcanoid may have, in part at least, fallen into the original cavity so as to leave only a small pit in its crater unfilled.

If it be the case that the originally great ramparts of Linné have disappeared, the event may be explained without having recourse to the theory of volcanic action. Against the hypothesis of such action may be set the fact that, though the moon is the subject of constant scrutiny, no trace of such explosive process has been noted. Moreover, if there was volcanic action in the case of Linné, it apparently must have consisted in an outpouring of very fluid lava, which formed the extensive white patch that took the place of the previously existing rampart and pit. In a word, the great wall must have been melted down into the flood. When we consider the fact that none of the other vulcanoids shows a trace of any such flows, that the evidence points to the conclusion that the lavas coming from the interior of the sphere never freely stream forth but consolidate on slopes of high declivity, we see how exceptional, and therefore improbable, is the occurrence of any such event. To the geologist it is inconceivable that in the late stage of the moon's history such an effusion of extremely fluid rock could have taken place. The explanation he would give may be set forth as follows :

Assuming that the lunar crust as the seat of high and varied tensions of contraction and expansion brought about its night and day, and that it abounds in cavities due to the ejection of the large amount of material contained in the ramparts of the vulcanoids, it is conceivable that from time to time ancient but unstable adjustments may be suddenly disturbed. The state of the lunar surface may in a way be compared with that of a Prince Rupert drop, a globular bit of glass greatly affected by stresses which any shock is likely to set in effective action. Now, if on such a surface a meteorite should fall, say a body of some tons in weight, no larger than many that have come upon the earth, the resulting shock might lead to widespread movements that would cause the walls of a vulcanoid to fall in. It is to be noted that there are many ill-defined pits on the moon

which may have had this meteoric history, and also that Linné is situated on a wide mare where such stresses are indicated by the continuous ridges and the rills, and where they would be more likely to accumulate than in the higher-lying, irregular country. So if the supposed destruction of this vulcanoid really occurred, a point which will ever remain doubtful, it may thus be accounted for by other than volcanic action. It needs to be so explained if we are to retain our conception of the moon as a sphere which has lost heat in the ratio that the earth has lost it.

The supposed variations in the shape of the twin craters known as Messier, changes which appear to pass through something like a cycle in the course of a lunar period, may possibly be due to the movement of extended masses of rock under the influence of solar heat. Assuming, as before, that a sheet of rock on one or more sides of the pits had, because of its expansion, developed a horizontal joint a few feet below the surface, this slab-like mass might slide to and fro with the variations of temperature. The expansion of a sheet fifty miles in diameter might amount to several hundred feet, enough to make evident alterations in the shape of the cavity. That some such migrations of rock masses under terrestrial compressive strains are possible is abundantly proved by the studies of geologists. Movements of ten miles or more are well ascertained; the only question is as to the possibility of a field of rock, such as we are considering, returning, in the process of shrinking, to its original position. On the earth, such a plate of stone would most likely be fractured as it cooled, so it could not return to its first state. On the moon, however, such a mass, because its weight is less than one-sixth what it would be on the earth, would encounter less friction in its movements; moreover, the grinding action of the adjacent surfaces would tend to form a mass of powdery matter between them which would readily shear so that the frictional resistance would be relatively small. The difficulties of this hypothesis are obviously great, but if it is finally determined that there are recurrent changes in process on the moon, such as appear to some observers to take place in Messier, it seems preferable to that of volcanic action, for it does not do violence to all we know concerning the processes of a cooling sphere.

We turn now to the changes of hue of certain fields of the lunar surface such as have been observed by W. H. Pickering and others. These changes are of two somewhat distinct kinds, those which appear to that observer to show the discharge of fumes from certain small craters, and those which are thought possibly to indicate the temporary development of an extended vegetation which is born in the brief season of a lunar day and dies in its night. As regards the blotches of color which seem to indicate eruptions, I have had no chance to see them, but from the account of the phenomena it appears most likely that they are due to peculiarities of reflection much like those which make the rays glow when the sun attains a high angle. The arguments against the existence of any such clouds of vapor floating above the surface of the moon are very strong; they seem to me, indeed, to be insuperable. The phenomena of occultation

prove, as already noted, that at a mile above the surface there is no trace of an atmosphere,—surely not more than the thousandth part of our own. The law of diffusion of gases makes it impossible that there should be any great increase in the density of such air at its contact with the sphere. How, then, could vapors slowly float away as clouds from a crater? If they came forth they should be swiftly and uniformly diffused in the essential vacuum. Change of hue due to the angle of illumination or fluorescence, or both actions combined, affords a far more satisfactory explanation of the observed facts. This explanation has difficulties, but they are much less serious than those we encounter in a hypothesis of volcanic action still existing and producing clouds.

The observations which indicate that extended fields of the lunar surface darken with its advancing day are extremely interesting for the reason that they show a departure from the general tendency of the surface to become brighter with the higher sun. There is no doubt that these changes are of great importance, but I cannot regard them as suggesting the development of any kind of organic life. This question as to the probability of life on the lunar surface has never been adequately discussed, and as the suggestion is recurrent I purpose to set forth below certain considerations which, in my opinion, make it appear to be most improbable that anything like organic structures can possibly develop there.

It is, in the first place, to be noted that all organic forms, from the lowest to the highest, plant and animal alike, absolutely depend for their existence on the solvent action of water on various substances. The conditions of life are that this water shall be readily obtainable either directly from the fluid in which the creatures dwell, from the rain, or from the moisture of the air. In all cases this water must contain free oxygen and carbonic dioxide, as well as certain minerals in solution. Although it is stated that certain lichens develop in rocks within the antarctic circle, where the temperature has never been observed above the freezing point, it may be safely assumed that these plants have now and then received during their growing period and have retained in their bodies water in the fluid state, otherwise their organic processes could not go on. Wherever on high mountains, say above the level of 20,000 feet, the surface of the rock has been examined, no resident life has been discovered. Thus in an air which is surely many times as dense as any that can exist on the moon, terrestrial life, for all its ample opportunities to become reconciled to such environment, has not succeeded in establishing itself at these great altitudes. The conditions for the formation of organisms suited to the higher peaks of the earth are vastly more favorable than they could have been on the moon, yet the result is that they have failed to develop in such conditions.

Whatever were the circumstances, as yet unknown, which led to the beginning of life on this earth, they were evidently of rare occurrence. The successions of organic forms suggest that they have been derived from few if not from one original form; and, further, that these initial stages have long since been lost. It is unlikely that fresh starts in the origination of the lowliest organisms are now making, for with all the skill of a host of well-trained inquirers we have

not been able to initiate an organic form. If the existing living species of this earth were destroyed, we do not know by what process a beginning could again be made. So much, however, is plain: First, that all of the existing organic forms have had the initial stages of their development in aquatic conditions, for there alone can the earlier stages of development be attained. Second, that the aqueous stages of the forms which now inhabit the land must have required a very long period of such life before the creatures were ready to enter on the more difficult conditions of the land. It may safely be presumed that a period of development such as is represented by thousands of species of successive forms was necessary to bring the terrestrial organisms into conditions of structure and function where even as the lowliest plants they were fit for stations in the air. This process of reconciliation with the environment demands, among other things, means whereby the spores may be diffused, and with all plants of rapid growth, such as have to be assumed if they are to give color to the surface of the moon, it requires a soil or air for food supply.

It is a favorite assumption with selenographers who adopt the hypothesis of plant life on the moon—a pure assumption—that there may be a thin atmosphere of carbon dioxide next the surface and that in such an air plants would grow with rapidity. This is a natural view, for it is based on the well-known fact that the carbon of plants is largely obtained by the decomposition of that gas, the carbon being taken into the structure and the oxygen set free. But the experiments made by a committee of the British Association for the Advancement of Science clearly showed that terrestrial plants, even the lowlier cryptogams, were not sensibly helped by an increase in the amount of CO_2 in the air and that any considerable augmentation of that gas was hurtful to them.

Therefore, in view of these facts: that terrestrial plants, notwithstanding all their ample opportunities for so doing, have never been able to reconcile themselves to the conditions which exist at heights where the density of the air is not more than one-third of what it is at the sea-level; that all organic life necessarily had its beginning in the seas or other masses of water; that the conditions of its origin are so peculiar that we have never been able to reproduce them; and that the development of every organic species known to us requires a considerable supply of water,—it appears most unlikely that the moon is now or has ever been the seat of organic life of the sort that exists on this earth.

It cannot well be denied that there may be on the other celestial spheres than this earth forms of association of matter in which other fluids than water may serve as the menstruum in which vital activities develop, and that the essential results accomplished in the organic forms of our planet may be thus attained. But, so far as we know, organic individuals are limited to very narrow conditions: to those in which water is exposed to temperatures between the freezing point and about sixty degrees Centigrade, and which afford air such as that of the earth in density equivalent to not less than what corresponds to a pressure of one-third that normally existing at sea-level. These conditions clearly do not exist, and, so far as we can determine, have never existed on the lunar surface. It is, in fact,

very doubtful if any other body in our solar system with the exception of the planet Mars is now in a viable state, for it is not likely that any but the earth, and possibly the Martial sphere, has the necessary combination of water and solar heat which has long existed on this planet.

The foregoing considerations concerning the possibilities of organic life on the moon show clearly that we must exhaust every valid hypothesis to explain the occurrence of changes on that sphere before we assume that they are due to the development of living forms. I would suggest that the patent facts of color-change shown by the blotches and rays, which gain intensity as the sun goes higher, lead naturally to the supposition that these other conditions of darkening are due to a like though somewhat diverse action. We may fairly suppose that the regions which thus darken are covered with crystals which reflect or refract the sun's light in such a manner that they send us less of it when the sun is about vertical than when it is relatively low. We have command of three certainly warranted agents for explaining changes of color in the moon: that of reflections from crystalline surfaces; that of refraction taking place in the interior of translucent crystals; and that of fluorescence. We have a right to combine these actions as needs be to account for such phenomena of varying color as may be observed, for all of them are well within the limits of what we note on the earth, but we have not a like right to bring in hypotheses of organic life when all we know of its conditions on this planet shows that it cannot exist on the lunar surface.

It is naturally painful to conclude that the moon is and always has been deprived of those features of existence which we deem the nobler; that it has never known the stir of air or water or the higher life of beings who inherit the profit of experience and thereby climb the way that has led upward to man. That these large gifts have been denied to the nearest companion of the earth has its lessons for the naturalist, since it clearly shows how vast are the effects arising from the interrelation of actions. The fate of our satellite was probably in large part determined by the ratio between its gravitative force and the energy of the kinetic movement of the gases such as constitute the atmosphere. If that energy had been sufficient to retain them on the satellite, there is no reason, at least so long as the original rotation on its axis continued, why it should not have had the history of a miniature earth. As it is, from the beginning it appears to have been determined that it should have no share in the solar energy which has given the most of the dynamic and all of the organic activities of the earth, and there is no imaginable accident that can alter its state except some catastrophe which may return the solar system to a nebulous mass. Just as it is, our moon is likely to see the sun's light go out.

SUGGESTIONS CONCERNING THE STUDY OF THE MOON.

From the point of view of the geologist and geographer I venture to make certain suggestions concerning the future work of selenographers. In the first place, it may be said that, while the delineation of lunar features has, within a

century, been so greatly advanced that of the visible part of the moon we have within the limits of telescopic vision much better maps than of most parts of the earth, the classification of features and their nomenclature are in a very crude shape. There is no sufficient categorizing of the various features, and the names for them, generally suggested by misconceived analogies with terrestrial objects, are often misleading. They serve, indeed, to perpetuate grave errors as to the real nature of the lunar surface. Many of the most conspicuous topographic features are unnamed, as, for instance, the promontories and capes along the shores of the maria. Much of the nomenclature is so inwoven with our records that it would be inadvisable to disturb it, but many changes and additions could be made which would bring some order out of the confusion. I therefore venture to suggest to selenographers that a committee should in some way be formed to undertake a revision, or at least an extension, of the system of names applied to the topography of the moon.

As to further detailed work on the moon, it appears highly desirable that small selected areas should be jointly studied and depicted by several well-trained selenographers, the task being done in such a manner as will enable us to form a judgment, first as to the effects of the personal equation of individual observers in seeing and depicting lunar features, and second as to the effect of diverse conditions of seeing, including the libration, on the aspects of lunar surface. In this way we may hope to attain something like certainty concerning the occurrence or non-occurrence of changes.

It is also desirable that a close comparison be made between some of the more ancient vulcanoids and those of evidently much newer age, as determined by their relations to one another, and this with a view to ascertaining what are the angles of slope of their respective ramparts and those buttress-like structures which I have assumed to be flows of viscid lava. In this way we may possibly obtain some idea as to the effect of the expansion and contraction due to solar heat, or other forces upon their reliefs.

A closer study as to the presence or absence of ash and other ejections of fragmental materials than I have been able to make is desirable. I have given reasons for believing that no such violent expulsion of broken-up lava, *i. e.*, volcanic breccias or ash, took place in the eruptions of the vulcanoids; but the proof of this rests necessarily on negative evidence which requires much scrutiny. This should be given to those cases where large well-developed craters lie adjacent to older like structures. Where there is a honeycombed structure or old ramparts near such newer craters, the surface should be narrowly scanned to find if the depressions have been filled with *débris*.

The observation of Trouvelot, that the rills are sometimes continued beyond their open fractures by light streaks, needs to be verified, for proof of such condition would go far to show that some of these bands at least are due to the passage upward of vapors which congealed at their point of escape, and afford a fair presumption that all of them are of this nature. This inquiry should be extended so as to determine if any of the radiating streaks are coincident with distinct rills.

The form of the so-called mountains demands a careful inquiry. It is asserted that in some cases the steeper slopes, in certain groups of these elevations, are all, or prevailing, in a particular versant; this point should be determined. It appears likely that the mountains in different fields vary in shape in a manner which will permit them to be classified according to areas. All such variations are sure to have meaning. As a part of this work, the cones in the center of vulcanoids such as that in Theophilus should be compared with the peaks in the mountain systems.

I have noted that the older vulcanoids in the central field of the moon's surface appear to have been elongated or "spooned" in a north and south direction, and that this change may be due to the loss of the original rotation of the sphere. This point needs further study. If my observations be verified, and it be found that the newer vulcanoids are not deformed as by a collapse of the equatorial bulge due to the loss of rotation, then the time of the change in relation to the development of the surface features may be determined, and as the loss of rotation would have been very gradual it would be incidentally shown that the period during which vulcanoid processes affected the surface was very extended.

The phenomena of contact of the maria with their shores needs close study. I have briefly stated the facts which lead me to the opinion that the lavas of these fields originally and for a brief time rose much above their present level and have since withdrawn from low areas they at first flooded over. If this be affirmed, then we have evidence that the order of fluidity of the lavas in question was far higher than that of the vulcanoids, where, as we have seen, the material appears to have been at a low average temperature, or at least very viscid, so that it consolidated on very steep slopes as soon as it escaped from the craters. Much depends on the determination of the relative temperature of these groups of lavas, for if those of the maria were decidedly hotter than those of the vulcanoids—hotter, indeed, than any molten material which is known to have come forth from the interior of the moon or the earth,—then the presumption that they were due to in-falling bodies is so far affirmed.

It is most desirable to ascertain the circumstances of contact of the lavas of the several maria which are obviously connected. If they are the result of the impact of one falling body, or of several which fell at about the same time and place, then the various connected areas should be perfectly confluent. If the bodies fell here and there, affording separate centers of melting, then there may be a trace of juncture of the lavas where they joined their floods. My own opinion, based on rather scanty observations, is that the confluence of the apparently connected maria is complete, and that their lavas were generated by one incident; the distinctly separated areas, the Mare Crisium and the Mare Australe as well as the Mare Humboldtianum, if the two last named be, indeed, true maria, having been formed apart from the main field, which includes all the other areas classed in this group.

The naturalist, trained in interpreting terrestrial phenomena, learns the value

of series in extending his conceptions. It is important that this method of inquiry should be applied to the features of the moon, so that we may have a foundation for a sound knowledge as to the categories into which its structures fall, and the limits of these groups. Thus with the group of vulcanoids a close study of their features by making extended series of their forms will be likely to bring out relations and diversities not now understood. Besides these notable structures, the mountains, cones, and ragged peaks, the rills and valleys, the light streaks and blotches of color, all bespeak the same treatment. It may, indeed, be applied to many other groups of objects.

It is obviously desirable to gather all the information we can concerning the unseen $\frac{41}{100}$ of the lunar surface. This inquiry I undertook more than thirty years ago, but the task was left incomplete. The method of my inquiry was as follows: on the limb of the moon in the successive extremes of libration so-called *mountains* appear. Several of these ranges have a continuity which is found only with the ramparts of the great vulcanoids. Of these, beginning at the north pole and passing by the west around the limb, I noted the range west of the Mare Crisium, another near Neper, the Leibnitz range near the south pole, the great range beyond the Doerfel Mountains, and a succession of like ridges down to ten degrees north. These and other fainter undelineated features appear to be resolvable into arcs of circular ramparts, such as enclose the larger vulcanoids. Plotting these as circles, the result was to establish, by fair hypothesis, over a considerable part of the unseen realm, the existence of a topography like that we see.

Looking closely at the limb of the full moon, observers with good eyes may agree with me in the opinion that certain faint light rays there discernible, though with difficulty, apparently converge to centers on the farther side of the moon. I brought to book enough of these to establish about half a dozen of these centers on the invisible field. A confirmation of these uncompleted observations would reduce the region of the entirely unknown part of the moon to less than one-fifth of its whole surface. I cannot hope to return to this interesting task of looking around the edge of the moon, but it appears to be the most interesting of the many inquiries that demand good eyes, and opportunities for observation when the rays are most clearly visible.

Owing to the difficulty of interpreting objects seen in very oblique conditions, the fields within five degrees of the limb have been much neglected. Among the problems there found is that concerning the existence of maria on the margin of the observable part of the surface. Except possibly in the case of the Mare Australe, the surface of such areas is not visible. I have never been certain that I saw the characteristic dark plain of that mapped sea. The question is whether it be only a little varied ancient portion of the crust or a true mare. It is also a question whether the tips of high peaks are not to be traced on the other side of the comparative level; if this be the case, then it is, if a mare, one of small area. The so-called Mare Humboldtianum also needs close attention to determine whether it be a mare or, as it seems to me, an ancient vul-

canoid of large size with rather low walls. If it should be proved that these so-called maria do not belong in that clearly-defined group of features, there will be some reason, from their distribution, for believing that they are limited to the hither side of the sphere.

There are many other lines of work beside that of simple delineation, to which selenographers have so generally confined themselves, which may well engage the attention of those who desire to advance the theory of our satellite. Some of these have been suggested in this memoir; others will present themselves in the course of further inquiry. In such work it should be borne in mind that, relatively few and simple as are the forces which have acted on the moon, in comparison with those which have shaped the earth, they are, in their effects, very complex. The variety of objects on that surface is very much greater than the existing accounts of them would lead the novice to suppose. It is only as they are compared after the manner of the naturalist that we may hope clearly to read the wonderful record of that marvelous dead sphere.

DESCRIPTION OF PLATES.

The following plates have been selected with reference to the illustration of the questions discussed in this memoir. The choice of illustrations has necessarily been limited to those features of which it has been possible to procure good photographic negatives. On this account many interesting structures are not pictured. As a whole, however, these delineations fairly present the more important aspects of lunar topography as seen with good telescopes.

In accordance with the usage of selenographers these plates are printed in the reversed order in which they appear in a celestial telescope. The top of each is the south, the bottom the north, the right hand the east, and the left the west. This will enable the student to compare them with the maps of the moon. Except when necessary for the immediate purposes of this memoir, the structures depicted in the several plates are left unnamed. On many accounts this omission is to be regretted, but an extended effort to designate by name the craters, mountains, etc., showed that to accomplish this end it would be necessary to have key maps for the greater number of these illustrations. If the student desires to determine the name of any of the more considerable features, he can readily do so by comparing the plate with any of the good maps of the moon. For this purpose the map of Elger is recommended.¹ The photographic atlas of the moon by W. H. Pickering, in the *Annals of the Observatory of Harvard College*, vol. li., 1903, and the same work in a more popular form entitled "*The Moon*," by Doubleday, Page, & Co., N. Y., 1903, will be found very useful for reference. Other reference would have been made to them in this work, but they were published after the pages which precede this were put to press.

In the description of each plate, attention is called to the more important features which it depicts and occasionally to the place in the text where the matter is discussed. This arrangement of necessity causes many repetitions. It is hoped that the reader will find that the convenience of the method compensates for this awkward mode of presentation, the aim being to provide in the illustrations a basis for a criticism of the theories of lunar structure as near as possible to that afforded by the use of a telescope.

It is suggested that those who desire to spare their time in obtaining what value this memoir may yield, should first read the text and then compare its statements with the facts presented in the plates; remembering that the matters of detail, such as those concerning the rills, the light streaks, and the other more delicate features, can not yet effectively be rendered by photographs.

¹ See *The Moon*, by Thos. Gwyn Elger. London. Geo. Philip & Son, 1895. The map is to be had separately from the volume.

PLATE I.

GENERAL VIEW OF MOON, AGE 6 DAYS. BY S. W. BURNHAM, LICK OBSERVATORY.

Plates I to VIII (inclusive) show the surface of the moon in progressive stages of illumination. Taken at the Lick Observatory.

In plate I the moon appears nearly half full. The crater of Abulfeda is coming into illumination. The most noteworthy features are the maria, which are evidently darker than the general surface. The lowest of these, the M. Serenitatis, is obscurely circular with rather definite margins. In it, on the west or left-hand side, are some faint folds of its floor. Just outside of this sea, to the west, is a rather large distinct crater (Plinius). Horizontally eastward (to the right) in the midst of the sea is a smaller dark crater (Bessel). The same line continued about as far still eastwardly shows in a faint white spot the position of the crater Linné, which is supposed to have been destroyed in 1866 (see p. 70). The mare on which Plinius stands is the M. Tranquilitatis. Next southwardly beyond Theophilus (Plate XV) is the M. Nectaris. On the southern (upper) margin of this sea is the crater of Fracastorius of which the northern part of the rim has evidently been melted down by the sea. This is perhaps the most conspicuous instance of this nature among the several score that may be noted on the margins of the several maria. The northernmost of the maria in this view near the lunar margin is the tolerably circular M. Crisium. South of it is the irregularly shaped M. Fœcunditatis, without distinct boundaries.

The observer should note the considerable range of brightness in the field, also how the craters and other features become fainter near the brightly illuminated margin.

GENERAL VIEW OF MOON, AGE SIX DAYS. BY S. W. BURNHAM, LICK OBSERVATORY.

PLATE II.

MOON 7 DAYS OLD. BY S. W. BURNHAM, LICK OBSERVATORY.

This plate shows the moon one day older than the preceding view. By comparison with plate III the effect of twenty-four hours' advance in the lunar day may be perceived. On the "terminator" or border of the advancing sunlight, a number of large vulcanoids may be seen in a tolerably linear order. The most important of these, beginning with that nearest the equator and reckoning southwardly, are Ptolomæus, Alphonsus, and Arzachel, then with an interval come Purbach, Regiomontanus, and Walter. Traces of a like alignment are visible in other groups of lesser vulcanoids.

At this stage of the illumination some of the light streaks or rays begin to be visible, and may be faintly traced on the left-hand side of the plate when the sun is highest. So, too, the bright patches whence most of the streaks emanate, are beginning to become lucent.

MOON SEVEN DAYS OLD. BY S. W. BURNHAM, LICK OBSERVATORY.

PLATE III.

AGE OF MOON 8 DAYS, 4 HOURS. SEPTEMBER 22, 1890. LICK OBSERVATORY.

In this plate the most noteworthy features are the maria of the western half of the visible portion of the sphere. The rudely circular form of these fields is well shown, also the fact that none of them extend to the margin or "limb" of the moon. The bright, slightly curved ridge in the lower half of the picture facing the partly illuminated mare, the Mare Imbrium, is the Apennines; the large vulcanoid at its southern end is Eratosthenes. The larger pit in the ocean opposite the center of the range is Archimedes; the two craters next to the north are: the nearer, Autolycus, and the farther and larger, Aristillus. The larger of the two dark pits near the northern end of the Apennines is Eudoxus, the smaller Aristoteles. Southeast from these craters lie the Alps, a group of bright peaks extending in a northeast and southwest direction. A faint dark streak shows the position of the Alpine valley. The flat, irregular area north of the range is the M. Frigoris.

Close inspection of this plate will show that many of the vulcanoids have pits or cones on their floors, and that these are very often in the center of these level spaces.

The radiating bands or streaks are beginning to appear.

In the Mare Imbrium, near the western end of the Alps, next north of Aristillus, is Cassini, of which the encircling cone appears to have been partly melted down by the lava of the mare so that it shows as a faint ridge with a distinct central crater.

AGE OF MOON EIGHT DAYS, FOUR HOURS. SEPTEMBER 22, 1890. LICK OBSERVATORY.

PLATE IV.

MOON'S AGE 8 DAYS, 22 HOURS. LICK OBSERVATORY, 1890.

This plate represents the moon as it appears eighteen hours later than shown in the preceding plate. The pictures were taken at different times of the year, which accounts for the difference in the position of the terminator or illuminated margin. It will be observed that several new features have appeared beyond the southern end of the Apennines. The light bands are more visible and the contrast of hue between the maria and the upland country is less distinct.

MOON'S AGE EIGHT DAYS, TWENTY-TWO HOURS. LICK OBSERVATORY, 1890.

PLATE V.

MOON'S AGE 10 DAYS, 12 HOURS. LICK OBSERVATORY, 1890.

The moon as delineated in this plate is thirty-eight hours older than as shown in the preceding plate. The most noteworthy changes are the great advance in the development of the fields of very bright hue, and in the bands radiating from them. These are most evident in the system of Copernicus. The system of Tycho also begins to be evident. This vulcanoid may be identified as the deep large crater with a central cone near the border of the illuminated area. The general irregularity of these light bands is well shown in those about Copernicus. So, too, the fact that they are projections from an illuminated or lucent field about the vulcanoid.

On the shores of the Oceanus Procellarum, east of Plato, near the margin of the sun-lit area, is the Sinus Iridum. This is probably a large vulcanoid which has had the part of its wall next the mare melted down by the lava of that field. (See p. 17.)

The relative absence of large vulcanoids on the maria is noteworthy. Those which exist lie nearly, if not altogether, on fields of high ground which appear to have risen above the floors of the maria and so escaped melting.

The problematical crater Linné now appears as a small white patch near the middle of the eastern side of the M. Serenitatis. (See p. 70.)

MOON'S AGE TEN DAYS, TWELVE HOURS. LICK OBSERVATORY, 1890.

PLATE VI.

MOON'S AGE 14 DAYS, 1 HOUR. JULY 19, 1891. LICK OBSERVATORY.

In this plate the moon is nearly full, the light being oblique enough to illuminate the crater walls on the eastern margin alone.

The maria are well shown nearly to the eastern margin. Separated by a belt of relatively high ground from the Oceanus Procellarum is the large vulcanoid Grimaldi. It has a small crater on its floor near its northern side. This vulcanoid has a floor nearly as dark as the seas. It will be noted that Plato has also a dark floor. On the margin of the Oceanus Procellarum, southwest of Grimaldi, is a crater Letronne, the wall of which that faces the maria is, as in other instances, ruined apparently by the lava of the sea. Other like examples are shown in this neighborhood. On the shores of the M. Humorum, there are three similar instances of crater-walls broken down on the seaward side.

It should be noted that none of the maria distinctly attain the margin of the moon's surface. On the eastern lands the O. Procellarum comes near to the border of the moon, but high rugged land is visible on the very edge. This is more clearly disclosed at certain stages of libration. On the southwest border some observers think there is a sea crossing the border, but, as will be seen, the level land there has not the characteristic dark hue of the maria.

It will be observed that in this nearly vertical light, except Grimaldi and Plato, the craters on the eastern margin only are distinctly visible. Those exceptions are due to the dark color of their floors. There are two or three craters near the south pole which, because they have rather dark bottoms, are faintly seen.

MOON'S AGE FOURTEEN DAYS, ONE HOUR. JULY 19, 1891. LICK OBSERVATORY.

PLATE VII.

MOON'S AGE 21 DAYS, 5 HOURS. NOVEMBER 3, 1890. LICK OBSERVATORY.

In this plate the moon is entering on the fourth quarter. The rays of the Tycho system have nearly disappeared. The two that are nearly parallel remain illuminated. So, too, the system of Copernicus and that of Kepler to the southeast of it remain in nearly full glow.

The vulcanoids near the south pole are better shown in this picture than in any other of the series. That with several craters on its floor is Playfair. Note the craters on the inner face of its wall. The same features can be observed in other like structures in this neighborhood.

The Alps near Plato are fairly well shown, as are also the Apennines that border the western side of the mare. The ruined craters about the M. Humorum are fairly well shown, but are faint.

The tendency to form a crater or cone in the centers of the larger vulcanoids is fairly well shown in those structures about the south pole.

MOON'S AGE TWENTY-ONE DAYS, FIVE HOURS. NOVEMBER 3, 1890. LICK OBSERVATORY.

PLATE VIII.

MOON'S AGE 23 DAYS, 7 HOURS. JULY 28, 1891. JACK OBSERVATORY.

At this stage of the waning moon the most interesting of its details are no longer visible. There are few that command attention in this plate. It may be noted that the system of light bands and the central patches whence they proceed, have their center in Kepler and still very bright. The dark mare-like floor of Grimaldi is visible near the bright margin of the sphere. The observer may obtain something of the impression such as is afforded by good seeing with a powerful telescope, that the Oceanus Procellarum is relatively shallow and by the number of fragments of what seems to have been the more ancient surface that protrude through it.

PLATE VIII.

MOON'S AGE 23 DAYS, 7 HOURS. JULY 28, 1891. LICK OBSERVATORY.

At this stage of the waning moon the most interesting of its fields are no longer visible. There are few that command attention in this plate. It may be noted that the system of light bands and the central patches whence they proceed, that have their center in Kepler, are still very bright. The dark mare-like floor of Grimaldi is visible near the bright margin of the sphere. The observer may obtain something of the impression, such as is afforded by good seeing with a powerful telescope, that the Oceanus Procellarum is a relatively shallow sea, by the number of fragments of what seems to have been the more ancient surface that protrude through it.

MOON'S AGE TWENTY-THREE DAYS, SEVEN HOURS. JULY 28, 1891. LICK OBSERVATORY.

PLATE IX.

MOON'S AGE 21 DAYS, 16 HOURS. 1895.

In this plate is depicted an area from near the moon's equator to near the south pole. On the eastern margin the sunlight is passing from the surface, the evening light being so oblique that the bottoms of the vulcanoids are more or less in shadow. Here and there, in the advancing night, there are lofty peaks on the margin of crater-rims, which still receive a touch of sun and appear as bright points in a black field. On the western margin the surface is still well illuminated, with the consequent effect that the surface appears to be much smoother than it is. A view taken a few hours later would show about as rude a margin as is here depicted.

Perhaps more effectively than any other this view shows how the general surface of the moon outside of the maria is essentially made up of vulcanoids and ridges, the apparently smooth parts appearing so only because the small irregularities are not visible. In this connection it should be noted that near the dark part the surface is seen to be beset by small shallow craters, the smallest visible being more than a mile in diameter, and probably several hundred feet deep. Such pits, in equal numbers to the unit of surface, exist on the bright part to the left when they are observed by the higher light.

The way in which the smaller craters cut the larger is shown at many points in this field of view. So, too, the relative lack of sharpness of outline of the greater vulcanoids as compared with the lesser objects of this group. The low, narrow ridges which surround the pits are insufficiently shown because the light does not bring them out. They are best observed near the uppermost part of the picture.

The generality of the fact that the larger craters have flat floors and that these floors are prevailing nearly level is well indicated. So, too, the fact that there is a prevailing tendency of these floors to have either a small crater or a cone in or near the center of each circular field. Four such craters in the central part of the area extending in an obscure line from near the base to near the middle of the picture have cones in their centers. In all, about a dozen of the hundred or so instances in which they would be recognizable have this feature. It will be evident that all the craters in this region have their floors far below the level of the encircling ring, and below the general lunar surface.

In sundry instances two adjacent vulcanoids of moderate size have their neighboring walls broken down so that they exhibit the first stage of "crater valleys" with a general north and south axis. There are in all about ten cases of this kind on this field, but several of them are not well-disclosed by this illumination.

MOON'S AGE TWENTY-ONE DAYS, SIXTEEN HOURS. 1895.

PLATE X.

MARE CRISIUM AND NEIGHBORING PARTS OF THE MOON. LICK OBSERVATORY.
ENLARGED TO TWICE THE SCALE OF PLATES I TO VIII.

This plate shows the region about the M. Crisium, the most circular of the seas. It is not completely illuminated, a portion of the western boundary being beyond the light.

In the M. Crisium the most noteworthy feature is the ruined character of its shores as if by the melting action of the lava of the field. There is an obscure step or bench along the shore of the mare as if the lava had subsided, as in the larger vulcanoids.

Northeast of the M. Crisium is a large crater, Cleomedes, with a small pit on its south wall and two craters and a cone on its floor; next farther to the northeast a vulcanoid known as Burkhardt. Note that this has two deformed craters beside it, one to the northwest, the other to the southeast. These features seem to have been produced by some compressive action due to the formation of Burkhardt. East and southeast of this point there is a remarkable confusion of deformed vulcanoids. Near the middle of the M. Fœcunditatis lie two small craters known as Messier, whence extend to the southeast two nearly parallel bands of light. The pits of this pair of vulcanoids have been thought to change their shape in a lunar period. By some early observers the bands were supposed to be artificial objects, and one astronomer suggested that they were built by the selenites to signal the people of the earth. There are several ridges on the mare to the westward of Messier.

The large vulcanoid to the southwest of Messier with a central crater, just beyond three smaller pits of nearly the same size, is Langrenus, next south Vendelinus, yet farther south Petavius. The first and last of these show distinct benches on their inner walls. The last has many pits on its crest.

On the southern margin of the M. Nectaris is Fracastorius, another vulcanoid with the seaward side of its wall demolished by contact with the maria, though it is still traceable; there are several other like instances about this mare.

MARE CRISIUM AND NEIGHBORING PARTS OF THE MOON. LICK OBSERVATORY.
ENLARGED TO TWICE THE SCALE OF PLATES I TO VIII.

PLATE XI.

ENLARGED VIEW OF A PART OF THE APENNINES.

This plate shows a portion of the Apennines near the Palus Putredinis, an embayment of the M. Serenitatis where it breaks through the mountain wall and nearly connects with the M. Imbrium. The three large vulcanoids are Archimedes, Autolycus, and Aristillus. The very steep or even undercut character of the front of the Apennines is well-known. So, too, the varied condition of the old craters, breached on the side towards the mare. These features strongly suggest a melting action of the once-fluid lava of the mare.

ENLARGED VIEW OF A PART OF THE APENNINES.

PLATE XII.

HYGINUS AND THE NEIGHBORING FIELD.

This plate is intended to show the general character of the area in which lie the Hyginus clefts. It should be noted that parallel and near to those of Hyginus there is another which also intersects a vulcanoid. It is less perfect but evidently of the same nature. A yet more indistinct object of the same nature lies near the west wall of the large crater north of Hyginus.

The group of mountains lying near Hyginus shows the elongate character which those ridges often assume. In other parts of the field they are distinctly conical. Near the clefts is a good example of crater valleys. Others less distinct lie near the southern border. A large vulcanoid

near the margin of the plate has evidently had a part of its rim broken down, probably by the lava of the neighboring mare.

The difference between the features shown in this plate and the drawing figured herewith will serve to show the reader how diverse are appearances of the moon's surface under different conditions of observation.

This drawing may be compared with the photographs of the same object (Pls. XII, XXII) to show the relative minuteness of detail grasped by a photograph and by the eye. It shows the vulcanoid Hyginus with the remarkable clefts which proceed from it as exhibited in a drawing. The crater is in no wise exceptional, except for the fissures which break through its encircling wall and extend for a great distance on either side. These are among the most instructive of this group of lunar features.

It should be noted that the general contour of the walls on either side of the clefts indicates that a number of small craters were

HYGINUS FROM A DRAWING WITH THE 13-INCH EQUATORIAL AT THE ALLEGHENY OBSERVATORY. F. W. VERV, DEL., 1890. THREE-EIGHTHS SIZE OF ORIGINAL DRAWING.

first formed and then divided by the formation of the vent and the separation of its walls. That such was the case is well shown by the fact that the cleft on the right has a part of the ring of at least four of these small vulcanoids on one side of its wall and a part on the other. There is a faint trace of the same feature in the rift on the left of Hyginus. A like separation has taken place in the walls of the principal crater. The fact that the floor of this crater is apparently not divided probably indicates that it was molten at the time when the rupture occurred, or that it afterwards was so.¹ The level surface of the bottom of the clefts can best be explained by supposing that they, too, are floored by lava which entered them at some time after they were formed. It is probable that this lava came from the depths, for the reason that, as elsewhere noted, there is reason to believe that the lunar lavas were not sufficiently fluid to flow readily. (See p. 12.) The facts appear to indicate that this crevice was formed before the interior of the moon had ceased to be fluid.

¹ Elger states that he has seen, though faintly, traces of the cleft crossing the floor of the crater. If this observation was well made, then we have to suppose that the lava did not quite fill this part of the rift, which does not appear on this drawing, though it exhibits features that Elger had evidently not observed. Such developments are very common in sketches of lunar structures.

HYGINUS AND THE NEIGHBORING FIELD.

PLATE XIII.

PHOTOGRAPHED BY RITCHEY WITH 40-INCH TELESCOPE, USING YELLOW COLOR
SCREEN AND ISOCHROMATIC PLATE.

This plate shows more than half of the fourth quadrant or the southwest quarter of the moon's visible surface, taken at about three-fourths full. The area extends from the equator on the lunar margin to about 55 south latitude, and from near the polar axis westwardly two-thirds the distance to the margin of the visible field—a district rich in instructive objects.

On the lower part of the plate is a portion of the Mare Tranquillitatis; on the middle of the left-hand side a portion of the Mare Nectaris. The observer should note the features of contact of these maria with the higher ground against which they lie, especially that there are some indications of a gradual passage from the rough surface of the upland to the relatively smooth floors of the maria, and also that several of the rings (at least five) facing the M. Tranquillitatis have the side towards that area destroyed. The wrinkles on the floor of this sea are fair but not good examples of the mountain-like ridges that are found on those areas. That on the margin of the M. Nectaris, extending northward from a crater half in the shadow, is noteworthy.

About a score of the vulcanoids in this field show the tendency to "spooning" or elongation of the crater in a general north and south direction, in some instances rather northeast and southwest. In the northeast part of the field some of them pass into crater valleys with a distinct northeast and southwest axis. In a few instances the axes of these deformed craters are inclined to the southeast and northwest. So that there appear to have been three different lines of strain developed on this part of the lunar crust.

The large, deep vulcanoid with the steep, ragged peaks rising from its floor, near the dark margin on the left, and about one-third the distance from the bottom of the plate, is Theophilus, one of the noblest structures on the moon. The width of the crater is about sixty-four miles; the greatest height from the floor to the crest of the wall eighteen thousand feet. The central mass, composed of several sharp peaks, rises about six thousand feet above the lava plain. In the center of these masses there appears to be an obscure crater about half a mile in diameter. The terraces in the inner wall of the cone are indistinctly shown.

It is to be noted that Theophilus in its development has partly invaded Cyrillus, the next large vulcanoid on the southeast, and also that the older structure seems more ancient with less steep slopes and exhibits a generally ruined appearance. Cyrillus is also more "spooned" or drawn out in a north and west direction than Theophilus. South of Cyrillus, at a distance of half its width, is Catherina. This crater is met by another of half its diameter which has developed on one side of its floor. From near the southeastern margin of Catherina a beautiful row of small craters extends eastwardly for a distance of over two hundred miles to the large vulcanoid Abulfeda. This is perhaps the most noteworthy crater row on the moon.

The long curved wall extending from Piccolomini, near the upper left hand corner (the large crater with its floor in shadow), to the east side of Catherina is the Altai Mountains. It should be noted that this step-like structure obscurely extends northwards to the M. Tranquillitatis, where it forms an irregular ridge-like promontory.

It should be observed that about a dozen of the larger vulcanoids have either a crater or a cone in the central part of their flat bottoms. In some instances on the brightly illuminated parts those structures exist, but are not revealed by the illumination.

The larger details of the general surface of the moon on the area to the left of the Altai escarpment are perhaps better shown here than in any other plate. They are rarely so well revealed in even the best telescopes. In the best seeing the trained eye has a chance to observe perhaps one-half more than is here shown. Note near the margin southwest of Catherina the existence of obscure ancient craters, their walls broken and shoved about, as well as the mingling of small cones and craters, suggesting that craters began with dome-like cones (see p. 30).

PHOTOGRAPHED BY RITCHEY WITH FORTY-INCH TELESCOPE, USING YELLOW
COLOR SCREEN AND ISOCHROMATIC PLATE.

PLATE XIV.

PART OF THE SHORE OF THE OCEANUS IMBRIUM. BY M. HENRY, PARIS OBSERVATORY.
AGE OF MOON, 240 HOURS.

In this plate there are a number of features discernible in the others, but here better exhibited than elsewhere in this series of illustrations. The Oceanus (or mare) Imbrium occupies the central part of the picture, its northern, western, and a part of its southern margin being shown. The large vulcanoid with the dark floor on the northern coast is Plato. South of it, a little way out upon the mare, is a group of noble peaks called the Teneriffe Mountains. The loftiest rises about eight thousand feet above the mare.

Following around the shores of the Oceanus Imbrium to the left hand, we note near Plato the great group of the Alps where there are some hundred peaks, one rising twelve thousand feet above the mare. Cutting across them the Alpine valley is faintly shown. Farther to the left we find the Caucasus, a ridge-shaped mountainous district, with one of its many peaks nineteen thousand feet high. South of this (upwards on the plate) is the passage connecting the Oceanus Imbrium with the Mare Serenitatis. On the left hand from this strait the first white spot is Linné (see p. 70). On the right of the strait are two craters, the lower Aristillus, the upper Autolycus. Farther up to the right is Archimedes. It is about fifty miles in diameter. Above the last-named structure is an unnamed mountainous district. The lower parts of these fields appear to have been swept over by the lava of the mare, but the higher are unaffected by it. The shore to the left of this field from the strait southward is termed the Apennines. The fine crater near the end of their distinct line is Eratosthenes. Farther on, out in the dark field of the Oceanus Procellarum, is the great vulcanoid Copernicus. Just below it, faintly shown, is a group of elevations termed the Carpathian Mountains.

PART OF THE SHORE OF THE OCEANUS IMBRIUM. BY M. HENRY, PARIS OBSERVATORY.
AGE OF MOON, 240 HOURS.

PLATE XV.

CENTRAL PORTION OF THE MOON FROM THE M. SERENITATIS TO STÖFLER.

BY M. HENRY, PARIS OBSERVATORY.

All the more important structures shown in this plate have been displayed in the preceding plates under different conditions of illumination. The most noteworthy features here illustrated are the seas. The lowest or northernmost is the southern part of the M. Serenitatis, which will be seen to have its surface apparently somewhat lower than the adjacent M. Tranquilitatis. This latter passes on the left hand or western side into the M. Fœcunditatis, which is shown only in small part, and on the south into the M. Nectaris. At the southern end of the M. Nectaris is the great vulcanoid Fracastorius with its northern wall broken down apparently by the melting action of the lava of the mare.

South of the distinct crater of Menelaus, a little to the right of the uppermost part of M. Serenitatis, at about one-fifth the distance from the bottom of the plate towards the top, is a very irregular vulcanoid, Julius Cæsar, which is partly broken down by the neighboring mare. Touching the northern or lower margin of Julius Cæsar is a good example of a crater valley. Several others are included in this plate. About half the width of Julius Cæsar farther to the south is the Ariadæus cleft, one of the straightest fissures on the moon.

On the most illuminated part of this plate the bright streaks begin to be traceable ; they are most visible on the M. Nectaris.

CENTRAL PORTION OF THE MOON FROM THE M. SERENITATIS TO STÖFLER.
BY M. HENRY, PARIS OBSERVATORY.

PLATE XVI.

COPERNICUS AND KEPLER. PHOTOGRAPHED BY RITCHEY. SCALE, ONE-HALF METER
TO MOON'S DIAMETER.

The following ten plates were photographed by G. W. Ritchey with the forty-inch Yerkes refractor, with color screen and isochromatic plate. As will be noted, they in part repeat the features exhibited by the other plates of this series, yet in all instances they serve to supplement or extend the information afforded by them.

The most important features exhibited by plate XVI are the systems of bright rays of Copernicus, Kepler, and Aristarchus. These three ray systems, though less extensive than those of Tycho, taken together constitute the greatest exhibition of the bright bands that exist over the northern part of the surface. The complex branched nature of these bands is particularly well shown, better, indeed, than the writer has ever been able to note with the telescope. The fact that the bright bands of each system are prolongations of a central bright field is tolerably well shown.

Although owing to the high sun and the consequent absence of shadows, Copernicus in this view hardly appears as an elevation, it is, under favorable conditions of illumination, perhaps the noblest object on the moon. The wall on the eastern side, according to the estimates of Schmidt, rises to a height of twelve thousand feet above the adjacent plain. The outer slopes of the cone are strongly ridged as by the flow from the crater of lavas which cooled on the steep slopes; some of these are faintly traceable in the plate.

COPERNICUS AND KEPLER. PHOTOGRAPHED BY RITCHEY. SCALE, ONE-HALF
METER TO MOON'S DIAMETER.

PLATE XVII.

CRATER REGION ABOUT THEOPHILUS. PHOTOGRAPHED BY RITCHEY.
SCALE, THREE-FOURTHS METER TO MOON'S DIAMETER.

A portion of this field, including the crater Theophilus, is shown in other plates. This most important structure lies just below the middle of the plate near the margin of the illumination.

The details of structure of the lunar surface, as shown on the margin of the illuminated field, are better exhibited in this picture than in any other; perhaps better than in any other photograph that has been published. The more important of them have been noted in the descriptions of preceding plates, but attention may well be called to certain of these features, viz., to the numerous shallow craterlets near Theophilus, to sundry wrecked craters in the same field, and to the association of small cones and small craters in the region south (upward on the plate) from Theophilus.

The frequent deformation of craters by elongation is fairly well indicated by several vulcanoids within the field of view. The invasion of the material of the maria is well shown in the region about Theophilus, and, as before noted, the central peak on the crater floor of that structure with its fairly distinct central pit is admirably depicted.

It is well to note the passage from the very distinct exhibition of the structures on the terminator, the margin of the illuminated field, to the obscurity of similar features when the sun is more than forty-five degrees above the horizon.

CRATER REGION ABOUT THEOPHILUS. PHOTOGRAPHED BY RITCHEY.
SCALE, THREE-FOURTHS METER TO MOON'S DIAMETER.

PLATE XVIII.

MARE SERENITATIS. PHOTOGRAPHED BY RITCHEY. SCALE, THREE-FOURTHS METER
TO MOON'S DIAMETER.

This plate shows the whole of the Mare Serenitatis; on the upper right-hand corner a part of the M. Vaporum; on the lower corner of the same side portions of the Mare (or oceanus) Imbrium, known as the Palus Nebularis. The largest vulcanoid near the dark margin is Posidonius. The bright patch showing no distinct structure, which lies on the parallel of Posidonius, about two-thirds across the field, is the problematical Linné. The partly illuminated portion of the mare below Posidonius is the Lacus Somniorum.

The most noteworthy structures exhibited in this plate are as follows: The great mountainous ridge which traverses the mare in a general north and south direction (this structure more distinctly resembles a terrestrial mountain-chain than any other elevation on the moon); the field abounding in conical elevations in the lower part of the plate; the crater of Le Monnier just above Posidonius, which has a part of its wall apparently broken down by the mare, and the crater valleys near the upper right-hand corner of the plate. There are a number of clefts, commonly known as rills, which are fairly well shown. A group of these lies just below Plinius, the large crater with a bright central cone emerging from the shadow of the crater wall, situated near the upper margin of the plate. Another notable group is found in the left-hand lower section of the plate. Faint traces of craters may be seen in these clefts.

It may be noted that a number of the larger vulcanoids here depicted exhibit that tendency to a development in a meridional direction which has been termed in this text "spooning." In Posidonius and the smaller vulcanoid, Jansen, on the margin above it, the southern (upper) walls are thus indented.

MARE SERENITATIS. PHOTOGRAPHED BY RITCHEY. SCALE, THREE-FOURTHS
METER TO MOON'S DIAMETER.

PLATE XIX.

RAY SYSTEM ABOUT TYCHO. PHOTOGRAPHED BY RITCHEY. SCALE, THREE-EIGHTHS
METER TO MOON'S DIAMETER.

This, the most extensive of the ray systems of the moon, has its origin in the field about Tycho, the large vulcanoid to which the numerous bands apparently converge. It appears under the high sun as a large pit with a compound central cone. The rays of this system should be compared with those which have their centers in Copernicus and Kepler. In these last named groups the streaks are developed on relatively level ground, while on that of Tycho they intersect a rugged surface.

On the right hand, some of the bands may be seen crossing the Mare Nubium. Two of them of great length are seen to be nearly parallel for a distance of some hundred miles.

A number of large vulcanoids, partly in shadow, are shown on the southeast margin of the moon. Of these the largest is Schiller. Its length, which is one hundred and twelve miles, will serve as a scale in estimating that of the rays.

RAY SYSTEM ABOUT TYCHO. PHOTOGRAPHED BY RITCHIE. SCALE, THREE-EIGHTHS
METER TO MOON'S DIAMETER.

PLATE XX.

COPERNICUS AND SURROUNDINGS. PHOTOGRAPHED BY RITCHEY, NOVEMBER 21, 1901, 7 HOURS 32 MINUTES P.M., CENTRAL STANDARD TIME. EXPOSURE, ONE SECOND. SCALE, THREE-FOURTHS METER TO MOON'S DIAMETER.

This plate of Copernicus should be compared with the plates showing the same structure under more nearly vertical illumination when the light bands appear.

In the plate the lower level area is a part of the Mare Imbrium. This is bordered on the left by a portion of the high country known as the Apennines, which extend as far towards the center of the plate as the large crater Eratosthenes. To the left, separated by a little more than the width of Copernicus, is the faintly outlined vulcanoid known as Stadius, which appears to have been in large part melted down by the lava of the Oceanus Procellarum which has invaded this field. On the right hand from Eratosthenes, the margin of the mare is formed by the peaks of the Carpathian Mountains. Immediately above Copernicus is a small, double crater, one of the simpler crater valleys.

The area about Copernicus exhibits several very interesting types of structure. The Carpathian Mountains show the mare penetrating into several rude craters, the seaward faces of which have had their walls destroyed by the fluid lava. A broken line of small craters lies midway between Copernicus and Eratosthenes. At either end it verges into a narrow crater valley of the "rill" type. The central part of the upper half of the field abounds in very perfect cones which are associated with small crater pits.

COPERNICUS AND SURROUNDINGS. PHOTOGRAPHED BY RITCHEY, NOVEMBER 21, 1901, SEVEN HOURS
THIRTY-TWO MINUTES P. M., CENTRAL STANDARD TIME. EXPOSURE, ONE SECOND.
SCALE, THREE-FOURTHS METER TO MOON'S DIAMETER.

PLATE XXI.

MARE NUBIUM AND SURROUNDINGS. PHOTOGRAPHED BY RITCHEY, NOVEMBER 21,
1901, 7 HOURS 32 MINUTES P.M. EXPOSURE, ONE SECOND.
SCALE, ONE-HALF METER TO MOON'S DIAMETER.

In this plate Copernicus is the large vulcanoid on the lower margin. The large crater near the upper margin, a little to the right of the center, with a cone somewhat to the right of its center and "rill" on its floor, is Pitatus. The three great vulcanoids in a row extending in a north and south direction, are, in succession from the lowest towards the upper margin of the plate, Ptolemæus, Alphonsus, and Arzachel. The large deep crater below and to the right of Pitatus, with a divided central cone, is Bullialdus.

The most noteworthy features in this plate are found in the many instances in which the lavas of the maria have partly destroyed the vulcanoids within their fields. In the upper right-hand fourth of the plate, there are a dozen or more of these ruined craters, some of them with their walls almost effaced. In this part of the field there are several important rills. Some of these are evidently rows of craterlets in which the adjacent walls of the pits have been broken down so as to form a ragged cleft. A number of these lines of craterlets are traceable on the external slopes of Copernicus. The long, dark line, sixty-five miles in length, in the upper third of the plate, a little to the left of the center, is the Straight Wall, the most extensive fault known on the moon. The height of its cliff is about five hundred feet. The crescent shaped structure at its southern (upper) end is the remnant of a crater, the remainder of the margin having been destroyed by the lava of the mare. To the right of, and near by the Straight Wall, is a rill extending in a slightly curved course for a length of about forty miles, terminating at either end in a distinct craterlet.

The brightly illuminated part of the field depicted on this plate, that to the left of the center, exhibits many excellent examples of crater valleys, which in their series afford something like a passage from the condition of rills to those wider depressions.

MARE NUBIUM AND SURROUNDINGS. PHOTOGRAPHED BY RITCHEY, NOVEMBER 21, 1901,
SEVEN HOURS THIRTY-TWO MINUTES P. M. EXPOSURE, ONE SECOND.
SCALE, ONE-HALF METER TO MOON'S DIAMETER.

PLATE XXII.

MARE TRANQUILITATIS AND SURROUNDINGS. PHOTOGRAPHED BY RITCHEY, AUGUST 3, 1901, 2 HOURS 30 MINUTES A.M., CENTRAL STANDARD TIME. EXPOSURE, $\frac{3}{4}$ SECOND. SCALE, THREE-FOURTHS METER TO MOON'S DIAMETER.

This plate includes nearly the whole of the Mare Tranquillitatis and, on the lower margin, a portion of the M. Serenitatis. The large crater near the strait connecting these maria is Plinius. The highland nearest to it is the promontory of Acherusia. On the southern, or upper, margin the view extends to the flanks of Theophilus.

The most noteworthy features in this plate are the mountain ridges on the maria, the manner in which the maria come in contact with the higher ground, the numerous crater valleys, and the great "rills."

It may be noted that ridges on the maria exhibit little trace of corresponding troughs between them, such as are usually found in terrestrial mountain chains.

The contact of the maria with the high ground has evidently resulted in the partial melting of the walls of several vulcanoids. Where these structures are not thus affected they are, apparently, in origin later than the formation of the maria. The crater valleys are abundant on the right-hand or eastern side of the field. Some of them have been invaded by the lava of the mare.

Some of the greater rills are very well shown. That on the extreme right side is Hyginus (see p. 44). It will be observed that the course of these rills is at high angles to the prevailing direction of the ridges on the mare.

MARE TRANQUILITATIS AND SURROUNDINGS. PHOTOGRAPHED BY RITCHEY, AUGUST 3, 1901,
TWO HOURS THIRTY MINUTES A. M., CENTRAL STANDARD TIME. EXPOSURE,
THREE-FOURTHS SECOND. SCALE, THREE-FOURTHS
METER TO MOON'S DIAMETER.

PLATE XXIII.

MARE IMBRIUM AND SURROUNDINGS. PHOTOGRAPHED BY RITCHEY, NOVEMBER 21, 1901, 7 HOURS 32 MINUTES P.M., CENTRAL STANDARD TIME. EXPOSURE, ONE SECOND. SCALE ONE-HALF METER TO MOON'S DIAMETER.

This plate depicts the western two-thirds of the Mare Imbrium : it does not show the interesting Sinus Iridum on its northern shore, nor the Harbinger Mountains on its eastern side. The most noteworthy features are the relatively level surface of the mare and the greater vulcanoids and peaks on its margin, or in its midst, and the Alpine valley on its northwest side.

The great crater near the lower margin of the mare is Plato. This crater has a diameter of sixty miles, and is very nearly circular. It is separated from the M. Imbrium by little more than its own wall, and from the narrow M. Frigoris on the north by a field of upland that declines gently to that mare. This field is thickly beset by small cones. The interior walls of the crater of Plato rise in general to a height of about four thousand feet above its floor. At some points, however, this wall is over seven thousand feet in height. The floor of the crater appears in the plate to be smooth and of a rather even, very dark hue. It is, however, the seat of rather extensive topographical and color features. There are at least six crater cones, about forty patches of peculiar coloration. The failure of these markings and structures to appear on this admirable plate may be taken as a measure of the difference between what is shown by the best reproductions of photographs now obtainable and the revelations of the telescope under the most favorable conditions.

On the sea south of Plato is a group of remarkable peaks. Those on the extreme right are known as the Straight Range ; those on the center as the Teneriffe Mountains ; the solitary peak yet farther to the west is Pico.

The wide cleft to the left of Plato, about one hundred miles away, is the Alpine valley. Owing to the high sun it is not well shown.

The three great vulcanoids near the left-hand margin of the mare are : the largest Archimedes, the intermediate Aristillus, and the smallest Autolycus.

MARE IMBRIUM AND SURROUNDINGS. PHOTOGRAPHED BY RITCHEY, NOVEMBER 21, 1901,
SEVEN HOURS THIRTY-TWO MINUTES P. M., CENTRAL STANDARD TIME.
EXPOSURE, ONE SECOND. SCALE, ONE-HALF METER
TO MOON'S DIAMETER.

NOV 20 1901
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PLATE XXIV.

ARISTOTELES, EUDOXUS, AND SURROUNDINGS. PHOTOGRAPHED BY RITCHEY, OCTOBER 13, 1900, 2 HOURS 40 MINUTES A.M. EXPOSURE $\frac{1}{2}$ SECOND. SCALE, THREE-FOURTHS METER TO MOON'S DIAMETER.

In this plate the large vulcanoid near the top of the lower third of the field, that which cuts the ring of the smaller crater on the left of its wall, is Aristoteles ; the somewhat smaller structure just above is Eudoxus ; that near the upper left-hand corner is Posidonius. On the right hand, at the same level as Aristoteles, the great Alpine valley is partly seen, the illumination being too nearly vertical to show it well.

Among the noteworthy features exhibited by this plate the following are the most important : The wall of Aristoteles evidently has broken that of the small unnamed crater adjacent to it on the west (left-hand) side. This shows that Aristoteles was in activity since the smaller vulcanoid was formed. The inner slopes of the first-named crater abound in rude terraces. Its limited floor bears numerous cones.

South of Eudoxus is an extensive field of elevations known as the Caucasus Mountains. The western portion of this field peculiarly abounds in cones and craterlets of about the same diameter as these cones, suggesting that the two groups of structure are in origin in some way related. Certain other good examples of these cones are exhibited in the lower part of the plate.

To the west of Eudoxus is a great, irregular vulcanoid with a large crater (Burg) somewhat excentrically placed on its floor. On this floor are some remarkable rills.

The greater part of the upper third of the plate is occupied by the Mare Serenitatis. A portion of its mountain-like ridges is well shown.

ARISTOTELES, EUDOXUS, AND SURROUNDINGS. PHOTOGRAPHED BY RITCHEY, OCTOBER 13, 1900,
TWO HOURS FORTY MINUTES A. M. EXPOSURE, ONE-HALF SECOND. SCALE,
THREE-FOURTHS METER TO MOON'S DIAMETER.

PLATE XXV.

CLAVIUS, LONGOMONTANUS, TYCHO, ETC. PHOTOGRAPHED BY RITCHEY, NOVEMBER 21,
1901, 7 HOURS 32 MINUTES P.M., CENTRAL STANDARD TIME. SCALE,
THREE-FOURTHS METER TO MOON'S DIAMETER.

In this plate the large crater, only partly illuminated, on the line of the terminator and cut by the upper edge of the plate, is Klaproth. Just below Klaproth is Blanchianus, which on its lower margin nearly touches the wall of Clavius, the largest structure in the field. Clavius is one hundred and forty-two miles in diameter. North of Clavius, on the edge of the illumination, is Longomontanus. Nearly in the center of the plate is Tycho, about which the great ray system, visible under a very high sun, originates. This structure may be recognized by its central, sharp, irregular cone. The large vulcanoid near the center of the lower part of the plate is Pitatus, situated on the margin of the Mare Imbrium. It may be better identified by the "rill" on the northeast part of its crater floor.

The most noteworthy features of this plate are as follows: The abundance of relatively large vulcanoids; the difference in the nature of their floors, some being relatively smooth, others much varied by pits and craters, and the association of small cones and craterlets of like horizontal section, in all parts of the field where the light is favorable for their exhibition.

The effect of the lava of the mare, when it comes in contact with the high ground, also deserves attention. It appears to have more or less completely destroyed the walls of several vulcanoids with which it came in contact.

CLAVIUS, LONGOMONTANUS, TYCHO, ETC. PHOTOGRAPHED BY RITCHEY, NOVEMBER 21, 1901, ?
SEVEN HOURS, THIRTY-TWO MINUTES P. M., CENTRAL STANDARD TIME.
SCALE, THREE-FOURTHS METER TO MOON'S DIAMETER.

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