THE MOON

THE FULL MOON
Photographed at Jamaica by the expedition sent out by Harvard College Observatory

THE MOON

A SUMMARY OF THE EXISTING KNOWLEDGE OF OUR SATELLITE, WITH A COMPLETE PHOTOGRAPHIC ATLAS

By

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ONE HUNDRED ILLUSTRATIONS

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PREFACE

IT IS INTENDED in the present volume to give an account of some of the more recent advances in our knowledge of the Moon, leaving to the text-books a statement of the information that was earlier acquired, and with which most people are already more or less familiar. Some of these topics are lightly touched upon, however, in the second chapter, where some reference to them seemed necessary.

After the perusal of this volume the question may perhaps be asked how it is that anything new could have been discovered in regard to so conspicuous an object as the Moon—an object that must have been constantly observed by the generations of astronomers already passed, many of whom were provided with far larger and more costly instruments than those used by the author.

The answer is a comparatively simple one. For many researches in astronomy, such as the study of faint stars, the separation and measurement of close doubles, the study of their spectra, etc., a telescope furnished with a large objective or lens is the paramount consideration. On the other hand, for planetary and lunar research the all-important consideration is a "steady" atmosphere. Such an atmosphere is found only in low latitudes, far from the great anti-cyclones of more northern regions. The earlier astronomers located their observatories either in high northern or high southern latitudes, thereby avoiding the very regions where the best results would have been obtained.

The Arequipa station of the Harvard Observatory, where most of the Harvard discoveries on the Moon, on Mars and on Jupiter's satellites were made, is furnished with a telescope of only a little more than twelve inches aperture. It has, however, the enormous advantage that it is situated within but sixteen degrees of the equator. The "seeing"—that is, the atmospheric definition—there is so good that many of the more obvious facts in the solar system not previously known were discovered. Of the obvious facts still unknown that were left, one—the canals in the Moon—was detected in Jamaica, a station similarly located, within eighteen degrees of the equator. Whether there remain any more readily observed but still unknown facts in the solar system we cannot of course say, but if there are any it seems probable that they will be found in connection with the Moon, which has been less studied under favourable circumstances than some other bodies, such, for instance, as Mars, and which presents, moreover, a far greater wealth of detail than any other of the celestial objects.

To understand better what is meant by the terms a "steady" atmosphere and good "seeing," let us imagine that our observations are all made at the bottom of a pool of water. As long as the weather remains calm we get along very well, but as soon as a breeze springs up we had best pack up our telescopes and go home. That is the case with the astronomer interested in planetary research. The breeze represents the air currents engendered by the continuous succession of cyclones and anti-cyclones forever sweeping through northern latitudes. These air currents of varying temperature are quickly recognized by the astronomer and send their disturbing ripples far toward the equator. Even in Jamaica, when the Sun went south in winter and the northern anti-cyclones began, our definition became at once inferior to what we had found it when the Sun was nearly overhead in the summer season and the northern barometer was comparatively quiet. In Cambridge, few observations on the Moon or planets can ever be made to advantage. If anything new is to be learned we must go south, and those who remain at home have little chance at the new discoveries. What is now needed is a large telescope located near the equator, but just how near it is necessary or desirable to go has not as yet been definitely determined.

The earlier selenographers mapped and studied the whole surface of the Moon. Later observers confined themselves to smaller areas. The author's plan has been to devote his attention exclusively to a few very small selected regions. Occasionally a whole crater has been observed, but more frequently especial attention has been directed merely to a few square miles of surface, thus obtaining a complete and accurate record of all the very finest detail visible in that particular region under all conditions of lighting. A comparison of many such drawings, all made on a nearly uniform scale, extending sometimes through a period of several years, but each described with full details upon a uniform system, will occasionally bring to light a new fact. It is believed that this will be the method of advance of the selenography of the future.

The question is sometimes asked how near does the telescope bring the Moon. It has been shown* that with a fifteen-inch telescope and perfect seeing a round black dot measuring 0.1″ in diameter can be seen on a white disk. This means that the telescope will show an object having only 1-300 the diameter that can be seen with the naked eye. This would be equivalent to bringing the Moon within 1-300 of its real distance, or about 800 miles, and this is probably as near as it has ever been practically brought by any instrument. An investigation by another method, made at Arequipa, indicated that the least distance for a twelve-inch telescope was about 1,000 miles.† As we have just seen, our largest telescopes are not located where the seeing is perfect, but if they were moved to a tropical climate they might perhaps occasionally, under the most favourable possible conditions, bring the Moon to within 300 miles.

With perfect seeing the fifteen-inch telescope would show an absolutely black object on the Moon that measured only 600 feet in diameter. If the seeing were such as we usually have in the northern United States and Europe, it might have to be half a mile in diameter. If it were not black it would have to be still larger. Under perfect seeing, a black object a mile long would be seen if it were only 100 feet in breadth.

Since an astronomical telescope turns all objects upside down, and since for northern observers most of the interesting objects in the heavens pass to the south of the zenith, it was the custom of the earlier astronomers to represent all astronomical objects, with the exception of star maps drawn on a small scale, with south at the top. This custom is still maintained, and has been followed in the present volume. The irregular line separating the bright from the dark portion of the Moon is called the terminator; the smooth edge of the Moon is called the limb. The large dark plains on the Moon visible to the naked eye are called the *maria*, from the Latin *mare*, a sea.

The edge of the Moon toward the western horizon is called the preceding or western limb; the other edge is called the following or eastern limb. This, it will be noted, brings the points of the compass in the reverse order from what they appear upon a terrestrial map. Longitude upon the Moon is reckoned east and west from a central meridian, west longitude being usually considered positive and east longitude negative. For many purposes, however, it is more convenient to reckon longitude from the central meridian east round through 360°. This, to distinguish it from the other, is known as the colongitude.

* Annals of Harvard College Observatory, XXXII., p. 147.

† *Ibid.*, p. 157

To indicate the portion of a lunar day at which an observation is made we must give the colongitude of the sunrise terminator. To make this a little more intelligible, we may apply it to the Earth and say that a given observation was made when the Sun was rising at longitude 70° W., measured on the equator. This statement clearly indicates a particular instant of time for the whole Earth and also for the whole universe. While this would not be a convenient method of expressing time for us, it would be entirely so for a lunar astronomer. From sunrise to sunset, for an object on the Moon, is about fifteen of our terrestrial days. As supplementary to the colongitude of the sunrise terminator, or as a substitute for it, we may state that a certain observation was made when the Sun had been shining on the given formation for so many terrestrial days. It is often convenient to give both these figures—thus on Plate B, facing page 42, under each figure is given the date of the observation, the number of terrestrial days that had elapsed since sunrise, and the colongitude of the sunrise terminator.

American and English astronomers when dealing with the Moon generally refer the time of their observations to the meridian of Greenwich. Thus, when it is stated that a certain observation was made at 14 h. 20 m. G. M. T. (Greenwich Mean Time), we must, if we wish to reduce it to Eastern Standard, subtract five hours, and we shall then find that the observation was made at twenty minutes past nine in the evening.

Most of the plates illustrating this volume, together with a portion of the text, are taken from the "Annals" of the Harvard College Observatory, Volumes XXXII. and LI. Much of this portion has, however, been rewritten, condensed, and expressed in a less technical and more popular form. Some of the illustrations and text here given are published by the courtesy of the Century Company, having first appeared in their magazine during the past two years. For the use of the illustrations representing the Moon as seen by the naked eye I am indebted to the officers of the Société Astronomique de France, these figures having first appeared in their Bulletin for 1900. The remainder, including several of the illustrations and a large part of the text, are entirely new. It should also be stated that in the establishment of the observing station in Jamaica and in the securing of the negatives I was most efficiently aided by my assistant, Mr. E. R. Cram.

THE AUTHOR.

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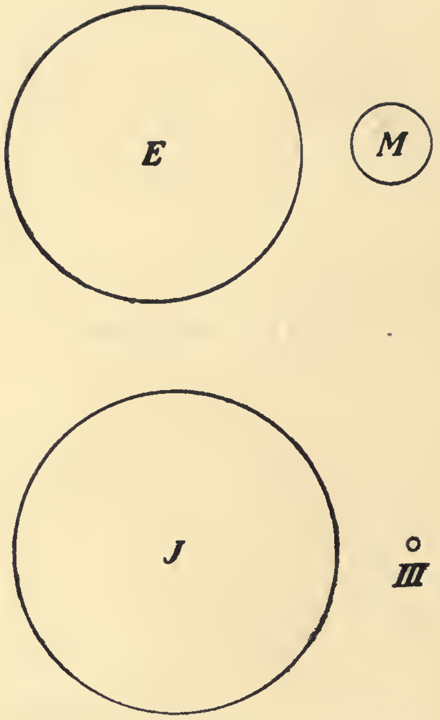

The Earth and Moon compared with
Jupiter and its largest satellite

CHAPTER I

Origin of the Moon

THE MOON is usually spoken of as the satellite of the Earth, but in point of fact it is more properly its twin. It is more attracted toward the Sun than toward the Earth, and if, when situated between the two, it were suddenly stopped in its orbit, it would leave the Earth, never to return to it, and drop directly into the Sun. Although the Moon appears to us to revolve about the Earth, yet an outsider would see that it should more properly be said to revolve about the Sun, since owing to the relative weakness of the Earth's attraction the Moon's path in space is always concave toward the Sun. The disturbance it produces in the orbit of its primary also far exceeds that produced by any of the other satellites. In fact, both bodies, while keeping relatively close together, really revolve about the Sun once in a year, following very closely an elliptical path called the ecliptic, the centre of each being alternately inside and outside of this path owing to their mutual attractions. As seen from the nearer planets, they must appear as a most beautiful double star. Thus from Venus, when it lies between us and the Sun, the Earth would appear two or three times as bright as Venus does to us when at its brightest. The Moon would appear about as bright as Jupiter, and the distance between the Moon and ourselves would never at any time appear greater than does the diameter of the Moon as seen from the Earth. To the assumed astronomer on Venus, the double planet, as he might properly call us, must be by far the most beautiful and interesting object in the heavens, and he would be able to see to advantage, what we unfortunately never can, that unknown country—the other side of the Moon. The diameter of the Moon is 2,163 miles (3,481 kilometers), or rather more than one-quarter of that of the Earth, while the next largest satellite in proportion to its primary measures only about one-twentieth of its diameter. In the figures, the circles represent the relative size of the Earth and Moon as compared with that of Jupiter and its largest satellite. The first pair are, for convenience, drawn on ten times the scale of the last.

The origin of the Moon is quite unlike that of the other satellites of the solar system.

The four larger planets apparently resemble our Sun in constitution more than they do the Earth, and their satellites were probably formed from rings left surrounding them when they cooled and contracted to their present dimensions. The well-known example of such a ring is the one at present surrounding the planet Saturn. This ring is composed of myriads of independent meteorites each moving in its own orbit. These may possibly in the future coalesce to form still another satellite to that already well-furnished planet.

The satellites of Mars may have been formed in this manner, or they may be captured asteroids, taken from that great swarm of little bodies, at some remote epoch when the eccentricity of the planet's orbit was greater than it is at present, carrying it at times far beyond its present greatest distance from the Sun. Under these circumstances Mars would be moving very slowly, and should it chance to pass near an asteroid moving at about the same speed it would be quite able to disturb the orbit of the latter to such an extent that the little body would be unable to escape from it, and in future they would therefore continue to travel together around the Sun for all time. The largest satellite of Mars, Phobos, is about thirty miles in diameter, or about the average size of those asteroids at present known to us.

Our own Moon was created by still a third method, and of this we are more certain than of either of the others. While the origin given of the other satellites may be described as probable, in the case of our Moon we are fairly certain, and it is perhaps the strangest of the three. We have all of us read of those little animals living in the sea, mere shapeless masses of jelly, that, instead of swallowing their dinner, having no mouths or stomachs whatever, simply wrap themselves around it. If we watch them under the microscope we may see one of them slowly lengthen out, then break in two, and each part go swimming away by itself, a perfect animal. It was Professor George H. Darwin, the son of the great naturalist, who proved mathematically that the origin of the Moon was such that we may properly compare it to that of the little animals above described.

To understand this matter better, we must first consider the mutual influences that the Earth and Moon exert upon one another at the present time. We all know that the Moon produces a double tide upon the Earth, in virtue of which large masses of water are transported over its surface. One tide is on the side of the Earth toward the Moon, and the other tide is on the opposite side. The Earth revolves between these tides very much as a wheel might revolve between two brakes. The result of this action is that the rotation of the Earth upon its axis is being gradually retarded, so that each day is a little longer than its predecessor. This action is so slight, however, that the change in the length of the day since the date of the Christian era is only a small fraction of a second. In the early geological times, on the other hand, when the interior of the Earth was molten, the effect was much more marked than at present, as an internal tide was then produced, distorting the surface much as our present tides distort an ice floe. In these early days the terrestrial day was much shorter than it is at present.

But if the Earth's rotation is being retarded by this action, since action and reaction are equal and opposite, the motion of the Moon in its orbit must be correspondingly accelerated. In fact, we have here a force which is constantly pulling the Moon forward. But if we increase the speed of a body in its orbit, its centrifugal force is increased, with the result that the body tends to fly away from its centre of revolution. As the result of this tidal action, therefore, the Moon is constantly moving away farther and farther from the Earth, and thus constantly traveling in a larger orbit. But if the Moon's orbit will be larger to-morrow than it is to-day, to-day it must be larger than it was yesterday, and if we carry our reasoning back into past geological times we come to a period when the distance of the Moon was only one-tenth of what it is to-day, and still further back it must have been almost touching the surface of the Earth. At that time our day was only about three of our present hours in length.

Now it can be shown that if our Earth were to revolve on its axis in rather less than three hours, instead of once in twenty-four, portions of it would be liable to fly away by centrifugal force. As the original Earth cooled and contracted from its nebulous form its rate of rotation upon its axis must have steadily increased. This increase was reduced somewhat by the powerful solar tides then in existence, but in spite of them the period finally shortened to about three hours. The force of gravity at the equator thus became less and less, and the solar tides in consequence higher and higher, until one day a catastrophe occurred, a catastrophe of such magnitude as has never been seen upon the Earth before or since—five thousand million cubic miles of material left the Earth's surface never again to return to it. Whether it all left at once or whether the action was prolonged we do not know, but we may try in vain to imagine the awful uproar and fearful volcanic phenomena exhibited when a planet was cleft in twain and a new planet was born into the solar system.

The date of this event cannot be fixed even approximately, but we know that it must have been rather recent, as astronomical events go, since the Earth must have been already condensed from a huge gaseous mass to a comparatively small solid or liquid form, not far from its present bulk. Indeed, the Moon must be one of the younger members of the solar system. At the same time, its age cannot be less than fifty million years, and may be much greater.

At its first appearance the shape of the Moon was not spherical, as the Earth would not have permitted so large a body to retain this shape so near to its own surface, but its present form was probably assumed after it had escaped to a distance of a few thousand miles.

The question may now occur to the reader, if the Earth gave birth in this manner to the Moon, why should not Venus and Mercury also have been supplied with companions? The explanation probably lies in the intensity of the solar tides, which would be many times greater upon those planets than upon the Earth and would thus effectually prevent their attaining a sufficiently high speed of rotation to throw off any satellites.

Looking forward now into the future, we find that the distance of the Moon must continue to increase, and the length of the terrestrial day also, but only up to certain limiting figures. When the distance of the Moon has increased by 100,000 miles, or to about 350,000 miles, the length of the lunar month will be fifty of our present days. At that remote epoch our day will have increased also to fifty of our present days in length; and the Earth and Moon will turn constantly the same face to one another as they did in the beginning. Thus the Moon will cease to rise and set, there will be one spot on the Earth where the Moon will be constantly overhead, and on the other side of the Earth the Moon will never be visible. This is assuming that at that remote time we still have seas and tides; but if we do not, which now seems far more probable, this latter condition of affairs will never be reached. It merely represents a goal toward which we are at present aiming.

Many persons while studying geography have been struck by the fact that the Atlantic coast lines of the eastern and western continents are strikingly similar, especially South America and Africa. Indeed, if we were to draw a straight line from Cape Sable, Nova Scotia, to Dutch Guiana, and fill the region to the west of it, a glance at a terrestrial globe will show that the western continent if carried eastward 2,500 miles would exactly fit into the eastern one from Behring's Strait nearly to Cape Horn.

This low, irregular coast line is very different from that of the Pacific. The outline of the latter is smooth and nearly that of a great circle whose centre lies on the Tropic of Capricorn in longitude 153° W. It is bounded everywhere from Cape Horn to the East Indies by a continuous row of active or extinct volcanoes, while a few thousand miles north of the centre of this area rises perhaps the finest group of volcanic peaks on the whole globe. This dissimilarity of outline has never been explained. No similar configurations are found upon either the Moon, Mercury or Mars, the only other bodies in the universe whose permanent surface features are as yet open to our scrutiny.

The somewhat fanciful suggestion has been made that the great depression now occupied by the Pacific Ocean indicates the spot once filled by the Moon, and that the eastern and western continents were torn asunder at the time of that great convulsion, floating like two huge ice floes on the denser, partially metallic, fluid of the Earth's interior. Later, when the surface had sufficiently cooled, these huge depressions were filled with water, forming our existing oceans.

A body of the size of the Moon would equal in volume a section of the Earth's crust having an area equal to the terrestrial oceans and a uniform depth of thirty-five miles. Since the mean depth of the ocean bottom may be taken at about three miles below the continental surface, this would indicate that a solid crust thirty-five miles in thickness was floating to a depth of thirty-two miles on the Earth's liquid interior. This would give a not improbable value for the specific gravity of the liquid interior, nor is thirty-five miles an improbable value for the thickness of the terrestrial crust at that date. The Moon's specific gravity (3.5 times that of water) is also a probable value for the density of a layer of the Earth's crust of that thickness. Moreover, if the Earth had a solid crust at that time, such a catastrophe would be almost certain to leave some permanent scar upon it.

While we at present know of no reason for rejecting this curious supposition, we must at the same time recollect that we do not know that all of the materials which form the Moon were carried off at the same time, or from the same place; nor do we even know that any portion of the Earth's crust was solid at that time. The supposition must remain, therefore, a mere conjecture, incapable either of proof or denial.

CHAPTER II

ROTATION, DISTANCE, ORBIT, LIGHT, LIBRATION, GRAVITATION

THE earliest observers must have noticed that the Moon always presented the same face to the Earth. This is due to the fact that it rotates on its axis in precisely the same time that it revolves around us in its orbit. If these two periods, each of a little less than a month, did not agree with each other within a fraction of a second, we should sooner or later see what was on the other side of the Moon. Of course, this exact agreement cannot be due to chance. For it we must again thank, or rather perhaps blame, the tides. But in this case it is not our tides raised by the Moon, but the Moon's tides raised by the Earth, that did the work.

This simple observation, that the Moon always shows us the same face, will then, when properly interpreted, lead us to the interesting conclusion that the Moon itself was formerly partly fluid and in this fluid condition was affected by the great tides of that early period—tides not of water, but of molten rock, rising not merely a few feet every twelve hours, but as many miles in height, or perhaps even more. Such fearful tides would quickly retard the rotation even of a body of the size of the Moon, with the result that it would soon cease to rotate with regard to the tides—that is, it would present always the same face to the Earth. Under these circumstances, as we have just seen, its period of rotation on its axis and of revolution in its orbit would coincide. If referred to some particular direction, such as that of some star, we find that at the present day they would very nearly equal twenty-seven and a third of our days.

That the Moon's interior is now practically solid is almost certain, while the great tides that fixed its rotation must have ceased ages before the human race was born. Since that early time the period of revolution of the Moon in its orbit must have, as we have already seen, increased. How is it, then, that since the tides have ceased its periods of rotation and revolution still coincide? The answer is that the tides must have left their permanent mark upon our satellite, so that its surface is not spherical, but slightly elongated, the elongation lying in the direction of our Earth. Consequently, if the Moon's time of revolution begins to exceed that of its rotation, the force of the

Earth's attraction on this projecting surface will retard its rotation by just the proper amount to bring about a coincidence with exactly the same result that a tide would have had.

Thus we never have seen and never shall see what is on the other side of the Moon. But we may perhaps console ourselves with the belief that it is undoubtedly very like the side that we do see. Hansen formerly suggested that the Moon's centre of gravity was thirty miles farther from us than its centre of figure. If this were true, we should be looking down upon a great tableland, while all of the Moon's atmosphere and oceans would have flowed around to the other side, rendering that side fertile while this side remained an absolute desert. This would be interesting if true, but we now know that such is not the case.

As we all know, the Moon apparently revolves about the Earth in an elliptical orbit once a month. If we disregard its motion about the Sun, this statement is literally true. This fact is determined by noting the difference in its apparent size in different portions of its orbit. Thus, owing to its varying distance, it sometimes appears about twelve per cent. larger than it does at others. While this difference is not noticeable to the unassisted eye, we can detect it on some of the photographs. Thus if we examine Plate 5A we shall see a large dark plain near the centre of it, known as the Mare Serenitatis. If now we turn to Plate 5E we shall see that the *mare* appears decidedly smaller. This is because when the second picture was taken the Moon was at a greater distance from the Earth. The greatest distance from us that the Moon ever gets is 253,000 miles; the nearest it ever comes to us is 222,000 miles. Its mean distance is 239,000 miles, or about one four-hundredth part as far as the Sun. Its maximum apparent diameter is 33′ 33″, its minimum apparent diameter 29′ 24″, and its mean diameter 31′ 08″.

The Moon is constantly moving rapidly eastward among the stars, although carried still more rapidly with them toward the west, owing to the Earth's rotation. Since its orbit is considerably inclined to the plane of the Earth's equator, it also sometimes moves northward and sometimes southward in the sky. When it is moving rapidly northward it rises at pretty nearly the same time night after night for several nights in succession. In the latitude of 40° the difference in the time of rising sometimes amounts to less than twenty-five minutes, instead of fifty—the average amount. As we go north the difference becomes less and less, until finally when far enough north we may at times find the Moon for a few evenings rising at an earlier and earlier hour. When the difference is slight, if the Moon at the same time happens to rise in the early evening, which it does when it is full, the phenomenon is quite noticeable and is called the Harvest Moon. This is the full moon which occurs nearest to the autumnal equinox. The next full moon following is called the Hunter's Moon.

The time required by the Moon to travel around the heavens until it arrives at the same point or star again is, as we have just seen, twenty-seven and one-third days. This period is called one *sidereal* revolution, and is the true period of revolution of the Moon. The time required by the Moon to again reach the same phase—as, for instance, from full moon to full moon—is twenty-nine and one-half days. This period is called its *synodic* revolution, and is what we ordinarily speak of as the lunar month. Both periods are liable to a slight variation; in the latter case it sometimes amounts to a little over half a day one way or the other. This period of twenty-nine and one-half days also represents the time required by the Sun to again reach the same altitude as seen from any particular lunar formation, and corresponds in the case of the Earth to what we ordinarily speak of as the solar day of twenty-four hours. The variation in length of this lunar day never amounts to more than a few minutes, so that, although it has the same average length as the synodic revolution, the two do not always exactly coincide. Thus, for instance, if the Moon is on the first quarter the same formation may sometimes be in full sunlight and sometimes in shadow. Since the lunar day is twenty-nine and one-half terrestrial ones, we always have to wait two months, or fifty-nine days, before we can repeat an observation with the terminator in the same position—or what comes to the same thing, with the Sun at the same altitude as seen from any given point upon the Moon.

The phases of the Moon are due to the fact that the Moon is a dark spherical body shining only by reflected light. Usually we can see but a portion of the hemisphere that is illuminated by the Sun. If we see less than half the illuminated hemisphere, the Moon is said to be a crescent; if more than half, it is spoken of as gibbous. When we see exactly half, the Moon is said to be on the quarter. Astronomically speaking, it is new moon only when the Moon is just between us and the Sun, and is therefore invisible. In ordinary parlance, however, we speak of it as new moon two or three days later, when we first see it in the west after sunset. Under these circumstances, when the sky is sufficiently dark, we can always see the complete outline of the disk, faintly showing against the background of the sky. This faint illumination is due to light coming first from the Sun, thence reflected from the Earth, thence from the Moon, and so back to the Earth. It is, in fact, earthlight shining on the Moon.

The first photographs which were probably ever taken of this faint illumination were made at the Harvard Observatory in 1888. From them it was possible to show that the Earth was photographically 23.6 times as bright as the Moon, or about 1.7 times as bright per unit area.*

The light given out to us by the Moon varies very rapidly with the phase. Thus the light of the Moon when it is full is about eight times as bright as when it is on the quarter. The full moon is about 60,000 times as bright as Vega, the brightest star in the northern heavens. The Sun is about 400,000 times as bright as the full moon, and is therefore about 24,000,000,000 times as bright as Vega. Astronomically, these facts are expressed by saying that Vega is of the 0.0 magnitude, the full moon is of the −12.0 magnitude, and the Sun is of the −26.0 magnitude.

As the Moon moves at different speeds in different portions of its orbit, according to its distance from the Earth, while its rotation on its axis is uniform, the result is that we sometimes see a little farther around one edge of the Moon and sometimes around the other. This is called the Moon's libration—*i. e.*, balancing—in longitude. As the axis of the Moon is somewhat inclined to the plane of its orbit, it turns sometimes one pole toward the Earth and sometimes the other, for the same reason that the Earth turns its poles alternately toward the Sun. This is called the Moon's libration in latitude. These librations each amount to about seven degrees, and as a result we do see a little of the other side of the Moon—in fact, about nine per cent.; there therefore remains only forty-one per cent. of which we never see anything at all. The librations of the Moon are quite readily detected with the naked eye if we are used to the configurations of its surface. They may be seen on the photographs if we compare Plate 16D with 16E and Plate 10B with 10C.

Although as compared with most of the celestial motions the speed of the Moon in its orbit about the Earth is extremely slow, yet as compared with our terrestrial standards it is quite rapid. It moves with a mean velocity of 3,350 feet per second, or a little faster than the highest speed yet given to a cannon-ball. This velocity is most readily observed at the time of a total solar eclipse, when the observer, if located upon a hill or mountain, may watch the shadow of the Moon as it sweeps over him across the

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* Annals of Harvard College Observatory, XVIII., p. 75.

landscape. The speed is really somewhat greater than that observed, since the observer is himself carried in the same direction, though at a slower speed, by the rotation of the Earth on its axis.

At the surface of the Earth it is known that bodies fall sixteen feet in the course of a second, owing to the force of gravitation. The same force causes the Moon to drop one-fifth of an inch toward the Earth in the same time. A deflection of one-fifth of an inch in 3,350 feet does not seem a very large amount, but it is sufficient to deflect the Moon's course out of a straight line into a closed orbit around the Earth.

It is singular that gravitation, the most predominant and all-pervading force in the universe, should be the one least understood. No satisfactory hypothesis has as yet been advanced to explain it, excepting that we know it must be a stress of some sort ~~transmitted through the ether, and~~ affecting all bodies alike. Yet, when we consider what a tremendous power it is, it is impossible to conceive how it can be transmitted through a material so impalpable as to offer no resistance whatever to the enormously rapid motions of the heavenly bodies, and to be capable of transmitting such vast stores of energy in the form of light and heat with such almost inconceivable velocity.

In order to comprehend the total amount of attractive force existing, for instance, between the Earth and Moon—two comparatively insignificant bodies in the universe—let us imagine all the ether removed, and that in its place we substitute a steel rod a quarter of a million miles in length and having no weight. In order that the rod may properly take the place of the ether, and not be broken by the strain placed upon it, it must be at least 225 miles in diameter. If it were less than this it would be snapped like a pipe-stem by the gigantic force that the invisible, weightless ether transmits without our even noticing it.

The mass of the Moon—that is, the amount of matter it contains—is one-eightieth that of the Earth. Bodies on its surface, therefore, are much lighter than they are here, notwithstanding the smaller size of the Moon. The ratio is almost exactly one-sixth; consequently a man weighing 180 pounds on the Earth, if transported to the Moon, would find that he only weighed 30 pounds there, and could carry two men at once on his back for twenty miles much more easily than he could walk that distance without a load here. He could throw a stone six times as far as on the Earth, and jump six times as high. Indeed, jumping over a moderate-sized house or tree would be a gymnastic feat scarcely worth mentioning upon the Moon.

CHAPTER III

ATMOSPHERE, WATER, TEMPERATURE

THAT the Moon's atmosphere is much less dense than our own we can learn without a telescope by mere inspection. If the Moon had a dense atmosphere we should see that large portions of its surface were at times obscured by clouds, as is the case with the Earth, Jupiter and Venus. We should also notice that its surface features, especially near the edge, were indistinct, and with the telescope these peculiarities would become much more conspicuous. Nothing of the sort is ever seen, however. The only possible exception consists of certain small local clouds, in whose existence some selenographers believe.

To say that the Moon's atmosphere is very rare is one thing, but to measure its density is quite another, and that astronomers can even get a clue to this without actually going there, barometer in hand, may at first sight seem very surprising. The method actually employed, however, is very simple. We know that when a ray of light coming from a star passes through the Earth's atmosphere in a nearly horizontal direction it is bent out of its course or refracted through an angle of about half a degree. Similarly, a ray of light coming from a star and passing very near to the Moon's surface should be refracted by its atmosphere, and by measuring the angle through which it is bent we should be able to compute how dense that atmosphere must be.

This is the view which astronomers generally have held, and it is undoubtedly correct when the atmosphere is reasonably dense. When, however, the atmosphere becomes extremely rare, so that the individual molecules of which it is composed are relatively far apart, we are not sure just what will be the effect on the refraction, and it is barely possible that the Moon may in reality have a much denser atmosphere than observation would seem at first sight to indicate. This refraction is extremely slight, for the Moon frequently passes in front of, or occults, small stars, but the displacement produced at such times is so small that we cannot measure it. We cannot therefore say what the exact density of the Moon's atmosphere really is. On the assumption that it is proportional to the refraction, we may state that its density probably does not exceed the one ten-thousandth part of our own.*

The question may now be asked, Is there any evidence that the Moon has any atmosphere at all? When the Moon is crescent-shaped some observers believed they detected a faint twilight prolonging the cusps or horns of the Moon. Again, in certain craters such as Stevinus, the central peaks can under favourable circumstances be seen for some hours before they are illuminated by the Sun. This latter phenomenon, however, is probably due to light reflected from some of the brilliant snow surfaces in the immediate vicinity. Perhaps the strongest evidence that we possess of a lunar atmosphere, based on direct observation, is found when the Moon occults a bright planet such as Jupiter. Under these circumstances a dark band is always seen crossing the planet, tangent to the edge or limb of the Moon. This absorption is never seen at the dark limb of the Moon, indicating thereby that the absorbing medium, whatever it is, is condensed to a solid by the intense cold that must prevail during the lunar night.

Some astronomers have attempted to explain this dark band as a mere contrast effect, due to the fact that the surface of the Moon is brighter than that of the planet; this would not be so were Venus, the planet, occulted by the Moon, but, unfortunately, favourable occultations of Venus are rare. Nevertheless, we have a very convincing proof that the dark band is a real phenomenon and not a mere subjective effect of contrast, inasmuch as it has been photographed. A photograph of an occultation of Jupiter was taken at the Harvard Observatory station at Arequipa, Peru, August 12, 1892. The two equatorial belts of the planet were well shown, while the dark absorption band due to the Moon's atmosphere was seen at right angles to them and tangent to the surface of the Moon. We thus have ocular proof that the Moon has an atmosphere. In the succeeding chapters we shall find further evidence bearing upon this subject.

The astronomers of a past generation believed that the Moon had no atmosphere at all, and it was one of the more interesting questions of the old astronomies as to what had become of it. We believe that the Moon at the present time possesses less atmosphere than it did formerly, and we shall now endeavour to explain why this is so.

When the Moon parted company from the Earth it is fair to assume that they divided their common atmosphere between them in proportion to their respective masses. Since the Moon's mass is to that of the Earth as 1 to 81.4 and its surface as 1 to 13.5, its

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*Annals of Harvard College Observatory, XXXII., p. 239.

atmosphere would then have contained almost exactly one-sixth as many molecules per square mile as that of the Earth. But since the force of gravity at the Moon's surface is, as we have seen, also one-sixth of that at the surface of the Earth, the density of the lunar atmosphere must have been only one thirty-sixth part of that of the Earth's. This would correspond to a pressure of .83 inches of mercury at the Earth's surface, and we should not under any circumstances expect to find a lunar atmosphere of greater density than this. But even this is 300 times more dense than what we actually find at the present time.

It is now known that the gases of which our atmosphere is composed are made up of little particles or molecules, each far too small to be seen even with the most powerful microscope, and each moving at ordinary temperatures with about the velocity of a cannon-ball. A few move many times faster than this, and a few many times slower. That they do not hurt us is due to their small size, but the result that we do feel is the well-known gaseous pressure. Now it may be shown mathematically that if a cannon-ball or any other body were fired directly upward from the Moon, with a velocity slightly exceeding one and a half miles a second, it would quit its surface never again to return to it. Those molecules, therefore, that are moving with the highest velocity, if they happen to be pointed in the right direction, will escape, and as time goes on, if the average velocity does not diminish, practically all of the molecules will ultimately get away.

It is also known that the molecules of the light gases like hydrogen and water vapour are moving much faster than the molecules of the heavy gases like carbonic acid and argon. The lighter gases would therefore escape first, and if the other gases were so heavy that their molecules never attained a speed of one and a half miles a second, they would never escape at all. It is probable, however, that all gases are escaping with more or less rapidity, not only from the Moon, but also from the Earth. In the case of the Earth it is a much slower process, because on account of our great mass as compared to that of the Moon a molecule to escape from us would have to attain a velocity of about seven miles a second. But even if we did lose a few million molecules every second it would not much matter.

Perhaps the best way to give an idea of the size of a molecule is to say that the number contained in a box holding a single cubic inch at the ordinary atmospheric pressure is represented by the figure sixteen followed by twenty-one ciphers. But this number is too large for us to understand. Let us, therefore, suppose that 10,000,000 of these molecules escape every second from the box into a vacuum, how soon will the whole number of molecules in the box have disappeared? One might at first thought suppose perhaps in a day, or a year, or perhaps even as long as a century. The time required is easily computed, and we shall find that it will take just about 50,000,000 years before the last molecule in that cubic inch has got away. In point of fact, our atmosphere is probably disappearing at the present time at the rate of many millions of millions of molecules every second.

In the case of the Moon, most of the molecules seem to have already got away, but even if the density of the lunar atmosphere is only one ten-thousandth of our own, there are still enough left there to produce a pressure of several tons upon every square mile of surface. The density of our atmosphere is halved for every three and a half miles that we ascend, therefore at an altitude of forty-six miles the density of our atmosphere will be just equal to that at the Moon's surface. The density of the Moon's atmosphere is halved for every twenty-one miles that we ascend, therefore at an altitude of fifty-six miles the atmospheres of the Earth and Moon will have the same density, and at greater altitudes the Moon's atmosphere will be the denser of the two. Meteors entering the Earth's atmosphere first become visible at an elevation of about eighty miles, while the swiftly moving ones, such as the Leonids, are destroyed before coming within forty miles of the Earth. Meteors would first become visible on the Moon at an altitude of 200 miles above the surface; it therefore appears that a concentrated meteor shower upon the Moon would be quite as brilliant an affair as it would be upon the Earth. Our highest auroras sometimes reach an altitude of 600 miles. Similarly upon the Moon they would reach a height of 3,300 miles. We thus see that the Moon's atmosphere, assuming it to have a density no greater than that we have assigned to it, is even then a factor in selenography by no means negligible.

The next question that arises is, of what gases is the lunar atmosphere composed? The chief gases of our air—oxygen and nitrogen—would escape from the Moon's atmosphere about as readily as hydrogen does from that of the Earth. Carbonic acid would be retained with somewhat greater facility, but in general it is likely that any gas that was not constantly renewed from the Moon's interior would have practically disappeared from its surface long ago. Let us now see what gases are at the present time being given off from the Earth's interior. We find that there are only two that escape in large quantities—carbonic acid and water-vapour. The former would remain for some time on the Moon's surface on account of its weight, and the latter because on account of the low pressure the rapid evaporation would cause it immediately to freeze. Its action, indeed, would be very like that of compressed carbonic acid when suddenly released at terrestrial atmospheric pressure. As is well known, the solidified gas which immediately forms appears like snow, and slowly disappears by evaporation without melting. Its temperature is –109° F.

The cold produced in the lunar snow at this low pressure would be not far from –80° F., and at this temperature the evaporation would be very slow, even when exposed to the Sun. During the night time the Moon's surface temperature must fall far below this figure, so there would be little evaporation then. The Moon's atmosphere probably consists chiefly of these two gases, while we should expect to find the water vapour also in the solid form, as hoar frost, in considerable quantities. Water in the liquid form cannot exist upon the Moon. This is because it requires a pressure of at least 4.6 millimetres to condense it from the gaseous condition, and such a pressure nowhere exists on the Moon's surface. While carbonic acid may also be found there in the solid form, yet such a very low temperature would be required to maintain it in this condition at this pressure that it is more likely to occur in the daytime at all events, chiefly as a gas.

Although the Moon's atmosphere is so rare, yet the quantity of carbonic acid (which is to plants what oxygen is to animals) contained in a cubic foot of the Moon's atmosphere may in certain places be quite as large, or even larger, than that contained in an equal bulk of our own. In the Earth's atmosphere we find about three parts of this gas in ten thousand of oxygen and nitrogen. The Moon's atmosphere a mile or two above the surface we have assumed does not exceed one ten-thousandth of our own in density, but close to the small volcanic vents and cracks where the gas would be given off there is every reason to suppose it would be much more dense.

It was first pointed out by Schlösing that the supply of carbonic acid in our own atmosphere is maintained chiefly by volcanic craters and springs, and that the quantity furnished by animal life is comparatively insignificant. As volcanic energy is undoubtedly diminishing upon the Earth, this question of supply may in future ages become one of serious interest.

The temperature of the night side of the Moon must be about that of interplanetary space. This, according to Professor Langley, is not far from absolute zero, or –273° C., or –460° F.* What the temperature of the day side may be under a vertical Sun is very uncertain. Sir John Herschel and Lord Rosse thought it might exceed that of boiling water. Ericsson concluded that it was far below zero, while Professor Langley considers it very uncertain, but probably not far from the freezing point.

The most satisfactory test hitherto made seems to be that of Professor Very, † who compared the amount of heat received from the Moon by a bolometer with that received from an equal angular area of sunlit melting snow. The heat was next in each case allowed to pass through a piece of clear glass before reaching the bolometer. The glass allows nearly all the reflected heat to pass, but absorbs that radiated by the body itself. The total radiation in the two cases was about the same, but while the reflected heat was much greater from the snow than from the Moon, it was found that the radiated heat was much greater from the Moon than from the snow. This means that while the snow is the better reflector, as, indeed, we can see by inspection, the Moon is the hotter body. The observation is so direct and simple that it seems impossible to deny the accuracy of the conclusion, but of course it gives us no clue as to what the actual temperature is.

From his researches on the lunar spectrum ‡ Professor Langley is convinced that the Moon's temperature must be considerably below that of boiling water, so that all we can say for the present is that when the Sun is in the zenith the temperature on the Moon must lie somewhere between the freezing and boiling points of water, and not very near either of them.

It would be interesting to repeat Professor Very's observation, comparing the radiation from the surface of the Moon with that from a surface of rock illuminated by the Sun, and at temperatures ranging from the melting point of snow to the highest attained by rocks on the Earth's surface when exposed to a nearly vertical Sun. It would seem that in this manner we might somewhat increase the accuracy of our present knowledge of this interesting subject.

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* Mem. Nat. Acad., 1887, Vol. IV., Memoir IX., p. 206.

† *Astrophysical Journal*, 1898, viii., p. 266.

‡ Mem. Nat. Acad., 1887, Vol. IV., Memoir IX., p. 193.

CHAPTER IV

ORIGIN OF THE LUNAR CRATERS

VARIOUS theories have been advanced at different times to explain the origin of the lunar craters. Thus some have thought them the scars of huge bubbles that had burst, others that they were formed out of ice, while still others supposed that they were the scars left by the fall of enormous meteorites. The most natural theory is that they were formed very much like some of the craters that we find upon our Earth.

Let us examine these various theories a little more in detail. It is true that in volcanic regions where the lava is very viscous huge bubbles many feet in diameter sometimes form. When they burst they sometimes leave scars not unlike the lunar craters, but they do not have a central peak, such as is common upon the Moon, nor is it possible to conceive of bubbles one hundred or more miles in diameter.

The ice theory, first suggested by S. E. Peal, supposes the site of each crater to have been originally occupied by a pool of water, kept warm from below. The water evaporated and was deposited as snow in the region immediately surrounding it, thus building up the crater walls. This theory does not account for the central peak, nor for the rough and jagged character of the crater walls. Since the craters must be very ancient, if the walls were composed of ice they would long before this have flattened out in the processes of glacial flow. To accomplish this upon the Earth would require only a few years. On account of the lessened force of gravity, it would take just six times as long to do it upon the Moon.

The meteoric theory was first suggested by Proctor in 1873.* Meteors of the necessary size, however, that approached with planetary velocities, would on striking the Moon generate so much heat that it would not only completely melt the meteor, but also the crater walls that it might form, besides a considerable area of the surrounding country. Moreover, many of the apertures would be elongated where the meteor struck the surface at a considerable angle. We have already seen that when the Moon first separated from the Earth it could not at once have taken its present form, but must have been more or less fragmentary. Gilbert, in 1893, † showed that these fragments, which would

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* "The Moon," p. 346.

† Bulletin Phil. Soc., Washington, XII., p. 241.

not be moving very rapidly with regard to the Moon, would in general strike nearly perpendicular to the surface. The two prominent objections to the meteoric theory would therefore be removed. He caused drops of water to fall on a surface of thin mud, producing craters with walls and also in some cases with central summits. Dr. W. S. Bigelow, of Boston, carried on similar experiments, in which he fired pistol bullets into hardening plaster of Paris. R. S. Tozer has recently projected clay balls against a clay surface, thereby producing craters very similar in some respects to those found upon the Moon. A photograph showing some of his results will be found on Plate A, Figure 1.

There are two objections to this theory, however, which cannot be readily surmounted. If the Earth were originally surrounded by a swarm of bodies which gradually coalesced by collision to form our present Moon, the earlier collisions would be those of small bodies. As time went on, larger and larger bodies would drop into the Moon, and we should accordingly expect, when two craters happened to overlap, that in many cases the larger crater, being of more recent origin, would partially obliterate the smaller one. If, now, we examine carefully the plates illustrating this volume, we shall find hundreds of cases where small craters have impinged upon larger ones, the wall of the larger crater being in some cases totally destroyed by the smaller and later formation. I have so far found only two instances where a large crater has impinged upon a smaller one. One example will be found on Plate 1A, just to the right of the centre. In the other case the two craters lie between Zach and Curtius, and are well shown near the top of Plate 8E. It will be noted, moreover, that in neither of these cases is there much difference in the size of the impinging craters.

The other objection to this theory depends on the laws of viscosity of matter. We know that certain solids like moist clay will yield to pressure, and may be formed into craters. We know, also, that many solids, like iron, for instance, if uniformly heated within a rather narrow range of temperature, will also yield to pressure. Again, still other materials, like the rocks of our terrestrial crust, will yield if the pressure is great enough and is applied very slowly through a period of ages. But we know that these same rocks will break and not yield, no matter what the pressure, if it is applied suddenly.

We therefore conclude that, unless the temperature was exactly right and uniformly distributed, the lunar craters could not have been formed by collision, and if the temperature had been uniform, and had been right, there would not have been left precipices nearly vertical and thousands of feet in height, such as we find scattered throughout the lunar surface, as they would in this case have sunk under their own weight.

Having presented the arguments for and against each of the other theories, let us now see in what respects the lunar craters resemble and in what respects they differ from those of our Earth. Terrestrial craters are of two types, those like Vesuvius and those like Kilauea. To most of us the former is the typical volcano. Volcanoes of this type, which are by far the most numerous upon the globe, emit thousands of tons of steam at every eruption. It is, indeed, mainly by the explosion of this steam that the other volcanic products are expelled.

A volcano is primarily a crack in the ground. Steam rushing out of this crack enlarges it at one or more separate places, while the rest of the crack gradually fills and closes up when the pressure which produced it is relieved. The solid material projected from the enlarged portion of the crack slowly builds up a volcanic cone. The crater at the top is always small as compared with the erupted matter of the cone, seldom reaching a mile in diameter, while it is usually only a few hundred yards. The cone itself is symmetrical, and sometimes reaches a height of three miles above its base.

In the case of the terrestrial volcano, after a long period of comparatively quiet eruptions, or more commonly of no eruptions whatever, a tremendous explosion will sometimes occur which completely blows away the top of the mountain. Such an explosion will scatter the débris in the form of fine dust and ashes over thousands or even millions of square miles of the Earth's surface. The dust caused by the explosion of Krakatoa in 1883 was scattered by our atmosphere over the whole surface of the globe. It is computed that the column of stones and ashes at the time of the eruption shot up into the air to a height of at least seventeen miles, while the sound of the explosion was distinctly heard in the island of Rodriguez, nearly 3,000 miles distant.

Sometimes nearly the whole mountain disappears, leaving only a large crater ring. Later a small volcanic cone sometimes forms at the centre. This may grow to large dimensions, nearly filling the original ring. Many volcanoes have this appearance. Part of such a ring, known as Monte Somma, appears about Vesuvius. Not infrequently the ring fills with water, forming a circular lake. These crater rings, especially where the central cone is small or lacking, strongly resemble the lunar volcanoes. The three largest crater rings found upon the Earth are a nameless one in northern Kamchatka, Mount Asosan in the Island of Kiushiu, Japan, and Lake Bombon in the Island of Luzon, Philippines. Each of these rings measures about fifteen miles in diameter. Two other rings of ten and seven miles, known as Lake Bolesna and Monte Cavo, are found in Italy. Still others, somewhat smaller, exist in the western part of the United States. On the Moon, owing to the smaller force of gravity, we should expect such craters to have about six times the diameter they would have here; therefore, allowing for this, the difference in appearance between our own crater rings and what we actually find upon the Moon is not very great. The chief difference in their appearance is that on the Moon the crater floor is always lower than the surrounding country, while on the Earth it is usually higher.

There is an objection, however, to this theory, which lies not so much in the difference in the appearance of the craters as in the fact that we find no great symmetrical crater cones upon the Moon. Frequently a small irregular peak appears inside of a lunar crater, but it is very seldom surmounted by a crater of its own, and even if it is, it is always insignificant compared to the great ring that surrounds it. In fact, the features that are most prominent in our ordinary terrestrial volcanic regions are never seen upon the Moon.

Turning now to the other type of terrestrial volcano, two specimens of which are found lying close together on the Island of Hawaii, namely, Kilauea and Mauna Loa, we find something much more closely resembling the lunar type than do our ordinary crater rings. From these craters there is no large eruption of steam, no tremendous explosions destroying the mountain summits, and no towering volcanic cones. While their extensive crater floors, measuring from two to three miles in diameter and from 500 to 1,000 feet in depth, are considerably elevated above the sea level, yet the outer slopes of the volcanoes themselves are so gradual that it is readily seen that if many of them occurred, arranged as closely together as those found upon the Moon, the floors would be placed decidedly below the general surface level.

According to Captain Dutton, * the openings in these craters are constantly enlarging when in action by the faulting and slipping in of their sides. Numerous cracks occur around them and across the craters themselves, while some follow parallel to their inner edge, in these various respects strongly resembling similar cracks found upon the

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* United States Geological Survey, Fourth Annual Report, 1882–83.

Moon, and known as rills. Each of the large craters is accompanied by two smaller ones formed upon their rims, and, in the case of Mauna Loa, intersecting and partially destroying the rim of the main crater. The rim of the crater of Mauna Loa is extremely rough, much more so than the comparatively smooth slopes of the mountain, and is riven by cracks and faults upon every side. This roughness is also characteristic of the Moon. Well toward the centre of the crater of Kilauea was found a conical pile of rocks, some 400 feet in height, which contained the great lake of liquid lava. This cone had been formed during the few previous years by gradual elevation from the crater floor. It was rough and very irregular.

There seems, indeed, to be no feature found upon the Moon which is not presented by these Hawaiian volcanoes, and there is no feature of the volcanoes that does not also have its counterpart upon the Moon. Even the cause of the bright streaks upon the Moon, as we shall see later, is partly illustrated in Hawaii.

CHAPTER V

ORIGIN OF THE OTHER FORMATIONS

ACCORDING to Captain Dutton, the origin of the Hawaiian craters is due to the collapse and falling in of the mountain summits. In this view we can hardly follow him, as a localised melting of the Earth's crust would seem a more natural explanation. As illustrative of this matter, we will now describe a very simple experiment, which is or rather was formerly constantly performed in the ordinary processes of manufacture at our great iron works. It was early noticed by several different persons * that when a large mass of iron slag is permitted to solidify small apertures will form in its surface resembling in some respects the craters on the Moon. One of these earlier observers, Mr. J. A. Brashear, made a special study of this subject, and to him I am indebted for the following description and for the photograph which appears in Plate A, Figure 2. The crater there represented was formed naturally without any human intervention whatever. The mass of slag on the surface of which it appeared was somewhat conical in form, measuring about four feet in diameter by one foot in depth at the centre, and weighing perhaps 800 pounds. The rim of the crater measured three and a half inches in diameter. Mr. Brashear states that it is rare for a mass of slag of this size to cool without forming some sort of a crater. The crater only appears after the whole surface has solidified. The contraction accompanying this solidification causes the liquid interior, aided somewhat by the gases formed at the time, to burst through the solid crust and gradually to build up the crater walls. The fluid then subsides, leaving in some cases terraces. The floor next solidifies, sometimes again bursting through to form minute craterlets, and sometimes cracks in the hardening surface. On breaking up the slag, large cavities are usually found under the craters, and in one instance a secondary crater similar and of the same size as the first was found directly beneath it.

Since iron slag is a somewhat difficult substance to manipulate, it occurred to the author some years ago that one might conveniently substitute for it some material

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* See note by Mr. Mattieu Williams in Proctor's "The Moon," p. 354.

like paraffine.* This substance melts at so low a temperature that it can be readily handled in the viscous form, while at the same time it becomes hard and firm at ordinary temperatures. Like slag and the materials composing the crust of the Earth, it contracts on solidifying, the change in volume in each case being quite large.

The paraffine was melted in an enameled-ware pan, measuring three and a half inches deep by eight in diameter, over a small spirit lamp. By employing a small source of heat the paraffine was melted locally above the flame and soon formed a little hole in the surface crust measuring about one-quarter of an inch in diameter. That portion of the liquid in contact with the bottom of the pan was at a much higher temperature than that above it, and was forced upward by the heat, rapidly enlarging the hole formed in the upper crust. The hole retained its circular or elliptical form, and continued to enlarge as long as the hot liquid was brought in contact with it. As soon as it had reached a convenient size the lamp was extinguished and the cooling process begun. As the lower regions of the paraffine cooled they contracted, and the liquid surface dropped, leaving a smoothly cut elliptical pit (Plate A, Figure 3). The sides were at first quite shelving, but by reheating the fluid once or twice they became steeper, and even overhung in some places. Probably a slower cooling at the surface and a more rapid contraction of the fluid, obtained by using a larger reservoir, would accomplish the same result. If the contraction is allowed to proceed too far, however, the floor of the crater pit becomes concave and may even be broken through by the pressure of the atmosphere.

In order to imitate the former powerful influence of the tides upon the liquids contained within and upon the surface of the Moon, a brass tube one inch in diameter and twelve inches long was inserted in the paraffine when it was first melted. The tube was fitted with a wooden piston packed loosely with cotton flannel. By working this piston up and down the melted paraffine could be made alternately to rise and fall inside the craters formed by it, and the cooling process could be hastened when desired by blowing upon the liquid surface. Craters (Figures 4 and 5) were formed in the same manner as the first one, excepting that after extinguishing the lamp the tidal action was brought into play, alternately pumping the liquid up to the rim of the crater, where it partially solidified, leaving a little ring of solid paraffine, and then drawing it down again into the interior, where it soon partly remelted, preparatory to a renewed elevation.

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* See also experiments by Ebert, using fusible metal, "Annalen der Physik und Chemie," 1890, XLI., p. 351.

PLATE A

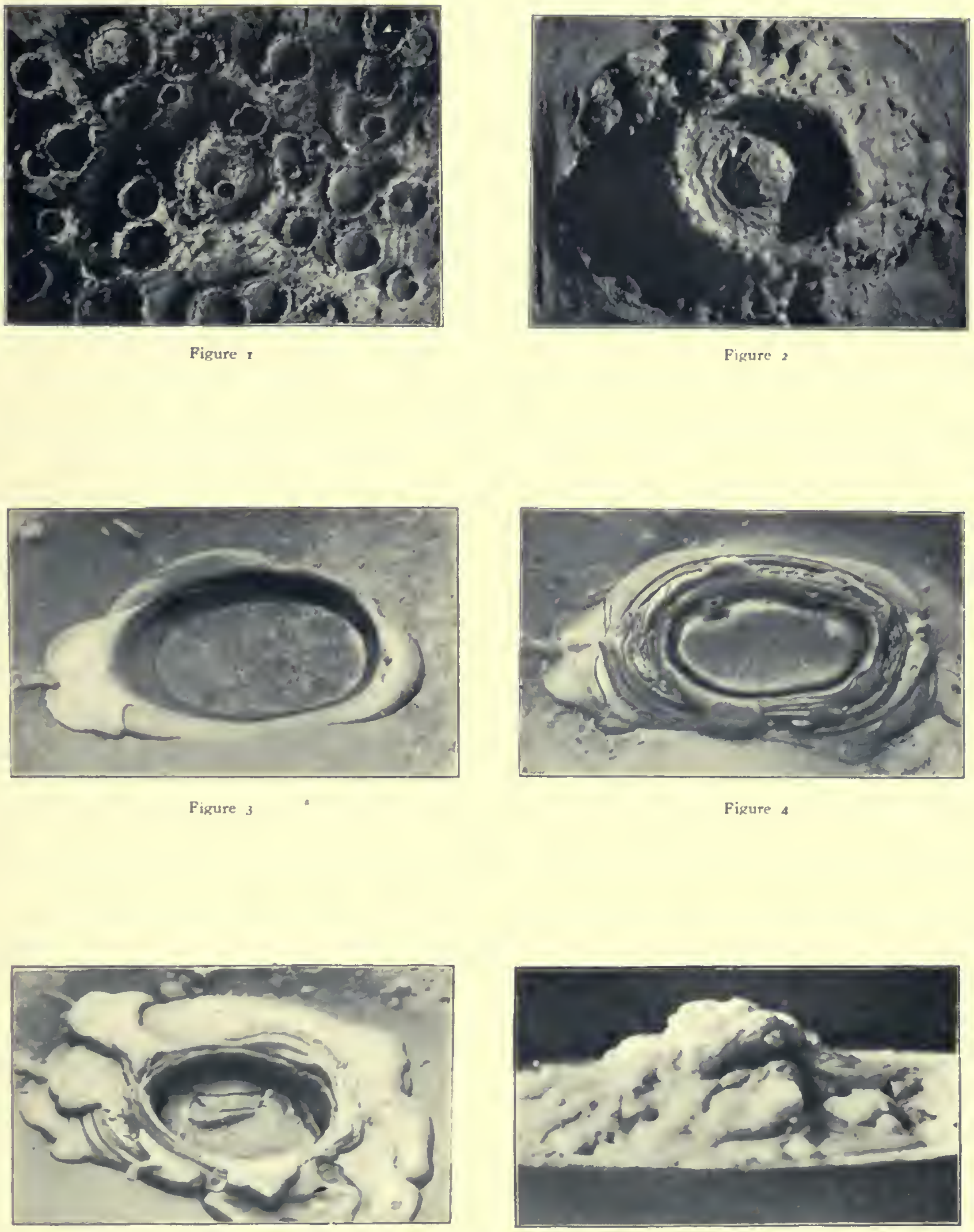

Figure 1

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6

ARTIFICIAL CRATERS

The craters shown above were formed artificially by various methods in order to illustrate different theories of the origin of the craters on the Moon.

This tidal action was continued until the fluid became quite viscous, solidifying into little hills and ridges inside the crater, and later, as the hardening surface was dragged out of shape by the pumping of the liquid below it, little cracks were formed around the edges and across the bottom of the crater, like the rills seen in similar situations upon the Moon.

If now we raise the piston high enough and wait for air to get underneath it, we may force this down into the melted paraffine. The result is an explosion, in which the paraffine may shoot up several feet into the air. If care is taken, however, the jets may be confined to a height of a few inches. A cone is soon formed (Figure 6), and the liquid paraffine trickles down the slopes in miniature lava streams. As the cooling process goes on the paraffine comes out in bubbles, like soapsuds, which break and rapidly build up the cone. If the process is continued further, partially solid lumps of paraffine are projected into the air, falling down upon the outer slopes of the cone. The crater now gradually narrows, and if care is not taken will soon become clogged. With care many well-known volcanic phenomena may be repeated, such, for instance, as the shifting of the crater to one side and the formation of a succession of crater rings and semicircles; also the bursting out of new craters near the base of the original cone. Indeed, the investigator is likely to perform this experiment involuntarily if he permits the main vent to get partially clogged and applies too much heat below. The introduction of air seems to transport us at once from lunar to terrestrial scenes, although in the case of the Earth the tides of course have nothing to do with the matter, their place being taken by irregularly recurring explosions of steam.

Applying now the results of our experiments to the case of the Moon, we may conceive that the order of formation was somewhat as follows. We will start with the Moon in the form of a liquid or viscous sphere, revolving about the Earth and not far from it. Under these circumstances the tides would be of enormous power and quite unlike in magnitude anything at present existing upon the Earth. Those constituents of the Moon having the least specific gravity would float upon the surface and soon solidify, forming a thin crust. Whether this occurred before or after the solidification of the central core through pressure is of no consequence. As it solidified the crust would contract, forming apertures, which would soon be enlarged into circular holes or craters by the hot liquid interior. Sometimes the craters would form along a crack. We have an illustration of this in the case of the great rill of Hyginus and the small craters distributed along its length. Hyginus is probably a later formation, however, as, if the crust had been thin, the craters would have been larger.

For the convenience of the reader, in the description of the various craters and other formations, a reference is given in each case to the plate at the end of the book on which the crater is shown to the best advantage. The position of the crater on this plate is indicated by two numbers placed in brackets. The first number gives the distance of the crater in inches and tenths from the left-hand edge of the plate and the second its distance from the bottom. Thus, Hyginus may be found on Plate 7E [2.1, 7.0].

It does not follow, however, that the statement made in the text can in every case be verified on the photograph. The best photographs ever made give by no means as satisfactory a view of the Moon as can be obtained by a telescope of even five inches in diameter, under suitable atmospheric conditions, and the more delicate features upon the Moon cannot be found on any photograph.

When the process of solidification first began on the Moon numerous comparatively small holes would form one after another. These holes would continue to enlarge, retaining their circular form, as the hot liquid was forced through them, until the action was stopped by a sufficiently thick crust forming upon the liquid surface. In the meantime, the tremendous tides engendered by our Earth, coursing through the imprisoned fluid interior, would fracture the thin and brittle crust in fresh places, where the same process would be repeated. When the crust was thin the enlargement of the crater would proceed rapidly, and the aperture might attain considerable dimensions before the restraining crust was formed, but as the original crust thickened and the passage connecting the aperture with the liquid interior lengthened we should find that the craters formed would be smaller but more numerous. We should thus expect, in general, that the older the crater the larger it would be, and that the smaller craters would impinge upon the larger ones, and not *vice versa*. An examination of the lunar surface, as we have just seen, shows this to be the case. The older and larger craters, like Clavius, 10A [2.1, 7.4], Albategnius, 8A [2.5, 2.8], and many others near the south pole, are pitted and sometimes almost concealed by numerous smaller and later craters, while craters of more moderate size, like Tycho, 10A [2.2, 6.2], Copernicus 11A [2.5, 6.9], and others still smaller, are comparatively free from such intrusions.

It can be shown that the maximum surface tension exerted by the Earth upon the Moon is produced upon the great circle forming the limb, and tends to separate the two hemispheres with a force which at the mean distance of the two bodies amounts to a tension of 9.6 pounds on the square inch. When the Moon was at one-tenth of its present distance from the Earth this tension would have been one thousand times as great, and would have been sufficient to shatter it to pieces had it then existed in the solid form. If, however, it were fluid or viscous, as we have supposed, the effect would have been merely to produce an enormous tide. In the meantime, if the Moon revolved rapidly on its axis, so that all portions of its surface were presented successively to the Earth, this maximum strain would be felt successively by all portions of its surface, the tendency being to separate or crack it in a meridional direction. We should thus expect to find that the earlier formations would have a tendency to lie in lines in a north-and-south direction. This we find actually to be the case with the craters that we have been discussing, particularly the larger ones. This fact has been pointed out by Webb, Neison and others.

The craters of this early period, of which Copernicus is a characteristic example, would be moulded by the enormous tides into forms resembling Plate A, Figures 4 and 5. The interior surface of one crater, Wargentin, 14B [1.7, 6.2], apparently solidified when the tide which filled it reached to its very rim. The aperture connecting it with the interior had in some way evidently become clogged, and the fluid which had formed the crater was thus caught as it were in the act, to serve as a clue and a perpetual illustration of the process of construction to all future generations. Another crater, Mersenius, 14A [2.5, 4.2], has a conspicuously convex interior. This was the case at first with the paraffine crater represented in Plate A, Figure 4, but subsequent cooling caused it to become concave. If the floors of the lunar craters when they solidified were in general convex, it is evident that the subsequent solidification of the fluid beneath them would tend to make the floor level, thereby producing a compression of the surface, which might well result in the formation of a central peak or ridge. If the paraffine model had been constructed upon a larger scale and the contraction of the fluid beneath it had been allowed to proceed more slowly, it is thought that this result might have been obtained, much as was the case in Figure 2. As it was, a tendency to form small ridges was noticed. In Figure 5 the internal surface of the crater was artificially broken, thereby producing the central mound.

As the cooling process continued, regions deeper down solidified and contracted. The upper layers, having now become completely solid, would not continue to contract at the same rate, with the fall of temperature, as when undergoing the process of solidification, and the result would be that the surface of the Moon, instead of being too small, would now be too large for its interior. When this "critical epoch" occurred, the formation of craters would for a time almost cease.

We have already seen that large cavities are usually found under the craters formed by the contraction and cooling of iron slag. In the case of the Moon, where such craters are numerous, these cavities would in many cases unite, and would thus cover considerable areas, leaving large empty spaces between the outer crust and the hot and viscous material of the Moon's interior. Should the partition walls between some of these cavities give way, large areas of the outer crust might thus be precipitated upon the partly liquid mass beneath, and since by the contraction due to solidification the specific gravity of the outer crust would now be greater than that of the fluid interior, the descending material would sink and melt, thus forming a fresh lunar surface in those places. This sinking and melting of the solid surface crust is frequently observed in the Hawaiian volcanoes. Whether the subsidence was cataclysmal or gradual is of little consequence; the subsident areas would be in general of circular form and of large area, as compared to the individual craters. This process is suggested as the probable method of evolution of the *maria* or seas upon the Moon. Conspicuous examples are the Maria Imbrium Serenitatis and Crisium, Frontispiece [4.2, 2.2], [2.5, 2.5] and [0.8, 3.1]. The darker colour of their floors would seem to indicate that they were formed from another kind of material, which, coming from a considerable depth, had united and mixed with the lighter-coloured molten matter which had formed the original surface. In these *maria* we often see the outlines of old crater rings which have been partially melted down and absorbed in the subsequent eruption of melted matter from the interior. Since in all cases the melting progresses outward from a centre, we see why it is that these large seas, like the smaller craters, all retain approximately the circular shape. In some cases where the original crust has subsided it has melted in the thinnest places only, such as the bottoms of the deeper craters. Thus Plato, Frontispiece [3.9, 1.4], probably had originally an interior like that of Copernicus [4.6, 3.3], but the melting process which destroyed the bottom was not carried far enough to ruin its walls also, as was partially done in the case of many of the older craters [5.6, 4.3]. The elevation of the surfaces of the *maria* probably indicates their relative age, the lower ones, since the interior of the Moon was constantly contracting, being formed last.

The characteristic difference between the *maria* and the larger craters, like Clavius, 10A [2.1, 7.4], Ptolemy, A [1.4, 2.3], and Schickard, 14E [1.9, 5.3], is that every crater is surrounded by a high, more or less continuous, mountain ridge or ring. In the case of the older and larger craters, when not too far destroyed by subsequent melting, the interior of the walls show a terraced structure due to the past tidal action. The *maria*, on the other hand, are usually surrounded by low shores. When they are high, as in the case of Crisium, 1A [2.4, 6.7], and Humorum, 14A [1.7, 4.6], the shore is either a plateau or a broken series of mountain peaks, rather than a continuous ring. The northern boundary of the Sinus Iridum, 11E [2.2, 2.4], is distinctly a plateau. The same was apparently true of the Apennines, 9A [2.0, 5.7], but the western side has sunk, leaving now a mountain range with very steep slopes on the east and a gradual decline on the western side. According to this view, therefore, the Apennines are merely the curved edge left to the original solid surface of the Moon by the molten flood, which, welling up from the interior, melted and destroyed everything before it, as long as the supply of heat lasted. Portions of the original surface, only partially destroyed, are seen in the regions about Archimedes, 9A [2.1, 4.4], and Autolycus [1.5, 3.9].

A considerable number of large and medium-sized craters, such as Aristoteles, 5A [3.3, 2.7], and Hercules [1.4, 2.9], show a single, well-defined internal terrace. In order to exhibit it the crater must be rather deep. Copernicus, 11E [1.7, 6.2], shows traces of several terraces, while Tycho, 10A [2.2, 6.2], which in many respects resembles Copernicus, scarcely shows any at all. Among large craters the single terrace is well shown in the case of Clavius, 10A [2.1, 7.4].

As soon as the surfaces of the *maria* had solidified, fresh compression of their molten interiors began, and a second era of crater formation was inaugurated. These craters necessarily differed from those of the earlier period in one respect, however, and that was that while the walls of the earlier craters were light-coloured, those of the secondary period were of the same colour as the material of the surrounding *mare*. Thus, of two craters located side by side in a *mare*, one may be light and the other dark. In such a case the former one survived the flood, the latter was formed subsequently to it. The craters of this second era are all of them of small dimensions. This secondary period seems to have extended to the present time, for, as we shall later see, small craters are even now being constantly produced, as in the case of the interior of Plato, 9A [2.3, 2.2]. Some craters, like Aristarchus, 13A [2.4, 5.3], and certain small craterlets, are intensely brilliant;

but this is an extraneous circumstance, to be presently described, having no bearing on the age of the crater. It is not probable that new craters would be formed anywhere but in the dark areas of the Moon.

The hypothesis is frequently maintained that the *maria* were originally covered with water. There seems to me no sufficient evidence to be found in support of such a conclusion. It is probable that the lunar atmosphere was never very dense, perhaps never exceeding one inch in pressure. Under these circumstances the evaporation from any large body of water exposed to the Sun's rays would be very rapid, and the condensation at night equally so. This more than tropical precipitation could hardly have failed to leave very conspicuous evidence of its former existence in denuded slopes and deep ravines. Moreover, the *maria*, although frequently in communication, are placed, as just noted, at very different levels. As the water gradually dried up, or was absorbed, and the upper seas emptied into the lower ones, channels would have been cut connecting them. Nothing of the sort is seen, however, although these would be the most favourable regions in which to observe them. In short, the evidence of the action of water upon the Moon is certainly very much less marked than upon the Earth, and seems quite inadequate to support the hypothesis that the *maria* were ever flooded.

The lunar craters may be divided according to their appearance into six classes, distributed in two periods. *Craters of the first period.* These all have bright walls. (*a*) Unaltered craters. These have high, sharp walls with rough interiors. Copernicus, 11A [2.5, 6.9], Tycho, 10E [2.1, 6.6], Arzachel [1.3, 3.9]. (*b*) Partially submerged craters. These have sharp walls but smooth interiors, which may be either dark or light. Plato, 9A [2.3, 2.2], Archimedes [2.1, 4.5], Ptolemy, 10E [1.3, 2.9], Schickard, 14B [1.9, 5.6]. (*c*) Softened craters. The whole crater floor and walls seem to have been softened and flattened. Posidonius, 5A [1.6, 4.5], Cassini, 7A [2.2, 3.5], Gassendi, 14A [1.9, 3.9]. (*d*) Submerged craters. Only portions of the rims of these craters show above the surface of the *maria*. Large nameless crater near Flamsteed, 13E [2.8, 8.4]. Numerous craters in nearly all the *maria*. *Craters of the second period.* All craters having dark walls belong to this class. (*e*) Dark craters shaped like Copernicus, but on a much smaller scale, rising in several of the *maria*. Lambert, 11E [1.6, 4.3], and other craters in Mare Imbrium. (*f*) Craters with smooth floors and walls, the interiors being much deeper than the exteriors. Most of the smaller craterlets found in the *maria* belong to this type. Helicon, 11E [1.6, 2.8], and Bessel, 5E [2.6, 4.8], are among the larger examples.

Owing to the sinking of the convex surface of the *mare* a compression will arise and ridges be formed. These are usually concentric, as in Maria Crisium, 3E [1.1, 6.1], and Nectaris, 6E [1.4, 2.7], but sometimes they pass through or near the centre, as in Mare Foecunditatis, 4E [0.7, 1.3]. When these ridges have sharp crests, owing to bending, they become less able to resist the internal compression, and craterlets often force their way through in such places. This compression, as we have seen, is the probable cause of the central ridge or peak found in many of the unaltered lunar craters, the weight of the surrounding mountain wall being an efficient aid in producing the requisite compression. As in the case of the ridges in the *maria*, a craterlet is sometimes found in the summit of the central peak, as occurs in Kilauea. Under these circumstances, as in the case of Timocharis, 11A [1.5, 4.7], the appearance is occasionally similar to that of the truncated cone of an explosive terrestrial volcano.

Among the most important of the smaller formations upon the Moon are the rills. These are simply gigantic cracks in the lunar surface, sometimes several hundred miles in length by one or two miles in breadth. They were formed at a time when the surface was too small for the interior and the fluid contents were so far removed from the surface that but little of it was able to escape and relieve the pressure. The rills are therefore of comparatively recent formation. They are rarely if ever found among the primary formations, unless these have been melted or softened by the subsequent application of heat. They are never found near the poles where the tidal action is small, although seen near other parts of the limb. Only three minute rills, therefore, are found in the Mare Frigoris, although they abound in the other *maria*. Nearly all the rills lie between latitude 57° North and 35° South. They are particularly numerous in the southeastern quadrant of the Moon and comparatively rare in the southwestern. The great rill west of Sirsalis, 16A [1.9, 1.8], the longest on the Moon, is supposed to be about 400 miles in length. Like most of the fine detail described in the rest of this chapter, it does not show on the photographs, but for the benefit of those wishing to look the matter up on the Moon itself the position of the various formations will be indicated by brackets, as before. The rill of Hyginus and its extension, which passes south of Julius Cæsar, are much the most conspicuous upon the Moon, and are shown in Plate 7E [2.0, 7.0 and 1.2, 7.1]. About a thousand of these rills are known to astronomers. They are frequently concentric with some *mare* or partially submerged crater. Striking illustrations of this are found just to the west of Mare Humorum, Frontispiece [5.5, 5.3], where three concentric systems of rills occur. The appearance of this *mare* is as if a thin skin had formed over the liquid surface and had then been broken and crumpled and drifted to the eastern side. Toward the centre and on the western side of Humorum are some long ridges, the western ones concentric with the *mare* and the rills. On the eastern side are some deep rills also concentric with the *mare*. One of them is shown on 14A [2.2, 4.6]. The paraffine crater (Fig. 4) shows a minute ridge stretching from the nearer side toward the centre. Later a rill formed upon the farther side concentric with the crater, thus showing that the surface was subjected first to compression as the floor of the crater fell, and later to tension as it contracted and receded from the crater walls.

The direction of the rill in many cases bears no apparent relation to the surrounding formations, and seems to be the result of a general contraction of the lunar crust. When it traverses a crater it is often evident that the latter is the earlier formation, as in Hippalus, 12E [2.8, 2.9], though in the case of Ramsden [2.7, 3.9] the crater seems to have been formed later. Some extremely broad and deep concentric rills are found in the interior of Wurzelbauer [1.0, 3.9]. The appearance of a crumpled skin seen in the Mare Humorum is also found in other formations, as in J. F. W. Herschel, 11B [1.4, 1.6].

An extremely rough and broken surface is found just to the north of Sinus Iridum, 11B [2.0, 3.1]. Few craters are to be seen, and it looks as if it might have been a part of the original surface of the Moon, before it had been pitted with craters or fused into *maria*. But what makes this region particularly interesting is that we have here a clear view of a section of the surface some two miles in depth, cut by the melted lava that formed the Sinus Iridum. An examination of this section shows a nearly vertical wall, in places perhaps overhanging, apparently composed chiefly of objects like huge boulders, measuring several thousand feet in diameter, but separated from one another here and there by interstices forming caves of surprising dimensions. As seen under favourable conditions, at Arequipa, the appearance was not unlike that of a piece of wood broken squarely across the grain. The structure of the wall is entirely different from that of the Apennines, which bound the Mare Imbrium on the west. Neither does it resemble the smooth, sloping terraced interiors of the larger craters.

Among the more noteworthy of the minor lunar features may be mentioned the following formations. To the north and also to the south of Copernicus, 11A [2.5, 6.9], are found a number of spindle-shaped cuts in the surface, like very elongated craters. They are on the average about two miles long by half a mile broad, and very much resemble in shape the mark that a bullet might make in penetrating obliquely a somewhat viscous surface. Scattered among them are a number of smooth, rounded mounds, some circular and some elongated. Some of the latter look as if they would exactly fit into the spindle-shaped cuts. Similar cuts are found in Cassini, 7A [2.2, 3.5]. To the north and west of Copernicus are a series of irregular elongated markings formed in part of craterlets, and due perhaps to the escape of gases through the formerly viscous surface from a submerged crack or rill. Similar markings are found to the southeast of Schiller, 12B [2.4, 6.2]. A little over one diameter due east of Gassendi, 14E [2.0, 2.2], is a curious ring of isolated elevations surrounding a central peak. A little north of Cavalerius, 15A [2.4, 6.7], is situated a very striking black peak.

A series of well-marked parallel grooves, each groove several miles in width, forms a characteristic feature of certain portions of the Moon's surface. They are well seen to the southwest of Pallas, 7E [3.2, 7.3], and lie in a direction nearly northeast by southwest. They extend from somewhat to the north of Hyginus, 7E [2.1, 7.0], as far south as Albategnius, 8E [2.4, 1.9], and are well seen on both these plates, also upon 10E, where more than a dozen grooved valleys may be traced. A less marked series of parallel grooves lies southeast of Sinus Iridum, 11B [1.9, 3.1], and another near the south pole. They are evidently similar to the great grooved valley of Rheita, 4B [2.5, 6.3]. Several similar smaller grooved valleys occur in this immediate vicinity, and are described by Gilbert, who ascribes their origin to large meteorites which just grazed the surface of the Moon. I have found no evidence of the meteorites at the end of the grooves. Their origin is more probably due to wide subterranean cracks, which caused the surface to soften and sag into them. A connecting link between them and the rills is to be found one diameter west of Posidonius. It is not well shown on the photograph, but its position may be found on 3B [3.1, 4.2]. It runs in a nearly north-and-south direction.

A large, nameless, ruined crater, 12E [0.9, 4.2], of oval shape, and exhibiting a curious spiral arrangement of supporting ridges, is to be found lying between Wurzelbauer and Heinsius. Although lava streams are seldom clearly defined upon the Moon, one may be seen where Wargentin, 14B [1.7, 6.2], overflowed its crater on the northeast, flooding the surrounding region. This overflow probably prevented the lava from rising higher in the adjoining crater [1.5, 6.3], north of Phocylades, [1.3, 6.5]. The interior of this nameless crater is on the same level as the surface of Wargentin and several hundred feet higher than the level in Phocylades proper.

In 1892 a small *mare* was observed at Arequipa* which apparently had never previously been described. It is of about the same shape and size as the Mare Crisium, but is rather lighter in colour. It is situated nearly due west of it 1C [1.1, 6.6], and is only brought into view under a favourable libration. It has recently been measured by Franz,† who proposes for it the name of Mare Marginis.

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* Annals of Harvard Observatory, XXXII., p. 249.
† Sternwarte, Breslau II., p. 33.

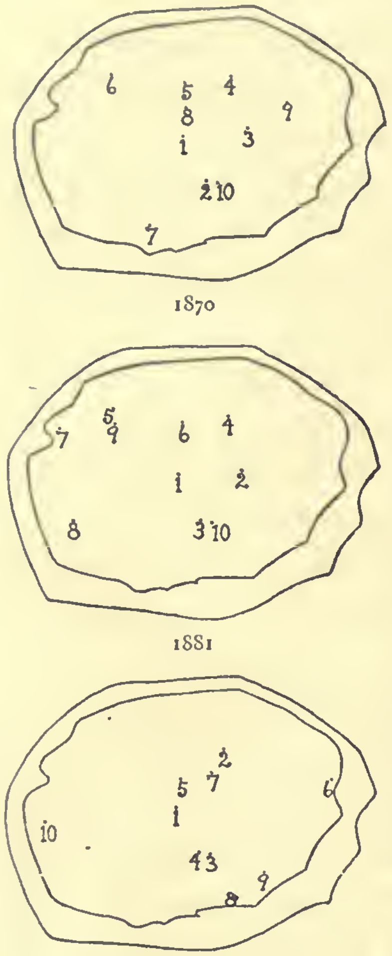
CHAPTER VI

Active Lunar Craters; Riverbeds

There is no doubt that in former times volcanic forces played a very important part in the history of the Moon. At the present time these forces have greatly diminished in intensity. All astronomers are agreed on these two points. The question is whether all volcanic action has ceased. The best-known example of possible volcanic activity within historic times is the little crater known as Linné, 7B [1.7, 4.2], after the great botanist Linnæus. Here our earliest evidence depends on a map constructed by Riccioli in 1651, where Linné is represented as a deep crater of moderate size. (See Plate I, facing page 84.) It is next noted by Schröter in 1788, who described it as "a very small, round, brilliant spot, containing a somewhat uncertain depression." It is certain that if the crater of Linné had been no larger then than it is now it could not have been detected by either of these astronomers with the imperfect telescopes of their times.

With more modern instruments, however, the testimony becomes much more precise. Thus, early in the last century Lohrmann described Linné as being very deep and as more than four miles in diameter. Maedler observed it seven times, and described it as very distinct under the oblique illumination of the Sun, when the contrast of shadow was strongest, and as measuring six miles in diameter. Schmidt drew it eight times, and represented it as being seven miles in diameter and one thousand feet deep. Schmidt, in 1843, was the last astronomer, apparently, to see it with any such dimensions, and in 1866 he announced that it had disappeared. A few months later, however, he found in its place a small craterlet about one-quarter of a mile in diameter, which, in the course of a couple of years, gradually increased to a mile and a half. Although still visible, its diameter has now sunk to three-quarters of a mile.

Another equally interesting but perhaps less well-known instance of lunar volcanic activity is the large crater known as Plato, 9A [2.3, 2.2]. The floor of this crater is a smooth, nearly level plain, some sixty miles in diameter, but studded over with numerous small volcanic cones. These range from about a mile in diameter down to a few hundred feet only. They were first carefully studied by a committee of the British Association between 1869 and 1872, and thirty-six craterlets in all were mapped. They were next studied by A. S. Williams and three other English astronomers acting in coöperation, who published a second map, showing thirty-eight craterlets. A few years later another map was published by the same astronomers. Finally, the craterlets were studied by the author in 1892, when he succeeded in mapping forty-two of them. The accompanying maps, however, show only the location of the ten most prominent craterlets in each of these three periods, the order of their prominence being in each case indicated by numerals.



1870

1881

1892

Fig. 2. Plato

It will be noted that the central craterlet is the most conspicuous throughout, but only three others are common to the three maps. The craterlet which was third in brilliancy on the first map was replaced in 1892 by a hazy patch of light. No. 5, as it is called on the first map, was so faint in 1892 that it could only just be seen. Nos. 6 and 9 could not be found at all, although a much larger telescope was used and the work was carried on under much more favourable atmospheric conditions. No. 10, on the other hand, was so conspicuous in 1892 that it was assigned the third place. The craterlet which was given the sixth place in 1892 may perhaps have been newly formed, as it had not been detected by any previous observer, while the seventh craterlet in 1892, which had been No. 13 in 1870, was entirely invisible in 1881, although seen as a very faint object a few years later by the same observers.

The next object to claim our attention on the Moon is the deep, winding cleft which has been named after its discoverer, Schröter's Valley, Plate 15E [0.7, 4.1]. At my first view of it in Arequipa I was struck by the strong resemblance of the crater which forms its source to the crater of a terrestrial volcano in a state of active eruption. Dense clouds of white vapour were apparently arising from its bottom and pouring over its southeastern wall in the direction of Herodotus. So striking, indeed, was this appearance, that, notwithstanding the fact that the supposition was distinctly opposed to what was at that time generally believed regarding the condition of the surface of our satellite, I determined to make a series of careful drawings of the apparent vapour column, in order to determine whether any variations in its outline might be detected from time to time, or whether, like a stain, it was immovably attached to the lunar surface. Since that time numerous drawings of it have been made, and of these, eight that were drawn in Arequipa, and eight that have been drawn since then in Cambridge, have been selected, and are arranged in Plate B, according to the portion of the lunar day in which they occurred. The scale is $\frac{1}{1,000,000}$, or one inch equals sixteen miles. The drawings are oriented, as is customary in astronomical works, so that south shall be at the top and astronomical east at the right hand. Since the crater is near the Moon's eastern edge, the volume should be so turned that east will be at the top, in order to compare the sketches with analogous terrestrial phenomena.

To the east of the main crater and included in the area covered by the sketches are seven craterlets, which we will designate, beginning at the south, by the letters *A*, *B*, *C*, *D*, *E*, *F* and *G*. *A*, *C* and *F* are shown in the first figure, drawn October 14, 1891. *B*, *C*, *D*, *E* and *G* are well shown in the twelfth figure, drawn April 6, 1898. A casual examination of the sketches shows the great changes that are from time to time undergone by the vapour column, as we shall for convenience call it—changes that are readily detected by a six-inch telescope under ordinary atmospheric conditions.

The most marked of these changes depend for their existence upon the altitude of the Sun, for apparently no volcanic activity whatever is exhibited until about one day after sunrise. The activity then increases to a maximum, diminishes, and finally ceases a few days before sunset. The changes thus produced are naturally very marked, but, besides these, others are found to occur, which can be differentiated from them, and which seem to be quite as spasmodic, and quite as unamenable to any apparent law, as any volcanic phenomena that occur upon the surface of the Earth.

Thus comparing the appearance of the region during the two periods discussed, we find the most marked distinction perhaps lies in the appearance of the jet of vapour which issued from the main column in the direction of craterlet *F* during the earlier period and which is shown as a continuous white area in nearly all of the first eight drawings. In nearly all of the Cambridge drawings, on the other hand, a distinct break occurs in this jet. The next most striking difference between the two periods relates to the eruption of craterlet *D*, which, while absolutely quiescent during the whole of the earlier period, with the possible exception of one day, as shown by the figures, was decidedly active throughout the whole of the later period. Another interesting feature was the drifting of the vapour column so as to sometimes conceal and sometimes expose craterlet *C*. The formation of a large gap in the main vapour column near the edge of the crater, in April, 1898, was something which had not previously been observed, although fine lines crossing it had been seen occasionally during the earlier period. As late as October 8, 1897, craterlet *C* was described, when compared with *D* and *E*, as "much the largest and most conspicuous" of the three. This had been frequently noticed and mentioned in the earlier period. Upon April 6, 1898, *E* is referred to as "much the most conspicuous of the three," while *C*, although not covered by the vapour, is described as the "least conspicuous." These statements were confirmed upon April 7th and 8th. The change in the direction of the vapour cloud arising from *F* in the month of October, 1897, was also a marked feature of the observations. Compare figures 10 and 11.

Whether these shifting white objects are due to streams of gas issuing from the craters and carrying with them white crystals of ice, thus forming real clouds upon the Moon, or whether the crystals are deposited as soon as formed, or whether they are formed only on the lunar surface itself like hoarfrost, it is impossible to determine at present. Perhaps all three of these conditions occur. That irregularly occurring lunar changes of some sort are in progress is all that we are sure of at the present time. One can see from these few examples that the evidence in favour of the idea that volcanic activity upon the Moon is not yet entirely extinguished is pretty strong, if not fairly conclusive.*

As the result of a very detailed study of the Moon in 1893, at Arequipa, a new kind of rill was discovered. From its resemblance to a terrestrial water-course it was named a riverbed, and it differs from the rills proper described in the last chapter in several important respects. In the first place, these minute rills or riverbeds are always wider at one end than at the other. Secondly, the wide end always terminates in a pear-shaped craterlet. Thirdly, their length is composed almost entirely of curves of very short radius, giving them a zigzag, winding appearance exactly resembling a terrestrial river as drawn upon a map. Fourthly, one end is nearly always perceptibly higher than the other. But here we come to a very marked distinction from the terrestrial rivers, for in the lunar rill the apparent mouth is always higher than the source. What this

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*Several other changes are described by S. A. Saunder in the Journal of the British Astronomical Association, XIV., 8.

PLATE B


Figure 1
1891, October 14, 0.6 days
56°

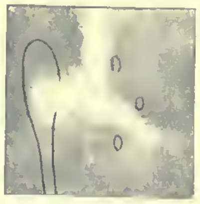
Figure 2
1893, January 30, 2.0 days
74°

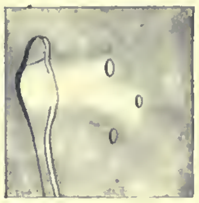
Figure 3
1891, September 16, 2.2 days
76°


Figure 4
1892, May 10, 2.6 days
81°

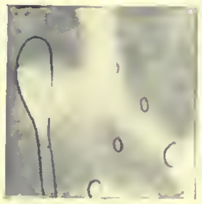
Figure 5
1891, September 17, 3.3 days
89°


Figure 6
1891, September 18, 4.3 days
102°

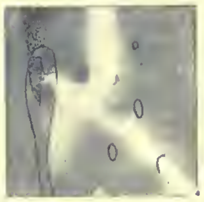
Figure 7
1891, September 23, 9.6 days
166°

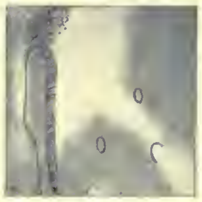
Figure 8
1891, September 25, 11.5 days
190°

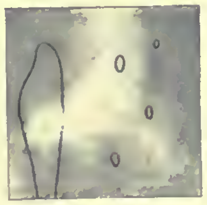
Figure 9
1897, October 8, 1.3 days
65°


Figure 10
1897, June 14, 3.4 days
91°


Figure 11
1897, October 10, 3.4 days
91°

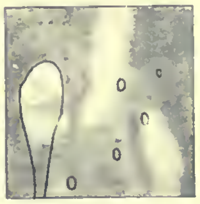
Figure 12
1898, April 6, 4.0 days
98°

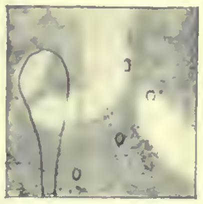
Figure 13
1898, April 7, 5.1 days
111°

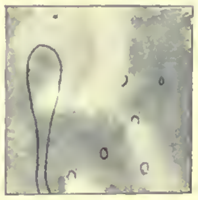
Figure 14
1898, April 8, 6.1 days
123°


Figure 15
1897, October 13, 6.3 days
126°


Figure 16
1897, October 15, 8.5 days
153°

SCHRÖTER'S VALLEY

Drawings of this formation made on different dates show changes which indicate volcanic activity

means, of course, is that if formed by the action of water, as seems from their appearance probable, the lake flowed into the river, and not the river into the lake.

Nor, when we come to think of the matter, is this result surprising. The pressure of the lunar atmosphere must always have been slight, and evaporation from the sunny side of the Moon extremely rapid. Indeed, several of the South American and also some of our own rivers, near the west coast, grow smaller and finally disappear after entering the desert regions of that portion of the continent. The only surprising feature seems to be that the sources of the lunar streams should have been so large. But the rills from the smaller sources cannot be detected, so that only the larger ones are seen, and they probably were not all flowing at the same time. With so much volcanic activity upon the Moon, it is not surprising that a considerable amount of water should have been expelled from its interior in the form of hot springs or geysers. The illustration (Fig. 3) represents a characteristic riverbed, which was classed by Schmidt as a rill, and which takes its origin on the Mount Hadley range, in the Apennines, upon the eastern slopes of the peak known as ς. Plate 7A [2.4, 5.3]. Its course lies a little west of north, and at the point of disappearance it is fifty miles in a straight line from its source, its length, measured around the curves, being about sixty-five miles. Its breadth at the point of exit from the craterlet is perhaps 2,000 feet; but it soon narrows to between 500 and 1,000 feet, although the stream itself was probably much narrower. This drawing was constructed from a series of sketches made February 6 and 25, March 5 and 27, 1893, and each curve and bend has been reproduced with all possible care and accuracy, so that the drawing represents, as nearly as may be, exactly what was seen and no more. Whether the forks shown near the bottom of the sketch on the right represent successive positions occupied by the stream, or whether they merely represent a couple of small rills of the ordinary type occurring by chance at that place, it is impossible to determine.


Fig. 3


Fig. 4

With one exception, this is the largest riverbed found upon the Moon. This exception is Schröter's Valley, which we have just been studying. The pear-shaped craterlet from which it starts is well shown in the various sketches (Plate B), while its general course is shown in Figure 4 and also on Plate 15E [0.7, 4.1]. At its exit from the craterlet it is three miles in breadth. It is about 120 miles long. Its apparent dimensions in a direction at right angles to the limb near which it is situated are considerably foreshortened. When near the terminator, it is seen that this riverbed originally took its origin in the crater of Herodotus itself, but that the exit was closed by a subsequent eruption of black material, nearly choking up the original valley. This cannot be seen as well when the Sun rises higher, and the valley actually at present terminates in the pear-shaped craterlet above mentioned. Although this formation is many times larger than any other member of its class, it is not so characteristic in form as some of the smaller ones, on account of its lacking the zigzag and winding appearance, which seems to have been nearly obliterated by its great width.

Returning now to the smaller riverbeds, we find that they have a marked tendency to occur in groups. Thus, five are found lying close together in the Harbinger Mountains, 13A [1.8, 5.0], and three more just to the east of them. One of the former group is forked, the two large southern branches uniting to form the northern one, which soon dwindles away and disappears. In all, thirty-five riverbeds, or possible riverbeds, have been detected upon the lunar surface. Of these, the next largest, after that upon Mount Hadley, occurs in Petavius, 2A [2.8, 4.4]. Most of them are only a few miles in length, and a few hundred feet in width at the widest part; and unless they are pretty deep, they are very difficult objects to detect—undoubtedly, taken as a whole, the most difficult class of objects to be found upon the Moon.

CHAPTER VII

ICE ON THE MOON; THE BRIGHT STREAKS

IF there are any active volcanoes upon the Moon, it is evident that they must expel something. In other words, there must be some gaseous pressure to make them active. As we have already seen in Chapter III., the gases which they are most likely to expel, judging from the case of the Earth, are water-vapour and carbonic acid. Water in the liquid state cannot exist upon the Moon. Above the freezing point it would be wholly gaseous; below it, it would be partly gaseous and partly solid, the formation in the latter case being analogous to snow, or perhaps, more strictly speaking, to hoarfrost.

Very many of the craterlets upon the Moon are lined with a white substance which becomes very brilliant when illuminated by the sun. The same white substance lines portions of some of the larger lunar craters and is found also on a few of the higher lunar mountain peaks. It may be noted in this connection that, owing to the bright yellow colour of a large part of the Moon's surface, the white regions present a greater contrast on photographs, and are thus more clearly defined than they are when observed visually through the telescope.

Besides these very bright patches and spots, there are other regions less brilliant, but exhibiting a curious characteristic. They are invisible for the first twenty-four hours after sunrise, but gradually appear as the sun rises higher and higher, becoming fairly conspicuous at the end of a couple of terrestrial days. Later they begin to fade, and finally disappear shortly before sunset. These "partly bright" regions, as they may be called to distinguish them from the wholly bright spots first noted, comprise considerable areas in the interior of some of the larger craters. They cover the upper slopes of many of the mountains, the rims and sometimes the central peak of numerous moderate-sized craters, and from a bright halo, so to speak, extending for miles around many of the smaller craters and craterlets. The most striking appearance, however, consists of long bright lines radiating in all directions—in some cases for hundreds of miles—from some prominent central crater.

It seems likely that these partly bright regions represent areas that are only partly covered with the white material of the more brilliant patches, which, perhaps in some degree through melting, has sunk into the hollows and crevices of the surface, leaving the projecting irregularities exposed. On account of the rarity of the atmosphere the lunar sky is absolutely black, and no substance, however white, will be visible until it is illuminated by the direct rays of the Sun. This explains why the partly bright regions are invisible at sunrise, since the white material which causes them can become visible only when the sun has risen high enough to shine into the crevices and cavities in which it lies.

The central range of mountains in Plate 9E is known as the Apennines. The photograph shows them at the close of the lunar day. It will be noticed that many of the peaks, although within a few hours of sunset, are still very brilliant, while other lower surfaces, equally inclined to the Sun's rays, are much darker. The brilliancy of the polar regions at the bottom of the picture is also quite noticeable, and is worthy of further attention. Thus, if we examine the photograph of the full moon (Plate C, Fig. 1), taken at a time when the two poles were about equally illuminated by the Sun, we shall find that it contains three large bright regions and numerous comparatively small ones. The latter are always associated with mountain peaks or craters. Of the three large areas, by far the most conspicuous surrounds the great crater Tycho, and extends northwestward from it as far as the Moon's equator. This whole region is elevated and mountainous. The two other large areas surround the two poles of the Moon; that at the south pole is virtually continuous with the region surrounding Tycho, although the space between them is slightly less luminous than either of these regions. The north polar region is quite isolated from the others. The entire limb or edge of the Moon is dark except for these two bright polar spots.

The position of the Moon's poles is shown by the two white lines. Plate C, Figure 2, is from the same original negative as Figure 1, but is so printed as to show the Moon as it appears to the eye in a small telescope. In comparison with Figure 1, it will be noted that the polar regions are but little brighter than the left-hand edge.

A comparison of Plates 6A and 6C shows a portion of the Moon taken at the time of lunar sunrise, and the same region five and a half days later in the lunation when the surface has become partially obscured by the appearance of the white material. The latter picture was taken two days before full moon, when nearly all the shadows had disappeared. A few small regions can be identified which are particularly bright in both pictures, and are permanently bright under all illuminations, but most of the

PLATE C

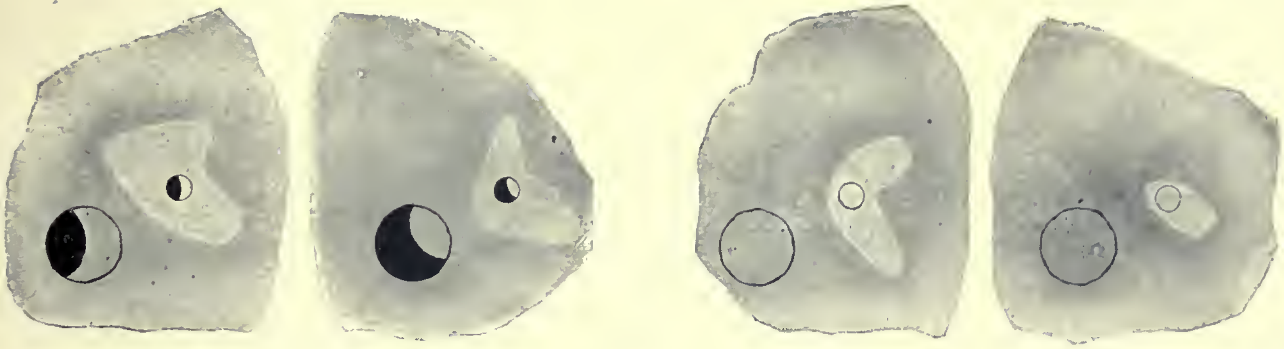
Figure 3
1901, June 25, 2.8 days
24°

Figure 4
1901, June 28, 5.7 days
60°

Figure 5
1901, July 1, 8.8 days
97°

Figure 6
1901, July 3, 10.8 days
122°

ABULFEDA *e*

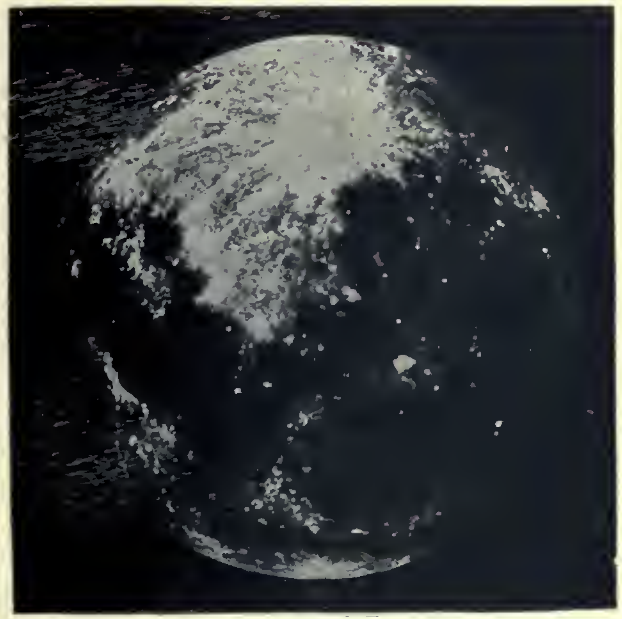
Figure 1
The Full Moon, Showing Ice


Figure 2
The Full Moon as Seen

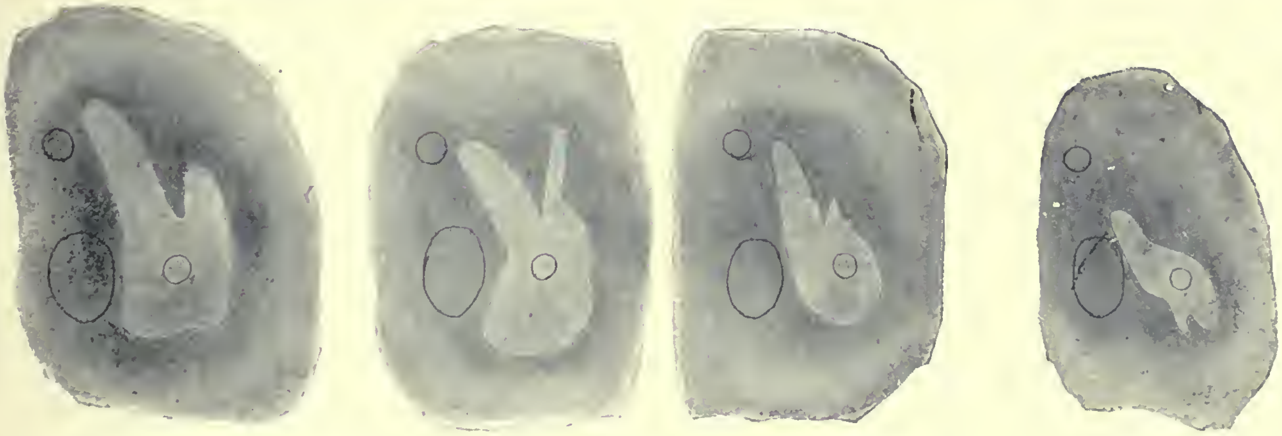
Figure 7
1901, March 27, 3.0 days
5°

Figure 8
1901, March 31, 7.0 days
54°

Figure 9
1901, April 5, 12.1 days
116°

Figure 10
1901, April 7, 14.1 days
173°

CENSORINUS

ICE ON THE MOON

These photographs and drawings show the location and the melting of the lunar ice deposits

white areas in the latter picture belong to the second class, that of partly bright regions.

The question now arises: Is this white material really snow? The fact that it gathers at the poles, on mountain peaks and about the rims of craters would lead us to suspect that such might be the case; but there are still other facts bearing upon the question which should first be considered. It will be convenient for this purpose to again refer to the crater Linné, 7A [1.4, 4.9], which has perhaps been more carefully studied than any other feature of the Moon's surface and about which our early knowledge is more reliable. This crater is surrounded by a halo of partly bright material, which becomes visible one day after sunrise. The diameter of the halo was measured a number of times by ten different astronomers during the years 1866, 1867 and 1868. For the most part, these measures lie between five and a half and nine and a half miles — a perplexingly wide range of variation. In 1897 and 1898 another series of measures of Linné was made by the author, who found that his measures, too, varied through a wide range, extending from two and a half to five miles. The result seemed inexplicable at first, until it occurred to him to compare the diameters of the area in question with the number of hours that it had been exposed, in each case, to the Sun. The whole matter then became clear. When the white spot first became visible, one and a half of our days after lunar sunrise, it was five miles in diameter. As the Sun rose, the spot rapidly diminished in size, until, one day after the lunar noon, it was only two and a half miles in diameter. From then on till one and a half days before sunset, when it disappeared, it steadily increased in size, reaching a diameter of four miles. During the lunar night it must have continued to increase, until after sunrise it again became, as before, five miles in diameter. We thus see not only that the spot was then permanently smaller than it had been thirty years before, but also that it was subject to a change in size dependent on the altitude of the Sun. The latter phenomenon is evidently analogous to that of the changing size of the polar caps of Mars and of our own Earth. The size of Linné may be compared on Plates 7A, 5B, 5C and 5E.

As the Sun rises higher and higher upon a lunar formation there are two diametrically opposite effects produced. One is a real, but comparatively inconspicuous, diminution in size of the white area, due to melting. The other is a very conspicuous increase, which, however, is really only apparent, and is due to the shining of the Sun into the hollows and crevices of the surface, and thus illuminating white areas which had not hitherto been seen. This apparent increase of size can be observed almost anywhere in the mountainous regions of the Moon, but the diminution due to melting is rare, and requires first a surface without deep crevices, where the snow can collect, and, second, a very thin layer of snow, such as can be vaporised by the heat of the Sun in the course of the lunar day. Such surface conditions occur on portions of the *maria*, and sometimes on crater rims. Thus in Plate 9B the rim of Pallas [1.4, 7.9] is seen to be white with snow. In Plate 9C a large part of this whiteness has disappeared, and in 9D and 9E the rest of it has vanished.

When the snow disappears toward the end of the lunar day it is impossible to determine whether the disappearance is due to evaporation or whether it is due to a low Sun which cannot shine into the crevices of the surface, but when the snow disappears in the middle of the day, as in this case, the only possible explanation, as far as we can see, is that it has evaporated.

On the lower slopes of most of the craters, wherever the frost or snow occurs, its apparent area increases with the rising Sun, indicating the existence of deep crevices in which it collects. The extent of the snow shown on a photograph of these regions depends largely on the exposure and development of the plate, so that no satisfactory evidence can be reached by this method.

At this point, however, visual observations come to our aid. The eye is so sensitive to minute contrasts of light that we can sometimes draw the outline of the brightest portion of the snowy region, and as this area diminishes in size under the effect of the Sun's rays we can obtain a series of drawings showing the changes in shape and gradual diminution in size of this brightest region. The eight smaller figures on Plate C give some sketches made in Jamaica showing the changes in the outline of some of these small white regions after they have been illuminated for different periods by the Sun. It will be noticed that in the case of Linné the spot was smallest one terrestrial day after lunar midday, and then again increased in size. In the case of the crater Abulfeda *e*, on the other hand (see also Plate 8E [1.7, 2.7]), the spot continued to grow smaller until it disappeared, and was not seen again until the next "lunation," or lunar day. The date of disappearance was about one day before sunset. Censorinus (see also Plate 6D [0.8, 0.4]) is another craterlet showing similar changes, except that the spot does not disappear until sunset.

Although the outlines of these white spots are sharply defined in the drawings for the sake of clearness, yet they are much more hazy when seen upon the Moon, and the observation, especially in the case of Censorinus, is not an easy one except under favourable atmospheric conditions. It has recently been found that the outlines are much more distinct when viewed through blue glass. The drawings of Abulfeda *e* are on a scale of $\frac{1}{2,000,000}$, or about thirty-two miles to the inch; those of Censorinus are on a scale of eight miles to the inch.

For a few days about the time of full moon a curious fountain-like structure or whorl may be photographed, proceeding south from Tycho, 10C [2.4, 5.6], toward the limb, then turning westerly and northward. It is well shown in the photograph, but is inconspicuous in the telescope.

There are no extensive unbroken snow-fields on the Moon which are brilliant at all altitudes of the Sun, unless they occur near the poles, where they cannot be well seen. The most conspicuous permanently bright regions generally occur within the lunar craters. Of these, Aristarchus, 13C [2.6, 4.7], is the most striking example. Outside of the craters the permanent snow-fields are usually small. On either side of Stevinus, 4B [1.6, 5.4], a bright region is found which is brilliant most of the time; there are two such regions to the east of the Mare Nectaris, 6C [0.8, 2.7], but perhaps the most conspicuous and permanent snow area found outside of a crater lies a few miles to the west of Hell, 10C [2.1, 4.4]. Another is found about three times as far to the east of it.

There is one other formation that may be mentioned in this connection that should have special interest for amateur astronomers, since it can be readily studied with even a four-inch telescope, and yet has gone through a series of changes that no astronomer has as yet been able fully to explain. I refer to the pair of craters known as Messier, Plate 4E [1.1, 1.1], and Messier *A*, [1.2, 1.1]. Their history, in brief, is as follows: Schröter first suspected some change in them, and represents Messier as the larger of the two. Beer and Mädler state that in size, shape and brightness they are precisely alike, and that the striking resemblance between them is most extraordinary. Webb pronounced them markedly dissimilar, *A* being now the larger of the two and of an entirely different shape. Neison describes *A* as elliptical; Elger says it is triangular, with curved sides.

Here would indeed seem to be sufficient evidence of a physical change on the Moon's surface, excepting for the fact that, as Neison justly observes, "it does not seem possible to conceive any admissible manner in which such a change could have been produced. . . . Until it can be shown with probability how on the Moon a round ring-plain some miles in diameter can be squeezed into a contorted form, the difference now existing between the two ring-plains of Messier will not in general be held to establish an instance of actual change in the formation on the surface of the Moon."

Now, singularly enough, not only was every one of these astronomers undoubtedly right in his observations, but any amateur can watch these identical changes going on from night to night before his eyes at the present time. He can watch a round "ring-plain" some miles in diameter as it is apparently in the process of being "squeezed" into a great variety of contorted forms. Moreover, at different lunations these forms are by no means identical. Sometimes one crater is the larger, sometimes the other. Sometimes one or both are triangular, sometimes elliptical. When elliptical, sometimes they are parallel, sometimes nearly at right angles.

As will be shown in Chapter IX., it is probable that a varying distribution of hoar-frost, instead of a definite distribution under definite conditions, is the cause of many of the changes observed. Some of these changes are shown in the drawings in Plate D. Figures 2, 3 and 4 were all taken at about the same time in the lunar day, on different lunations, but not only their shapes but even the dark markings within them all are different.

We will now discuss what some astronomers have considered the most enigmatical feature upon the Moon's surface—the great systems of bright streaks which surround certain craters, notably Tycho, and radiate from them in all directions, in some cases for hundreds of miles (see Frontispiece). Various theories have been proposed to account for them. Nasmyth supposed them due to cracks in the surface filled by a flow of white liquid material from beneath. Neison thought them due to some process of weathering not fully explained. Würdemann* suggested that they were caused by the splash of a meteorite, much like the splash that an egg might make if projected with sufficient force against a brick wall.

What has hitherto been considered one of their strangest features is that they are never visible at lunar sunrise or sunset, but require that the Sun shall have an altitude of at least five or ten degrees in order to render them visible. This peculiarity we have already explained as being due simply to the fact that the snow which forms them lies

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* Bulletin Philosophical Society, Washington, XII., p. 284.

in crevices instead of on a smooth surface. The Sun must therefore necessarily attain a certain altitude before they can become visible. This explanation is further sustained by the fact that the bright streaks are well seen under favourable circumstances three or four days after new moon, upon the dark side of the Moon, where they are illuminated only by light reflected from the Earth. This shows that they must be there throughout the lunar night, and that the reason that we do not see them at sunrise and sunset is merely on account of the direction from which the light reaches them.

Before attempting to explain their peculiar shape we must state certain facts with regard to them. Hundreds of these streaks exist upon the Moon, but in the great majority of instances they are found to issue from minute, intensely white craterlets. These craterlets are seldom over one mile in diameter, and are usually much less. The streaks are very brilliant when they issue from the craterlet, but broaden and grow fainter as they recede from it. Their maximum breadth seldom exceeds five miles and their length usually lies between ten and sixty miles. The nature of the individual streaks is seen very clearly in the telescope in the crater Pitatus, 10C [2.7, 4.1]. It is also well shown in Copernicus, 11C [1.7, 7.1], but does not become clearly visible there until the day before full moon.

Those streaks which do not issue from minute craterlets usually lie upon or across ridges, or in other similarly exposed situations. Frequently a number of the craterlets producing streaks are found to be arranged in the same direction in which the streaks lie. In such a case, before one streak comes to an end another will begin, thus forming a nearly continuous white band. A few of these white bands extend for more than six hundred miles. The combination of the streaks to form such a band is most readily studied in the conspicuous marking stretching from Tycho to Mare Nectaris. (Frontispiece [2.5, 5.7]; see also Plate 6C.) Under favourable atmospheric conditions it can be seen in the two parallel bands extending from Tycho toward Kepler, Frontispiece [4.5, 5.7], and in the band stretching from Menelaus across the Mare Serenitatis [2.5, 2.6].

The visibility of the streaks can be studied very satisfactorily from photographs. They become visible in general about twelve hours after sunrise and brighten for one or two days. They remain visible until about the same period before sunset. Latitude has little if any effect on the time of their appearance. It has been suggested by Professor N. S. Shaler that the existence of prominent craters on the other side of the Moon might be indicated to us by the presence of bright streaks radiating from them and showing around the limb. After a careful study of the Moon he thought he had discovered several such streaks. One of these is perhaps shown on Plate 3B [2.0, 2.4].

The streaks surrounding the different craters are not all alike. Most of them belong to the class so conspicuously represented by those surrounding Tycho. The streaks surrounding Copernicus, on the other hand, differ from them in several important respects. In the first place, the streaks about Copernicus are yellowish, while those about Tycho are white. Secondly, the streaks about Copernicus are somewhat curved and branching, while the others are straight. Thirdly, the streaks about Copernicus issue in general radially from the crater, while those about Tycho issue tangentially to the crater's rim. Fourthly, the crater of Tycho is surrounded by a dark halo, most conspicuous at lunar noon (Plate 10C); nothing of the kind is seen about Copernicus. Fifthly, under favourable atmospheric conditions we can distinguish the craterlets from which the streaks about Tycho take their origin. If such craterlets exist about Copernicus, they cannot in general be seen, except on the very rim of the crater itself, when under suitable conditions they are fairly conspicuous. While the streaks about Tycho are in general much the brighter, yet when they cross a *mare*, as do those radiating from Copernicus, the difference in brilliancy of the two systems is not very great.

That the background should affect the brilliancy of the streaks of the Tycho system indicates either that the material causing the streaks is partially transparent or that it occurs in small, separate areas between which the background is seen. The latter suggestion seems on the whole the more probable, and tends to confirm the accuracy of the explanation of the streaks already advanced.

Kepler, 13C [1.9, 6.5], differs from the two craters already mentioned in being surrounded by a bright continuous halo, with one or two dark spots on the northeastern side. This halo retains its brilliancy under nearly all illuminations.

The cause of the dark halo surrounding Tycho at full moon is unknown. If we compare the five plates, 10A, B, C, D and E, we shall see that there is a progressive darkening, reaching a maximum at noon, and then fading out again. The effect reminds us somewhat of Linné. But if the snow melts, which certainly seems to be the case, why should it occur only upon the slopes of the crater? Possibly the effect is analogous to the variable spots described in the next chapter, which always darken toward noon.

In attempting to give a satisfactory explanation of the shape of the bright streaks, we may start with the observed fact that those craterlets producing streaks which are situated in the vicinity of a prominent streak centre, such as Tycho, for instance, are distributed not uniformly, but with a tendency to occur along radial lines. Their positions probably indicate lines of weakness, or cracks in the surface, due to the original contraction of the crust. In the Hawaiian craters to which we have already compared those of the Moon radial cracks are sometimes found extending twenty miles or more directly away from the summits. Along these cracks are found small crater cones a few hundred feet in height from which occasionally issue jets of steam and other volcanic gases.

It is evident that upon the Moon, where the atmosphere is very rare, when those craterlets upon the rim of Tycho, for instance, become active, they would give rise to a wind blowing away from that crater in every direction. As this wind proceeded outward it would be reinforced by the wind from the various active craterlets that it encountered upon the way; there would, therefore, in general, be no opportunity for diverse currents, and if the wind were strong enough the bright streaks would necessarily lie radially as we observe them.

The objection to this explanation is the doubt as to the adequacy of such a wind to produce the results observed. Another and perhaps better explanation is that electrical repulsion, such as we see in our auroral streamers, acting in the rare lunar atmosphere, furnished the radial force which caused the arrangement in question. In this case the little white triangular area proceeding from each craterlet, which helps to form the white band that we observe, merely represents a little cometary tail of vapour, which has been rendered visible to our eyes by deposition upon the lunar surface in the solid form.

We thus see that the reason why these white radial bands are formed upon the Moon, but not upon the Earth, is due not to any difference in the volcanic eruptions of the two planets, but rather to the great difference in the densities of their atmospheres.

CHAPTER VIII

VEGETATION; THE LUNAR CANALS

WHILE the differences in the atmospheric conditions of the Earth and Moon render it impossible that similar organic forms should exist upon them, the differences, nevertheless, between the two are less marked than those which exist above and below the surface of the ocean—differences which certainly do not serve as a hindrance to a luxuriant organic growth in either region. If the Moon possesses an atmosphere containing water-vapour among its ingredients, no matter how rare it may be, there is no reason in the nature of things why organic growth upon its surface should be impossible, although it seems probable, under these circumstances, that any such growth would be of a low order as compared with that existing under the more favourable conditions upon the surface of the Earth. Moreover, if we find evidence of such growth, this, in its turn, increases the evidence in favour of the existence of water-vapour, and, consequently, in its frozen form, of hoarfrost.

We have already seen that in some localities the Moon's atmosphere may contain as much carbonic acid gas (which is to plants what oxygen is to animals) as our own. How vegetation can exist without water in the liquid state, however, seems at first a more difficult question to answer than how it can exist in a rare atmosphere; but even here we find partial analogies upon the Earth. That certain forms of desert vegetation can go for several years without water is well known, but whether they could continue to grow if the supply in the liquid form were absolutely cut off and only water-vapour furnished them is perhaps doubtful. On the antartic continent a certain kind of lichen is said to exist where the temperature rarely if ever reaches 32°—the melting point of ice. This probably represents pretty closely the condition of affairs upon certain parts of the Moon, and it is possible that water-vapour or hoarfrost deposited upon the vegetation is sufficient to supply all its needs.

Looking at the matter now from another standpoint, we find that the lunar vegetation would have two distinct advantages over our own. In the first place, since the force of gravity is less upon the Moon, the same leaves or fronds or branches would require but one-sixth the effort to lift and support themselves that would be necessary were they transported to our Earth. Secondly, since there are no high winds upon the Moon, if it were any advantage to plant life to lift itself above the surface of the ground it could do so with safety, instead of clinging close to the rocks, like our own arctic and antartic flora.

My attention was first drawn to the "variable spots," as I then called them, while observing at Arequipa in 1893. On leaving there it was possible to give little attention to the matter until 1901, when a return to a low latitude in Jamaica enabled me to continue the researches under suitable atmospheric conditions. The general phenomena exhibited by a variable spot are a rapid darkening, beginning shortly after sunrise, followed by an equally rapid fading toward sunset. The darkening is sometimes accompanied by a diminution in size, and the fading by an increase. Near sunrise and sunset the spots are almost invisible. At their maximum some of the spots are intensely black, some are a dark gray, and others a light gray. Near the equator the changes in density occur frequently in the course of a few hours after sunrise; in higher latitudes several days pass before the changes begin, but they are then usually very rapid. No spots are known north of latitude +55° or south of latitude—60°. The spots are always associated with small craterlets or deep, narrow clefts, and are often symmetrically arranged around the former. This again suggests volcanic activity and the expulsion of water-vapour. When found inside of a crater, they always, unless very extended, occupy the lowest portion of the floor. If the floor is smooth and level, few changes of interest occur in the spot during the lunation; but if rough, very marked changes are liable to be seen. Since those spots found near the centre of the lunar disk are blackest when the Moon is full and fade out at sunrise and sunset, it is evident that they cannot be due in any way to shadows, which are geometrically impossible at full moon. Consequently, *there must be a real change of some sort in the nature of the reflecting surface.* Organic life resembling vegetation seems to be the only simple explanation of this change, and if we consider the long lunar day as being analogous, on a small scale, to our terrestrial year, the theory of such life seems to be an adequate explanation—coming up, flourishing, and dying, just as vegetation springs and withers on the Earth. At least, the burden of proof would seem to lie with those who have any other solution of the observed facts to offer.

A good example of a variable spot is found in the crater known as Franklin, 3A [2.5, 3.3]. See also Plate D, Figs. 6, 7, 8, 9 and 10 . When the Sun first rises upon

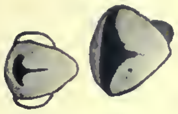

Figure 1
1898, June 26, 4.3 days
6°

Figure 2
1898, August 26, 6.4 days
31°

Figure 3
1901, June 26, 6.6 days
34°

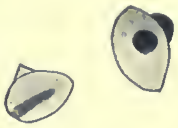

Figure 4
1898, April 1, 6.7 days
35°

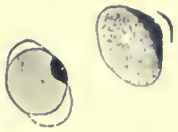

Figure 5
1901, July 2, 12.8 days
109°

Figure 11
Mars
1894, July 31, 0^h G. M. T.

Figure 12
Mars
1894, August 17, 1^h G. M. T.

Figure 6
1901, March 24, 1.1 days
326°

Figure 7
1901, April 26, 4.7 days
11°

Figure 8
1901, March 31, 8.1 days
52°

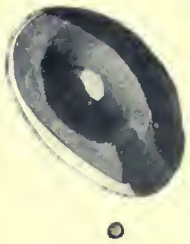

Figure 9
1901, April 4, 12.4 days
104°

Figure 10
1901, April 5, 13.4 days
116°

LUNAR CRATERS. MARS

These drawings show changes in the lunar ice deposits and vegetation. The two central figures show the canals of Mars.

it the floor is bright. It soon darkens uniformly, but on the third day the extreme northeastern portion begins to fade and by the sixth day the faded region covers one-quarter of the floor. On the fourth day a slight darkening is noticed to the south of the central peak. This rapidly develops, and the next day the region is seen to contain two very dark spots, each located in the vicinity of an elongated crevice which may be observed earlier in the lunation. These spots remain virtually unchanged until the twelfth day. They then suddenly fade and by the next day have completely vanished, leaving only the gray tint in the southwestern half of the floor, which disappears at sunset.

Other craters, such as Atlas, 5A [1.0, 2.9], Alphonsus, 8A [3.3, 3.1], and Riccioli, 15 A [2.7, 7.6], present similar phenomena. In the last, which is near the equator, the changes are exceptionally rapid, and occur immediately after sunrise. Thus while in the case of Atlas, in latitude +46°, the changes require six days for their completion, in Riccioli they are completed in about twenty-four hours, and a noticeable change takes place in less than five hours. Since it is located near the eastern edge of the disk, sunrise occurs a day or two before full moon, and the complete series of changes can therefore be watched in the course of a single night. These changes are very striking, but can be seen to advantage on only two or three nights in the course of a year when the libration is favourable—that is to say, when that edge of the moon is turned slightly toward the Earth so as to bring the crater well into view.

Fig. 5

The three drawings here reproduced are upon a scale of $\frac{1}{2,000,000}$. The first drawing was made between 11^h 10^m and 11^h 20^m Greenwich Mean Time on the night of

October 9, 1897. Colongitude of the sunrise terminator, 77°. The eastern wall of Riccioli was just visible. Most of the interior of the crater was darker than anything in its immediate vicinity excepting the shadows, but it was of a nearly uniform tint, and no trace whatever could be found of the eastern boundary of the dark spot, which in a few hours was to become very conspicuous. The northeastern boundary, later equally conspicuous, was described as a delicate shaded band, barely visible. The next observation was made two and a half hours later. The northeastern boundary of the spot was now clearly marked and the contrast throughout had begun to increase.

The second drawing was made four and a half hours after the first one. The outline of the dark spot was now much more nearly complete, and the range of hills just east of Riccioli was on the terminator. Two hours later the spot was drawn, and described as very distinct and strongly marked throughout its entire extent, although not as much so as it was later in the lunation. It resembled in general the third drawing.

The third drawing was made upon the next day, October 10th, between $14^h\ 0^m$ and $14^h\ 15^m$. The spot was then fully developed, and no further change, either in shape or density, took place in it from that time on until just before sunset, at which time it rapidly faded out. A well-defined dark spot southeast of the larger one is shown in the last drawing which is not found in either of the others. At what time it developed is not certain, nor whether it actually coincides in position with the bright spot shown in the first drawing.

In the course of a few days the entire crater of Riccioli became practically invisible with the exception of the black spot, 15C [2.8, 7.5], by which it may always under these circumstances be found. The same is the case with Alphonsus, near full moon, whose location at that time can best be determined by means of the three conspicuous variable spots which it contains. Since the latitude of Alphonsus is —13°, we should expect these spots also to develop very rapidly, and such in fact is found to be the case, although no visual observations have as yet been secured which are as complete as those relating to Riccioli. We may study the variable spots in Atlas and also in Hercules, 5A [1.4, 2.9], as they increase in intensity on Plate 5C, and as they disappear on Plate 3E. The formation and disappearance of the spots in Alphonsus is shown on Plates 8A, 10C [1.5, 2.1] and 10E [1.4, 3.4].

The word "canal" as used in astronomy is applied to a dark, narrow, straight or smoothly curved surface marking. The term does not necessarily imply the presence of water. Figures 11 and 12, Plate D, represent the planet Mars. The narrow markings in Figure 11 are the canals. The coarser markings or bands in Figure 12, which were discovered at Arequipa in 1892, seem to be analogous to them, and are sometimes referred to as the "canals in the dark regions." These two sketches were made with the eighteen-inch telescope of the Lowell Observatory at Flagstaff, Arizona, in 1894.* They are drawn on a scale of $\frac{1}{100,000,000}$, or about 4.4″ or 1,600 miles to the inch. Since two observers, seated at the same instrument, may represent what they see quite differently on paper, it is important in making a comparison of the surface markings of the different heavenly bodies that all the drawings should be by the same observer.

In the course of my observations of the Moon made in Jamaica in 1901, special attention was paid to the crater 9E [2.5, 5.4] Eratosthenes. This was due to the fact that it was known to contain extensive variable spots, and that being near the Moon's equator, in latitude 14° N., it was considered highly probable that at some time in the course of the lunar day these spots would be subject to rapid changes. Moreover, being near the centre of the Moon's disk, in longitude 11° E., the crater could be well seen, and its appearance at different times would be unaffected by the slight apparent shiftings of the Moon about its central position due to libration. On Plates E and F are given four drawings of this crater, made on a scale of $\frac{1}{2,000,000}$, or about 28″ or thirty-two miles to the inch.

After the drawings were finished and in the hands of the printer, it occurred to me that it would be interesting to compare them with photographs taken at about the same intervals after lunar sunrise. The photographs would thus give a very interesting independent check on the accuracy with which the drawings were made, and would show at the same time, in general, the kind of errors into which a draftsman is liable to fall.

Since one of the main objects of the Jamaica expedition was to obtain the pictures used in the present Atlas, we had negatives to select from in abundance, although none were taken with special regard to Eratosthenes itself. The advantage of photography as applied to the lunar surface is that it gives with absolute accuracy the size, shape and relative positions of the various formations. Unfortunately, however, in the representation of the finer details it is at a hopeless disadvantage as compared with the eye. The best photograph of the Moon ever taken will show nothing that cannot readily

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* Astronomy and Astrophysics, XIII., p. 645.

be seen with a five-inch telescope under favourable conditions. At first, therefore, it appeared doubtful if our photographs could be used to advantage.

Four negatives were selected, however, and enlarged to the same scale as the drawings, and are reproduced beside them on the plates. The first photograph, it will be noticed, was taken 2.6 days after lunar sunrise, or 1.6 days later than the first drawing. In the same way the second photograph was taken 1.0 day later than the second drawing, the third photograph 1.5 days later than the third drawing, and the fourth photograph 0.9 day before the fourth drawing.

A casual glance at the drawings shows, in Figure 1, Plate E, near the bottom of the picture and within the crater, a number of markings that may be described as more or less canal-like. At the same time there are numerous fine lines, which probably merely represent cracks in the surface, and which later disappear under a higher Sun. In Figure 3, and Plate F, Figure 5, however, the real canals come out. In Figure 8 they have again become invisible. It is at first a little difficult to recognise any particular region on all of the different photographs and drawings, but a portion of the crater walls and the three central peaks can be found in every case, and starting from these the other regions may always be identified.

There is a dark kite-shaped marking on the planet Mars, shown near the bottom of Plate D, Figure 12, which is known as the Syrtis major. If Plate F, Figure 5, be inverted, at least two such dark markings will be found upon it. In Plate D, Figure 11, a dark peninsula-like marking to the right of the centre is known as the Solis lacus. Above it and half surrounding it is a dark semicircular region. Canals radiate from it in various directions. If Figure 5 be again inverted, the counterpart of this marking will be found just below its centre. In both cases the canals radiate from the centre to an incomplete dark circumference, and in both cases the intervening bright region is darkest on the side of the darkest exterior.

It has been said that the canals of Mars never end save in a sea or another canal. That this is not quite true is shown by a canal seen just above the centre of Figure 12. This fading out into nothingness seems to be rather more frequent, however, upon the Moon, several such instances occurring in Figure 5. In both Figures 3 and 5 rounded lakes or oases are found at the junctions of some of the canals. In Figure 5 a little lake is seen above and to the left of the centre, without any connecting canals, but in Figure 3, drawn a month later, the canals belonging to it are shown intersecting like an X, although

PLATE E

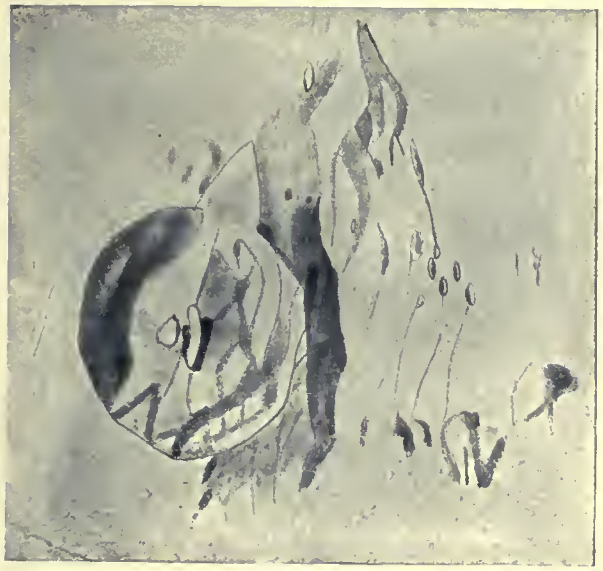

Figure 1
1901, August 23, 1.0 days
23°

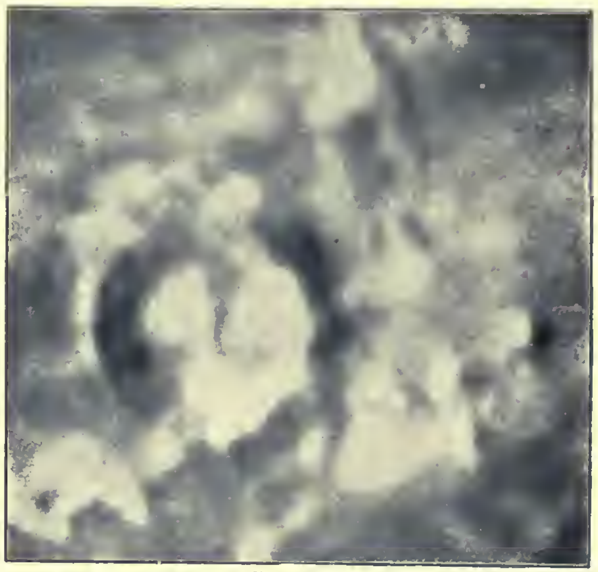

Figure 2
1901, July 26, 2.6 days
43°

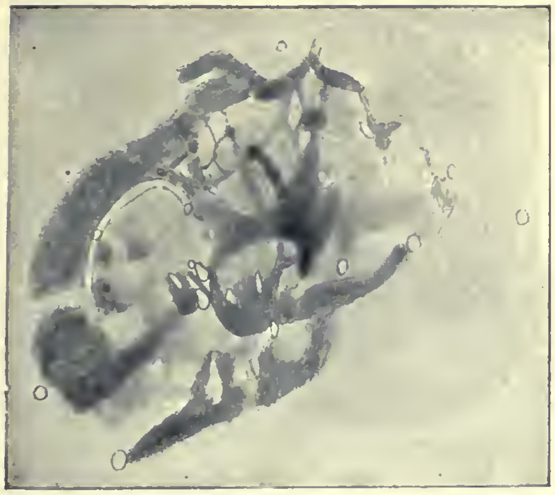

Figure 3
1901, August 28, 6.1 days
85°

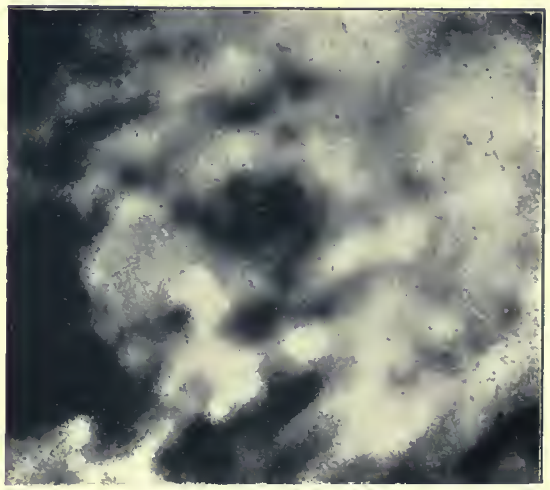

Figure 4
1901, March 5, 7.0 days
97°

ERATOSTHENES
Drawings and photographs of this formation show the lunar canals discovered in Jamaica

the lake itself does not appear in that sketch. The large dark areas known as seas upon Mars have their counterparts, too, in the dark regions surrounding the main crater.

Figure 3 was drawn only 0.7 day before full moon. Figure 4 was photographed 0.8 day after full, and Figure 5 was drawn only 1.7 days after it. But from full moon until lunar midday at the formation in question, or 7.4 days after sunrise, it is geometrically impossible for any shadows to be visible, and for a day or two before and after that the shadows would be too small to be recognisable. Therefore, none of the markings shown in these three figures can be due to shadow, but all must owe their origin to some surface discolouration whose intensity and shape vary with the interval during which it has been exposed to the Sun. Figure 6 was photographed 2.7 days after lunar midday, but even here it is evident that most of the dark regions are identical with those in Figure 4, and are therefore not due to shadow. In Figures 1, 2, 7 and 8, on the other hand, the presence of true shadow is plainly visible, combined with, and in some cases indistinguishable from, the surface discolouration.

With regard to the so-called double canals of Mars I may say at once that, although I have often looked for them, and sometimes looked when others told me they were visible to them, yet I have never succeeded in seeing them. Since 1894 I have had little opportunity to examine Mars under favourable conditions, but a few years ago I was able to show,* from the observations of others, that the double canals had this curious property, namely, that their linear separation was inversely proportional to the diameter of the object-glass of the telescope and directly proportional to the distance of the planet. In other words, if we use a telescope of twice the diameter we shall find the same canals will measure only half as many miles apart. Again, when Mars gets to be twice as far from the Earth as formerly, we shall find that the canal-diggers have placed their second canal twice as far from the first as it was before! The inference that I believe must be drawn from these facts is that, while the canals themselves are undoubtedly genuine, their doubling is an optical illusion, due to some peculiarity of the eye, which many astronomers are capable of seeing while many others are not. No double canals, properly so called, have been detected upon the Moon.

Although on the whole the lunar canals are much smaller and perhaps broader, in proportion to their length, than those of Mars, yet on account of the nearness of the Moon its canals are much more readily seen than the Martian ones. At the time the two

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* Annals of Harvard College Observatory, XXXII., p. 149.

drawings of Mars were made its apparent diameter was a little less than half the diameter of the crater of Eratosthenes, as shown in these drawings.

Besides this difference in actual size, there is another real point of difference between the lunar and the Martian formations. On Mars the so-called seas are green in the spring, gray in the summer and yellow in the autumn. On the Moon, gray and yellowish-white are the only shades visible; the markings merely darken and fade out again. This difference might very naturally be ascribed to the comparative lack of air and water-vapour found upon the Moon.

In 1888 the writer suggested * that the markings known as the canals of Mars, as well as its seas, were in reality caused by processes of vegetation, and were in no way due to the presence of large bodies of water upon the planet. In 1892 our Arequipa observations showed that in some instances the canals crossed the seas. This fact somewhat added to the difficulties of explaining them on the supposition that both were due to water. Latterly the vegetation hypothesis has been advocated by several astronomers, Mr. Lowell among others, and so forcibly and so widely have they propagated this idea that it is believed that at the present time there are comparatively few astronomers who are adherents of the old theory that Mars is a marshy planet, peopled by a race who devote their lives chiefly to excavating ditches and then filling them up again.

Turning now to the observed facts, we shall begin by describing some of the changes that are found to take place in these dark areas of vegetation as the lunar day progresses. It must be premised that the four drawings, Figures 1, 3, 5 and 8, are representative of some thirty drawings in all, made chiefly between June 25 and September 1, 1901. Each of these four drawings is confirmed in all its essential details by at least two others, made upon different dates and frequently during different months. Therefore the more marked changes that are shown on them—for instance, between Figures 3 and 5—cannot be ascribed to mere errors of drawing nor to defective telescopic definition.

Perhaps the most marked change due to the growth of the lunar vegetation itself is shown in the darkening of the region situated just to the right of the central peaks of Eratosthenes. In Figures 1 and 2 this region is comparatively light. In Figure 3 it has appreciably darkened, although still retaining in part the shape shown in Figure 2. The inner wall of the crater to the right of the spot has now begun to darken. In Figure 4 the shape of the spot on the floor has changed, the darkening of the crater wall is now

* Science, XII., p. 82. See also "Astronomy and Astro-Physics," 1892, XI., 670.

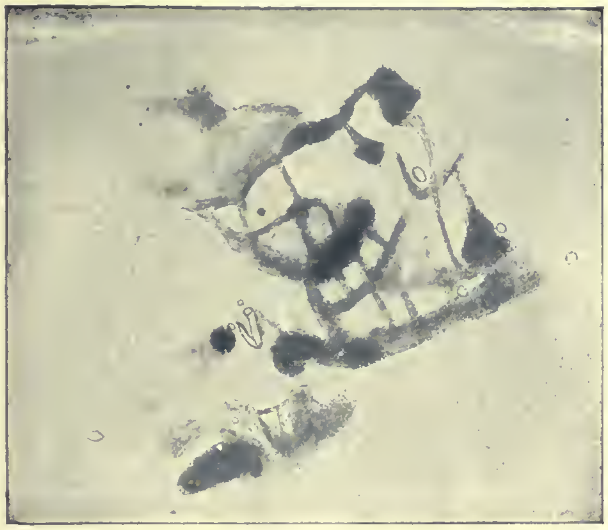

Figure 5
1901, August 1, 8.6 days
116°

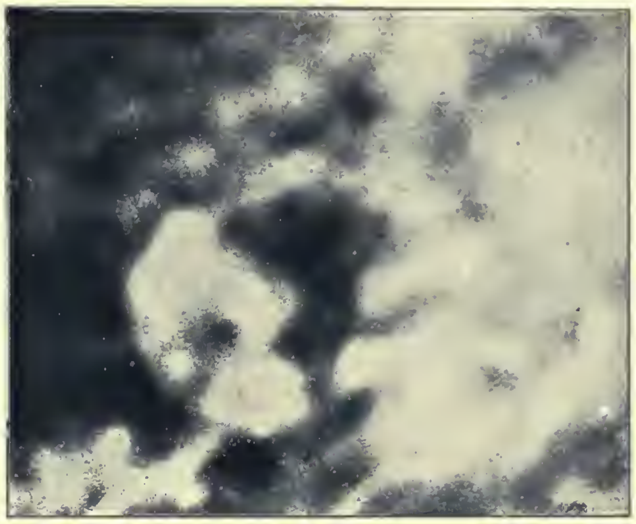

Figure 6
1901, May 6, 10.1 days
135°

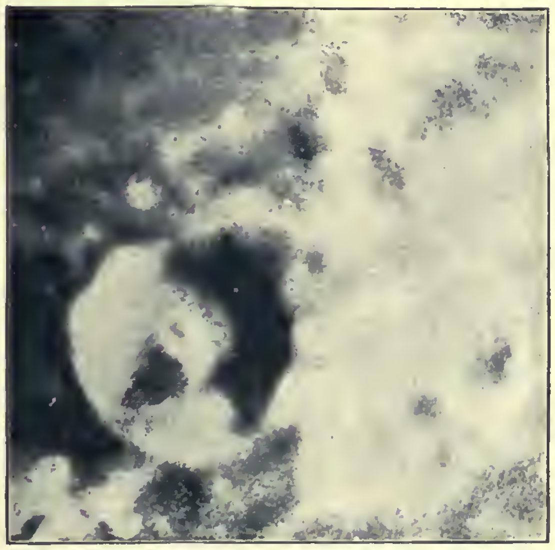

Figure 7
1901, August 4, 11.9 days
156°

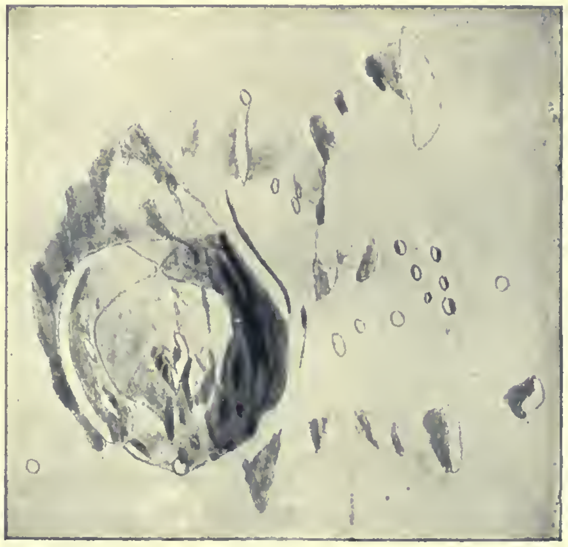

Figure 8
1901, August 5, 12.8 days
167°

ERATOSTHENES
Drawings and photographs of this formation show the lunar canals discovered in Jamaica

well shown, and the spot itself has grown very much darker. The fact that in Figure 4 the region is intensely illuminated by the almost vertical Sun, while in Figures 1 and 2 the Sun was comparatively low, makes these changes still more striking. In Figures 5, 6 and 7 the spot is still dark, but in the last two the shading of the eastern wall by the setting Sun has materially changed the shape of the spot as compared with its appearance in Figures 4 and 5. Figure 8 shows that the spot has now clearly faded, although a part of its area is already deeply enveloped in the heavy shadows that precede the absolute blackness of coming night.

Another spot, to the left and below the central peaks of the crater, first makes its appearance in Figure 2. In Figure 3 a dark marking connects it with the crater wall and a second dark marking appears to be forming. In Figures 4, 5 and 6 the second marking is well shown, although in the last it has begun to fade. In Figures 7 and 8 it is no longer visible, and in the latter the spot itself has vanished. To express the matter more fully in words, we may say that a triangular area partly shown in Figure 2 gradually darkens. After reaching its maximum intensity the central portion begins to fade, leaving the canals, as shown in Figure 4. These later fade, as shown in Figures 6 and 7, and finally the darkest part—the lake—disappears. It is believed that we have here an illustration of the formation and destruction of a canal, a phenomenon never yet satisfactorily observed upon Mars.

A comparison of the upper portions of the central dark marking in Figures 2 and 4 further illustrates the formation and growth of a variable spot as the lunar morning advances, while a comparison of the upper portion of the same spot in Figures 6 and 7 shows how it fades out as the day declines.

Turning now from these changes that are so conspicuous that even the coarse, reliable photographs are capable of showing them, we will next examine a set of markings where, for the present, at all events, the human eye and hand must reign supreme. In the delicate system of canals shown in the upper part of Figure 3, by far the most conspicuous is the one which starts from a little lake near the centre of the system. This lake is well shown in Figure 1, where it is found to be situated upon the very crest of the crater wall. The canal flows from it in a northeasterly direction—that is, downward and to the right—for about twelve miles, when it heads northerly, still following the crater rim, but apparently remaining chiefly on the outer slopes. This darkening may be due in part to shadow, but that it is really a canal is shown by reference to Figure 3, where, as we have already seen, no shadows are visible. If the canal could contain water, we should say that at this point it overflowed its banks, for the darkening now spreads out in all directions down both the inner and outer slopes of the crater wall. Whatever really occurs, it would be interesting to see what would happen to this dark area if the canal could by any means be cut off from it for a few weeks.

In Figure 3, to the left of the prominent canal and nearly parallel to it, a lighter one is found whose course follows in part the position of certain cracks seen in Figure 1. This same canal is well seen in Figure 5, but its companion to the eastward has shrunken and apparently moved away from it down the slope of the outer crater wall. This shrinking and shifting of position is confirmed by other drawings made during both July and August. The same thing has been observed on Mars, but owing to the difficulty of the observation the shifting has generally been ascribed to defective drawings. The two canals are found to be equally dark 6.5 days after lunar sunrise, or about the time of full moon. Before that date the western canal is found to be much the fainter of the two, after that date the eastern one. In Figure 8 the eastern canal has either entirely disappeared or its place is occupied by a long, narrow line. A new dark marking, due, perhaps, largely to shadow, has appeared just to the west of the western canal, which now for several miles follows pretty closely *inside* the crest of the crater rim.

It seems to the writer that the importance of these observations lies primarily in the aid they may give us in the interpretation of the real significance of the markings on Mars, but incidentally, also, in exemplifying the tenacity with which life will exist throughout the universe in situations that seem to us, from our ignorance, most unfavourable and most unsuited to it. A study of these markings should assist us in the study of those upon Mars for the following reasons: In the first place, as previously noted, the lunar canals are more readily seen than those upon Mars; the observer must not, however, expect to find them easy objects; it can merely be said that, with good seeing, they are not very difficult. In the second place, they are visible to advantage everywhere upon the Earth throughout the year, hence many more observations of them can be obtained by the same observer. Thirdly, they go through more rapid changes, and the same conditions are frequently repeated, so that a failure to observe a particular phase on one evening is readily remedied by another observation made a few months later. Fourthly, a greater number of individual specimens occur, scattered mainly in the lower latitudes, giving opportunity for a greater variety of conditions, and therefore a better chance of discovery of some hitherto unknown fact. Thus, a large canal exists in the western portion of Alphonsus, shown faintly on Plate 10C [1.3, 2.1]; two small but well-defined ones are found in Hell, 10E [1.9, 5.5]. Fifthly, and most important, we are able to study the surface conditions and determine the relation of the various details to the natural elevations, slopes and depressions of the surface. Sixthly, since no water in the liquid form can exist upon the Moon, this fact will enable us to rule out many seductive but erroneous hypotheses. Seventh, and lastly, we know that so little air and water-vapour exist there that we can confidently also rule out all aid in the construction of these formations from intelligent or intellectual life.

While from this point of view the observations may have their disappointing side, still it must be remembered that they do not disprove that intelligent life may exist either on Mars or elsewhere in the universe. They merely weaken the strongest argument hitherto found for the existence of highly intelligent life upon Mars. I do not believe that any astronomer will be tempted to use the inverse argument that we now have evidence of such life upon the Moon!

CHAPTER IX

RECENT INVESTIGATIONS

IN this chapter we shall deal with such work as has been done within the last few months prior to the publication of this volume. In treating of Linné, however, it will be necessary to refer first to some earlier work. In astronomical investigations it is generally more convenient to express distances in angular rather than linear measure, and in what follows we shall use as our unit the second of arc, which at the centre of the Moon is a distance a trifle more than one mile in length.

In Chapter VII. it was shown that the white spot surrounding Linné is subject to fluctuations in size analogous to those of the polar caps of our Earth and of Mars. Soon after sunrise on Linné the spot appears of its maximum diameter. As the Sun rises higher and higher upon it, it rapidly diminishes in size, reaching its minimum dimensions about one day after noon. This would correspond to a colongitude of the sunrise terminator of 90°. The spot then immediately begins to increase in size, nearly reaching its original dimensions shortly before sunset. In 1898 the maximum diameter was 4″.0, the minimum 2″.1. In 1899 the minimum reached 2″.0, since which time it has gradually increased until it is now about 2″.8 in diameter. Compare the size of Linné on plates 7A, 5B, 5C and 5E.

Assuming that the spot was due to a deposit of hoarfrost, which evaporated under the intense solar radiation—Linné is in latitude +28°—it occurred to the writer that a crucial test of the truth of this hypothesis could be made at the time of a lunar eclipse. At such a time the spot is at about its minimum area, and during the interval of the withdrawal of the Sun's rays it was thought that it might sufficiently increase in size to render the change visible from the Earth. Accordingly an effort was made to measure its dimensions before and after the total eclipse of December 27, 1898. Unfortunately, the sky was so hazy on that occasion that nothing could be done in Cambridge. Fearing bad weather, the writer had asked Mr. Douglass, of the Lowell Observatory, also to make some measures. He had more favourable skies and found a marked increase of size. This increase lasted, he thought, for perhaps half an hour after the shadow had passed off from the spot. Three different methods of measurement gave for results 0″.82, 0″.73 and 0″.15.* At the eclipse of December 16, 1899, the author was more fortunate in the weather, and found an increase in size amounting to 0″.14. The diameter of the spot at this time was only 1″.97 and the duration of obscuration of Linné 2^h 29^m.†

The next eclipse which it was possible to observe was that of October 16, 1902. A remarkable increase of size was noted at this eclipse. The obscuration lasted for 2^h 26^m, the minimum size of the spot was 2″.7, and the enlargement during the eclipse 2″.8.‡ The change in the appearance of Linné due to this enlargement was so great that it was not at first recognised on its reappearance, although the writer was very familiar with the object and its location. Three-quarters of an hour later the Moon was obscured by clouds, but during that interval the spot showed no clear evidence of reduction in size. Four days later, however, the size of the spot was reduced about 1″, preparatory to the final increase preceding sunset.

The eclipse of April 11, 1903, was an unusually dark one. Although not quite total, its magnitude was more than 0.97. At the middle of the eclipse the Moon was one hour above the horizon in Cambridge, and only a segment whose breadth was about half the radius could be seen. Had the eclipse been central, the Moon would have been invisible here. Linné was obscured for an hour and a half, reappearing from the shadow at 13^h G. M. T. The sky was very hazy at this time, so that the first set of measures following the obscuration was not secured until twenty minutes later. Successive measures seemed to indicate that the spot was diminishing in size.

As compared with the observations made before the eclipse on the previous evening, the enlargement this year, according to my measures, amounted to 0″.55. Of this enlargement, 0″.35 was lost during the first hour and a quarter after the reappearance.**

In England many persons having small telescopes are interested in the Moon, and one of these, fortunately, Mr. S. A. Saunder, succeeded in obtaining some measures of Linné upon the night in question. To him the white spot appeared somewhat larger than it did to me, but the interesting feature of his observations is that after the eclipse the spot was found to have increased in size by 0″.50—a result almost identical with that above given.††

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* Annals of Harvard Observatory, XXXII., p. 261.

† Popular Astronomy, VIII., p. 57.

‡ Harvard Circulars, No. 67.

** Annals of Harvard Observatory, LI., p. 25.

†† Journal British Astronomical Association, XIII., p. 274.

We may summarize the results of these four eclipses in the following table:

SUMMARY

Year	Obscuration	Min. Size	Enlargement
1898	$2^h 30^m$	2″.08	0″.57
1899	2 29	1 .97	0 .14
1902	2 26	2 .73	2 .78
1903	1 30	2 .79	0 .55

Figures 1 and 2 of Plate G represent the floor of Plato. They are on a scale of $\frac{1}{2,000,000}$, or about thirty-two miles to the inch, and are enlarged from the same negatives that were used in printing Plates 9C and 7D, with which they may be compared. These are the first photographs published, so far as I am aware, showing the details of the floor so that they may be clearly distinguished. The best ones hitherto issued are those of the Paris Observatory, Plates 11, 23 and 34, and of "Weinek's Atlas," Plates 7 and 8.

We have now reached a position, I believe, where the details of the bright streaks on the floor of this formation can be better studied by means of photography than they can from drawings made even under the most favourable atmospheric conditions. This is chiefly because photography enables us to obtain much greater contrasts than the eye is capable of detecting, and also perhaps somewhat because the eye is dazzled by the brightness of the more brilliant portions of the Moon. For delicate detail, such as that involved in depicting the smaller craters on the floor, photography, of course, cannot compete with the eye. Still, in both Figures 1 and 2 we can readily locate the positions of craterlets numbers 1, 2, 3 and 4 (see upper figure, page 40).

Comparing these photographs with some taken at the Harvard station on Mount Wilson in California in 1890, and at Arequipa in 1894 and 1897, we find that no change in the markings has taken place since 1897, and only a slight change since the earlier photographs were taken. This change, however, is interesting if real. Each of the four craters whose numbers are given above is indicated by a bright spot upon the photographs. The brightest spot on the floor, however, situated in the southeastern part—that is, the upper right-hand region—does not show on any of the photographs taken in 1890. It was faint in 1894 and conspicuous in 1897. It does not correspond with any important craterlet visible in 1892, but coincides exactly, judging by the bright streaks, with a certain craterlet which was most conspicuous in the earlier observations of Plato made from 1869 to 1884, and is designated as 9 on the upper figure, page 40. This craterlet could not be found, although carefully looked for in 1892. Whether it has now reappeared can only be determined by accurate visual observations made under favourable atmospheric conditions.

Comparing the photographs with the map constructed by the Committee of the British Association, and published in their report for 1872, page 247, we find no difficulty in identifying the more prominent markings, and we see that no very important change can have occurred during that period.

A brief account of Messier and Messier *A* has already been given upon page 49. It was there shown that sometimes one of them is the larger and sometimes the other. The craters themselves vary in shape, sometimes one being triangular and the other elliptical, and sometimes *vice versa.* If both happen to be elliptical at the same time, their major axes are sometimes parallel and sometimes nearly at right angles. Some of these changes and some others are illustrated by drawings (see Plate D, Figs. 1 to 5).

Since the Jamaica photographs were taken it appeared that it would be a matter of interest to illustrate these changes by means of photography. While some of them can be detected by a careful examination of the plates at the end of this volume, yet it was not possible to publish the atlas on a sufficiently large scale to show all the detail of which the negatives are capable; and the atlas labors under a certain disadvantage on this account. It, therefore, seemed best to select six negatives of these craters, not necessarily those giving the best definition, but those which showed the changes under investigation to the best advantage. These negatives have all been enlarged between four and five times, to the same scale as that of Plato. On this scale the Moon would be five feet nine inches in diameter. The advantages of enlargement are clearly shown if we compare any of the six figures of Messier on the adjoining plate with the unenlarged plates of the atlas taken from the same original negatives. In the case, for instance, of Plates 2A [3.2, 1.2] and 2C [3.2, 1.8], a comparison with Figures 3 and 6 of Plate G will show that a great deal of detail is sacrificed when it becomes necessary to publish on a small scale.

Messier also appears upon Plates 21 and 27 of the Paris charts. At the time these plates were taken the colongitude of the terminator was practically the same as in Figures 3 and 4. In "Weinek's Atlas" Messier is shown on Plates 57 and 58. As this atlas gives only sunrise and sunset views, the more interesting features of these craters are not shown.

In the table the first column gives the number of the figure on Plate G, the second the corresponding plate of the atlas, the third and fourth the date and Greenwich mean time at which the negative was taken. The fifth column gives the colongitude of the sunrise terminator, the sixth the number of terrestrial days that had elapsed since the Sun rose on the craters, and the seventh the east and west libration of the Moon at the time. Since the craters are near the equator, the north and south libration has but little influence on their appearance. When the libration is positive the effect is to bring them toward the centre of the Moon's disk, and therefore lengthen them in an east-and-west direction. The longitude of the craters is +47° and their latitude is —2°. Messier is the western or left-hand crater, and is situated nearest to the limb.

If now we examine the photographs closely we shall find that in Figures 3, 4 and 8 *A* appears to be the larger of the two craters. On the other hand, in Figures 5, 6 and 7 Messier appears the larger. The craters are lengthened sometimes in one direction and sometimes in another. Thus in Figures 5 and 8 the lengthening is in an east-and-west direction, while in Figure 7 the direction is north and south. That this difference is not due to libration, as might at first be supposed, is shown, since the libration at the time the last-mentioned plate was taken lies between that of the two others. We may express this fact another way by saying that the libration tends to expand the craters in an east-and-west direction in Figure 7 and to contract them in Figure 8. Since the effect actually observed is the exact reverse of this, it is obvious that it cannot be due to libration.

Description of Figures

Fig.	Plate	Date	G. M. T.	Colong.	Days	Lib.
3	2A	Feb. 22	$12^h\ 34^m$	322°	0.7	+2°5
4	2B	July 21	12 15	340	2.2	+3.2
5	3B	Feb. 25	12 43	358	3.7	+5.2
6	2C	Feb. 27	15 23	24	5.8	+5.7
7	2E	Mar. 5	15 54	97	11.8	+2.3
8	3E	Aug. 31	15 35	122	13.9	−1.1

If we measure the distance from the little craterlet north of Messier to that south of *A* on these two figures we shall find that they are on very nearly the same scale. Nevertheless, the increased size of *A* in Figure 8 is very noticeable. An examination of the original negatives confirms this observation.

With regard to their shapes, Messier is elliptical in Figures 4 and 7, pear-shaped in 3 and 8, and triangular in 5 and 6. *A* is elliptical in Figure 7, round in 8, irregular in 4 and 6, triangular in 3 and 5. In Figures 5 and 7 the two craters are similar in shape, but in 3, 4, 6 and 8 they are quite different. In Figure 4 the major axes are clearly inclined to one another; in 7 they are parallel.

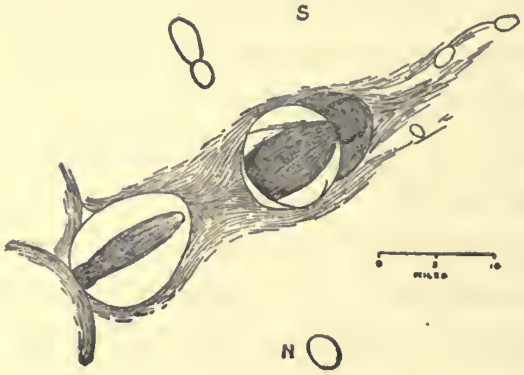


Fig. 6

Many changes not visible in these photographs are described in Volume XXXII. of the "Harvard Annals," and are shown in the accompanying drawings. In many cases the photographs did not happen to be taken at the proper time to show the changes to the best advantage. Thus we have no photograph showing the craters exactly alike. This resemblance, first noted by Beer and Madler, occurs only at 5.0 days and between 8.5 and 9.5 days after lunar sunrise. Again, although Figure 5 shows Messier as larger than *A*, yet the time when the difference is most marked, and is even more conspicuous, occurs a day later in the lunation. We have no negative taken at that time. No photographs are capable of showing the changes in the interior spots to advantage.

Nearly 100 drawings of these craters have been made at various times during the past ten years, besides numerous studies, when descriptions, but no drawings, were secured. As a result of the study of this material, and of the various photographs of the craters, I would suggest the following explanation of the various phenomena and changes observed.

Figure 6 is a copy of a drawing made at Arequipa with the thirteen-inch telescope and a power of 795 diameters, on May 4, 1892, at $12^h\ 50^m$, G. M. T. Time elapsed since sunrise, 4.5 days. Figure 7 is a diagram upon the scale of $\frac{1}{500,000}$, or eight miles to the inch, measured on the Moon's axis. The full lines represent the outlines of these craters, their sizes and shapes, as I believe they should be drawn, and are based upon a study of the photographs. Owing to the inferior seeing, the separation of the crescent at the right into three divisions, *l*, *m* and *n*, has never been observed at Cambridge, although sometimes the central division and sometimes the three divisions, taken as a whole, can be seen. The broken and dotted lines represent

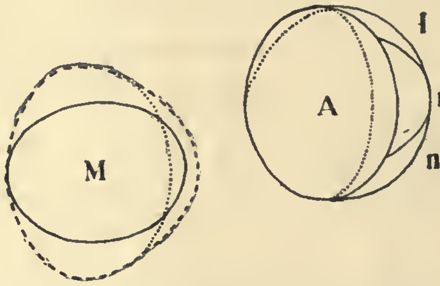


Fig. 7

1

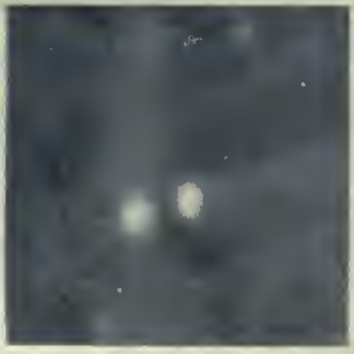
2

3

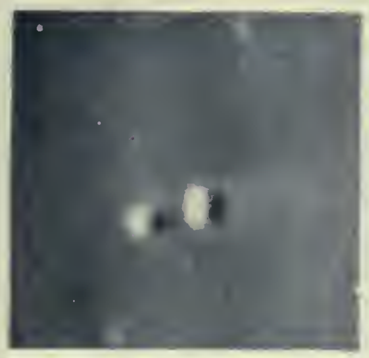
4

5

6



7



8

Figure 1
1901, March 5, 7.1 days
97°

Figure 2
1901, May 6, 10.2 days
135°

Figure 3
1901, February 22, 0.7 days
322°

Figure 4
1901, July 21, 2.2 days
340°

Figure 5
1901, February 25, 3.7 days
358°

Figure 6
1901, February 27, 5.8 days
24°

Figure 7
1901, March 5, 11.8 days
97°

Figure 8
1901, August 31. 13.9 days
122°

PLATO. MESSIER AND MESSIER *A*

Details on the floor of Plato. Photographs showing changes in size and shape of the craters Messier and Messier *A*

the boundaries of the shifting white layer of hoarfrost which is formed periodically about these craters.

When frost is found lying in the interstices of a broken surface it does not become visible upon the Moon, as we have already seen, until a day or two after sunrise, and it disappears a day or two before sunset. This is the normal condition, according to our observations, except in those comparatively small areas where the snow surface is continuous, and where it is therefore visible at all times from sunrise to sunset. Certain still smaller areas also are found, however, where the snow disappears about or soon after midday. This disappearance cannot be explained by means of black shadows in crevices, and apparently can be due only to evaporation. It implies necessarily an active monthly deposition of hoarfrost to make up for that which disappears.

In the photographs, Plate G, Figure 3, shows the true outline of *M* and the true outline of *A*, *l*, *m* and *n* combined. Neither *l* nor *n* is as bright as *m*, so that there is a slight tendency to make the combined outline triangular. A temporary brightening of *l*, as the Sun rises higher upon it, causes the slight irregularity in the form of the combination crater in Figure 4. In Figure 5, divisions *l* and *n* have faded so that they are of the same darkness as the surrounding *mare* and are therefore invisible. The evaporation of a thin layer of frost under the Sun's rays would readily account for this darkening. The spreading of the white haze north, south and east upon the outer crater walls of Messier as the Sun rises higher upon them, as shown in Figure 5, and its subsequent disappearance in Figures 7 and 8, illustrate the same phenomenon upon a larger scale. Thus Messier becomes larger in Figure 5 than *A*.

In Figure 6 the melting about Messier has already begun; *m*, too, has become somewhat fainter, while the variable spots in the bottoms of the craters are making themselves visible. The difference in brightness between the snow-craters and the two smaller craters north and south of them, shown in Figures 5 and 6, is very striking. In Figures 3 and 4, where the frost has not yet appeared, no such contrast is found.

In Figure 7 the frost in *m* has completely evaporated, rendering it invisible. At the eastern end of both craters it is also disappearing, partly, perhaps, through evaporation and partly because the Sun is getting low and shining down into the craters tangentially to the surface on the eastern side. It must be remembered that on the Moon the Sun sets in what we call the east. As the frost disappears, both craters shorten, but Messier still appears broader in a north-and-south direction than it is in fact, because we still confuse the bright interior with its white outer walls. This confusion of the white frost with the bright interior of Messier was well shown in a sketch made July 1, 1901, which looked very much like the photograph, Figure 7. Indeed, the two were made at exactly the same number of days after sunrise. Another sketch was made the day following, when the hoarfrost had still further evaporated, and one could then distinctly trace the rounded brilliant crater outline, with the fainter hazy blur extending to the north and south of it. A close inspection of Figure 7 enables one, though with some difficulty, to make this distinction between the crater outline and the hazy blur to the south of it. In Figure 8 the true outlines of Messier and of *A*, *l*, *m* and *n* combined in one are again shown. In a drawing made September 1, 1898, 12.5 days after sunrise, the line separating *A* from the three smaller divisions is clearly shown.

The indistinctness of the western walls of the two craters upon the fifth day after sunrise, and shown partly for Messier in Figure 5, is due, not as some have contended, to fog or mist rising from the craters, but simply because the regions inside and outside of them at these places are of equal brightness and the boundary line between them cannot therefore be distinguished. The varying irregular shapes of *A* and of the small patch of vegetation in its bottom, upon the fifth and sixth days, are due to the irregular deposition of hoarfrost on the crater walls at the time that the shadow of the crater upon its inner western wall disappears. The fact that neither Messier nor the vegetation in its bottom participates to the same extent in these irregular changes at this time is of interest, and may be due to more uniform aqueous conditions and to a different shape of the crater floor, which in this case is long and narrow.

The interior brightness of these craters presents rather unusual phenomena. The interiors of most small snow-craters are equally bright when the Sun shines on them from sunrise to sunset. At noon the bright areas are somewhat enlarged by extending over the crater walls. In Messier and *A*, however, the interior eastern walls are dark for the first two days after sunrise, as already noted. They brighten and then darken again later, and disappear, as shown in Figure 7, only reappearing when their shadows make them visible. They seem, in fact, to be brilliant only for a few days during the early middle part of the lunation. The interior western walls, on the other hand, at least of Messier, are brilliant as soon as the Sun strikes them, and remain so till sunset This difference in the appearance of the eastern and western walls is perhaps due to the difference in their slope, the western walls being nearly vertical while the eastern ones are very shelving. This difference of slope, which is very marked, is very unusual upon the Moon. If the crevices which gave off the vapour were located at the foot of, and therefore nearer to, the western walls, we should expect them to be more heavily coated with frost.

The studies described in this and in the previous chapter will serve to illustrate what may be called "the new selenography"—the selenography which consists, not in a mere mapping of cold dead rocks and isolated craters, but in a study of the daily alterations that take place in small, selected regions, where we find real, living changes—changes that cannot be explained by shifting shadows or varying librations of the lunar surface.

CHAPTER X

FANCIES; APPARENT SIZE; SUPERSTITIONS; INFLUENCE ON THE WEATHER

It is probable that from prehistoric times men have noticed the face of the Man in the Moon. The first reference we find to it is by the historian Plutarch, who, surprising as it may seem, wrote a whole book on the Face in the Moon. The face is not a very good one, and when we look at the photographs we wonder how we can see it at all. The explanation seems to be that the Oceanus Procellarum, being very near the limb, is only seen by the naked eye as a faint shading, if seen at all; and eliminating this, the remaining *maria* more nearly resemble a human face. This fading out of dark objects near the limb has an interesting bearing on the telescopic drawings of Mars, which always show the same effect. This fading has hitherto been generally ascribed exclusively to the absorption of the atmosphere of Mars, but it would appear that the phenomenon is probably also due in some part to this subjective effect.

But besides the face numerous other objects are supposed to be visible—such, for instance, as the faggot-gatherer, which is really poorer than the face itself. There seems to be no general agreement as to its location upon the Moon. The Chinese liken the dark markings to a monkey pounding rice, in India they are said to resemble a rabbit, while the Persians say they represent our own oceans and continents reflected as in a mirror. It was once suggested to me by a friend that the dark markings looked a good deal like Britannia as represented on the English penny—the Mare Imbrium corresponding to the shield, and even the lighthouse and ship being visible. It is probable that the discoverer first noticed the resemblance in the Southern Hemisphere, where the Moon appears turned upside down.

In the year 1900 M. Flammarion collected in the "Bulletin de la Société de France" a series of sketches by different persons, some showing what they really saw in the Moon with the naked eye and some showing what they fancied they saw. The former are instructive, the latter amusing. Five of these last are given in Plate H, showing the face, the crab, the girl reading, the donkey, and the lady. The last sketch is more artistic than scientific, yet that it has a certain basis of truth is shown by the drawing of M. Antoiniadi, the well-known astronomer, which is placed next to it, and which shows what he really saw, and not what he fancied. The crab and the girl reading were both evidently drawn from photographs (see Frontispiece), and not from the Moon itself, as they both show far more detail than can possibly be seen with the naked eye. If in the latter we imagine Tycho as the setting Sun, a rather pretty picture could be devised without straying very far from the outlines as presented to us by our satellite.

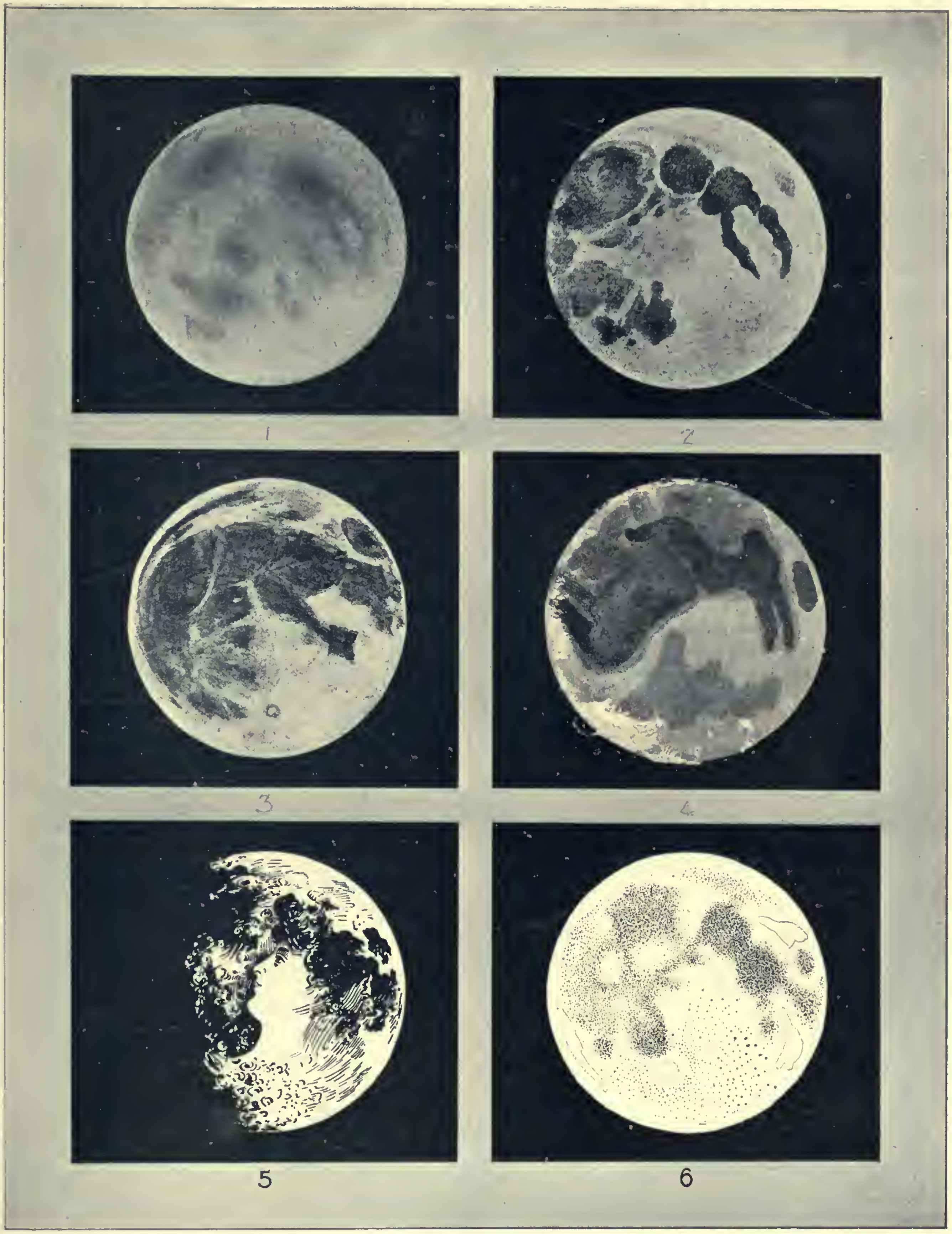
The size of the Moon as seen in the sky is very deceptive, and according to different persons differs from that of a cart-wheel to a silver dollar, depending on the distance at which these objects are assumed to be placed. Most people think it appears to be about a foot in diameter, from which Professor Young argues that to most people the distance of the surface of the sky is about 110 feet. Artists usually represent the Moon of much too large a size in their paintings to agree with the perspective of the rest of the picture. They also occasionally represent it in evening scenes with the horns of the crescent turned downward instead of upward. A little thought will show us that the horns must always point away from the Sun. The true angular size of the Moon is about half a degree; it can therefore always be concealed behind a lead pencil held at arm's length.

The Sun and Moon when rising or setting appear to most persons of from two to three times the diameter that they have when near the meridian. The cause of this phenomenon has been a source of speculation from the earliest times. Before optical science was thoroughly developed, some thought that the image was really magnified by the vapours near the horizon. Not only is this incorrect, but in point of fact the Sun is slightly and the Moon measurably smaller when near the horizon, because they are farther off than when overhead.

The true explanation is twofold. Human estimates of angular dimensions are dependent not merely on the angular dimensions themselves, but also on several extraneous circumstances. The case is analogous to our estimates of weight, which are dependent primarily on the real weight of the object, but secondarily upon its bulk. Thus a pound of lead feels much heavier than a pound of feathers.

One circumstance affecting our estimates of angular dimension is the linear dimension of the object itself. It was pointed out by Alhazen about 900 years ago that if we hold the hand at arm's length and notice what space it apparently covers on a distant wall, and then move the hand well to one side so that it is in front of some very near object,

PLATE H



The Face
The Girl Reading
The Lady

The Crab
The Donkey
An Astronomer's Drawing

LUNAR FANCIES

Various objects imagined in the Moon. These drawings should be compared with the photograph of the full moon, Plate C, Figure 2, which must, however, be turned upside down for this purpose.

we shall find that it will appear to us decidedly smaller than the part of the wall which it previously covered. It is an analogous effect which makes the full moon when rising or setting appear larger than when it is well up in the sky. On the horizon we can compare it with trees and houses and see how large it really is; overhead we have no linear scale of comparison.

It is certain that this is not the only reason, however, nor even the chief one, that makes the Moon appear larger when near the horizon. The same optical illusion applies when at sea, and it applies also to the constellations—for example, to Orion. When rising they appear decidedly larger than when near the meridian, and yet no comparison of their size with that of terrestrial objects is usually possible. There is evidently another circumstance affecting our estimates of angular diameter. The explanation of this was first given by Clausius about thirty years ago, as has recently been pointed out by Professor Searle, but it has not as yet got into the text-books. The circumstance chiefly affecting our estimates of size depends on the angular altitude of the object under consideration.

When we pass under an archway or under the limb of a tree we know that we are nearer to the object than we are when we see it under a lower altitude; at the same time it appears just as large to the average person angularly as it does when we are several feet farther away. We are, in fact, used, all our lives as we walk about, to see objects rapidly shifting their angular positions, yet not appearing as we pass them any larger than they do when we are slightly more distant from them. We thus always unconsciously make some compensation in our minds for the real changes in angular size that actually occur.

If now the limb of the tree that we passed under, instead of really growing angularly smaller at the low altitude than it was when overhead, should remain of the same angular size in all positions, we should say that it looked larger at the low altitude. This is exactly what happens in the case of the heavenly bodies. Unlike all terrestrial objects, they are practically of the same real angular dimensions when on the horizon that they are in the zenith. We involuntarily apply to them the same compensation that we are accustomed to apply to terrestrial objects, and are then naturally surprised to see that they appear larger at the lower altitude.

The superstitions relating to the Moon are many, the majority of them concerning the weather. Besides these, one of the commonest, particularly among sailors, is the belief that sleeping in the moonlight, especially if the Moon is full, induces insanity. A belief in the connection between the Moon and insanity was formerly very widely diffused, as witness our word lunacy. Farmers believe that the Moon exercises a certain influence over vegetation, and that beans, for instance, should be planted when the Moon is light, and potatoes when it is dark. What this really means is not very obvious, but presumably that beans should be planted about full moon, and potatoes when the Moon is new.

Many people believe that a change in the weather will come at or about the time of a change in the Moon. Since the Moon changes every seven and a half days, every change in the weather must come within four days of a change in the Moon, and half the changes will necessarily come within two days of a lunar change. We must not confuse this superstition with the real but ill-defined seven-day period of the weather, which is a genuine phenomenon, and holds true to a certain extent. Thus if one Sunday is stormy, there is a certain probability that the several Sundays following may have the same sort of weather. This phenomenon is probably due to terrestrial causes, and has nothing whatever to do with the Moon.

Another superstition is that if the horns of the new moon will hold water it will be a dry month; if they are so tipped that the water will run out, it will be rainy. It should be stated, however, that nearly as many people hold the reverse view. Both views are erroneous. The line joining the Moon's horns is always perpendicular to the direction of the Sun, and therefore depends merely on the place of the Moon in its orbit. It is sometimes said that the full moon clears away clouds. It is a fact that it is often cloudy at moonrise and that as the Moon rises higher the clouds disappear. The explanation, however, is that the full moon always rises about sunset. It is on the whole more cloudy at sunset than it is later in the evening. The clouds therefore clear away in any case, but when the Moon is full we are more likely to notice this fact than under other circumstances. A large number of proverbs relating to the Moon were collected by the United States Signal Service, and published in 1883, under the title "Weather Proverbs." To these I must refer those who are especially interested in this matter, discussing now merely a few influences of the Moon for which there really appears to be some foundation in fact.

It has been said that thunderstorms are influenced by the Moon. Doctor Hann refers to this in his "Lehrbuch der Meteorologie," page 662. He cites two series of German observations, one extending through sixty years and the other through eighty-six, both of which indicate that about seventeen per cent. more thunderstorms occur in the first half of the lunar month than in the last half. Nearly 12,000 observations collected by Hazen in the United States in the year 1884 show a preponderance of thirty-three per cent. in the first half of the lunar month. Similar results have been obtained by numerous other authorities. The greatest number of thunderstorms come between new moon and the first quarter, the least number come between full moon and the last. This subject is taken up in more detail in "Popular Astronomy," 1903, XI., 327.

It has been suggested that a certain connection exists between thunderstorms and auroras, the former being most frequent when the latter are rare, and *vice versa*. If such is the case, it is natural to expect to find some relation between the Moon and the aurora. Several such relations have, in fact, been found and described by H. H. Clayton.* He finds that the least number of auroras are visible at the time of full moon. The reason for this is obvious; but he also finds that the maximum number occurs at about the time of last quarter. Since much the greater number of auroras in the middle latitudes occur in the first half of the night, and, since there are many more observers also at that time, we should expect that during that half of the month when the Moon is not visible in the early evening, or when its light is faint, it would have little effect upon the number of auroras observed. This half of the month may be said to begin at about the fourth day after full moon. Nevertheless, the number of auroras observed at the beginning of this period is nearly three times as great as the number found at the end of it. This is exactly the reverse of what we have already found for the frequency of thunderstorms, which confirms the hypothetical relation already stated as occurring between these two forms of electrical manifestation.

Another relation between the aurora and the Moon found by Mr. Clayton depends on the lunar declination. When the Moon is farthest south in its orbit there is a marked increase in the number of northern auroras, amounting to about fifty per cent. Minor maxima also occur when the Moon is farthest north, and when it is crossing the terrestrial equator, minima being found at the four intermediate dates. Closely related to the aurora we find that certain disturbances of the Earth's magnetism occur when the Moon is at its greatest and at its least distance from us.

MacDowall counted the number of very rainy days recorded at Greenwich during the last twenty-four years. (*Nature*, LXIV., p. 424.) He found that the greatest

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* *American Journal of Science*, 1898. Fourth series, V., p. 81

number fell on the week which contained the new moon, while the least occurred during the week of the fourth quarter. Ellis, in *The Observatory*, 1902, XXV., page 342, states that earlier observations contradict this generalisation. There is a certain amount of evidence that severe earthquakes and volcanic eruptions are more likely to occur at new and at full moon, when the Sun and Moon pull together, than at other times, when they pull in different directions. The ratio is 51 to 49 per cent.* The Moon's influence on the tides has been known from the earliest times.

We thus see that, notwithstanding the number of years that the subject has been studied and the number of different minds that have been at work upon it, in only one case, that of thunderstorms, have we found any satisfactory evidence that the weather is influenced by the Moon. In this case the effect is so slight that it has only a theoretical interest, and we may therefore repeat what has been said by so many others before us, that for all practical purposes the Moon has no influence upon the weather.

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* These results are based on 17,249 observed earthquakes occurring between 1843 and 1872. For further details on this subject see "Earthquakes," by J. Milne, in "The International Scientific Series."

CHAPTER XI

HISTORY OF LUNAR RESEARCH

THE earliest recorded observations of the Moon relate to eclipses. The first of those that has come down to us was made by the Chinese about 2158 B. C. But even at this early date the prediction of an eclipse was possible, as we know from the sad fate of the royal astronomers, Hi and Ho, who, we are informed, owing to their indulgence in strong drink and riotous living, failed to predict this particular eclipse and were therefore summarily executed. Recently some very interesting astronomical observations have been discovered at Nippur, made by the ancient Babylonians before the time of Abraham, about 2000 B. C. It is certain that they knew that the Earth was spherical, and they also were familiar with the Saros, which is a period of a little over eighteen years, and was used by the ancients for the prediction of eclipses. Aristotle (384–322 B. C.) showed that the Moon was spherical, and was nearer to us than Mars, since he observed an occultation of the latter by the former. Aristarchus (320–250 B. C.) believed that the Sun was the centre of our system. He measured the distance and diameter of the Moon. The former he determined to be fifty-six times the radius of the Earth—a result that was very nearly correct. The latter strangely enough he placed at about two degrees—a figure nearly four times too large. Hipparchus (190–120 B. C.) was the greatest of these early astronomers. He determined the shape and inclination of the Moon's orbit, and also its distance and diameter, with considerable accuracy. He was followed by Ptolemy (100–170 A. D.), who discovered the chief irregularity in the Moon's orbit, which is caused by the action of the Sun, and is known as the evection.

From the days of Ptolemy no important discoveries pertaining to the Moon were made until Tycho Brahe (1546–1601). This distinguished astronomer, by means of improved instruments, greatly increased the accuracy of our knowledge of the Moon's orbit, and discovered the two other large inequalities of its motions—the variation and annual equation.

By means of the telescope Galileo (1610) greatly increased our knowledge of the surface of our satellite, for he substituted facts for theories. He recognised that it was largely a mountainous region, and he constructed the first map of its surface. He discovered the libration in latitude, and measured trigonometrically the heights of some of the principal mountains.

The first satisfactory map of the Moon was constructed by Hevelius, the celebrated astronomer of Dantzic, in the year 1647. He named some 250 points on the Moon's surface, in general after terrestrial formations that they were supposed to resemble. These names, accepted at first, were later rejected, and only six of them are in use at the present time. He discovered the libration in longitude.

In 1651 Riccioli published his map of the Moon, based largely on drawings made by his pupil, Grimaldi. It is perhaps slightly inferior in accuracy but superior in detail to that of Hevelius (see Plate I). He proposed a new system of nomenclature in which the *mares*, or seas, were named after astrological influences that were supposed to be exerted by the Moon, while the craters were named for astronomers and men of science. Unfortunately, his plan superseded that of Hevelius, about 200 of his names being still in use, many of them commemorating persons whom the modern astronomer would scarcely think of associating with the Moon.

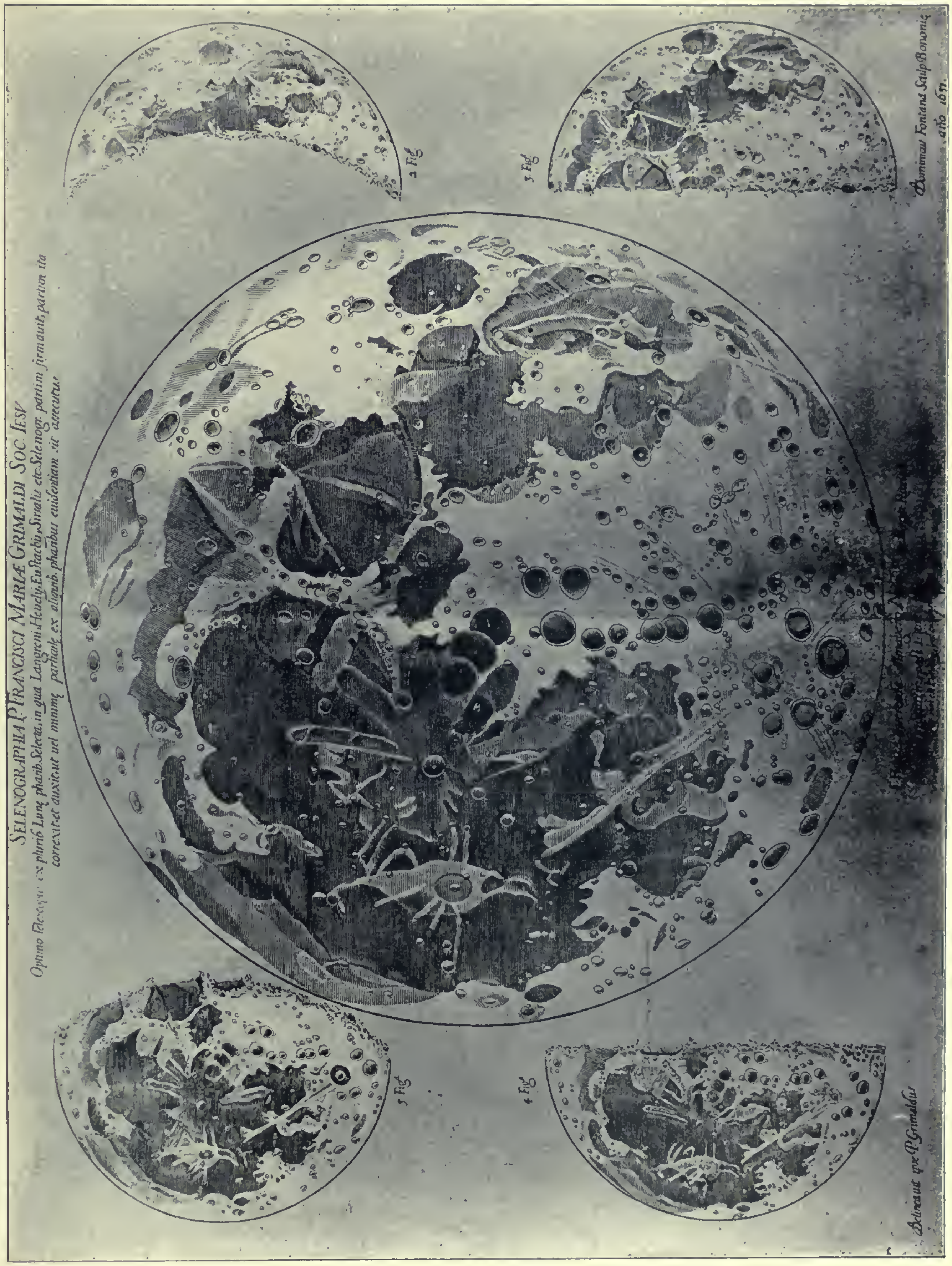
In 1680 Dominic Cassini published his map of the Moon on a scale of twenty inches in diameter. It was more complete than those of Hevelius and Riccioli, but rather deficient in accuracy.

In 1687 Newton published his great work, the "Principia," stating the law of gravitation and applying it to the case of the Moon. He showed not only why the Moon revolved about the Earth, but he also explained the causes, and computed the amount of the chief inequalities in its motion.

During the first half of the eighteenth century but little of moment was discovered with regard to the Moon, but during the last half the six great mathematicians, Euler, D'Alembert, Clairault, Lalande, Lagrange and Laplace, contributed profound researches on the theory of the Moon's motions, and published tables from which at any time its position could be computed.

In 1775 appeared Tobias Mayer's map of the Moon, based on accurate measurements with the meridian circle (see Plate J). Although only eight inches in diameter and lacking in detail, it was the first and only accurate map of the Moon until about 1805.

In 1791 and 1802 appeared the two volumes of Schröter's "Selenotopographische Fragmente," the first great work giving detailed drawings and descriptions of the various lunar formations. Schröter was practically, if not the founder, at least the first great



RICCIOLI'S MAP OF THE MOON
The best early map. 1651

contributor to what is now termed Selenography. He added about sixty names to the lunar nomenclature—principally in the southwestern quadrant. He also measured the height of many of the lunar summits by an improved method, and even at the present day he is considered one of the three great authorities on this subject. He was the discoverer of those curious cracks in the Moon's surface which are known as the lunar rills, and introduced the system of designating the less important points on the Moon's surface, in the vicinity of any given formation, by means of letters from the Greek and Roman alphabets. Schröter lived to see his observatory, his library and his unpublished observations wantonly destroyed by fire by the French under Vandamme in 1813. His life was wrecked, and he survived the blow but a few years.

In 1824 Lohrmann issued four sections of a map on a scale of thirty-eight inches to the Moon's diameter, which, had it been complete, would have been by far the best in existence at that time. Failing eyesight, followed by his death in 1840, delayed publication, and the remaining twenty-one sections were not issued until 1878. A small, complete map, fifteen inches in diameter, was published by him in 1838.

In 1837 appeared Beer and Mädler's great work on the Moon, accompanied by a map on nearly the same scale as Lohrmann's uncompleted charts, but both more detailed and more accurate. This publication was and is still considered in some respects the standard authority on the Moon, yet the observations, chiefly due to Mädler, were all made with a telescope of less than four inches aperture. These measurements include also the heights of some 830 summits. About 150 names were added to lunar nomenclature. The work was in fact so accurate and comprehensive that it served to discourage lunar observation in other quarters, and even until within a few years its influence was shown in the very prevalent opinion that the Moon was dead and unchangeable, and so accurately charted and known that it was a waste of energy for an astronomer to devote his time to it, except to study its motions.

One astronomer, however, Schmidt, of Athens, was not discouraged, and for thirty-four years devoted himself assiduously to selenographical work, producing at the end of that time his great map of the Moon, published in 1878 by the German Government. The map consists of twenty-five sections, and is upon a scale of seventy-five inches to the Moon's diameter. This map contains upward of 32,000 craters, together with about 1,000 rills, the great majority of the latter having been detected by Schmidt himself. The heights of many summits were also determined.

In 1879 appeared George H. Darwin's mathematical treatment of the theory of the tides, in which he demonstrated the real origin of the Moon, already explained in the first chapter of this volume.

Two English works which are accompanied by maps should here be mentioned, those of Neisen (1876) and Elger (1895). The former is by far the most complete work on the Moon in the English language, while the latter is a very convenient little volume for the amateur.

Three photographic atlases of the Moon upon a large scale have been begun within the last few years. One of these is by the Lick Observatory. It is upon a scale of 38.36 inches to the Moon's diameter. About three-quarters of the Moon's surface has been covered, but it is understood that the work has now been discontinued.

The second atlas is by Weinek. This is based chiefly on photographs taken at the Lick and Paris observatories. The Lick photographs are all enlarged just twenty-four times, and therefore represent the Moon on a scale of about ten feet in diameter. The Paris photographs are all enlarged to a scale of exactly four metres to the Moon's diameter, or 13 feet, 1.5 inches. Two views are given of each formation, one taken at sunrise and the other at sunset. Thus far 200 views have been published of the more interesting formations of the Moon. It is hoped some time in the future to publish 200 more, thus completely covering the whole lunar surface.

The third atlas is composed of the very artistic set of charts published by the Paris Observatory. These charts measure twenty-four by thirty inches and represent different portions of the Moon on various scales, ranging from 47 to 106 inches to the Moon's diameter. All the charts are taken near the sunrise or sunset phases. Forty-one have so far been issued, covering about seven-eighths of the lunar surface, at one phase or another, and the work is still progressing. The charts are not arranged in any particular order, about one-third of them being devoted to the mountain region to the north of Tycho. The others are scattered at various points over the surface, except along the eastern limb. Many of them have been reproduced upon a smaller scale by the Belgian Astronomical Society.

An interesting account of the process employed by Messrs. Loewy and Puiseux in the production of these charts is given in the *British Journal of Photography* for September 26, 1902, and reproduced in *Popular Astronomy*, 1902, X., page 502. The instrument employed is the well-known equatorial coudé of the Paris Observatory, in

PLATE J

MAYER'S MAP OF THE MOON

The first accurate map, 1775. A comparison of this plate with the Frontispiece and Plate I illustrates the progress of selenography and methods of illustration at intervals of about 125 years

which the light before it reaches the photographic plate is reflected from two mirrors, one in front of and one behind the object glass. The aperture is 23.5 inches and the focus 62 feet. The lens is corrected for the photographic rays, and is usually reduced in aperture to 21.3 inches (54 cm.) when in use. The focal length is redetermined every month. The diameter of the Moon on the original negatives, which are subsequently enlarged, is about 6.7 inches. The most rapid plates are employed, and the exposures vary from 0.5 to 4 seconds. During the exposure the telescope remains stationary, while the plate is moved by clockwork. The total number of photographic negatives already secured is about 400. This monumental work, showing the very best photographic results of the nineteenth century, may very properly bring our history to an end.

Our knowledge of the surface of our satellite is now so complete that while we do not know any portion of it as well as we do large tracts in Europe and the United States, yet at the same time there is no portion of its surface that is readily visible that is not known far better than large areas of the readily accessible surface of our own globe.

CHAPTER XII

The Photographic Atlas

A number of years ago the author suggested the use of a telescope of twelve or fifteen inches aperture and several hundred feet focal length for photographing the Moon. It was not possible to carry out the plan at that time, but early in the year 1900, owing to the generosity of two anonymous givers, an opportunity occurred which permitted the experiment to be tried. The amount of the donation permitted the use of a twelve-inch (30 cm.) objective, and it was decided that the photographic focus should be 135 feet 4 inches (4,125 cm.), thus representing the object on a scale of exactly 5″ to one millimetre. It was obvious that with so long a focus the tube must be fixed in one position and a reflection of the object viewed in a movable mirror. It was later found best to reduce the aperture of the lens to six inches, and all save three of the negatives used in the atlas were taken with this reduced aperture.

An expedition to the island of Jamaica in 1899, during which a five-inch telescope was used at five different stations upon the island, had shown that the atmospheric conditions were extremely favourable to astronomical work during the summer season, and it was hoped that they would be equally so during the winter, which is the time of the greatest freedom from clouds. Later investigations showed that while the seeing in winter is good, yet it is decidedly inferior to that in the summer season. The latitude of the island, which is about 18° N., permitted the mounting of the telescope with the axis of the lens parallel to that of the Earth, the tube being placed upon the side of a hill, with the mirror and lens at the lower end. The mirror was supported in a steel fork, which was also placed with its axis parallel to that of the Earth. The mirror could be clamped at different angles with regard to the fork. The fork was caused to revolve about its axis once in twenty-four hours in the opposite direction to that in which it was turned by the Earth. It therefore had no angular motion with regard to the heavenly bodies. A similar rotation was given to the photographic plate.

This form of mounting does not permit the portion of the sky in the immediate vicinity of the Pole to be examined, but as the instrument was devised for use on the members of the solar system, this objection was of little consequence. The mirror was of silver on glass, eighteen inches in diameter and about four inches thick. Owing to the length of the instrument, it was decided to drive it by electric motors capable of control from the eye end of the tube, instead of by clockwork actuated by gravity, as has heretofore always been done. The plan proved very successful.

On our arrival in Jamaica in October, 1900, we proceeded at once to Mandeville, where we had decided to locate the station. There we hired an estate called Woodlawn, situated about two miles to the east of the town, in latitude +18° 01′, longitude 5^h 10^m $02.^s5$, altitude 2,080 feet above sea level. In Plate K is given a view of the instrument. On the extreme left is shown a part of the dwelling-house, which was built in the form of a bungalow. The long inclined tube of the telescope consisted of a wooden frame covered with wire netting and supported on posts driven into the ground. The netting was covered at first with builder's paper, and later with cotton cloth. In the bottom of the tube were strung twelve insulated copper wires, permitting the operator at the upper end of the tube to control the motions of the mirror at the lower end. The small building at the upper end contained the observing room, the laboratory, the computing and dark rooms. The building at the lower end had a movable roof, divided in the middle. This could be slid apart, exposing the mirror and lens to the sky. The light of the Moon was reflected from the mirror up through the lens to the observer at the upper end of the tube. By turning the mirror the observer could see the Moon, no matter in what part of the sky it chanced to be, and it always appeared below him, and in the same direction. This was an important advantage, as when observing with an ordinary telescope it is very difficult to do good work when the Moon is directly overhead. This is a position that it frequently assumes to an observer located in the tropics.

We obtained our first view through the telescope a few minutes after midnight on December 31, 1900, the beginning of the new century. Eight days later our first photograph was taken, and from then until August 31st, when the telescope was dismounted, not a clear night passed when the Moon was visible but that some observations or photographs were secured. Our first satisfactory photograph of the Moon was taken on January 29, 1901. Our last photograph was taken August 31, so that the material for the present volume was collected in about seven months.

In planning the work, it was decided to divide the Moon's equatorial diameter into

PLATE K

THE JAMAICA TELESCOPE

The instrument with which the photographs and many of the observations were made. The observer, seated in the small upper building, looked down through the white tube toward the lower building, where the Moon appeared to him

eight equal parts, and erect perpendiculars at the dividing points. This, as shown in the figure, divides the visible surface into sixteen regions, eight north of the equator and eight south of it. According to the original plan, three views of each region were to be taken, one at lunar sunrise, one at lunar noon and one at lunar sunset. It was soon found, however, for certain regions, notably those in the southern half of the disk, that the change in appearance produced by the difference in lighting rendered it absolutely impossible to identify the same formation upon the plates taken at sunrise and sunset and those taken at noon. To overcome this difficulty, two more plates, designated as morning and evening plates, were added, one taken about two days after sunrise and the other about two days before sunset. We thus obtained eighty plates, covering the entire surface of the Moon five times. Certain small regions where the images overlapped might appear on as many as twenty plates, representing the region under ten different phases of illumination.

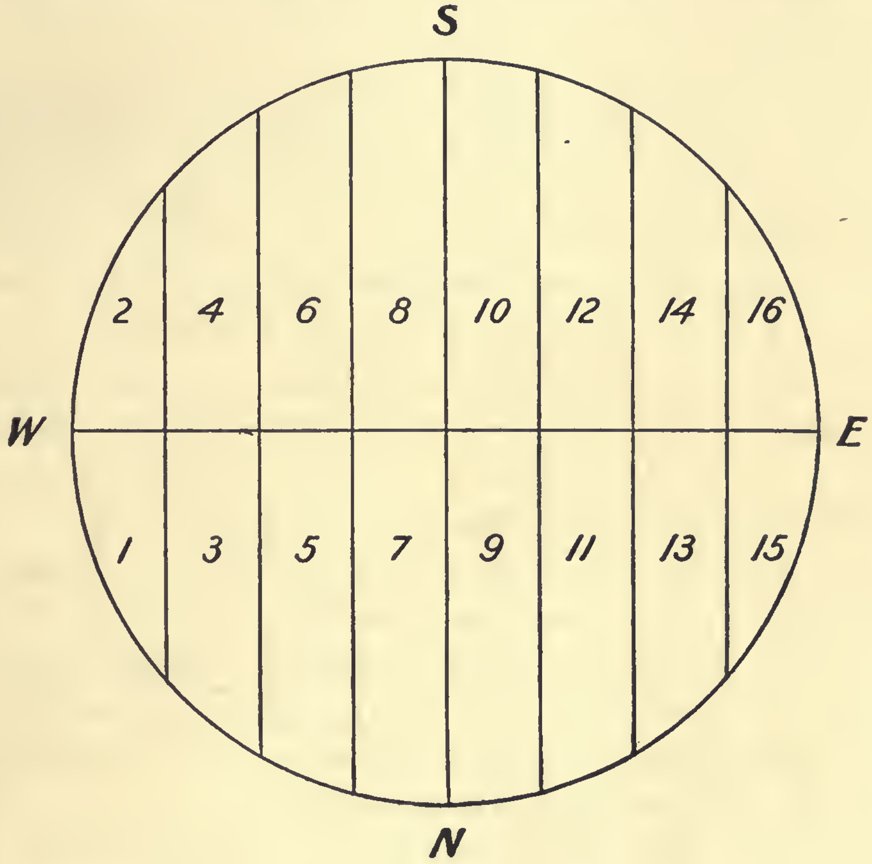


Fig. 8

To illustrate more clearly the difficulty of identification of the same region under different illuminations, if the reader will turn, for instance, to region 8, he will find that, in the southern portion especially, under phase C, it is impossible to identify any particular crater recognised in phase A by a direct comparison of these two plates. A use of the intermediate plate B, however, will enable him, after a little study, to find any desired formation.

The north polar regions are best shown on Plate 9B and the south polar regions on Plate 8C. The highest peak upon the Moon, according to Neison, attaining an altitude of about 30,000 feet, is situated in the Leibnitz Mountains near the South Pole, and is indicated upon the maps by a small cross. The alterations in appearance that similar craters undergo with a given difference in phase are sometimes quite unlike. Thus, on Plate 11A the craters Copernicus [2.5, 6.9] and Eratosthenes [1.4, 6.2] are very much alike in appearance. But while on Plate 11C Eratosthenes [0.6, 6.5] has grown darker, Copernicus [1.6, 7.1], on the other hand, has grown lighter, and the resemblance has ceased to exist. On 11A the craters Reinhold [2.9, 7.7] and Landsberg [3.4, 8.2] are quite conspicuous, while the small bright craterlet [2.4, 8.0] southwest of the former would scarcely excite notice. On 11C the large craters have almost disappeared, while the smaller one is now a conspicuous object. Similarly on 11A Pytheas [2.4, 5.4] and Lambert [2.4, 4.8] are not unlike, but on 11C Lambert is almost invisible, while Pytheas is a brilliant object. It is obvious that changes of this character can only be adequately represented by a photographic atlas, and by one representing the same region at several phases taken at very different distances from the terminator.

One possible use to which the atlas may be put is to suggest research. Thus the changes occurring in and about Eratosthenes were discovered by observations in part suggested by a study of the atlas which was at that time in process of construction. We must be careful, however, not to put too much confidence in results obtained from a mere comparison of photographs, as slight changes in exposure and development will sometimes produce results that are very misleading. The only safe course to follow is to confirm all suspected changes by a careful visual study of the formation at different ages of the Moon, and if near the limb the changes should be studied also under different librations.

As an instance of an apparent photographic change, we may, on Plate 5A, take the snow in the crater Plinius [1.9, 6.6]. If we turn now to Plate 5B we shall find that the snow has increased in area and conspicuousness. This is the normal course upon the Moon, but if we turn to Plate 5C, instead of having increased still further in conspicuousness, as we should have expected it to do, it has returned more nearly to the appearance that it had on Plate 5A. This is the case notwithstanding the fact that on Plate 5C the snow about Menelaus [2.1, 6.1] and Manilius [2.9, 6.4] is more conspicuous in both cases than it is on Plate 5B. This apparent change in Plinius is probably not due to the melting of the snow, but is merely an effect of photographic contrast. It is quite possible, however, that a visual study of it under sufficiently favourable atmospheric conditions might lead to interesting results.

CHAPTER XIII

THE MAP OF THE MOON; INDEX TO LUNAR FORMATIONS

SOME of the maps of the Moon, prepared by hand, that have hitherto been published, contain much detail, but all of them show large errors in position, shape and size, even of the important formations, while the minor features are often very inadequately and incorrectly represented. This is only what would naturally be expected in maps based so largely on drawings, and can only be avoided with certainty by having recourse to photography. Even the trigonometrical positions given at the end of Neison's work on the Moon are found to be largely discordant when compared with the more recent photographic measurements. The positions lately published by Franz (Sternwarte Breslau, I.), based on five negatives of the full moon taken at the Lick Observatory, have been adopted as standards in the location of the paralels and meridians on the present map.

Of the 479 craters common to Neison's map and the one given at the end of this volume, more than forty per cent. of the positions were found to differ from one another by more than one degree. Many of these deviations occur near the limb, especially in high latitudes, but still a very large number of them were found near the centre of the disk. In none of these cases did the deviation exceed two degrees, although in high latitudes deviations of ten and even twenty degrees sometimes occurred. Owing to the method of construction here employed, based on photography, it is believed that these large discordances are due to errors in Neison's map, rather than in the present one.

The first step in the construction of this map consisted in the selection of a suitable negative of the full moon. The one finally chosen was taken at Jamaica on the night of August 29, 1901, at $16^h\ 50^m$ G. M. T. The image measured 15.7 inches or 399 millimetres in diameter. This was enlarged on bromide paper to a diameter of 705 millimetres. The craters, parallels and meridians were then inserted. When completed the map was reduced by photography to an approximate diameter of 13.7 inches, or 348 millimetres, which is just one ten-millionth of the diameter of the Moon. This would be on a scale, measured on the Moon's axis, of ten kilometres to the millimetre, or about 160 miles to the inch.

For the convenience of those who may wish to use them, the ends of the polar and equatorial axes are indicated on the maps by short lines, and their intersection at the centre of the disk by a cross. At the time the photograph was taken, the libration in latitude as seen from Jamaica was —5.°63, that in longitude —3.°78. The equatorial defect, or breadth of the region not illuminated by the Sun, measured along the equatorial axis, is 0.6 millimetres. Similarly the polar defect is 0.5 millimetres.

Since of all the craters and peaks on the lunar surface which so far have received names but a very small number can be recognised on the Moon itself when it is full, it was evident that a map showing these craters, although founded on a photograph of the full moon, must be constructed largely by hand. In the location of these craters the photographs taken at five different phases proved an indispensable assistance, and by their aid identifications were easily secured which would have been absolutely impossible without them from a mere inspection of the lunar surface with the telescope. It is probable that the total number of craters and craterlets visible upon the Moon under favourable conditions exceeds 200,000 but is less than 1,000,000.

In the key maps of the four quadrants, only those craters are inserted that have received names, while in the four photographic maps, besides the craters already named, all the most conspicuous anonymous craters to be found upon the Moon are shown. The conspicuousness of a crater depends primarily on its location, the height of its walls and the brightness of its interior, and only secondarily upon its size. It is probable that the most conspicuous craters not shown upon the map are most of them of small size. At the time of full moon only a small proportion of the named craters are visible, while a large number of the most conspicuous craters are anonymous. Any object upon the Moon not named upon the map may be readily designated with sufficient accuracy for most purposes by its latitude and longitude.

It was first pointed out by Schröter that if we measure the length of the shadow of a lunar peak, and know its distance from the terminator, we can compute the difference of elevation between the peak and the region where its shadow is cast. Many measures were made by Schröter, by Madler and by Schmidt. For some reason the agreement between the results of these different observers is not very satisfactory, the difference averaging about 1,000 feet. A considerable portion of this difference is probably due to the irregular nature of the surface of the Moon, the regions where the shadow was cast in the different observations being themselves at different altitudes. Even the *maria* and those crater floors which appear to us flat are in reality decidedly convex as compared with the general spherical surface of the Moon. The results so far obtained, therefore, are not only uncertain, but from the fact that the altitude of the lower station is unknown are rather unsatisfactory. It is just as if we should state the height of our terrestrial mountains above the valleys near which they are situated, instead of giving their height above the sea-level.

While there is no sea-level on the Moon, yet we can adopt a spherical surface as a reference plane whose distance from the centre of the Moon shall be equal to the mean semidiameter of the Moon in a plane perpendicular to the line of sight. By measuring the displacement of a crater under different librations of the Moon, it is easy to compute its real height above such a reference plane. Such computations have been made by Franz ("Königsberg Beobachtungen," XXXVIII., Part 5) and by the author ("Annals of Harvard College Observatory," LI.), but they are rather too technical to be dealt with in this place.

These computations also seem to show that the Moon is slightly egg-shaped, the longest axis pointing toward the Earth. This, as we have seen in Chapter II., had been already predicted from theory. The amount of the projection toward the Earth is very slight—probably not more than a mile. For a more complete account of this subject, and also for a discussion of the effect of elevation on the computed longitudes and latitudes of the various lunar craters, the reader is referred to the volume of the Harvard Annals above mentioned.

In closing this chapter it may be well to point out some of the respects in which this atlas differs from the lunar photographic atlases that have preceded it.

(*a*) It is the only complete photographic atlas of the Moon in existence. Not only so, but it covers the whole visible surface of the Moon five times.

(*b*) The plates are all arranged systematically, and in a form easily remembered, even without reference to the key given on page 91.

(*c*) The plates are of such a shape that all the objects shown are similarly illuminated. Had fewer, broader plates been used, many objects could not have been shown near the terminator. The similar illumination also permits the most suitable plate and exposure to be used for the whole of the particular region under consideration.

(*d*) Every region is shown at five different phases, many details being conspicuous at one phase of the Moon that are not seen at all at another. In this way changes in the snow patches and in the vegetation are shown which could not possibly be indicated by any single photograph.

(*e*) Sometimes the same region contains some very bright and some very dark areas, such as a bright mountain mass and a dark *mare*. In such cases, both cannot be shown to advantage on the same photograph. By having five photographs, however, the exposures and printing can be so adjusted that every object will be shown with a suitable exposure upon at least one plate.

(*f*) All the plates are on the same scale, 5″ to the millimetre, and while there are some differences in the linear dimensions which are unavoidable by this plan on account of the varying libration and distance, there is no great range of scale such as occurs in some photographic atlases, where one plate may be on more than twice the scale of another.

(*g*) All the plates are approximately oriented parallel to the lunar axis, with south at the top.

(*h*) Since all the plates are printed the same size as the original negatives, there has been no enlargement of the grain of the plate, and we have in consequence a much smoother surface than is possible in the case of those pictures enlarged from negatives taken with a lens of shorter focus.

(*i*) A considerable overlapping of the plates is allowed. This is a great convenience when working near the edge of a region.

(*j*) The photographs were taken, whenever possible, under favourable libration, and especial attention was paid to this point in the original plan.

(*k*) No shading of the limb was permitted, therefore every region appears in its true photographic relations of light and shade.

In the following pages an alphabetical index is given of all the formations upon the Moon, together with the quadrants in which they are situated and their approximate longitudes and latitudes. By this means they can be readily found upon the maps. The northwestern quadrant is designated as 1, the northeastern as 2, the southeastern as 3 and the southwestern as 4.

INDEX TO NAMES

Name.	Quad.	Long.	Lat.	Name.	Quad.	Long.	Lat.	Name.	Quad.	Long.	Lat.
Abenezra	4	+12	−21	Bacon	4	+19	−51	Cabeus	3	−30	−85
Abulfeda	4	+14	−14	Bailly	3	−70	−66	Calippus	1	+10	+39
Acherusia Prom.	1	+22	+17	Baily	1	+30	+50	Campanus	3	−28	−28
Adams	4	+69	−31	Ball	3	− 9	−36	Capella	4	+35	− 7
Aenarium Prom.	3	− 8	−18	Barocius	4	+17	−45	Capuanus	3	−26	−34
Aestuum, Sinus	2	− 7	+11	Barrow	1	+ 8	+70	Cardanus	2	−72	+13
Agarum Prom.	1	+65	+14	Bayer	3	−33	−51	Carlini	2	−24	+34
Agatharchides	3	−31	−20	Beaumont	4	+29	−18	Carpathian Mts.	2	−25	+16
Agrippa	1	+10	+ 4	Beer	2	− 9	+27	Carrington	1	+62	+44
Airy	4	+ 6	−18	Behaim	4	+79	−16	Casatus	3	−30	−73
Albategnius	4	+ 4	−12	Bellot	4	+47	−12	Cassini	1	+ 5	+40
Alexander	1	+14	+40	Bernouilli	1	+61	+35	Cassini, J. J.	2	−22	+69
Alfraganus	4	+19	− 5	Berosus	1	+70	+33	Catharina	4	+23	−18
Alhazen	1	+73	+16	Berzelius	1	+51	+36	Caucasus	1	+10	+36
Aliacensis	4	+ 5	−30	Bessarion	2	−37	+15	Cauchy	1	+38	+10
Almanon	4	+15	−17	Bessel	1	+18	+22	Cavalerius	2	−67	+ 5
Alpetragius	3	− 4	−16	Bettinus	3	−43	−63	Cavendish	3	−54	−24
Alphonsus	3	− 3	−13	Bianchini	2	−35	+47	Cayley	1	+15	+ 4
Alpine Valley	1	+ 4	+49	Biela	4	+51	−55	Celsius	4	+20	−34
Alps	2	0	+45	Billy	3	−50	−14	Censorinus	4	+33	− 1
Altai Mts.	4	+25	−26	Biot	4	+50	−23	Cepheus	1	+45	+40
Anaxagoras	2	− 8	+72	Birmingham	2	−10	+64	Chacornac	1	+32	+30
Anaximander	2	−46	+66	Birt	3	− 9	−22	Challis	1	+17	+79
Anaximenes	2	−36	+72	Blanc, Mt.	1	0	+45	Chevallier	1	+51	+45
Ansgarius	4	+80	−13	Blancanus	3	−22	−64	Chladni	1	+ 1	+ 4
Apennines	2	0	+22	Blanchinus	4	+ 3	−26	Cichus	3	−21	−33
Apianus	4	+ 8	−27	Bode	2	− 3	+ 7	Clairaut	4	+14	−48
Apollonius	1	+61	+ 4	Boguslawsky	4	+41	−73	Clausius	3	−44	−37
Arago	1	+21	+ 6	Bohnenberger	4	+40	−16	Clavius	3	−15	−59
Aratus	1	+ 5	+24	Bond, G. P.	1	+36	+32	Cleomedes	1	+55	+27
Archimedes	2	− 4	+30	Bond, W. C.	1	+ 4	+65	Cleostratus	2	−77	+62
Archytas	1	+ 5	+59	Bonpland	3	−18	− 8	Colombo	4	+45	−15
Argaeus, Mt.	1	+29	+20	Borda	4	+47	−25	Condamine	2	−29	+53
Argelander	4	+ 6	−16	Boscovich	1	+11	+10	Condorcet	1	+69	+12
Ariadaeus	1	+17	+ 5	Bouguer	2	−36	+52	Conon	1	+ 2	+22
Aristarchus	2	−47	+24	Boussingault	4	+50	−70	Cook	4	+48	−17
Aristillus	1	+ 1	+34	Bouvard	3	−80	−40	Copernicus	2	−20	+10
Aristoteles	1	+17	+50	Bradley, Mt.	1	+ 2	+23	Cordillera Mts.	3	−80	−15
Arnold	1	+35	+67	Brayley	2	−37	+21	Crisium, Mare	1	+60	+16
Arzachel	3	− 2	−18	Briggs	2	−69	+26	Crozier	4	+50	−14
Atlas	1	+44	+47	Buch	4	+18	−39	Crüger	3	−67	−17
Australe, Mare	4	+80	−50	Bullialdus	3	−22	−21	Curtius	4	+ 3	−66
Autolycus	1	+ 1	+30	Burckhardt	1	+57	+31	Cuvier	4	+10	−50
Auzout	1	+63	+10	Burg	1	+28	+45	Cyrillus	4	+24	−13
Azophi	4	+12	−22	Büsching	4	+20	−38	Cysatus	3	− 6	−65
Babbage	2	−55	+59	Byrgius	3	−65	−24	D'Alembert Mts.	3	−90	− 3

Name.	Quad.	Long.	Lat.	Name.	Quad.	Long.	Lat.	Name.	Quad.	Long.	Lat.
Damoiseau	3	—60	— 5	Galileo	2	—63	+10	Hind	4	+ 7	— 8
Daniell	1	+31	+35	Gambart	2	—15	+ 1	Hippalus	3	—30	—25
Davy	3	— 8	—12	Gärtner	1	+35	+59	Hipparchus	4	+ 5	— 5
Dawes	1	+26	+17	Gassendi	3	—40	—18	Hommel	4	+32	—54
Delambre	4	+18	— 2	Gauricus	3	—13	—34	Hooke	1	+55	+41
De la Rue	1	+51	+59	Gauss	1	+80	+36	Horrebow	2	—40	+59
Delaunay	4	+ 4	—22	Gay-Lussac	2	—21	+14	Horrocks	4	+ 6	— 4
Delisle	2	—35	+30	Geber	4	+14	—19	Hortensius	2	—28	+ 6
Deluc	3	— 3	—55	Geminus	1	+57	+34	Humboldt, Wilhelm.	4	+80	—27
Democritus	1	+34	+61	Gemma Frisius	4	+14	—34	Humboldtianum, Mare	1	+80	+58
De Morgan	1	+15	+ 3	Gérard	2	—85	+47	Humorum, Mare	3	—40	—24
Descartes	4	+15	—11	Gioja	1	+25	+85	Huggins	3	— 1	—41
De Vico	3	—60	—20	Goclenius	4	+45	—10	Huygens, Mt.	2	— 3	+20
Dionysius	1	+17	+ 3	Godin	1	+10	+ 2	Hyginus	1	+ 6	+ 8
Diophantus	2	—34	+27	Goldschmidt	2	0	+72	Hypatia	4	+23	— 4
Doerfel Mts.	3	—90	—70	Grimaldi	3	—67	— 6	Imbrium, Mare	2	—20	+30
Dollond	4	+14	—10	Grove	1	+33	+40	Inghirami	3	—69	—48
Donati	4	+ 6	—21	Gruemberger	3	—10	—66	Iridum, Sinus	2	—32	+45
Doppelmayer	3	—41	—28	Gruithuisen	2	—40	+33	Isidorus	4	+33	— 8
Drebbel	3	—49	—41	Guericke	3	—14	—11	Jacobi	4	+11	—57
Egede	1	+10	+48	Guttemberg	4	+41	— 9	Jansen	1	+29	+14
Eichstädt	3	—79	—22	Hadley, Mt.	1	+ 5	+26	Janssen	4	+40	—45
Eimmart	1	+65	+24	Haemus Mts.	1	+15	+17	Julius Cæsar	1	+15	+ 9
Encke	2	—37	+ 5	Hagecius	4	+46	—60	Kant	4	+20	—11
Endymion	1	+56	+53	Hahn	1	+75	+31	Kästner	4	+80	— 6
Epigenes	2	— 4	+66	Hainzel	3	—33	—41	Kepler	2	—38	+ 8
Eratosthenes	2	—11	+14	Halley	4	+ 6	— 8	Kies	3	—22	—26
Euclides	3	—30	— 7	Hanno	4	+71	—56	Kinau	4	+15	—61
Euctemon	1	+39	+76	Hansen	1	+73	+14	Kirch	2	— 6	+39
Eudoxus	1	+16	+44	Hansteen	3	—52	—11	Kircher	3	—44	—67
Euler	2	—29	+24	Harbinger Mts.	2	—41	+27	Klaproth	3	—26	—70
Fabricius	4	+41	—43	Harding	2	—70	+43	Krafft	2	—72	+17
Faraday	4	+ 9	—42	Harpalus	2	—43	+52	Kunowsky	2	—32	+ 3
Faye	4	+ 4	—21	Hase	4	+61	—29	Lacaille	4	+ 1	—24
Fermat	4	+20	—22	Hausen	3	—75	—59	Lacroix	3	—59	—38
Fernelius	4	+ 5	—38	Hecataeus	4	+79	—21	Lagrange	3	—70	—33
Firmicus	1	+63	+ 7	Heinsius	3	—18	—39	Lahire	2	—25	+27
Flammarion	3	— 4	— 3	Helicon	2	—23	+40	Lalande	3	— 9	— 5
Flamsteed	3	—44	— 4	Hell	3	— 8	—32	Lambert	2	—21	+26
Foecunditatis, Mare	4	+50	— 3	Heraclides, Prom.	2	—35	+41	Landsberg	3	—26	0
Fontana	3	—57	—16	Hercules	1	+39	+47	Langrenus	4	+60	— 9
Fontenelle	2	—20	+63	Hercynian Mts.	2	—85	+25	Lapeyrouse	4	+77	—11
Foucault	2	—40	+50	Herigonius	3	—34	—13	Laplace Prom.	2	—26	+46
Fourier	3	—53	—30	Hermann	3	—57	— 1	Lassell	3	— 8	—15
Fracastorius	4	+33	—21	Herodotus	2	—50	+23	Lavoisier	2	—79	+39
Fra Mauro	3	—17	— 6	Herschel	3	— 2	— 6	Lee	3	—40	—30
Franklin	1	+48	+39	Herschel, J. F. W.	2	—40	+62	Legendre	4	+70	—29
Fraunhofer	4	—40	+59	Herschel, Caroline	2	—31	+35	Legentil	3	—78	—75
Frigoris, Mare	1	+58	0	Hesiodus	3	—17	—29	Lehmann	3	—56	—40
Furnerius	4	—36	+60	Hevel	2	—67	+ 2	Leibnitz Mts.	4	+90	—80

Name.	Quad.	Long.	Lat.
LeMonnier	1	+30	+27
Letronne	3	−42	−10
Leverrier	2	−20	+40
Lexell	3	− 4	−36
Licetus	4	+ 7	−47
Lichtenberg	2	−67	+32
Lilius	4	+ 6	−55
Lindenau	4	+25	−32
Linné	1	+12	+28
Littrow	1	+31	+21
Lockyer	4	+36	−46
Lohrmann	3	−67	− 1
Longomontanus	3	−21	−50
Louville	2	−45	+44
Lubbock	4	+42	− 4
Lubiniezky	3	−24	−18
Maclaurin	4	+66	− 2
Maclear	1	+20	+10
Macrobius	1	+46	+21
MacClure	4	+50	−15
Mädler	4	+30	−11
Magelhaens	4	+44	−12
Maginus	3	− 6	−50
Main	1	+25	+82
Mairan	2	−44	+41
Malapert	4	+10	−87
Manilius	1	+ 9	+15
Manners	1	+20	+ 5
Manzinus	4	+26	−67
Maraldi	1	+35	+19
Marco Polo	2	− 2	+16
Marinus	4	+78	−40
Marius	2	−50	+12
Maskelyne	1	+30	+ 2
Mason	1	+30	+43
Maupertuis	2	−27	+49
Maurolycus	4	+14	−42
Maury	1	+40	+37
Mayer, Christian	1	+19	+63
Mayer, Tobias	2	−29	+15
Medii, Sinus	2	− 1	+ 1
Menelaus	1	+16	+16
Mercator	3	−26	−29
Mercurius	1	+67	+47
Mersenius	3	−49	−22
Messala	1	+60	+40
Messier	4	+48	− 2
Metius	4	+44	−40
Meton	1	+22	+74
Milichius	2	−30	+10
Miller	4	0	−39
Moigno	1	+28	+66
Moretus	3	− 7	−70
Mortis, Lacus	1	+32	+47
Mösting	3	− 6	− 1
Murchison	2	0	+ 5
Mutus	4	+30	−64
Nasireddin	4	0	−41
Neander	4	+40	−31
Nearch	4	+39	−59
Nebularum, Palus	1	+ 1	+39
Nectaris, Mare	4	+35	−15
Neper	1	+85	+10
Newcomb	1	+43	+30
Newton	3	−14	−78
Nicolai	4	+26	−42
Nicollet	3	−12	−22
Nonius	4	+ 4	−35
Nubium, Mare	3	−15	−20
Oenopides	2	−63	+58
Oersted	1	+47	+42
Oken	4	+77	−44
Olbers	2	−79	+ 8
Oriani	1	+78	+25
Orontius	3	− 4	−41
Palitzsch	4	+64	−26
Pallas	2	− 2	+ 6
Parrot	4	+ 3	−14
Parry	3	−16	− 8
Peirce	1	+54	+17
Pentland	4	+11	−65
Petavius	4	+60	−25
Peters	1	+28	+69
Phillips	4	+74	−26
Philolaus	2	−28	+71
Phocylides	3	−57	−53
Piazzi	3	−67	−36
Picard	1	+54	+14
Piccolomini	4	+32	−30
Pico	2	− 9	+45
Pictet	3	− 7	−44
Pingré	3	−70	−54
Pitatus	3	−14	−30
Pitiscus	4	+30	−51
Piton	2	0	+40
Plana	1	+28	+42
Plato	2	− 9	+51
Playfair	4	+ 9	−23
Plinius	1	+23	+15
Plutarch	1	+83	+25
Poisson	4	+10	−31
Polybius	4	+26	−22
Pons	4	+21	−25
Pontanus	4	+15	−29
Pontécoulant	4	+68	−59
Posidonius	1	+30	+32
Procellarum, Oceanus	2	−50	+15
Proclus	1	+47	+16
Protagoras	1	+ 7	+56
Ptolemäus	3	− 2	− 9
Purbach	3	− 2	−26
Putredinus, Palus	1	+ 1	+27
Pyranees Mts.	4	+40	−14
Pythagoras	2	−65	+63
Pytheas	2	−20	+20
Rabbi Levi	4	+24	−35
Ramsden	3	−32	−33
Réaumur	4	+ 1	− 3
Regiomontanus	3	− 2	−28
Reichenbach	4	+49	−30
Reiner	2	−55	+ 7
Reinhold	2	−22	+ 3
Repsold	2	−77	+54
Rhaeticus	1	+ 5	0
Rheita	4	+47	−37
Riccioli	3	−74	− 3
Riccius	4	+27	−37
Riphaean Mts.	3	−27	− 7
Ritter	1	+19	+ 2
Robinson	2	−46	+59
Rocca	3	−72	−13
Römer	1	+37	+26
Rook Mts.	3	−90	−30
Roris, Sinus	2	−55	+45
Rosenberger	4	+42	−55
Ross	1	+21	+11
Rosse	4	+35	−18
Röst	3	−33	−57
Sabine	1	+20	+ 1
Sacrobosco	4	+17	−24
Santbech	4	+44	−21
Sasserides	3	− 9	−39
Saussure	3	− 4	−43
Schiner	3	−28	−60
Schiaparelli	2	−58	+23
Schickard	3	−55	−45
Schiller	3	−39	−52
Schmidt	1	+19	+ 1
Schomberger	4	+25	−77
Schröter	2	− 7	+ 3

Name.	Quad.	Long.	Lat.
Schröter's Valley	2	−50	+26
Schubert	1	+82	+4
Schumacher	1	+60	+42
Scoresby	1	+16	+77
Secchi	1	+43	+2
Segner	3	−48	−59
Seleucus	2	−66	+21
Seneca	1	+81	+29
Serenitatis, Mare	1	+18	+26
Sharp	2	−40	+45
Short	3	−7	−75
Shuckburgh	1	+52	+42
Silberschlag	1	+13	+6
Simpelius	4	+14	−73
Sirsalis	3	−60	−12
Smyth, Piazzi	2	−3	+42
Smythii, Mare.	1	+90	+3
Snellius	4	+55	−29
Sömmering	2	−7	0
Somnii, Palus	1	+44	+14
Somniorum, Lacus	1	+30	+36
Sosigenes	1	+17	+9
South	2	−50	+58
Stadius	2	−14	+11
Steinheil	4	+47	−49
Stevinus	4	+54	−32
Stiborius	4	+32	−35
Stöfler	4	+6	−42
Strabo	1	+52	+61
Straight Range	2	−20	+48
Street	3	−10	−46
Struve	1	+67	+43
Struve, Otto	2	−77	+23
Sulpicius Gallus	1	+12	+20
Tacitus	4	+19	−16
Tannerus	4	+22	−56
Taquet	1	+19	+16
Taruntius	1	+46	+6
Taurus Mts.	1	+40	+30
Taylor	4	+17	−5
Teneriffe Mts.	2	−13	+47
Thales	1	+50	+61
Theaetetus	1	+6	+37
Thebit	3	−4	−22
Theon, Jr.	4	+16	−2
Theon, Sr.	4	+15	−1
Theophilus	4	+26	−12
Timaeus	2	−1	+63
Timocharis	2	−13	+27
Torricelli	4	+29	−5
Tralles	1	+52	+28
Tranquillitatis, Mare	1	+28	+9
Triesnecker	1	+4	+4
Tycho	3	−11	−43
Ukert	1	+1	+8
Ulugh Beigh	2	−80	+34
Vaporum, Mare	1	+5	+13
Vasco de Gama	2	−82	+15
Vega	4	+64	−45
Vendelinus	4	+61	−16
Vieta	3	−56	−29
Vitello	3	−37	−30
Vitruvius	1	+31	+18
Vlacq	4	+38	−54
Walter	4	+1	−33
Wargentin	3	−60	−50
Webb	4	+60	−1
Weigel	3	−40	−59
Werner	4	+3	−28
Whewell	1	+14	+4
Wichmann	3	−38	−8
Wilhelm I.	3	−20	−44
Wilson	3	−40	−69
Wolf Mt.	2	−6	+17
Wollaston	2	−47	+30
Wrottesley	4	+56	−24
Wurzelbauer	3	−16	−34
Xenophanes	2	−75	+59
Zach	4	+6	−61
Zagut	4	+22	−32
Zuchius	3	−50	−61
Zupus	3	−52	−17

LUNAR CONSTANTS

Synodical revolution, or interval from new moon to new moon. Synodical rotation, or interval from sunrise to sunrise on the same formation	$29^d.5305887$ $(29^d\ 12^h\ 44^m\ 2.^s684)$
Sidereal revolution, or interval in passing from one star to the same star again	$27^d.3216614$ $(27^d\ 7^h\ 43^m\ 11.^s545)$
Tropical revolution, or interval in passing from the vernal equinox to the same point again	$27.^d321582$ $(27^d\ 7^h\ 43^m\ 4.^s68$
Anomalistic revolution, or interval in passing from perigee to perigee	$27.^d55460$ $(27^d\ 13^h\ 18^m\ 37.^s44)$
Nodical revolution, or interval in passing from the ascending node to the ascending node again	$27.^d21222$ $(27^d\ 5^h\ 5^m\ 35.^s81)$
Eccentricity of Orbit	0.05490807
Inclination of Orbit to Ecliptic	5° 8′ 40″
Inclination of Equator to Ecliptic	1° 32′ 9″
Maximum geocentric libration in longitude	7° 45′
Maximum geocentric libration in latitude	6° 44′
Maximum geocentric libration	10° 16′
Maximum diurnal libration	1° 1′ 28.″8
Maximum physical libration	3.′0
Surface of the Moon visible at one time or another	0.59
Surface of the Moon never visible	0.41
Distance, maximum	252,972 miles (407,116 km.)
Distance, minimum	221,614 miles (356,650 km.)
Distance, mean	238,840 miles (384,372 km.)
Diameter, maximum	33′ 33″.20
Diameter, minimum	29′ 23″.65
Diameter, mean	31′ 08″
Diameter, linear	2,163 miles (3,481 km.)
Mass	0.01228 or $\frac{1}{81.40}$ of the Earth
Surface	0.07448 or $\frac{1}{13.43}$ of the Earth
Volume	0.02033 or $\frac{1}{49.20}$ of the Earth
Density	0.60419 of the Earth
Density	3.444 Water being unity
Force of Gravity at the surface	0.16489 or $\frac{1}{6.065}$ of the Earth
Angle subtended by one degree of selenographical longitude or latitude at the centre of the Moon's disk when at its mean distance	16.″566
Linear value of the same	18.871 miles (30.370 km.)
Selenographical arc at the centre of the Moon's disk, when at mean distance subtending an angle of one second of arc	3′ 37.″31
Linear value of the same	1.139 miles (1.833 km.)

MARE CRISIUM

334° 1 B

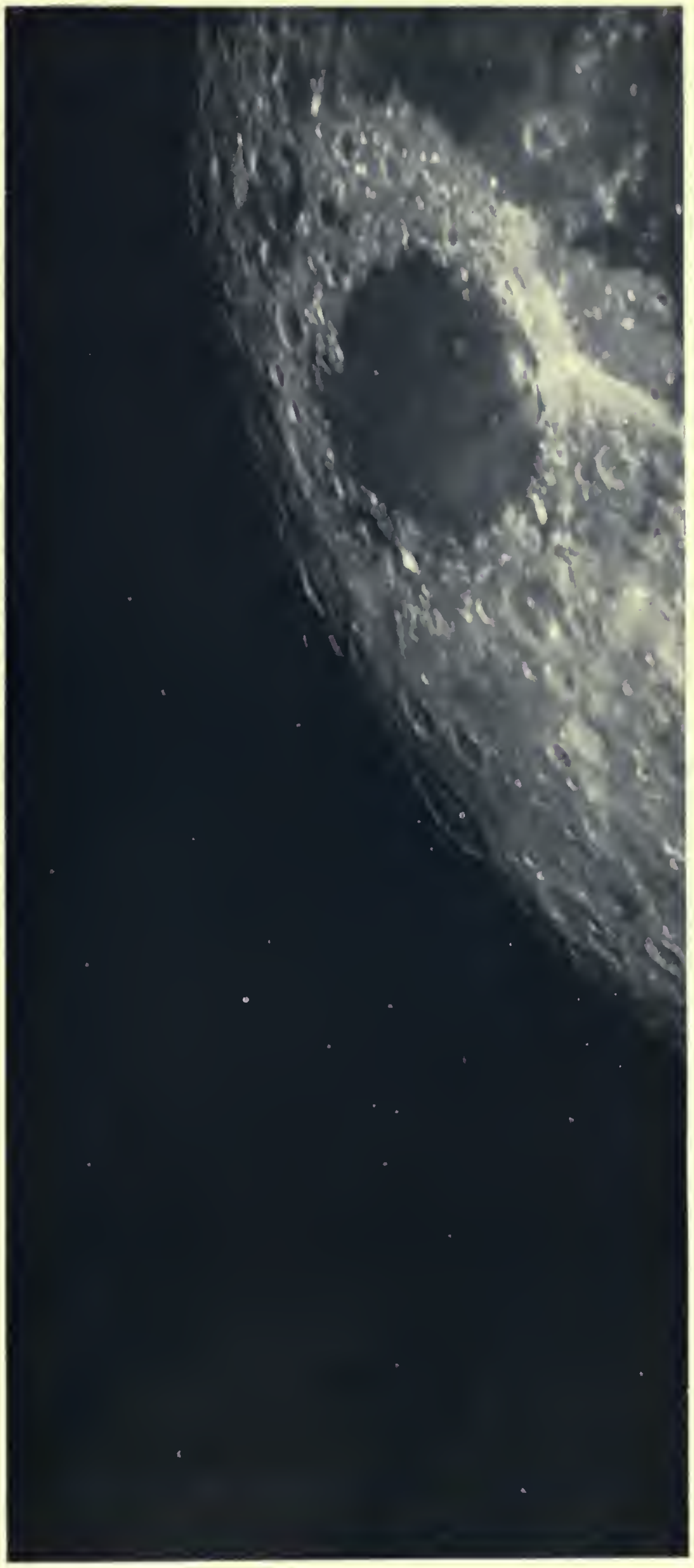
MARE CRISIUM

23° 1 C

MARE CRISIUM

MARE CRISIUM

97° 1 E



MARE CRISIUM

PETAVIUS. LANGRENUS

340°

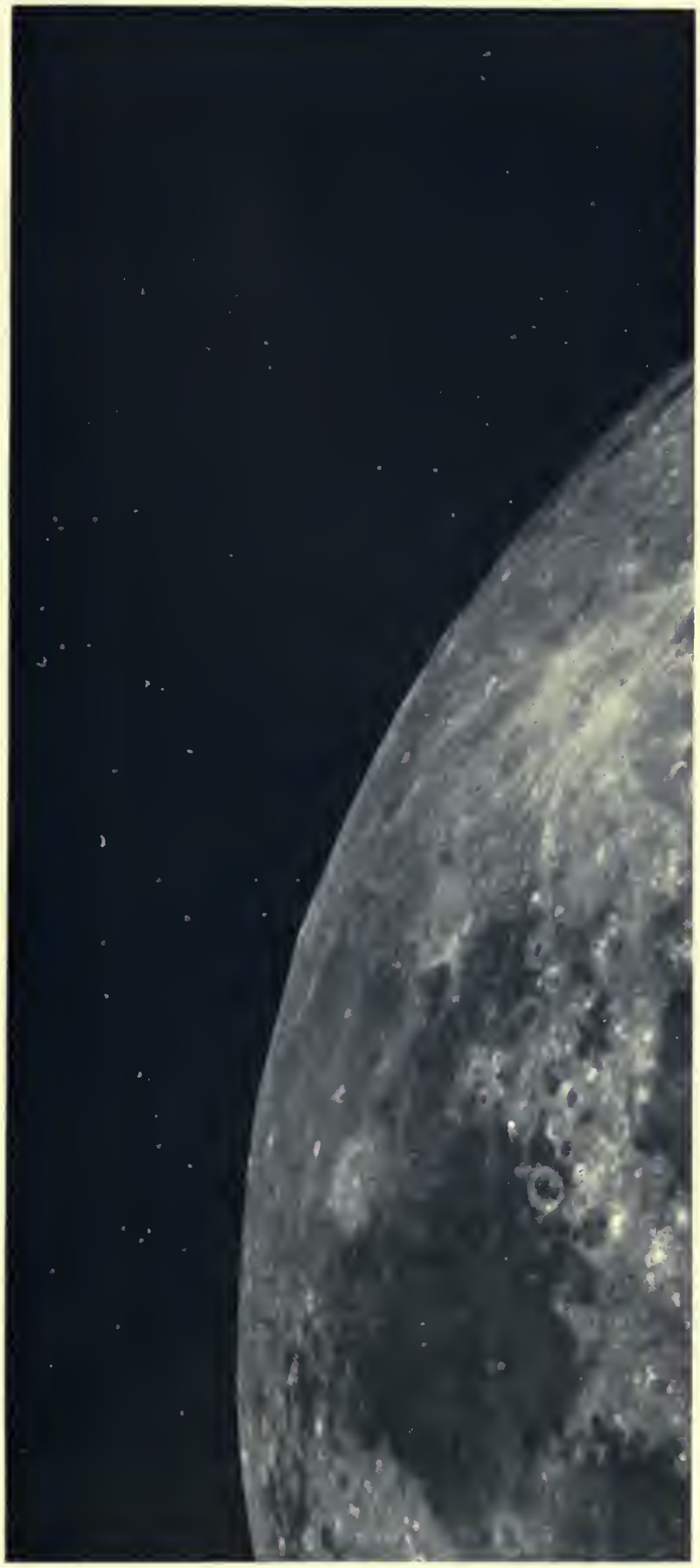
2 B

PETAVIUS. LANGRENUS

PETAVIUS. LANGRENUS

93°

2 D



PETAVIUS. LANGRENUS

97°

2 E

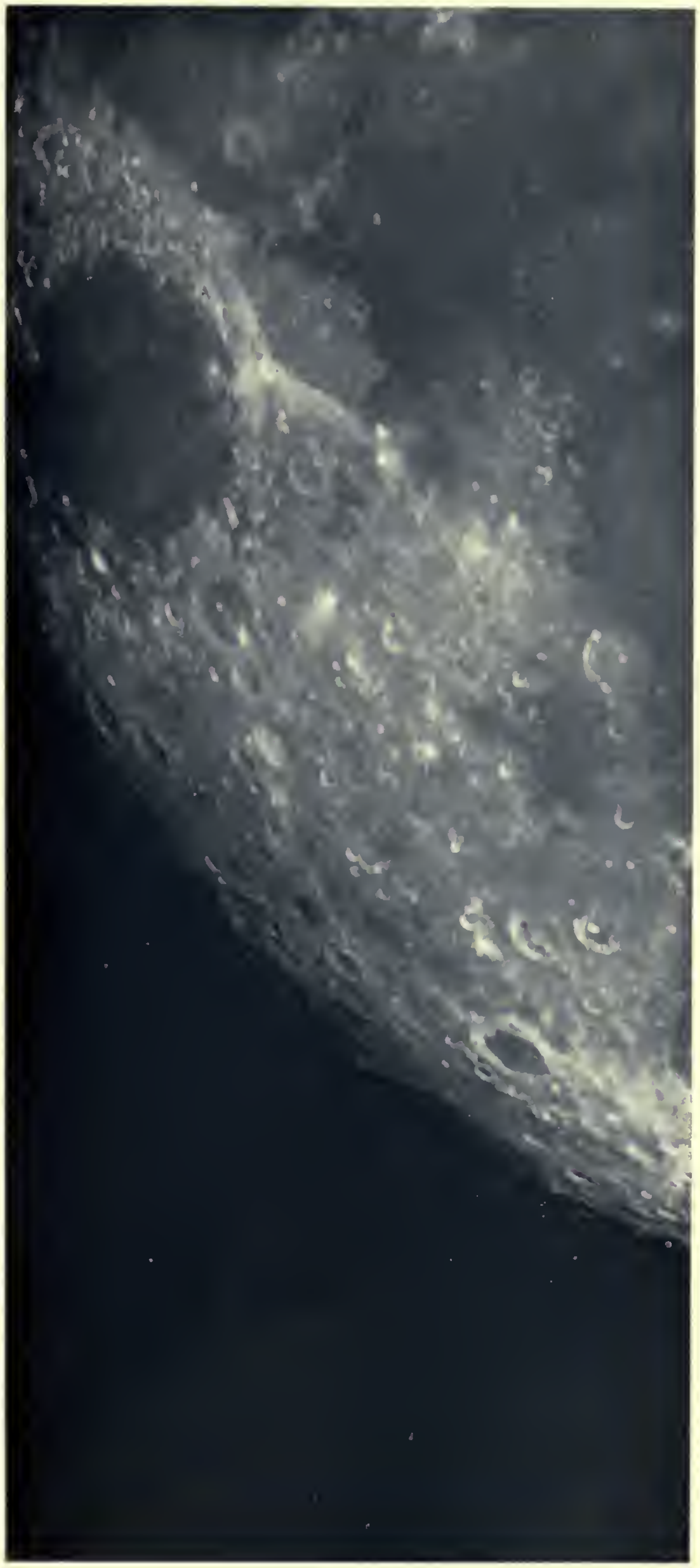
PETAVIUS. LANGRENUS

334°

CLEOMEDES. ATLAS

CLEOMEDES. ATLAS

CLEOMEDES. ATLAS



CLEOMEDES. ATLAS

122° 3 E

CLEOMEDES. ATLAS

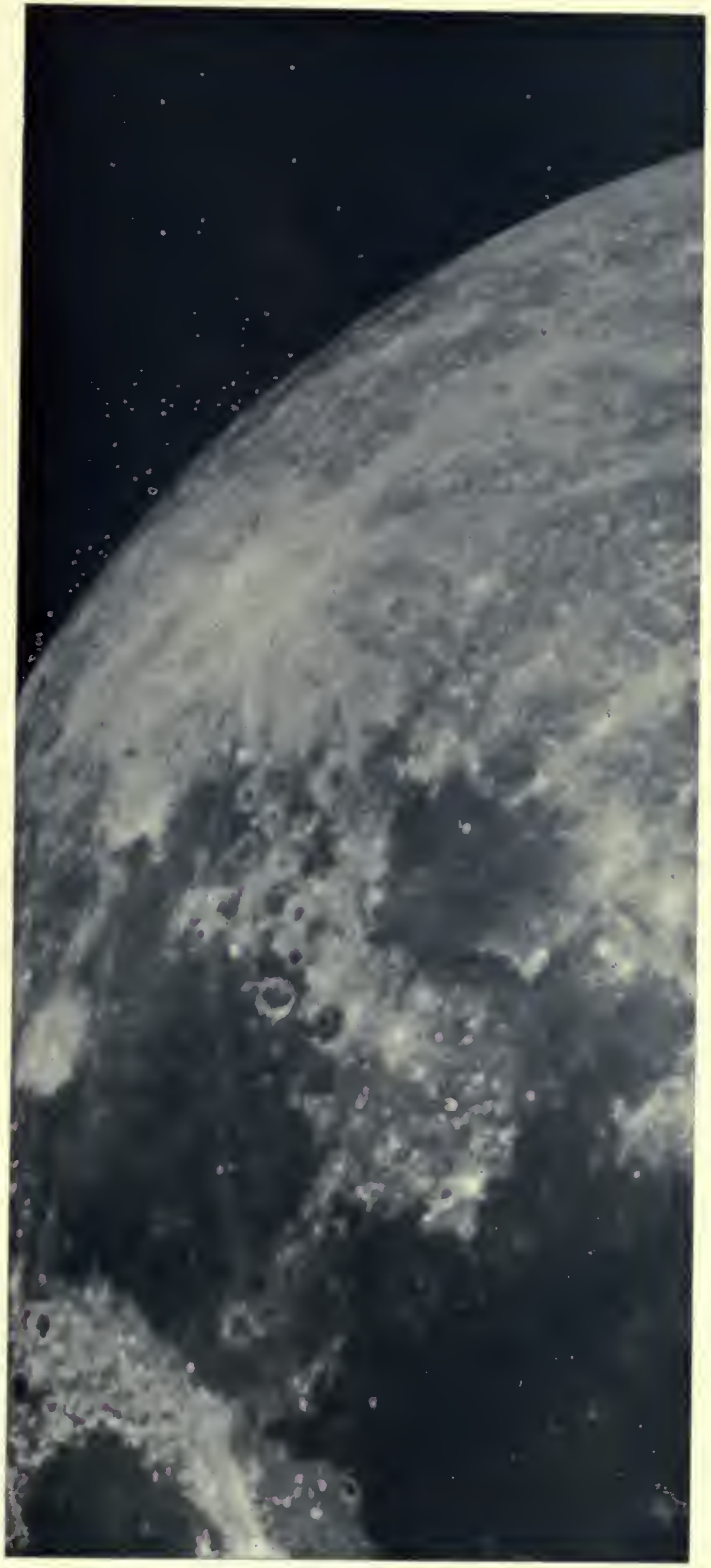
MARE FOECUNDITATIS. MARE NECTARIS

358°

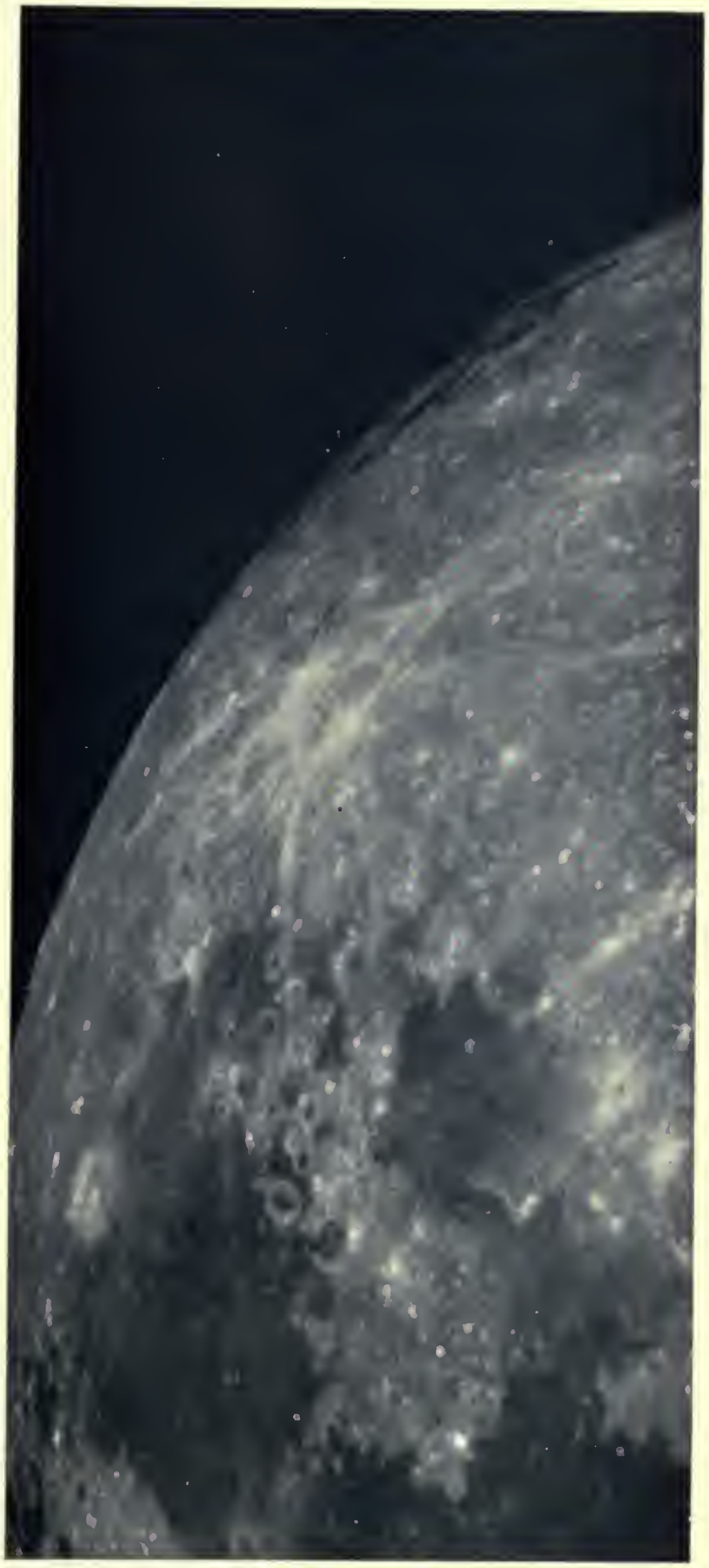
MARE FOECUNDITATIS. MARE NECTARIS

47°

4 C



MARE FOECUNDITATIS. MARE NECTARIS

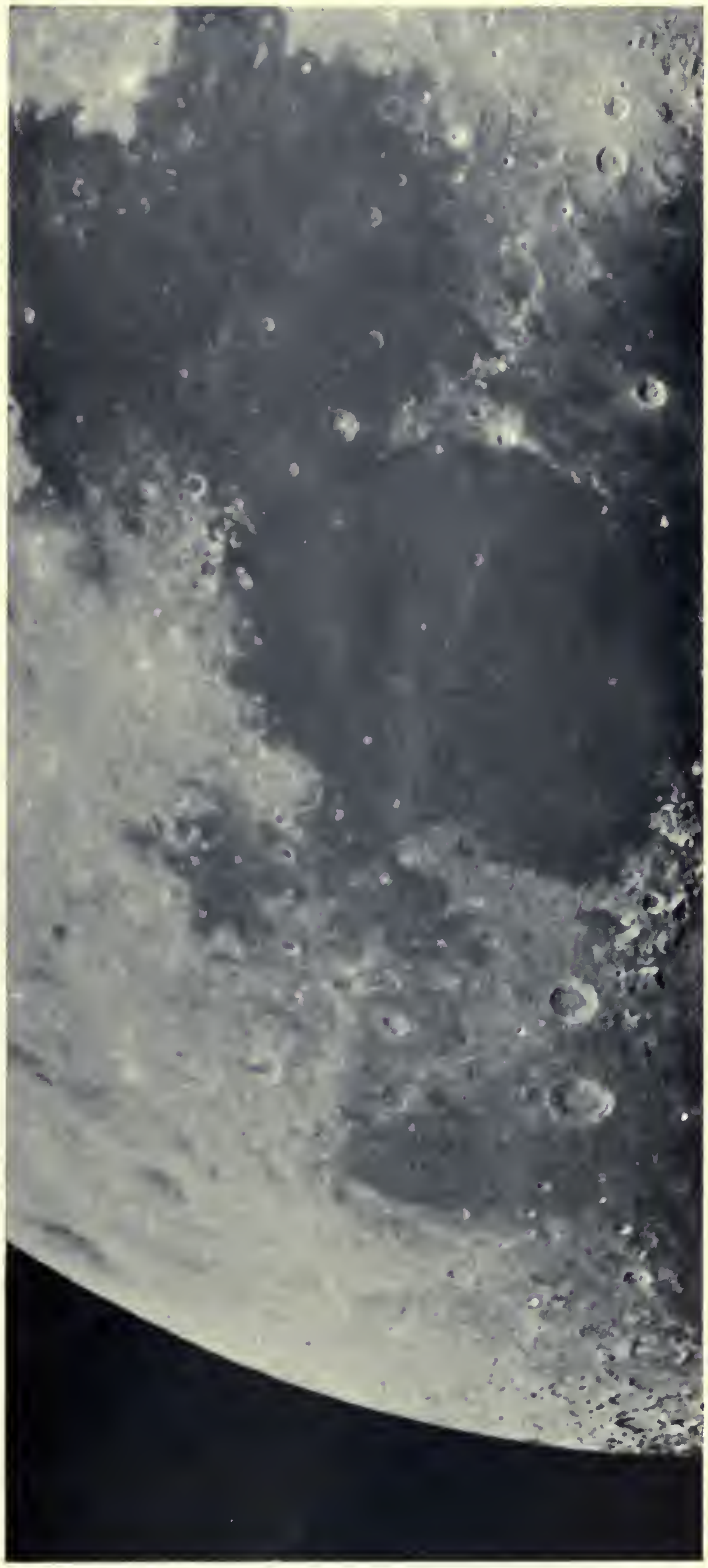


MARE FOECUNDITATIS. MARE NECTARIS

122°

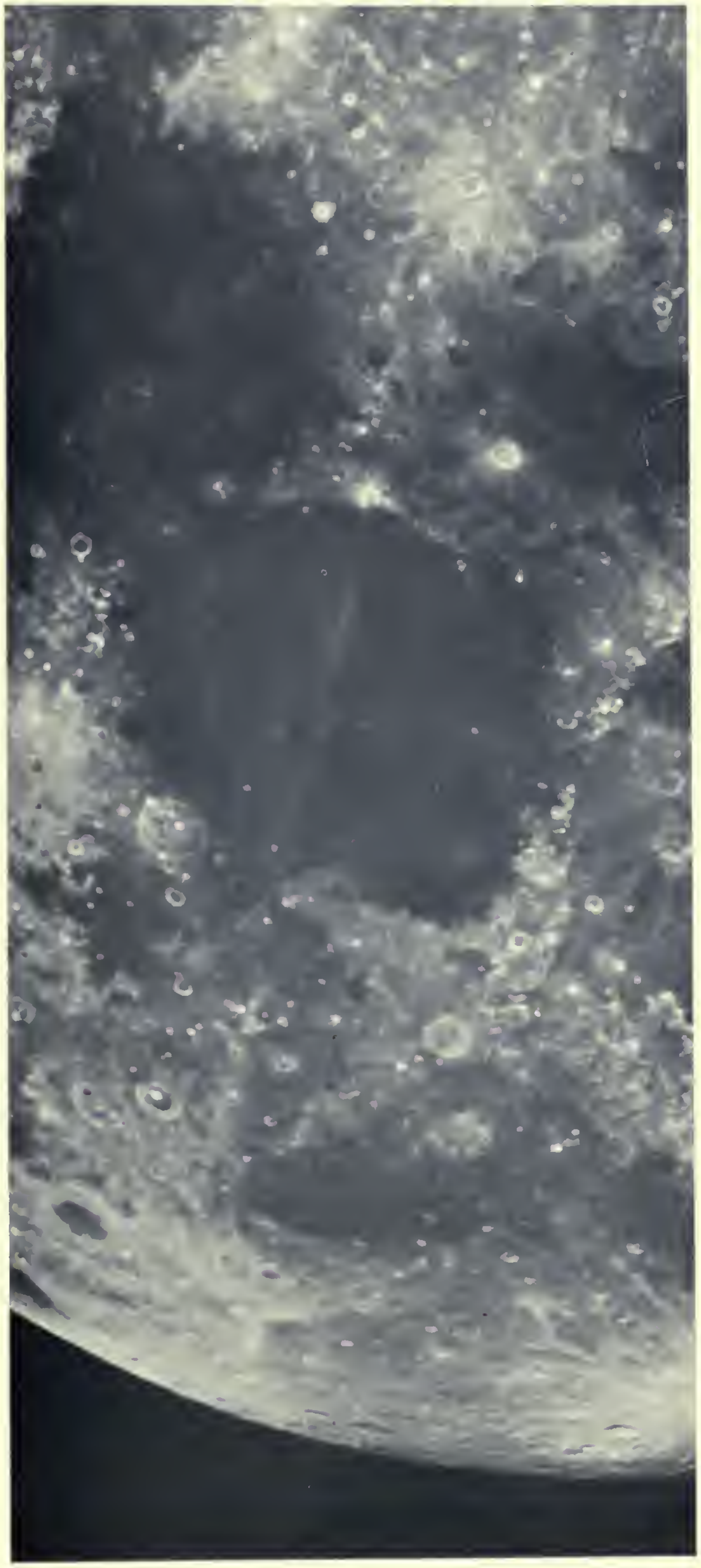
4 E

MARE FOECUNDITATIS. MARE NECTARIS



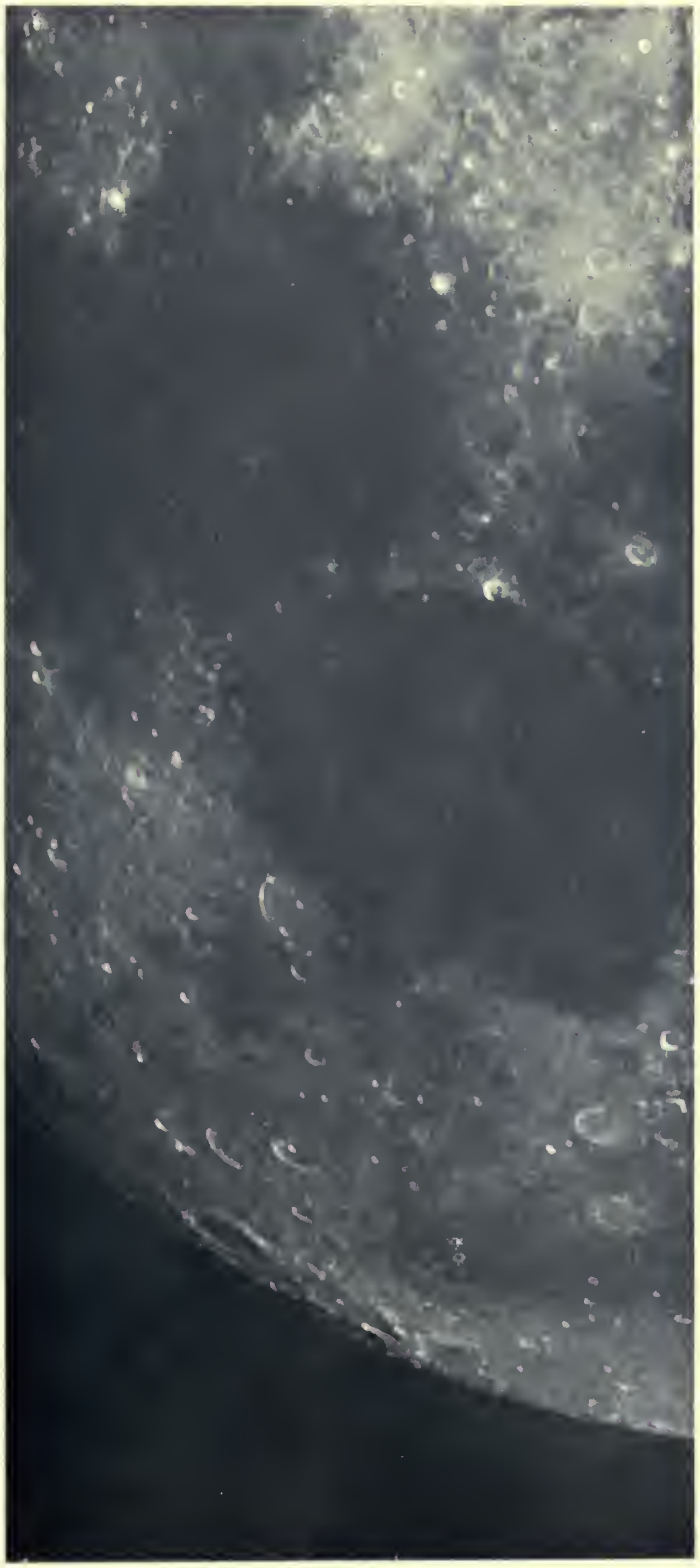
MARE TRANQUILLITATIS. MARE SERENITATIS

79°　5 C

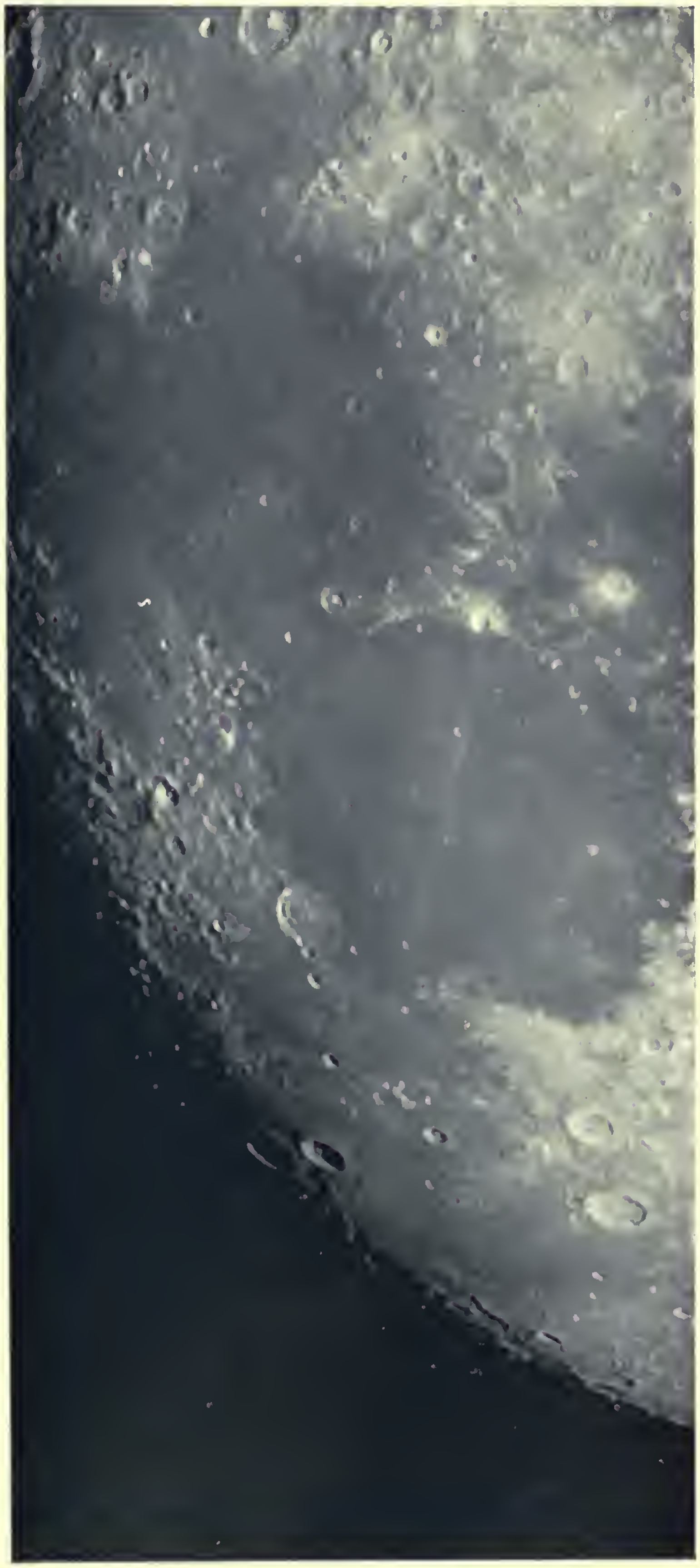


MARE TRANQUILLITATIS. MARE SERENITATIS

110°　　5 D



MARE TRANQUILLITATIS. MARE SERENITATIS



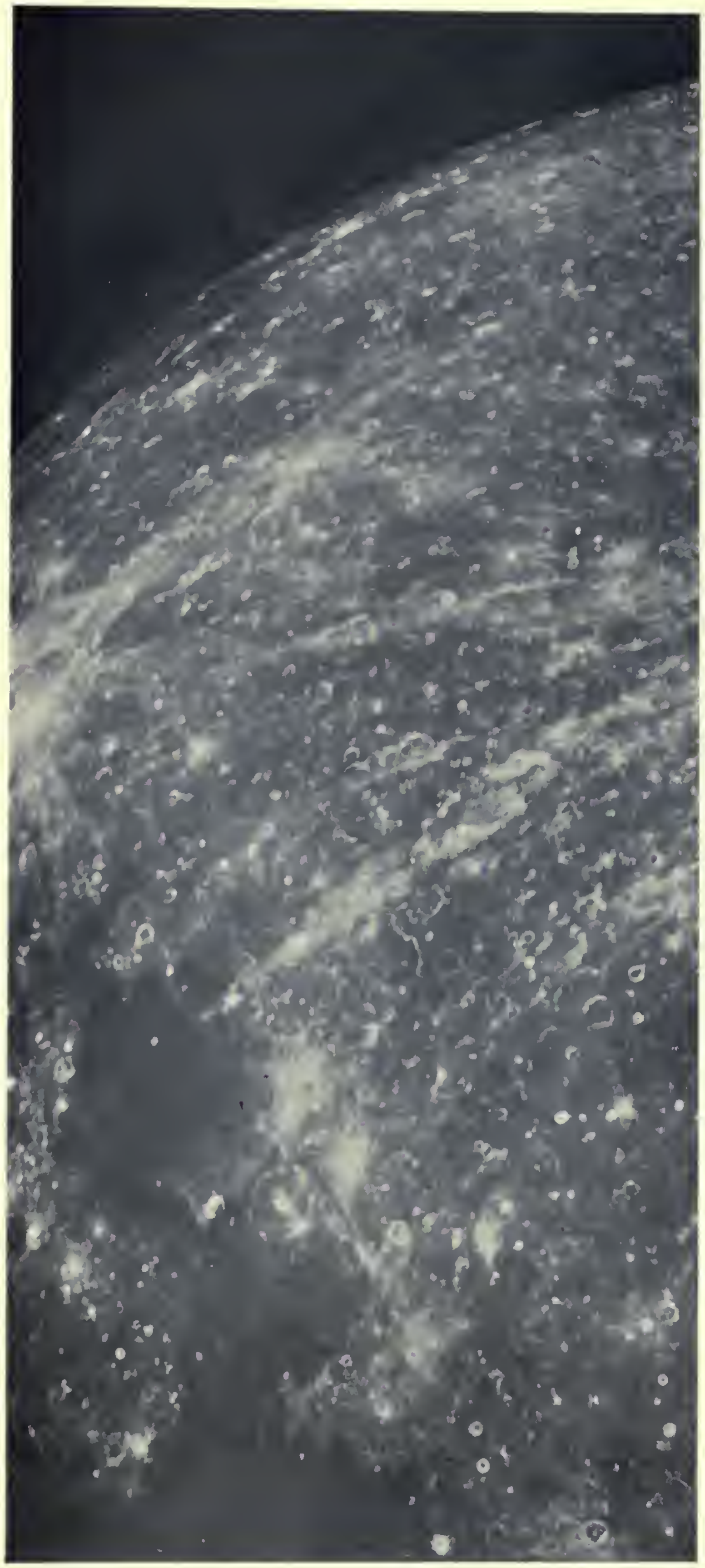
MARE TRANQUILLITATIS. MARE SERENITATIS

358°

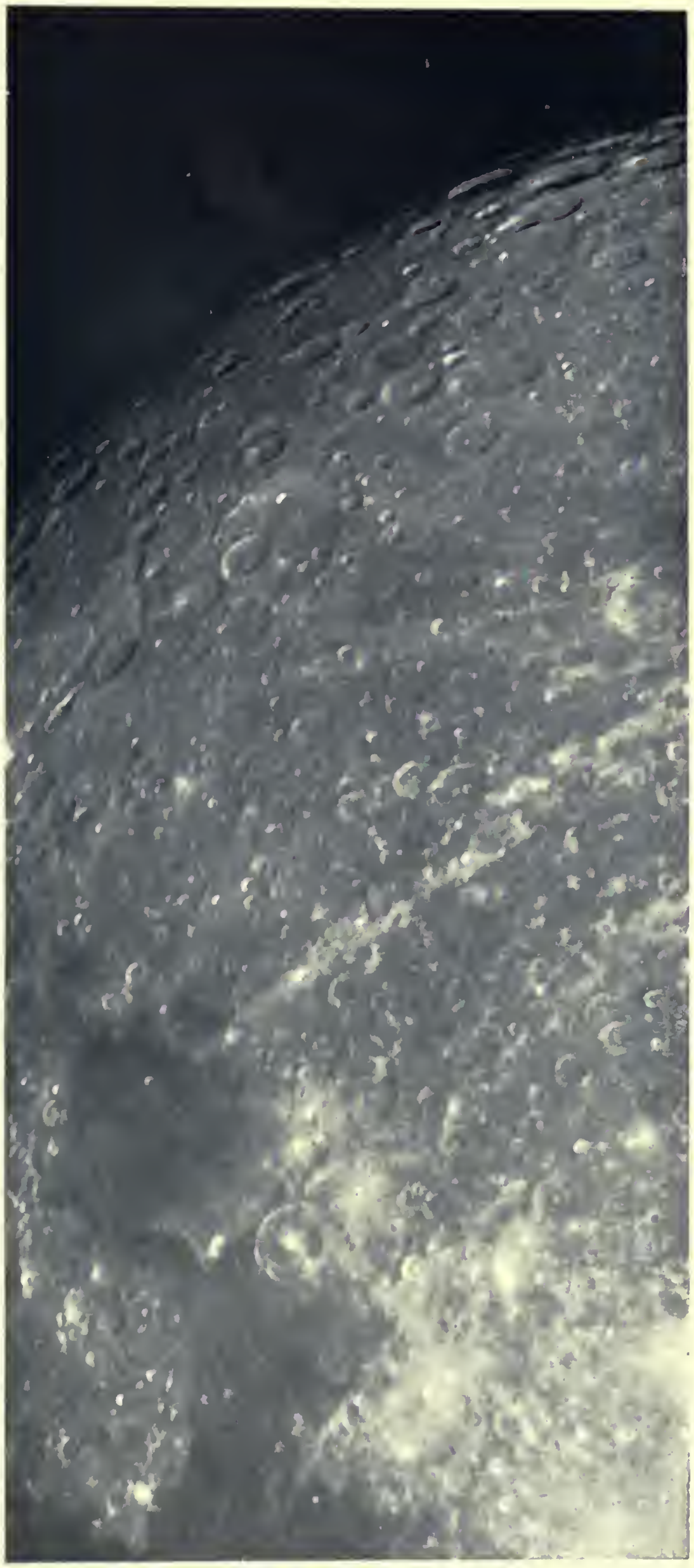
6 A

PICCOLOMINI. THEOPHILUS

PICCOLOMINI. THEOPHILUS



PICCOLOMINI. THEOPHILUS



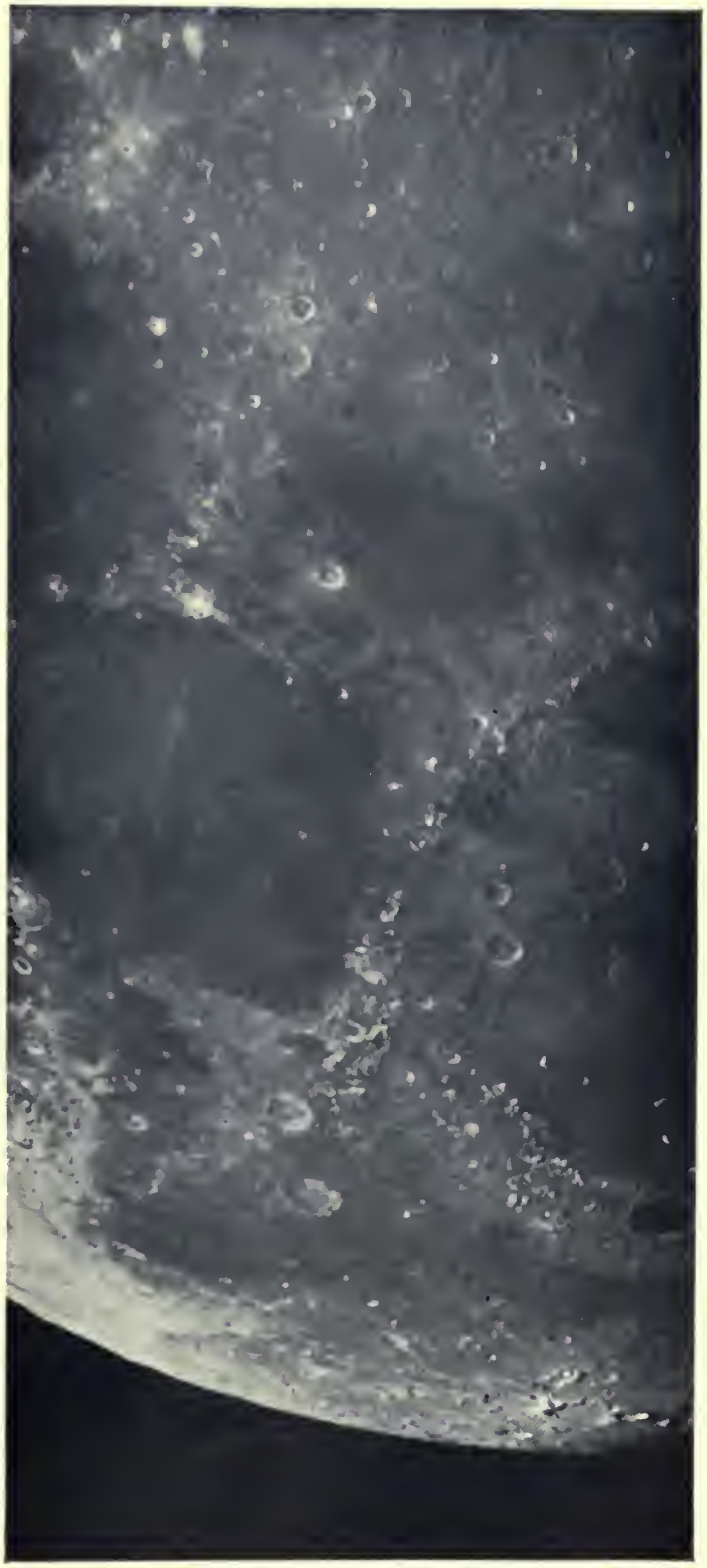
PICCOLOMINI. THEOPHILUS

135°

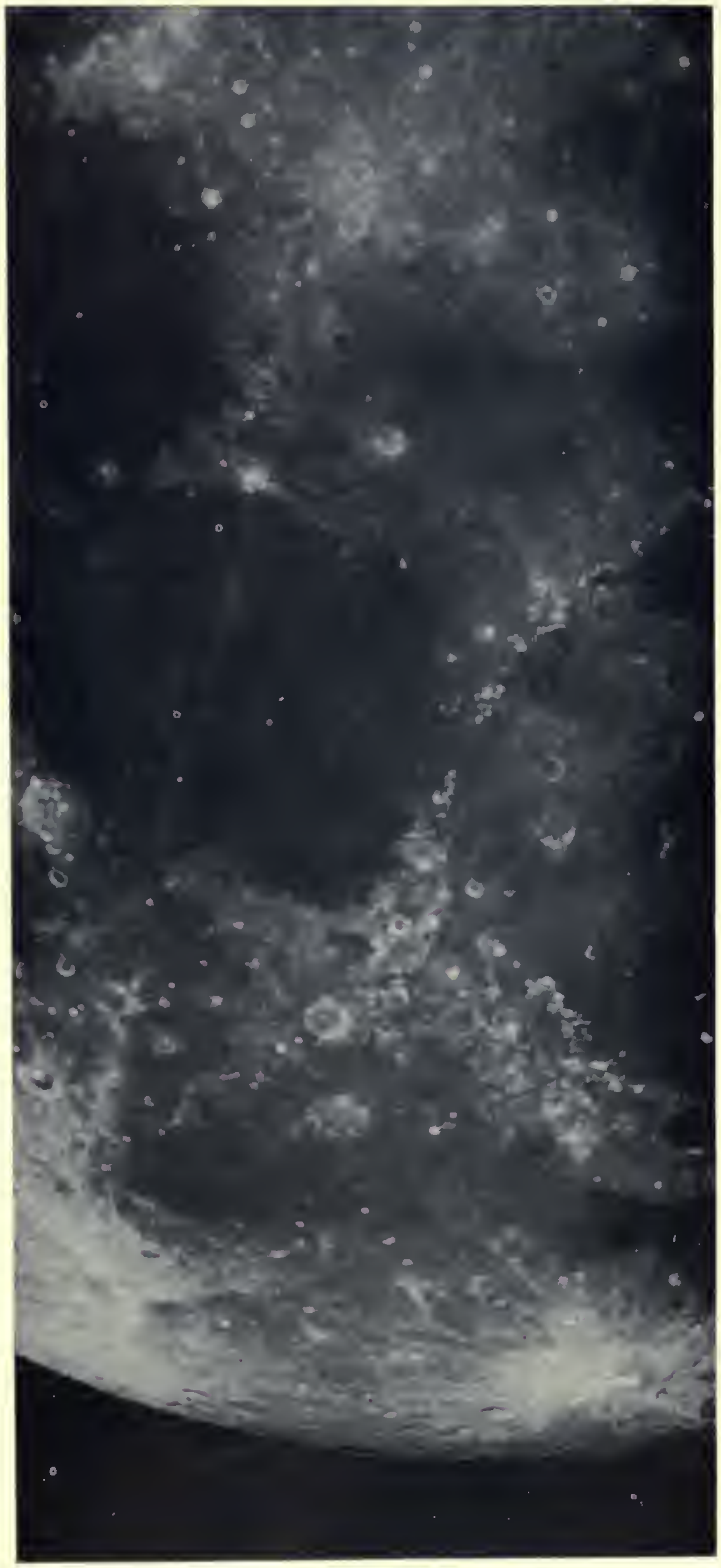
6 E

PICCOLOMINI. THEOPHILUS

APENNINES. ARISTOTELES.



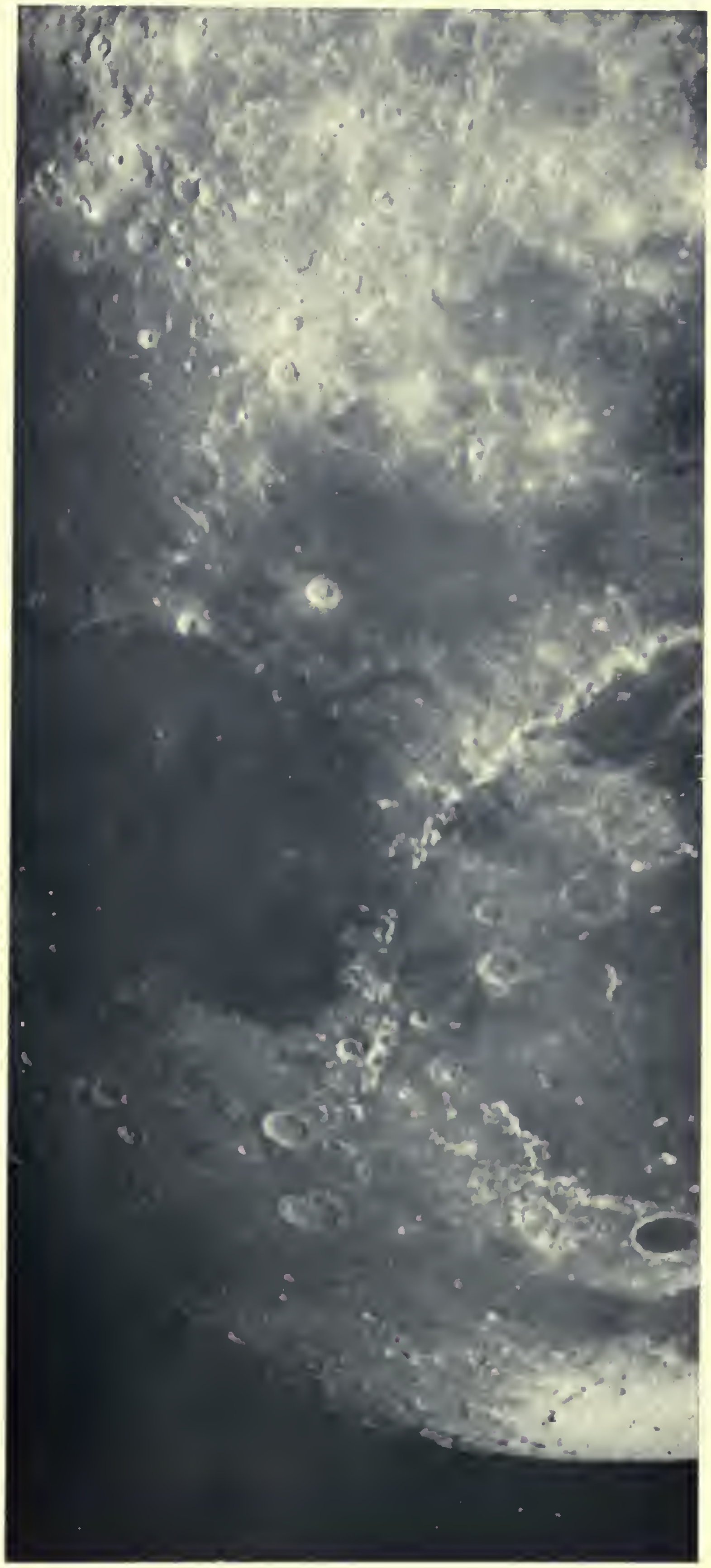
APENNINES. ARISTOTELES



APENNINES. ARISTOTELES

135°

7 D



APPENNINES. ARISTOTELES

APENNINES. ARISTOTELES

MAUROLYCUS. ALBATEGNIUS

MAUROLYCUS. ALBATEGNIUS

73° 8 C

MAUROLYCUS. ALBATEGNIUS

135°　8 E

MAUROLYCUS. ALBATEGNIUS

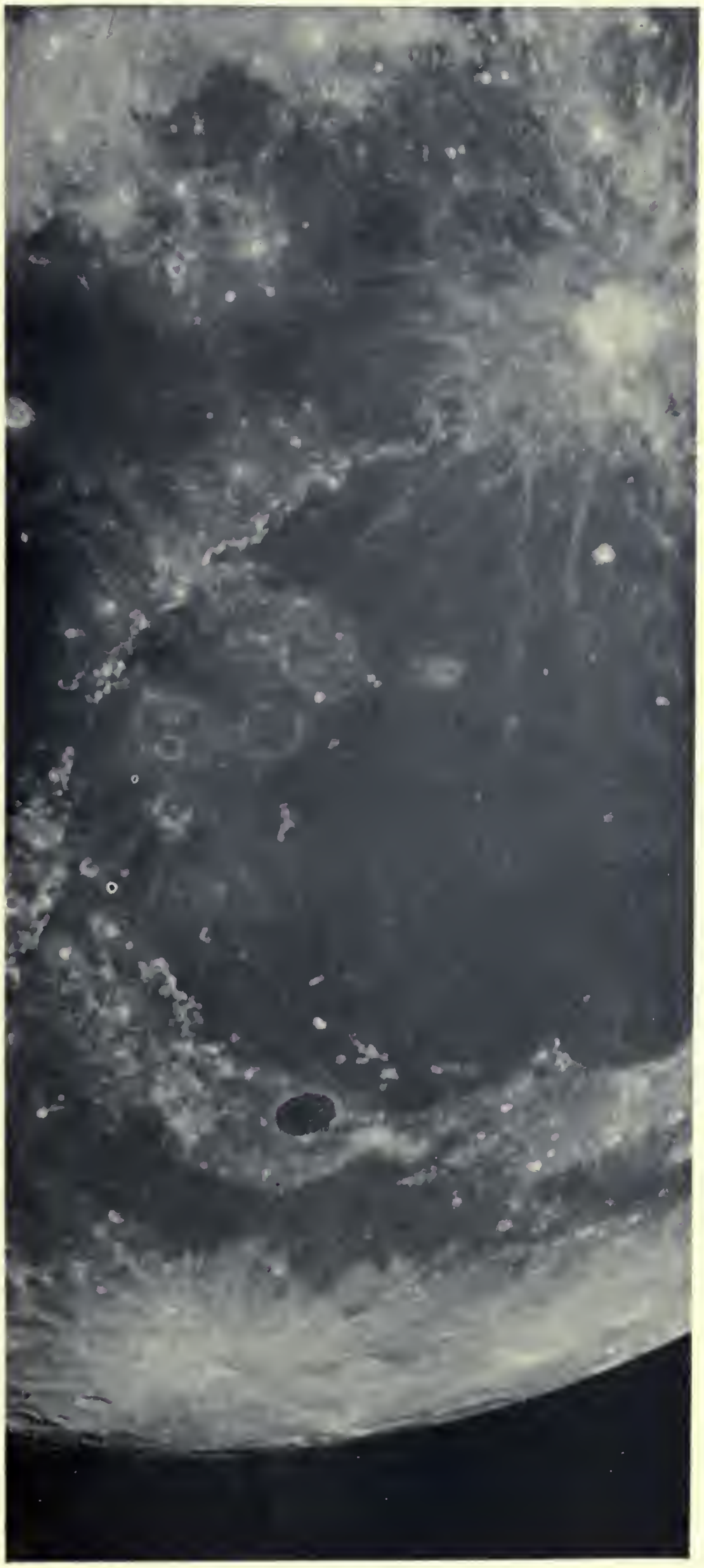
MARE IMBRIUM. PLATO

53°

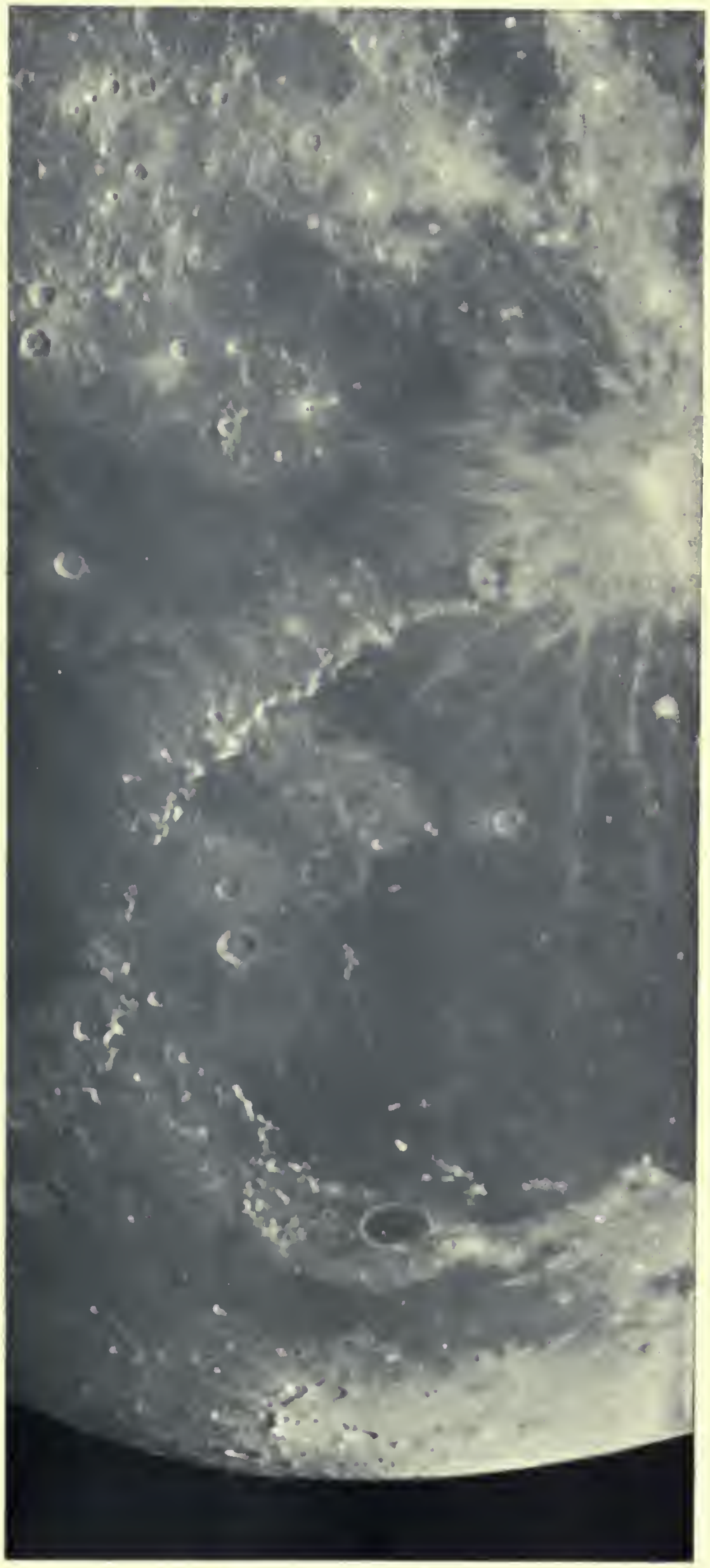
9 B

MARE IMBRIUM. PLATO

97° 9 C



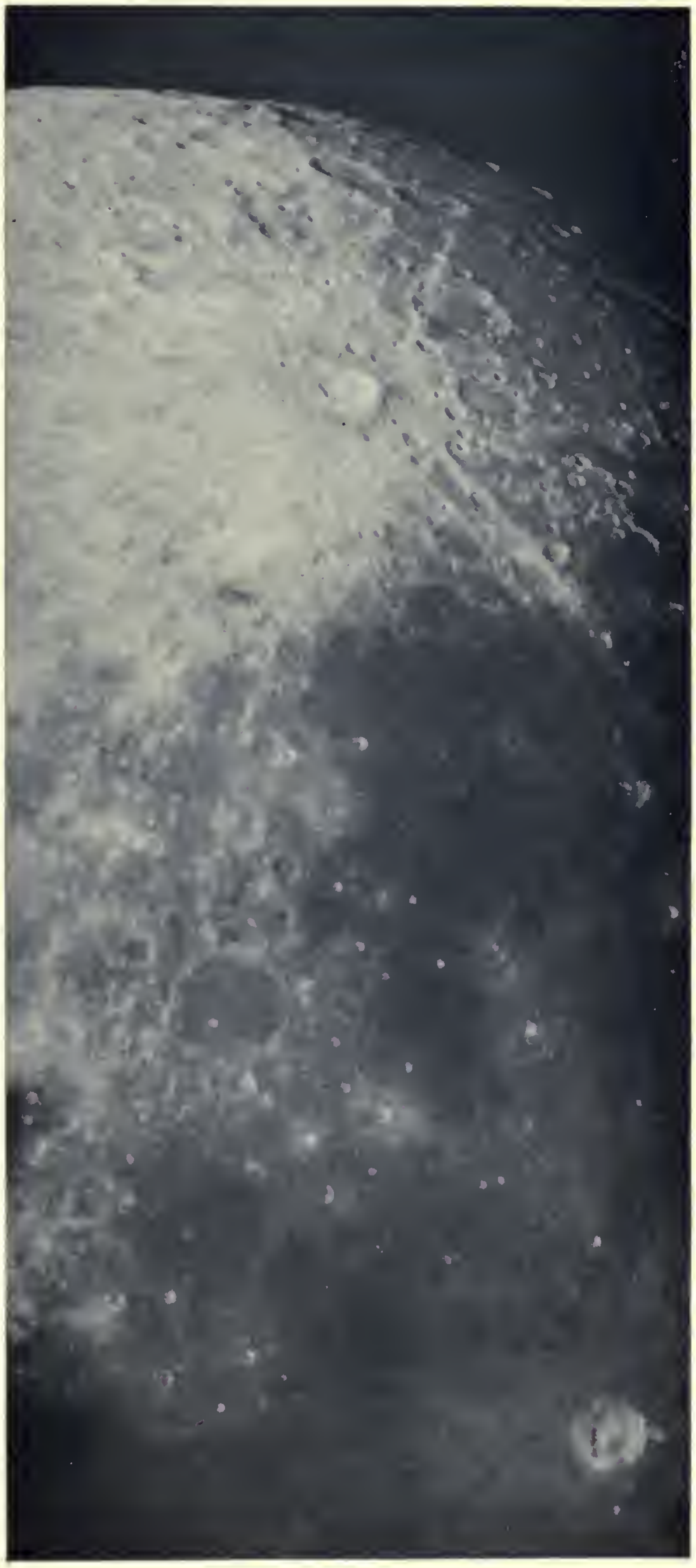
MARE IMBRIUM. PLATO



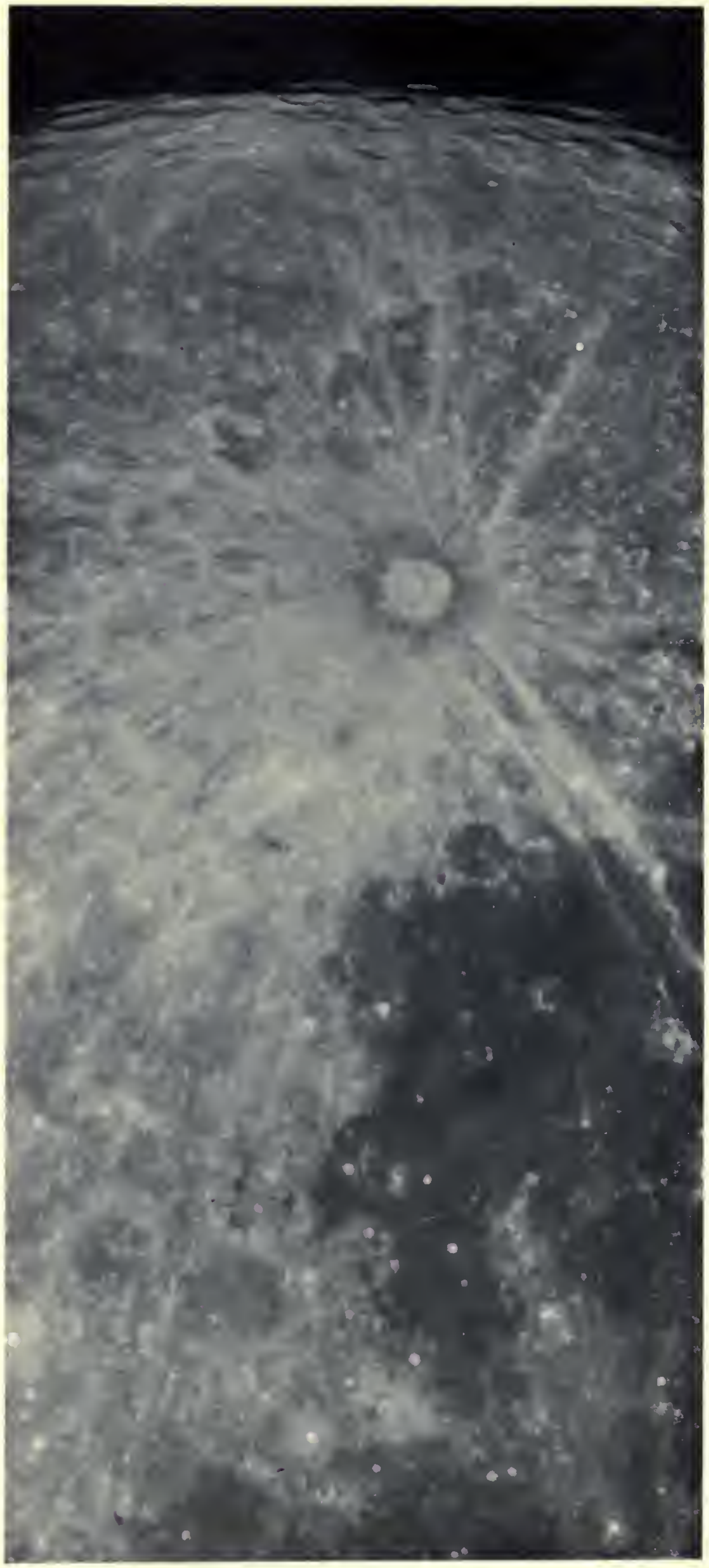
MARE IMBRIUM. PLATO

MARE IMBRIUM. PLATO

TYCHO. MARE NUBIUM



TYCHO. MARE NUBIUM



TYCHO. MARE NUBIUM

TYCHO. MARE NUBIUM

TYCHO. MARE NUBIUM

30°

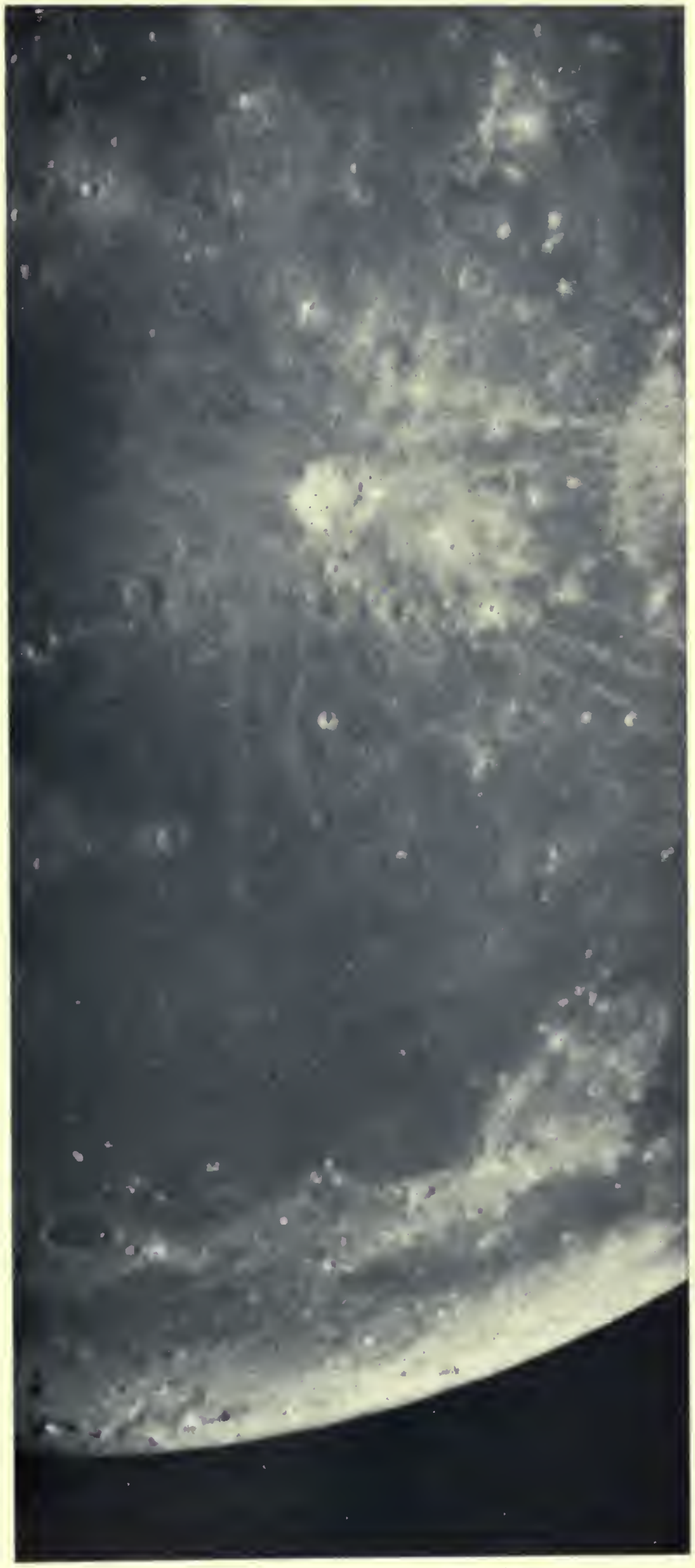
11 A

COPERNICUS. MARE IMBRIUM

COPERNICUS. MARE IMBRIUM

130° 11 C

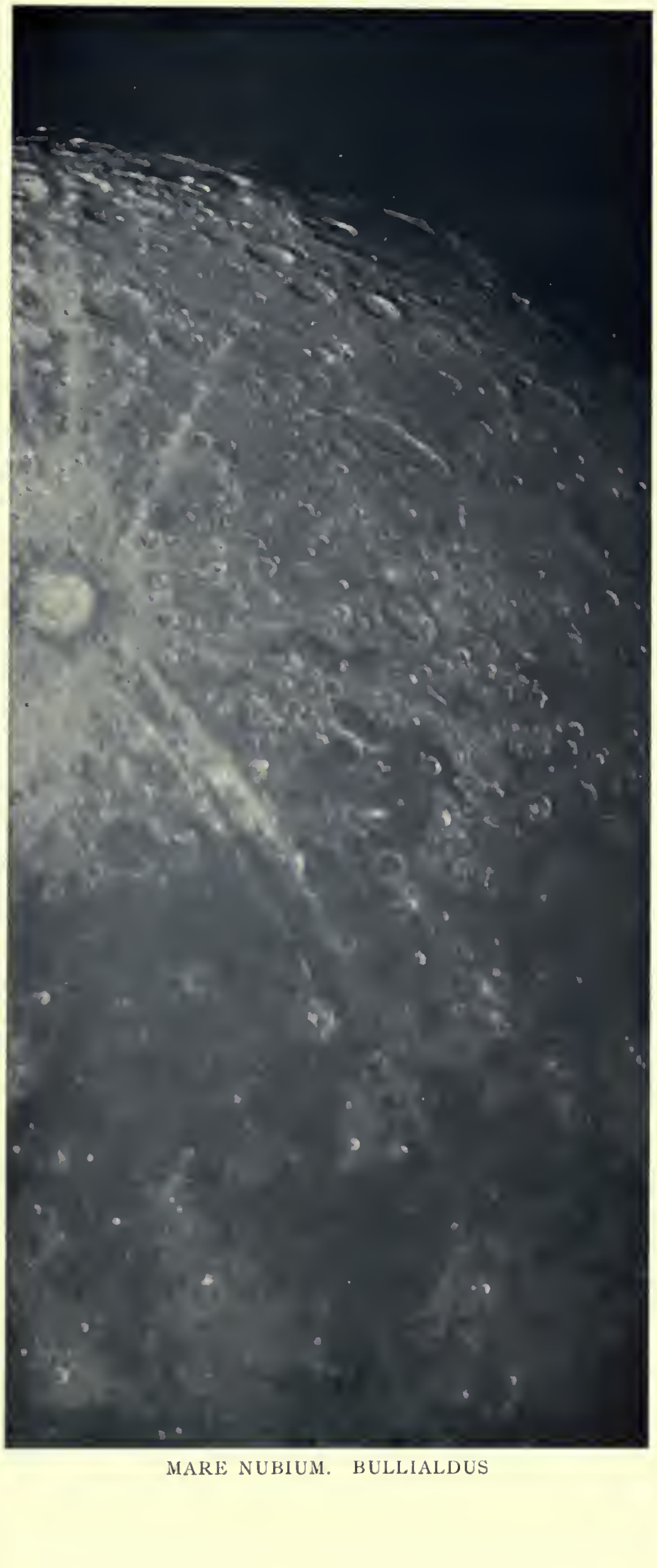
COPERNICUS. MARE IMBRIUM



COPERNICUS. MARE IMBRIUM

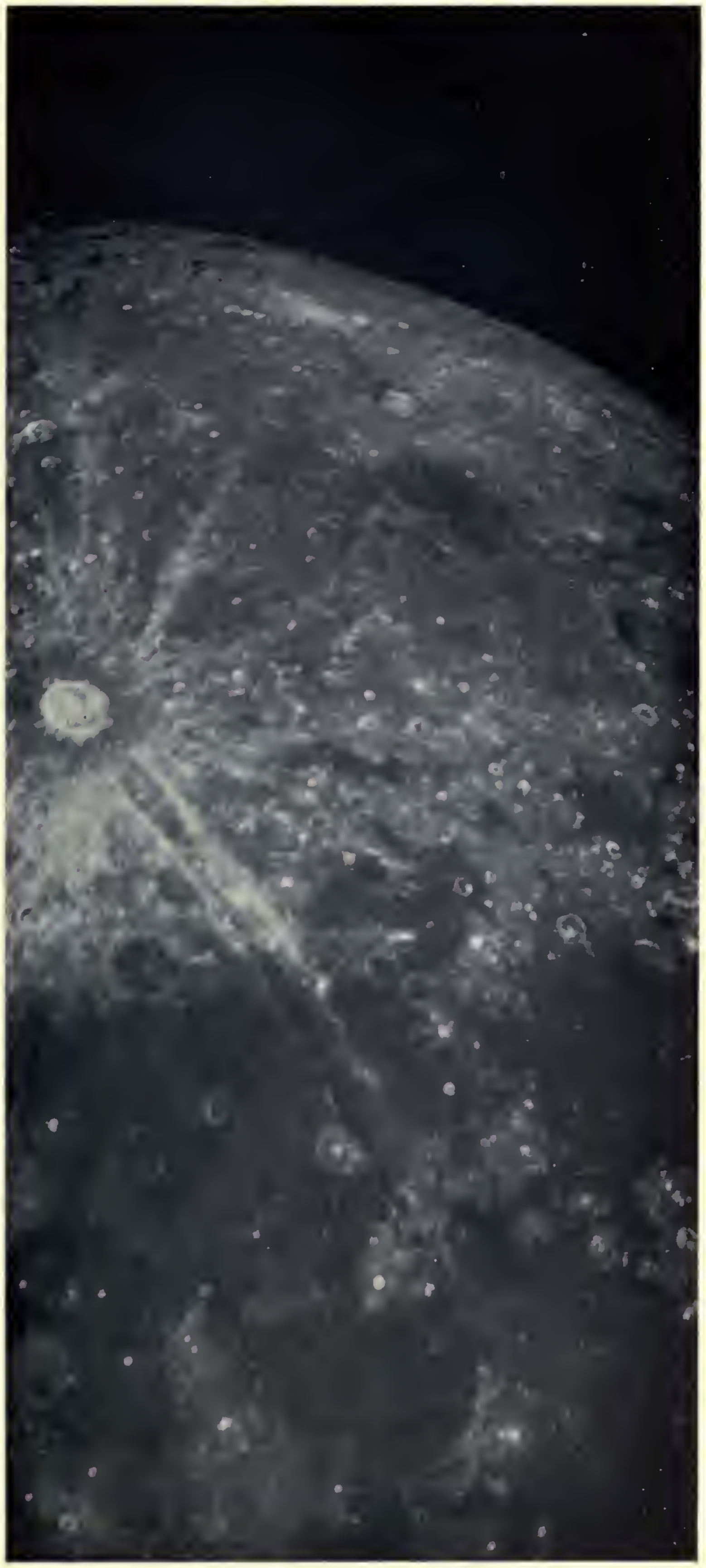
COPERNICUS. MARE IMBRIUM

MARE NUBIUM. BULLIALDUS



MARE NUBIUM. BULLIALDUS

121° 12 C



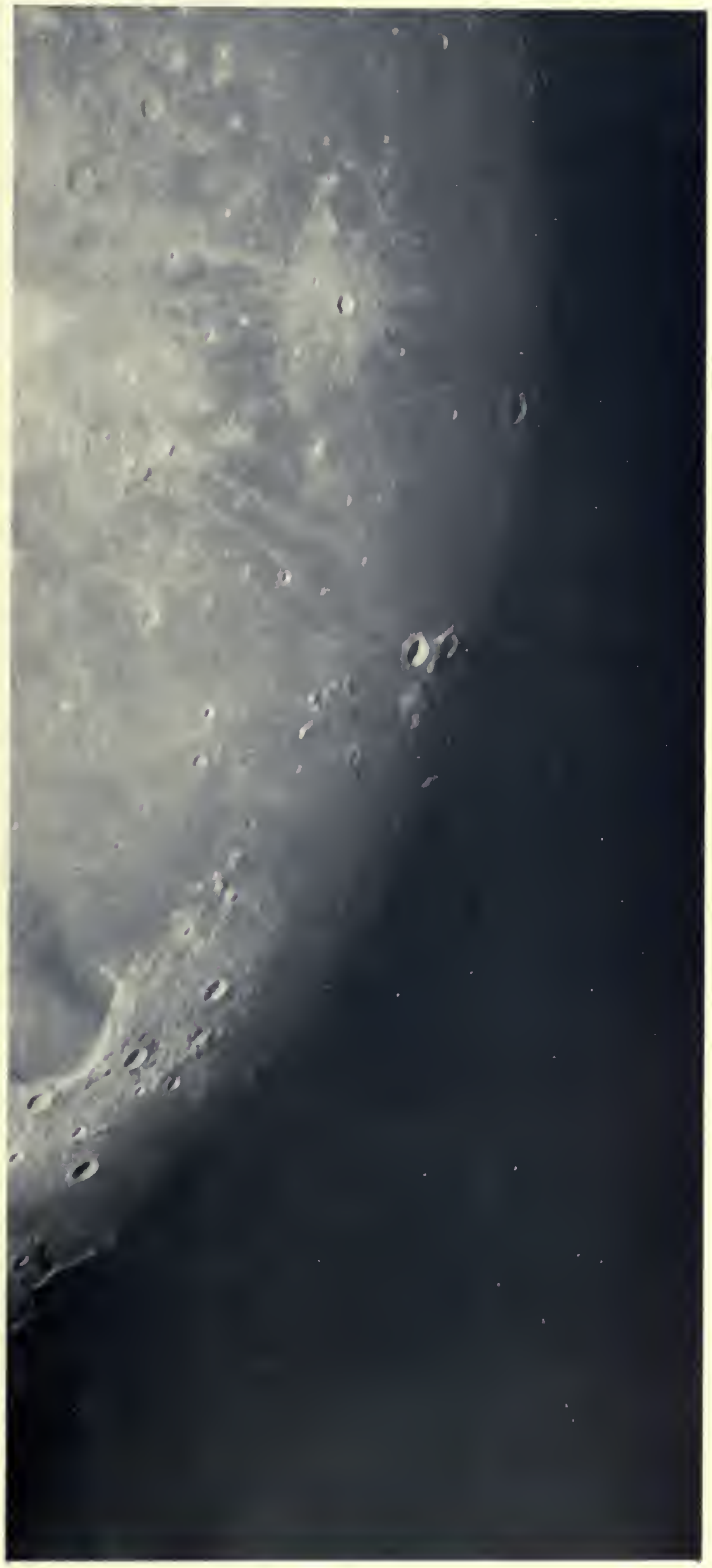
MARE NUBIUM. BULLIALDUS

MARE NUBIUM. BULLIALDUS

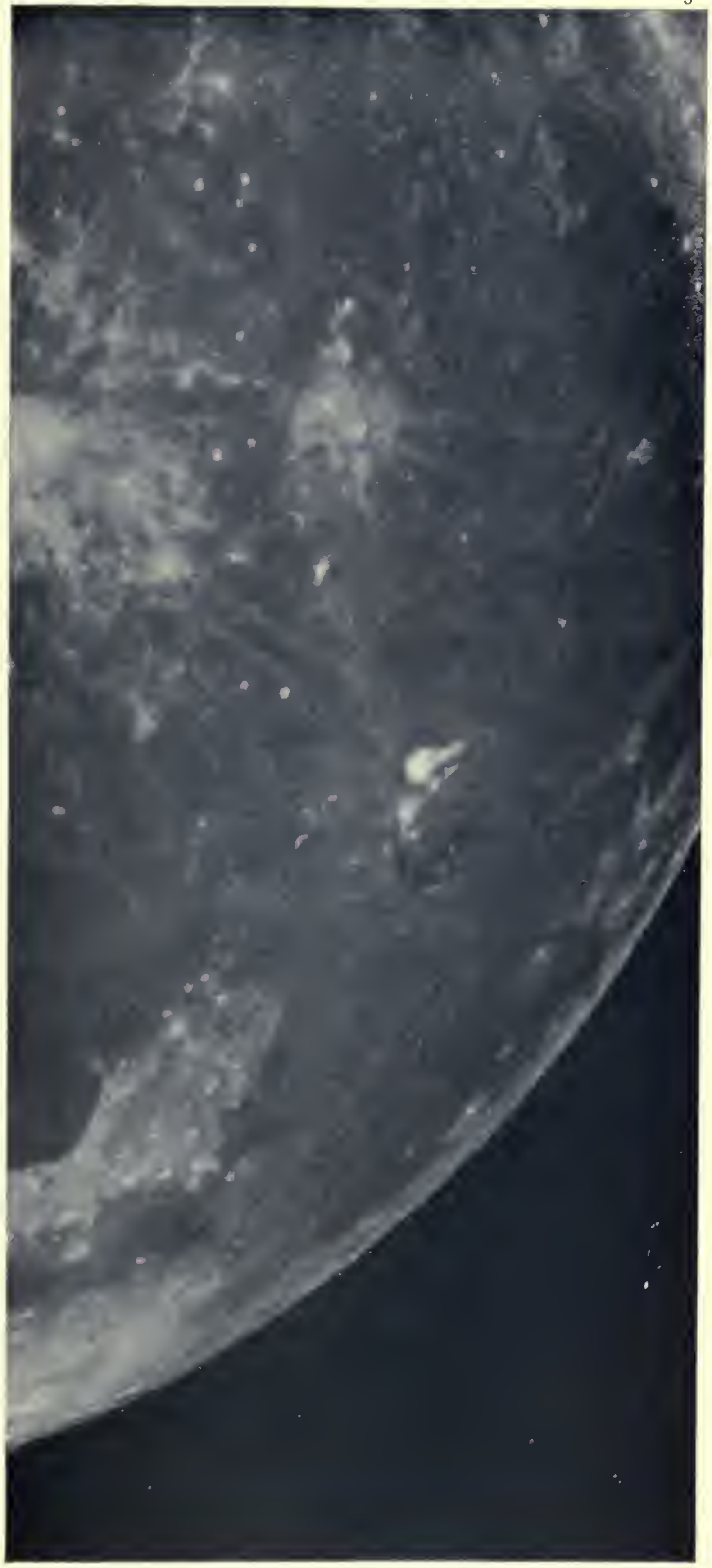
MARE NUBIUM. BULLIALDUS

54°

13 A



KEPLER. ARISTARCHUS



KEPLER. ARISTARCHUS

135°

13 C

KEPLER. ARISTARCHUS

KEPLER. ARISTARCHUS

198° 13 E

KEPLER. ARISTARCHUS

MARE HUMORUM. GASSENDI

MARE HUMORUM. GASSENDI

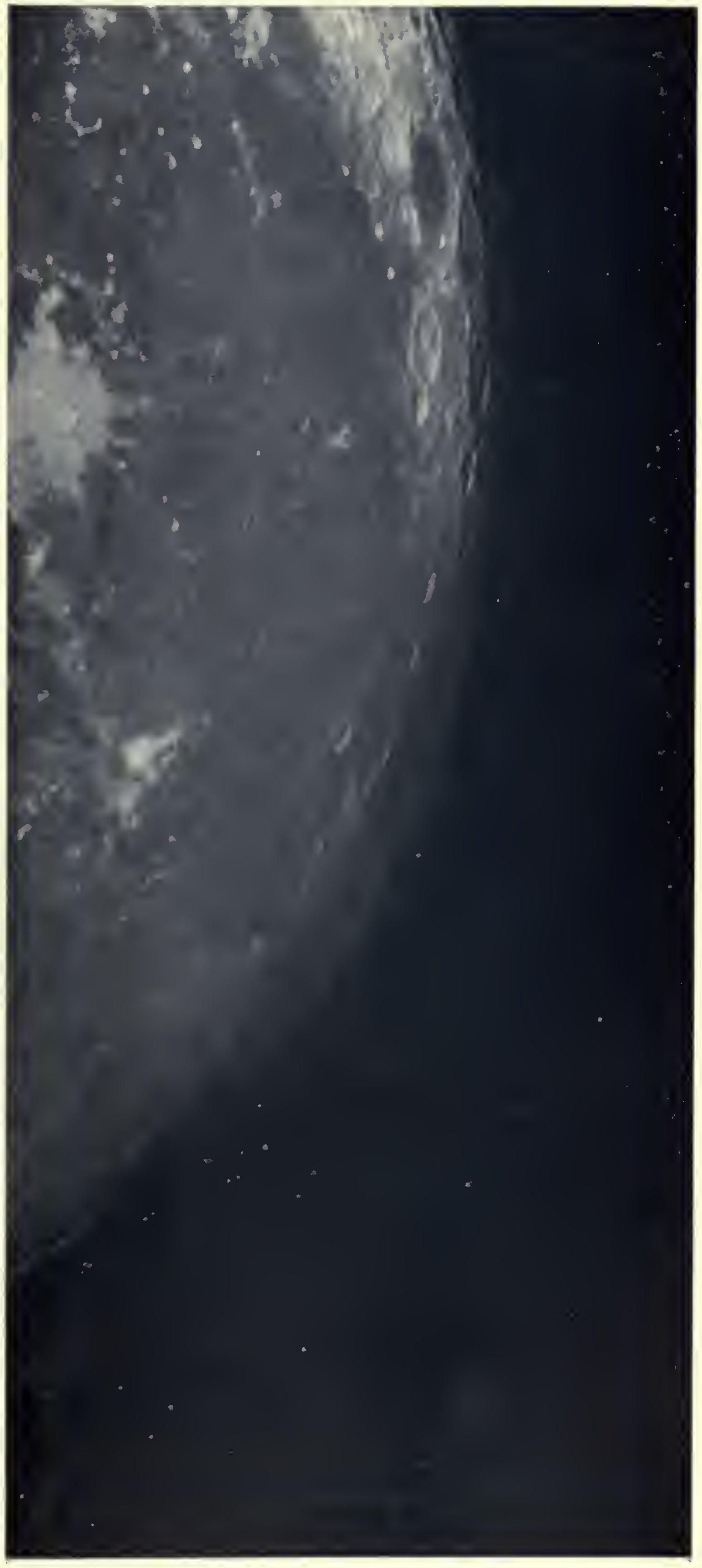
MARE HUMORUM. GASSENDI

MARE HUMORUM. GASSENDI

198°

14 E

MARE HUMORUM. GASSENDI



OCEANUS PROCELLARUM

OCEANUS PROCELLARUM

OCEANUS PROCELLARUM

OCEANUS PROCELLARUM

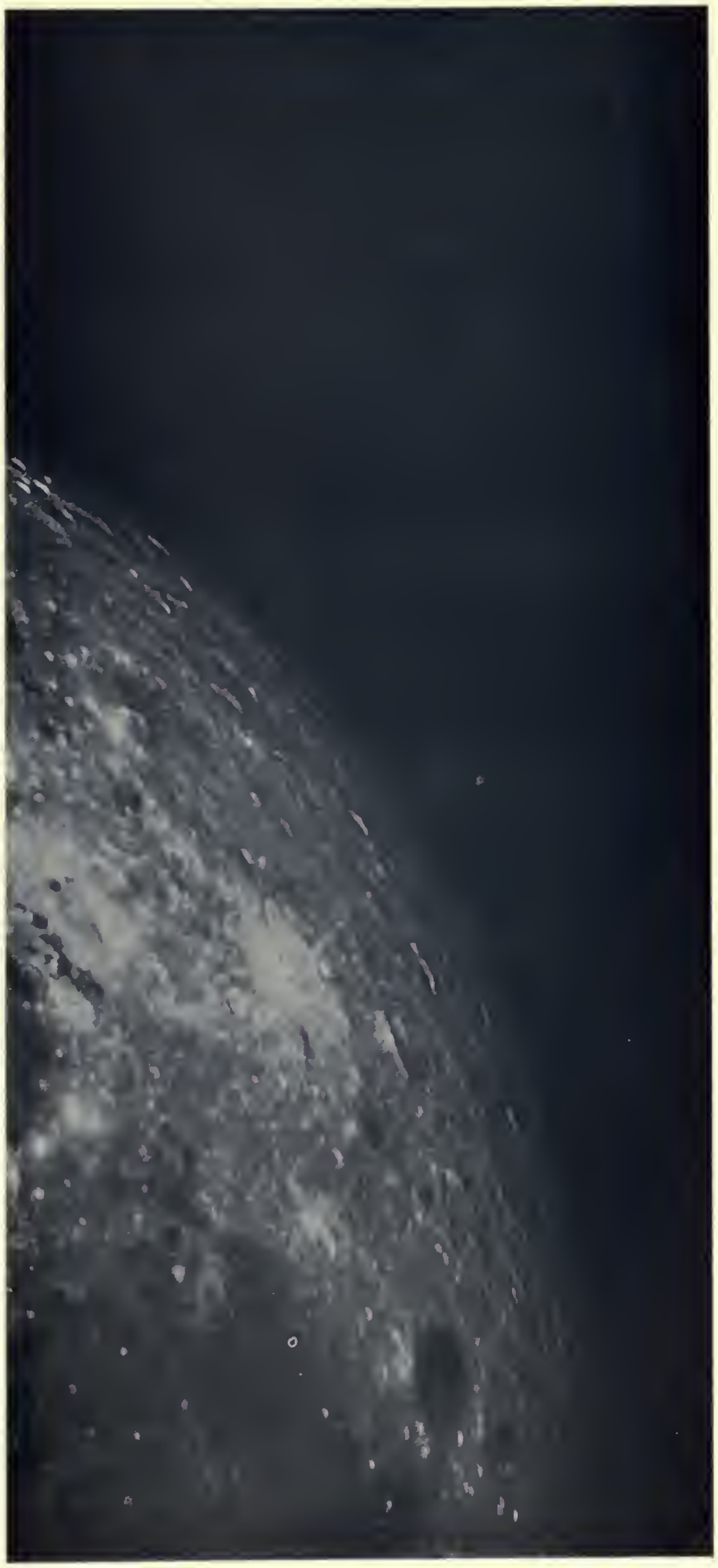
217°

15 E

OCEANUS PROCELLARUM

87°

16 A



BYRGIUS *A*. GRIMALDI

94°

BYRGIUS *A.* GRIMALDI

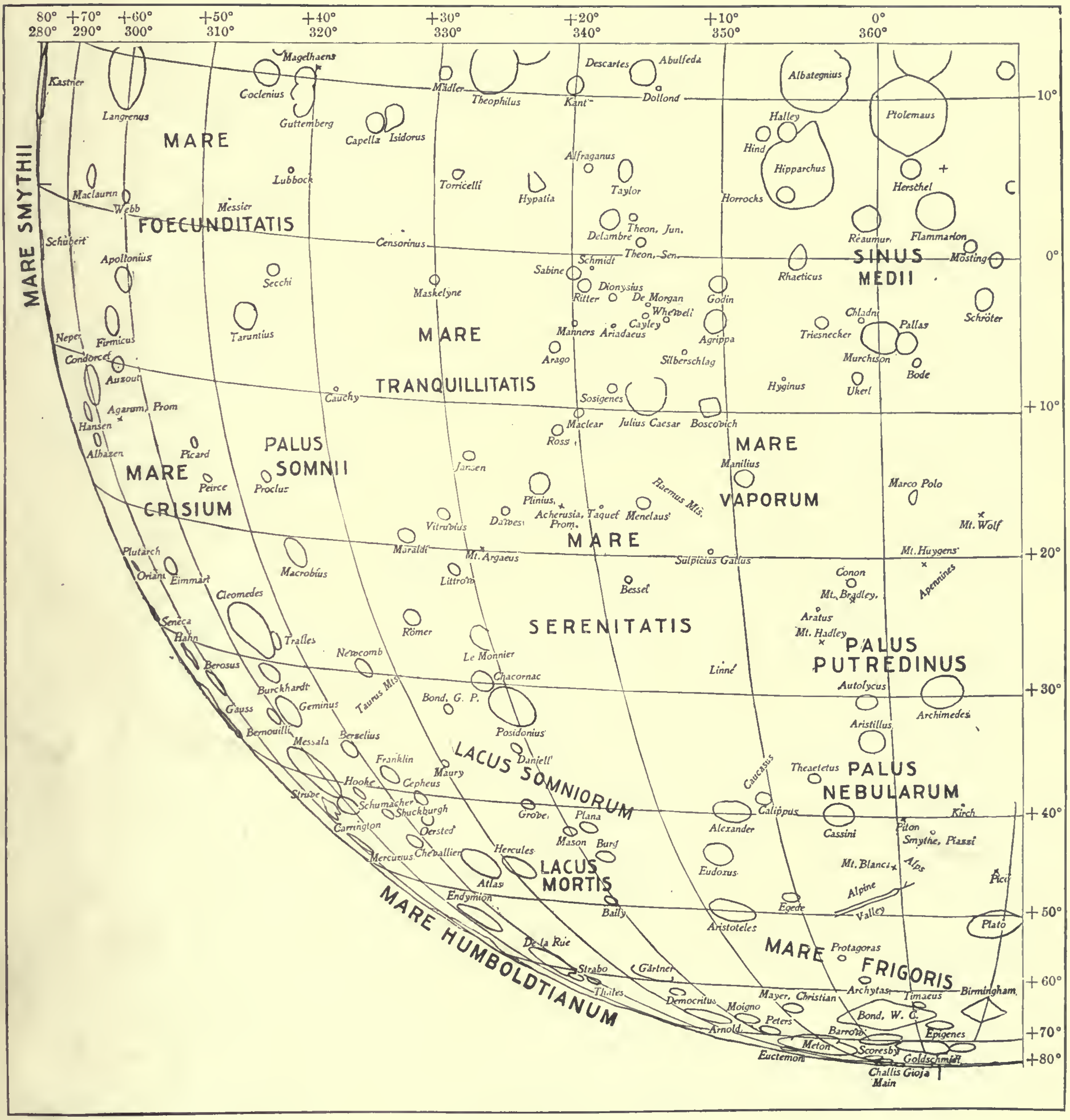
BYRGIUS *A*. GRIMALDI

BYRGIUS *A.* GRIMALDI

217°

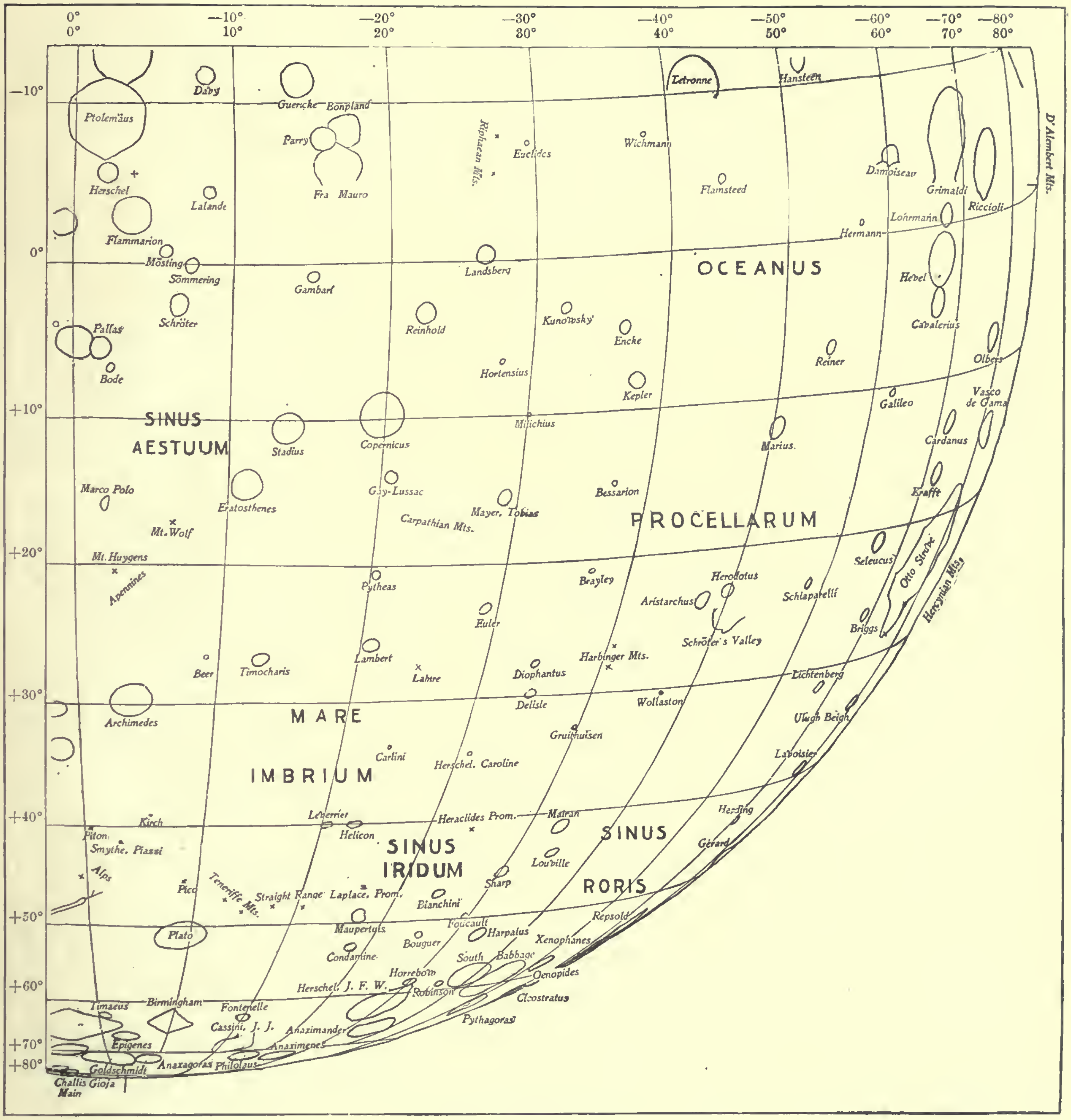
16 E

BYRGIUS *A.* GRIMALDI



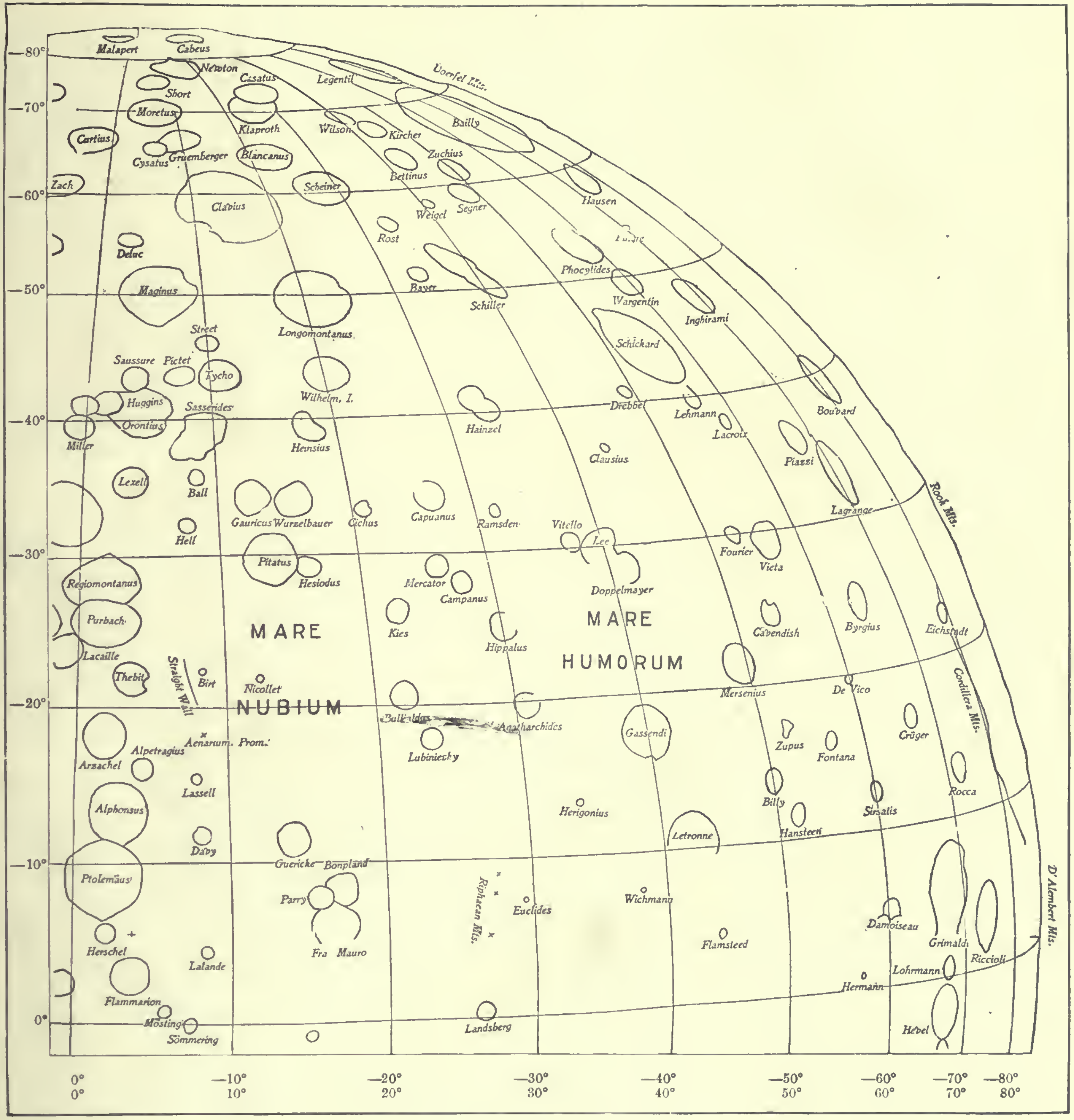
FIRST QUADRANT

FIRST QUADRANT

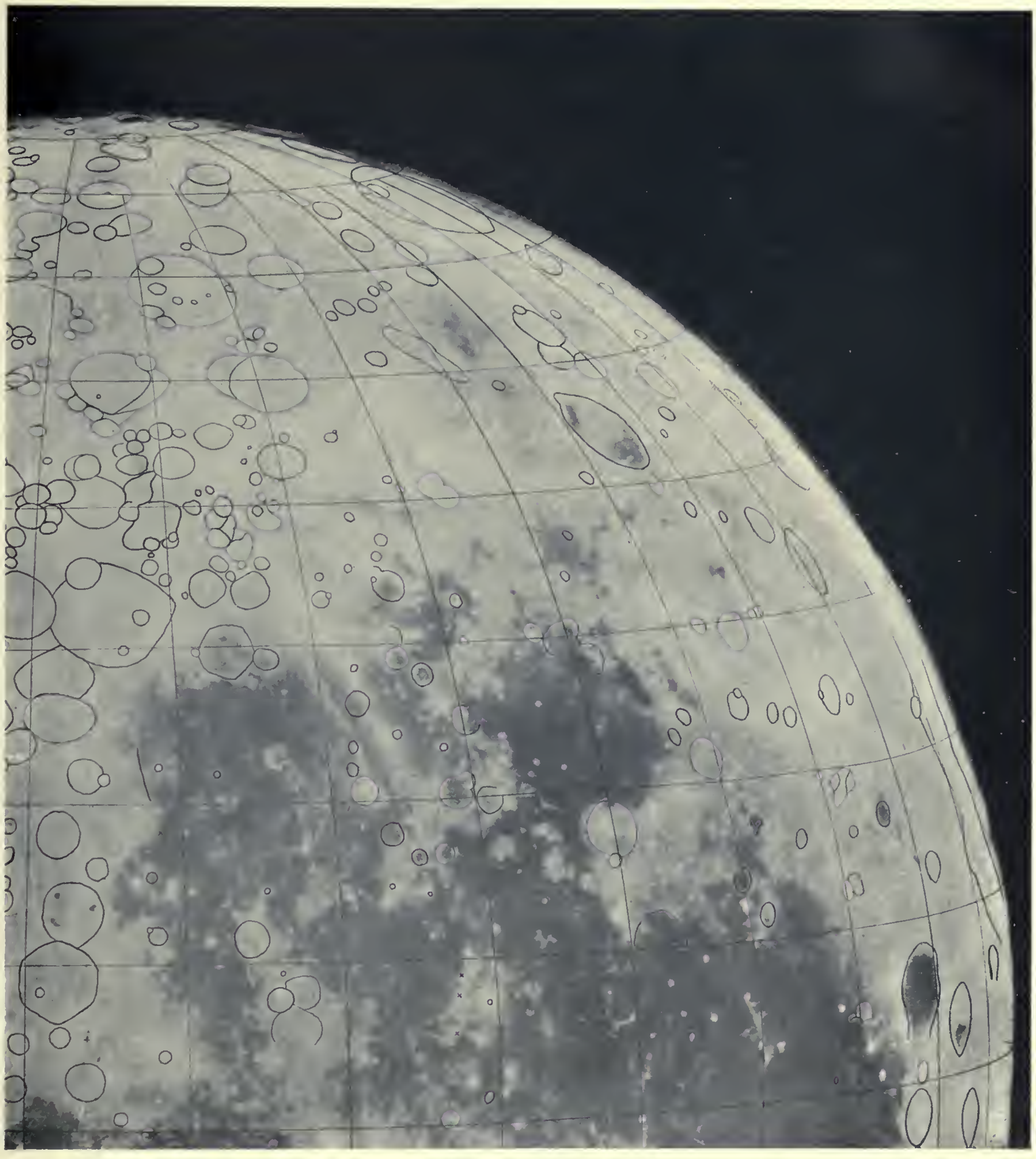


SECOND QUADRANT

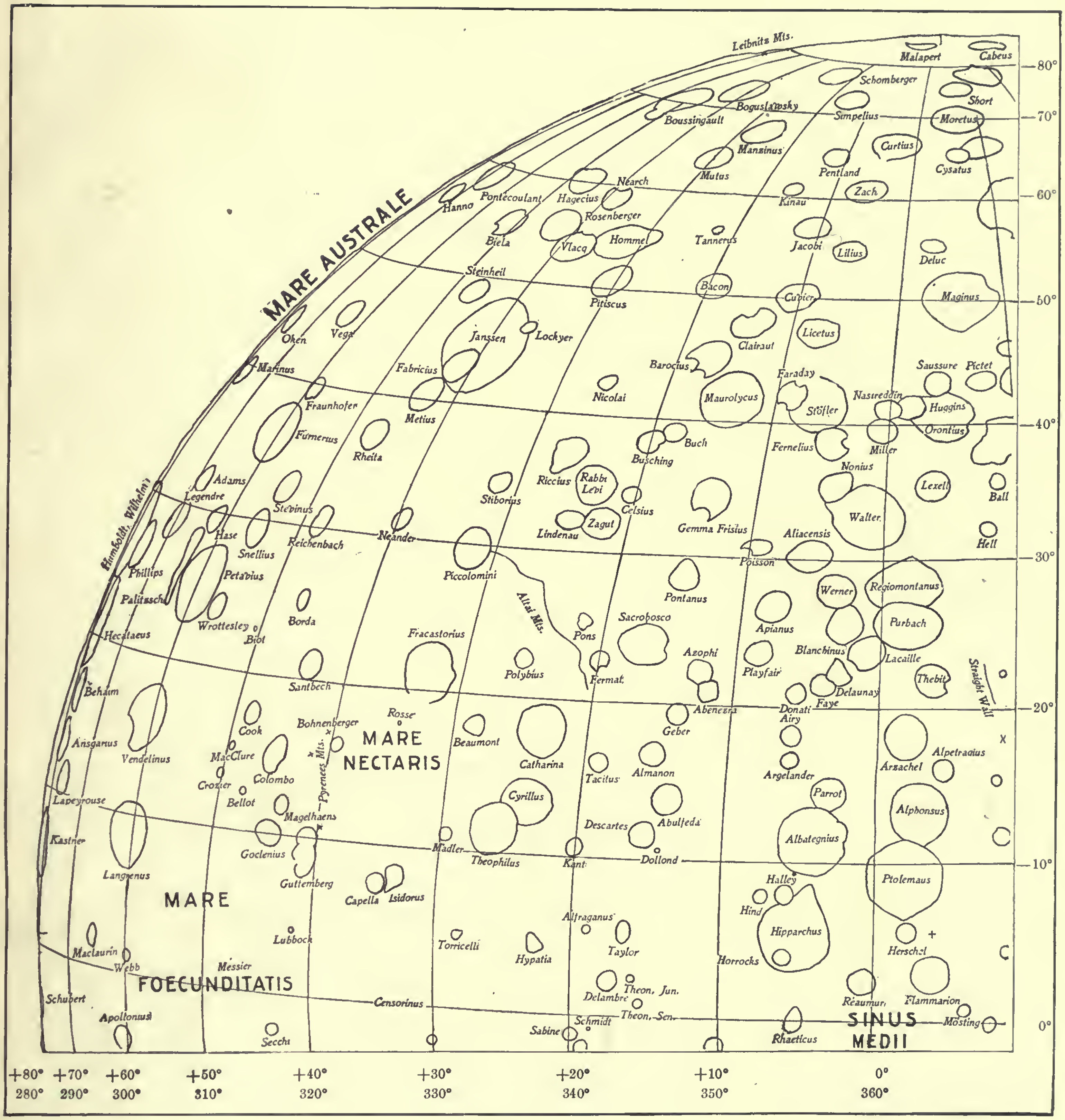
SECOND QUADRANT



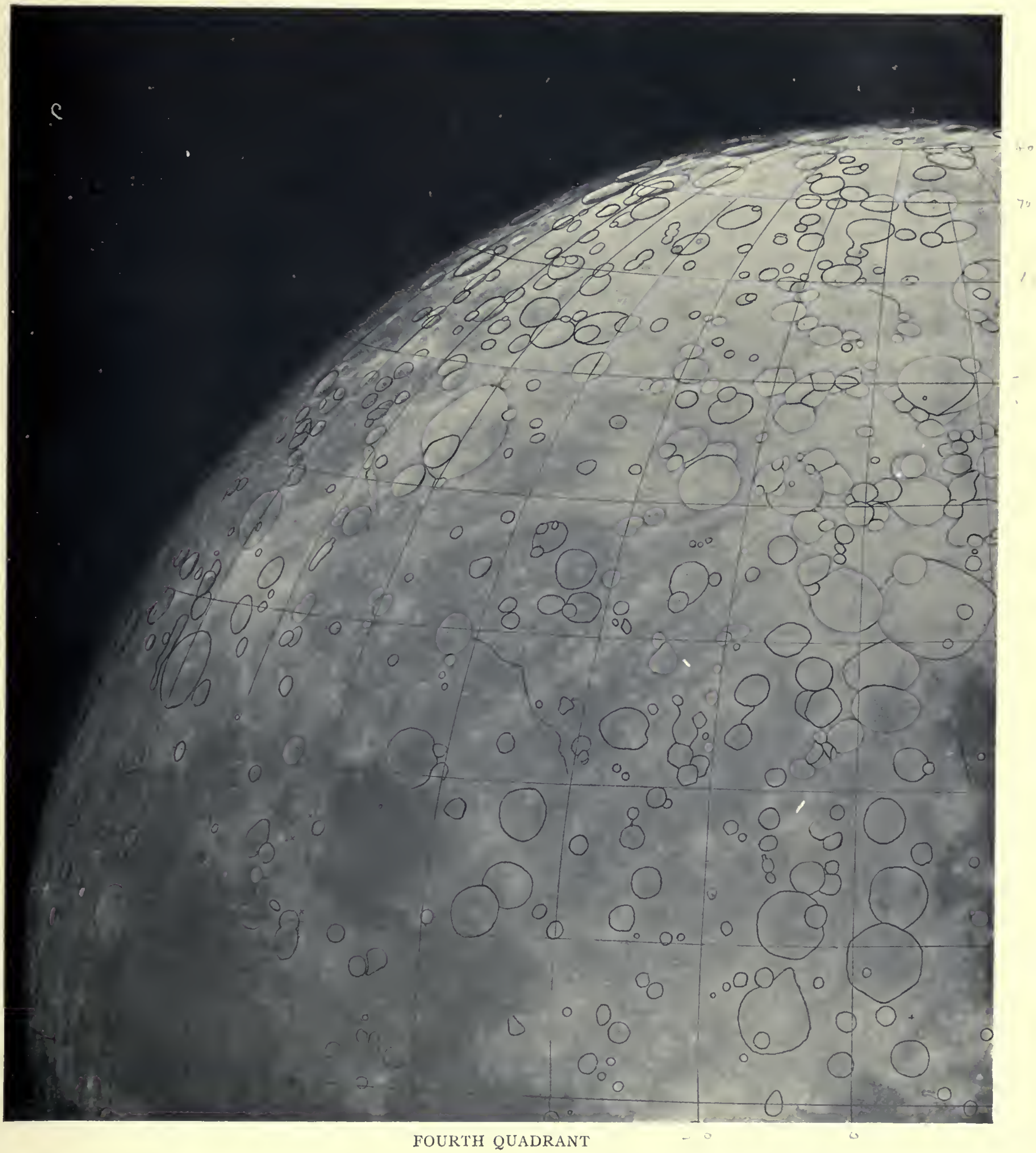
THIRD QUADRANT



THIRD QUADRANT



FOURTH QUADRANT



FOURTH QUADRANT