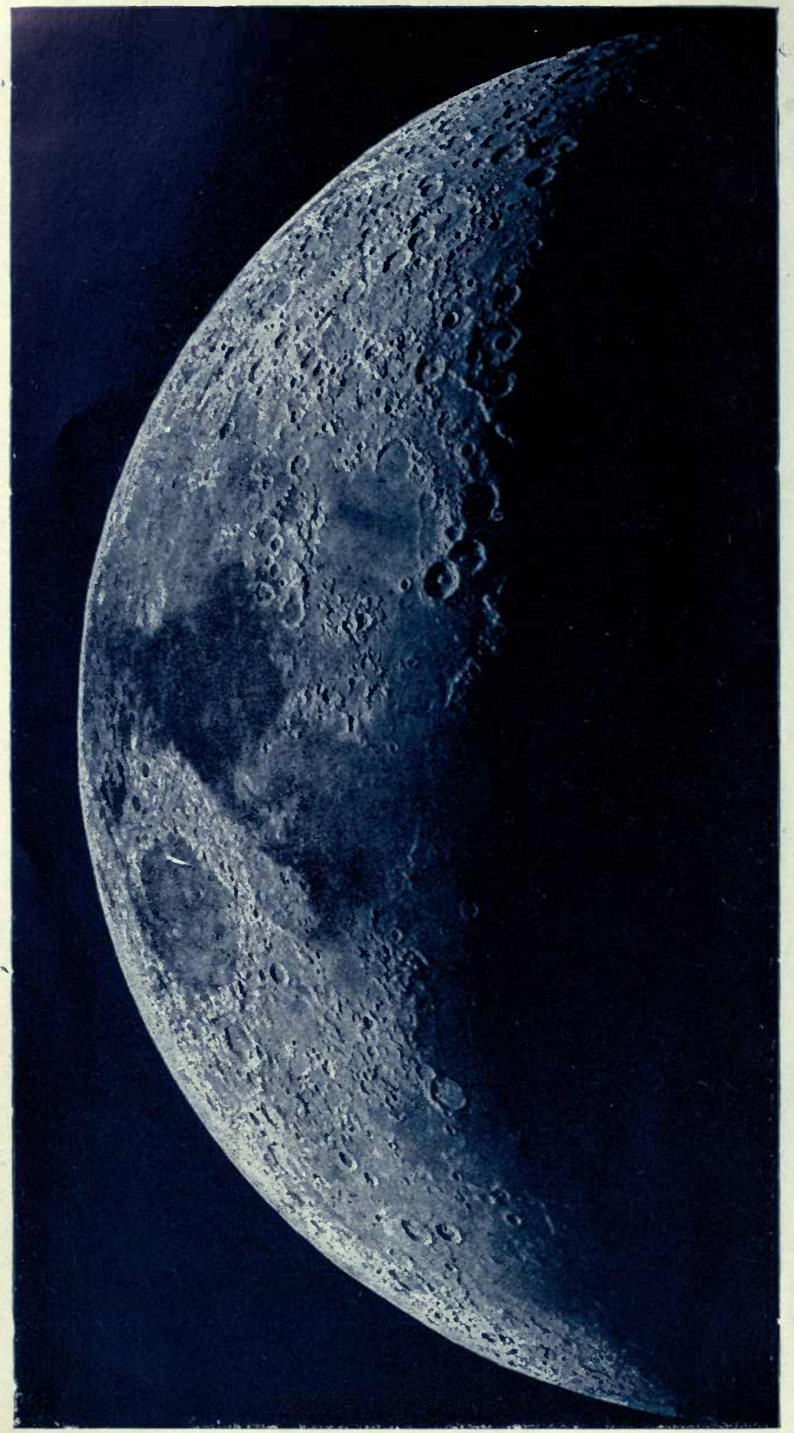
THE MOON



THE MOON

IN

MODERN ASTRONOMY

A SUMMARY OF TWENTY YEARS SELENOGRAPHIC WORK, AND
A STUDY OF RECENT PROBLEMS

BY

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With 66 *Illustrations and a Frontispiece*

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INTRODUCTION

The moon being the nearest celestial body to the earth naturally forms an object of especial interest. Its mean distance from the earth is about 238,840 miles, but, owing to the elliptical shape of its orbit, this distance is sometimes increased to nearly 253,000, and sometimes diminished to about 221,600 miles. The mean period of revolution round the earth is 27 days, 7 hours, 43 minutes, 11½ seconds, and as it rotates on its axis in the same time that it revolves round the earth, this is also the length of its day. Its diameter is about 2160 miles, so that in volume the earth is about 49¼ times larger. In mass, however, the earth is about 81 times greater, and hence the moon's density is equal to 49¼ divided by 81, or about 0·608 that of the earth, or taking the earth's density as 5·53, that of the moon is 3·36 (water equal unity). From the above data it follows that the force of gravity at the moon's surface is about one-sixth of terrestrial gravity. If, therefore, a man of 12 stone weight were transferred to the moon he would weigh only 2 stone, so that a much larger race of men than ourselves would be theoretically possible on the moon. As, however, the moon has neither air nor water, the existence of any form of life on its surface seems more than doubtful. The moon's surface is about equal in area to North and South America, but as we only see one side of it—owing to its period of axial rotation being equal to that of its revolution round the earth—the surface we see may be stated as roughly equal to that of North America.

Examined with the naked eye or an opera glass the moon's surface is seen to be chequered with bright and dusky patches. Near the southern edge of the disc is a luminous spot known as Tycho, an immense 'crater ring,' which has been well termed by Webb 'the metropolitan crater of the moon.' Near the northern limb is a darkish spot known as Plato. In the north-east quadrant, not far from the moon's visible centre is the magnificent crater Copernicus. Near the centre is another fine walled plain called Albategnius, and between the centre and Plato a very regular one known as Archimedes. The most brilliant spot on the moon's surface is the 'crater' Aristarchus, near the north-eastern edge. The dark portions, formerly termed Maria, under the mistaken idea that they represented lunar seas, cover a considerable area of the moon's surface, and are conspicuously visible even to the naked eye. Two of these remarkable spots are seen near the northern edge. Of these the western one is known as the Mare Serenitatis or Sea of Serenity, and the eastern the Mare Imbrium or Sea of Clouds. To the south of the Mare Serenitatis is another large patch called the Mare Tranquillitatis; and to the west of this, and near the edge of the disc, is a conspicuous spot known as the Mare Crisium. Near the eastern edge is another well-marked spot called the Oceanus Procellarum, and there are other dark markings in the south-eastern portion of the disc.

The most remarkable features of the moon's surface may be divided into: 1.—Maria or Seas; 2.—Mountain Chains; 3.—'Crater' Mountains, Walled and Ringed Plains; and 4.—Valleys and Clefts or 'Rills.'

1. *Maria.*—The most conspicuous of these have been already referred to. They are comparatively level surfaces and are known *not* to be seas from the fact that where the moon's 'terminator' (or bounding line between light and darkness) crosses them it has a broken and irregular outline, whereas the edge of the shadow would form a regular curve if it crossed a water surface. These so-called 'seas' are, however, not quite level, as they include many small hills and pits, but they may be considered as flat when compared with the other parts of the moon's surface which are exceedingly rugged and irregular.

2. *Mountain Chains and Ridges.*—These are somewhat similar in their general outlines to the mountains of the earth, but are comparatively much higher. The most conspicuous of these mountain ranges is that known as the Apennines, which runs from Copernicus to the Mare Serenitatis, a distance of about 460 miles. They are of considerable elevation with peaks ranging from 11,000 to about 20,000 feet in

height. Near Plato there is a lofty range called the Alps, and to one of its summits, about 12,000 feet in height, Schröter gave the name of Mont Blanc. Cutting across this chain of mountains is a marvellous valley nearly 100 miles long and several miles wide, in which our terrestrial Mont Perdu would be literally lost! In the south-western quadrant there is a long range known as the Altai mountains, about 280 miles in length and attaining an altitude of about 13,000 feet. At its southern extremity there is a fine 'crater' ring called Piccolomini, a circle about 57 miles in diameter, on the eastern edge of which is a peak about the height of our Mont Blanc.

On the extreme southern edge of the disc is a wonderful range known as the Leibnitz Mountains. Several peaks reach a height of nearly 30,000 feet, and to one of them Neville (Neison) assigns an altitude of nearly 36,000 feet, or 7,000 feet higher than Mount Everest, the highest of the Himalayas! Under favourable conditions these giant mountains are actually visible in profile on the moon's limb. The same remark applies to the Doerful Mountains situated near the Leibnitz range on the south-east limb, the highest of which was estimated by Schröter at 25,000 or 26,000 feet. As the sun never sets on the Leibnitz and Doerful Mountains, Flammarion calls them '*the mountains of eternal light.*' Along the eastern limb are ranges called the Cordilleras, and the D'Alembert and Rook Mountains which reach a height of nearly 20,000 feet. Another lofty mass is the Caucasus, north-east of Archimedes, with peaks rising to 18,000 or 19,000 feet. Some of the 'ridges' are narrow backs of small height but of great length. One of these runs for a length of over 600 miles, apparently connecting Copernicus with a small 'crater' called Kirch (between Archimedes and Plato).

3. *Crater Mountains, Walled and Ring Plains.*—The so-called 'craters' are, perhaps, the most remarkable and interesting features of the moon's surface. They are usually supposed to be of volcanic origin, but their enormous size seems opposed to this hypothesis. Of these curious objects Tycho, already referred to, is a perfect specimen. It has a diameter of over 50 miles, with a depth of nearly 17,000 feet, and a central hill of about 6,000 feet in height. The diameter of Copernicus is about 56 miles, with a peak on its ring rising to a height of about 11,000 feet above the floor of the 'crater' and several central hills. Theophilus, a 'crater' in the west quadrant, has a diameter of 64 miles, and a depth of 1,400 to 18,000 feet, perhaps the deepest of the lunar 'craters.' In curious contrast to this is Archimedes, which, although 50 miles in diameter, has a depth of less than 700 feet, with an interior almost quite smooth. Plato, the conspicuous dusky spot near the northern limb, is a walled plain about 60 miles in diameter with a comparatively flat interior, on which, however, some bright streaks and small 'craterlets' are visible in powerful telescopes. Albategnius, near the centre of the disc, is a fine walled plain over 60 miles in diameter with a central hill and a peak on the north-eastern border of about 15,000 feet in height. Near Archimedes

are two fine 'craters' known as Aristillus and Autolycus. Near the western limb is a fine walled plain called Langrenus with terraced ring of 10,000 to 15,000 feet in height. Some distance south of this is another fine example known as Petavius, with a wall nearly 11,000 feet high, and a central hill, so common in these formations. Among large walled plains the following may be mentioned: Ptolemæus, near the centre of the disc, has a diameter of about 115 miles with a comparatively level interior and a rampart wall which rises in some places to a height of nearly 13,000 feet. Near the southern point of the disc is an immense ring called Clavius, about 140 miles in diameter with a very high wall. Close to the south-east edge of the disc is a vast plain known as Schickard, the diameter of which is about 130 miles. The interior is nearly flat, and from the centre of this immense enclosure a lunar spectator could scarcely see the rampart wall, although rising at one point to a height of over 10,000 feet! Close to the eastern limb is a very dark spot called Grimaldi, which is nearly as large as Schickard and has occasionally been seen with the naked eye. There are many other remarkable ring plains on the visible lunar surface, but the above examples may suffice for our present purpose.

4.—*Valleys and Clefts or Rills.*—The great Alpine valley has been already referred to. Near the 'crater' Rheita, in the south-west quadrant, is an immense valley about 187 miles long and 20 miles wide. The 'Hyginus cleft' near the centre of the disc intersects the ‘crater’ of that name and runs for a distance of about 95 miles, with a width of 1½. The Aridæus cleft, which lies to the west of the preceding, is even longer and wider. These ‘clefts’ and ‘rills’ form some of the most remarkable of the lunar features, but are sometimes so narrow as to be only visible in large telescopes. M. Fauth has seen over 1,600.

Another interesting and mysterious feature of the moon’s surface is the system of bright streaks or rays which diverge from several of the ‘craters.’ Of these the most remarkable are those which radiate from Tycho. The ‘craters’ Copernicus, Kepler, and Aristarchus, also form centres of rays. These bright streaks are most conspicuous on the full moon, and seem to pass over mountains, valleys, and ‘craters’ in a way which renders a satisfactory explanation of their nature and origin a matter of great difficulty. Proctor was of opinion that they were formed during the process of cooling when the lunar surface was in a heated and plastic condition.

Near the boundary between light and darkness—the ‘terminator,’ as it is called—there are visible in nearly all phases of the moon bright spots within the dark part shining like stars. These are the tops of mountains lit up by the rays of the rising or setting sun while the low-lying lands remain in darkness. When fully illuminated these mountains cast shadows which are best seen about the time of first and last quarter.

The aspect of the heavens as viewed from the moon will differ in many respects from that visible to us. The stars and planets will present very similar phenomena, but owing to the absence of an atmosphere they will shine with greater brilliancy and will be visible in the daytime as well as the night. Mercury especially will be much more easily seen than with us. Stars which on earth are only visible with an opera glass will there be distinctly seen with the naked eye, and the Milky Way, here so dimly seen, must there form a brilliant spectacle. But the behaviour of the earth as seen from the moon will be wholly different from any celestial phenomenon with which we are familiar. It will show a disc of nearly two degrees in diameter, or about thirteen times larger than the moon appears to us. From any point on the visible surface of the moon the earth will appear constantly immovable, or nearly so, in the sky, all the stars moving round as they appear to do on earth, but much more slowly, the lunar day being nearly a month long. From the centre of the visible hemisphere the earth will appear nearly immovable in the zenith; from points near the edge of the disc it will appear constantly near the horizon, and from other points it will be seen at different altitudes varying with their distance from the edge of the visible surface. From points *on* the limb it will—owing to the variation known as *libration*—be seen sometimes to sink a little below the horizon and sometimes to rise a little above it. The earth will show phases similar to those of the moon but in *reverse* order, the earth being ‘full’ at ‘new moon,’ and ‘new’ at ‘full moon.’ Of course from the opposite side of the moon the earth will remain permanently invisible, in the same way that the stars near the south pole are invisible to the inhabitants of England. Although the earth remains fixed in the lunar sky, its rotation on its axis will be clearly visible, the various continents, oceans, and islands, being seen in turn, when not obscured by cloud, and the polar regions, of which we know so little, might then be easily examined with a powerful telescope. Owing to the apparent fixity of the earth in the sky, the study of astronomy would be, to a lunar inhabitant, beset with many and great difficulties. He would probably imagine that the earth was really an immovable body in space, and the small variations visible in its position referred to above would only add to the mystery of celestial motions.

The solar corona and ‘prominences,’ the zodiacal light and Gegenschein will be clearly visible from the moon even without the aid of a solar eclipse, and especially just before sunrise and immediately after sunset they will present a splendid and striking spectacle.

In the following pages M. Fauth gives a very interesting account of the features visible on the moon's surface derived from observations made by him during the last 20 years with refracting telescopes of 6½ or 7 inches aperture. He considers the ‘meteoric theory’ of the formation of the lunar ‘craters,’ and shows that a ‘bombardment’ of the moon's surface by large meteors would be quite inadequate to produce such enormous ‘ring mountains’ as some of those we see on our satellite. In this conclusion I fully concur. As M. Fauth asks, how could the earth have escaped a similar bombardment? He gives a very interesting historical account of the work done in past years in the delineation of the lunar surface. With reference to photographs he shows that, although for the purpose of fixing the relative positions of objects, they are more accurate than maps made from eye observations, they are deficient in detail, and in the sharpness of definition seen by the eye even in moderate sized telescopes. Judging from the lunar photographs I have seen this objection seems well founded. Photography has certainly not been so successful on the moon as it has been in other branches of astronomy.

M. Fauth shows that in the large lunar ‘ craters ’ and ring plains the proportion of depth to height of walls is comparatively small. They are more like shallow dishes, and contrast strongly with terrestrial volcanoes, which are usually high cones with a comparatively shallow crater on the top. For this reason he thinks it doubtful that the so-called lunar ‘ craters ’ are really of volcanic origin. They seem to be entirely different from the volcanoes with which we are acquainted on the earth and may possibly have had a different history. He calls them ‘ walled plains,’ and this seems a better term for the larger objects, such as Clavius, Schickard, Grimaldi, Plato, etc. It should be stated, however, that the late M. Gaudibert observed some high volcanic cones on the moon with small crater openings on the top. One has recently been found on a photograph by Professor W. H. Pickering about 12 miles east of Kies ; and doubtless many selenographers will still adhere to the volcanic theory of lunar surfacing. However this may be, M. Fauth's work is well worth reading by those who take an interest in the moon.

M. Fauth favours the idea that *the moon is covered with a thick layer of ice.* This hypothesis has also been advocated by Andries and Ericson, and there seems to be some ground for the idea, as the temperature of the moon's surface must be very low. M. Fauth has in preparation a large scale map of the moon which will show an enormous amount of detail, and will certainly, I think, be more reliable than any photograph hitherto taken. From this elaborate work, any suspected changes in lunar topography in future years may be either verified or disproved.

J. ELLARD GORE

PREFACE

The science of the moon cannot yet be said to have been elaborated in proportion to our material. Though the works issued in the last two decades have not been few in number, and, even taking full account of the marvellous results obtained by the application of telescopic photography, far from slight in quality, still, the peculiar conditions under which the structure of ‘Selenography’ is slowly rising have not facilitated publication. In Germany the only works recently issued are my ‘Atlas,’ with the textual explanation (1895), and the first volume of Krieger’s ‘Atlas,’ (1898).

My maps were meant in the first place to show how to complete the study of the moon’s topography, and they give a much more extensive and accurate picture than the existing maps. Krieger went on to explore a large number of craters and rills by means of excellent enlargements of photographs, and by making models of them. He has died since, and I have myself pressed on with the topography of the moon on a large scale. With the use of good instruments (objectives by Dr. Pauly, of Jena), under good conditions (my observatory has an altitude of 450 feet), I have penetrated into the features of the moon’s face to an extent that no other eye has yet done, and that has surpassed all my own expectations. I owe a great deal to the liberality of the Zeiss Institute, which lent me the use of a good modern objective of 7 inches aperture from 1896 to 1903, at the request of Dr. Pauly. To this fine instrument I owe the discovery of thousands of small objects, an invaluable exercise in minute vision, and a very useful experience in appreciating lunar forms. My own objective has an aperture of only 6½ inches. I have, after 17 years' use, grown to love it, as one does love such instruments, for the endless intellectual enjoyment it has afforded me and the work it has done for Science; yet I have regretted that I was unable at times to apply a more powerful instrument. Not that I desired to posess one of our giant telescopes! I have often felt that I could work with more success than the observers at larger instruments. But, as I have got to the limit of my faculties, and my apparatus can hardly show me anything new in the regions I have studied, it might be possible for me, under better conditions, to determine certain points of great interest in the development of selenology and of cosmology generally. That would only indirectly be a personal merit, since I have an eye that is remarkably adapted in structure for such research, and has improved more and more with use in the power of perceiving tiny features. Hence, I should hope, with a large instrument, to make maps (on the scale of our large general maps) of certain localities on the moon which it is most important to explore both for the sake of lunar science and of science generally.

The present work is issued in response to an invitation to tell the story of the development of lunar science. Only those who know well the limitations of this subject will venture to look beyond the sparse material of the present into the future, and back into a past on which careful study can throw much light. There are plenty of historical bye-ways even in our limited field. They can be followed in any technical work on the moon, and they afford a good deal of historical material, as well as an interesting glance at the modest workshops, and still more modest inventory, of early explorers. But we do not find a critical appreciation of the material already acquired, a study of lunar problems based on personal vision and supported by long years of experience.

Probably there never were so many hypotheses floated in regard to the riddles of the moon as in the last few years; but they have not advanced our knowledge, because, though theoretical students were plentiful enough, the practical observer was not. It is quite certain that a man who is not familiar with the actual moon, and only interprets photographs, knows as little about it as one who would try to learn the taste of fruit from a picture. The greatest German selenologist, J. Schmidt, has expressed himself on this point in words that should be taken to heart. It is equally clear that the time has gone by when a man could pass as a specialist on the ground of literary work alone. The work to be done to-day is practical: to throw light on what has been acquired and show how the field must be worked with new success.

I trust the attentive reader who is making his way through a material that is unfamiliar to him will realise, from the pictures and maps of the work, how much ground must be covered before one can appreciate certain lunar forms, and what an enormous amount of detail-work we have succeeded in doing. I go more fully elsewhere—especially in the astronomical journals—into particular problems, and trust that, with text and pictures, I can give even the uninitiated a clear idea of what are called the ‘changes’ on our neighbour planet. In the special maps which have been prepared from my own photographs (though, unfortunately, reduced to a very small scale), one can pretty well see the limits of my means of research. Further, I give an account of the most recent work in the science and a glance at the questions that press for solution in the future, in order that we may understand the matter that forms the outer shell of our satellite. Unfortunately, the twentieth century has not yet constructed the new map of the moon which I projected six years before it commenced. May it be included amongst the achievements of the future! The chief aim of my little work is to prepare the way for it, and point out the direction of research.

PH. FAUTH

CHAPTER I

An Historical Survey

It might be thought that a popular account of the science of the moon is not the most appropriate to present to the general reader. Other branches of astronomy may seem to have more promise of interest for him. But the reader who will go through these pages will learn to his satisfaction that our moon, with its peculiar riddles and its special forms, particularly affords a clear general introduction to the natural history of our little world, the solar system, and to the main lines of the plan of the visible universe. The close proximity of our attendant orb, so strikingly impressed on us by its large disk, is enough of itself to claim our first attention, when we set out from the familiar ground of our earth to explore the obscure and remote features of the world's structure. Every child is familiar from its own observation with the changing forms of the moon and its illumination of our earth at night; and poetry has never ceased to sing its praises. It is true that in these cases quite other sensations are evoked than those that we hope to induce in the following study. But it is more stimulating than any work of the poet's fancy, to every mind that is accessible to deep impressions, to turn from familiar things and look out into regions of creation of a quite different nature, and of different proportions—to turn to a foreign world, in a word. The mysterious magic of novelty has always had a charm for men. And if a curiosity in regard to less important matters is one of the least culpable frailties of humanity, surely the noble ambition to master the larger features of the universe needs no defence. Our nearest neighbour in the scheme of things offers to our astonished vision in a peculiar degree all that the ardent desire of the investigator has ever dreamed of finding, all that the lively imagination and creative fancy of any child of earth has ever conceived. To give some idea of the wealth that awaits any man who peers out into the depths of the universe, and to awaken a desire for a larger knowledge of the whole visible universe and our relation to it, is the aim of this work.

The study of the moon is only a small part of the science of astronomy. This science, moreover, has no immediate aim of attaining results that will have a practical utility in connection with the daily needs of human life; although in our time it does a good deal in that direction, and has apparatus with very practical aims, such as the measurement of time and the assistance of navigation. But in the main, the science of the great cosmic movements of matter and force aims almost exclusively at the satisfaction of the spiritual craving for knowledge. Astronomic research is its own end. The active research needed to attain valuable results, the peculiarity of the field of study, and the purely intellectual nature of the work combine to give a noble stimulus and an exquisite enjoyment. It is a feeling that Lessing fitly appreciated when he declared the search for truth to be preferable to perfect knowledge. The human mind feels itself impelled to extend its powers beyond the sphere of mere necessity into the realm of the true and the beautiful. Hence our investigation of the accessible provinces of the surrounding universe and its vindication. The aspect of lunar study which we are engaging upon is at first sight destitute of any practical application to human purposes. It may be taken as a proof of the self-denial of those who devote their time and energy to so apparently aimless and unprofitable an enterprise.

The observer who directs his gaze, with whatever optical aid his age affords, to the bright disk of the moon, will first study its general features in much the same way as the botanist studies a plant that is new to him. A mere acquaintance with the object is stimulating and often very gratifying. But, when the statistical side of the matter is done, the great questions of what it is, and why it is so, press upon the student; we are hurried on to a study of the deeper nature of the object and of its development, the way in which it came to be what it is.

It was, therefore, inevitable that the figure of the moon should, like some strange manuscript that called for interpretation, soon draw attention, and it was not long before the geological study of the earth's crust invited a comparison. In time ideas took shape from the mass of investigations of its surface, and the likenesses and peculiarities of earth and moon led to a closer attempt to determine the nature of the latter. At length, with the advance of mechanical and optical contrivances, (Cf. Agnes Clerke's *Astronomy during the Nineteenth Century*, chapters VI and XIII,) our knowledge increased so much that the explorer sought to penetrate into the mysteries of its life and the action of its forces. Certain changes were perceived which seemed to bring the distant moon nearer to the restless mind of man. But it was especially sought to bring the results of our study of the one cosmic body that is 'accessible' to us into harmony with our knowledge of the earth, so that we might find the key to the creation of our solar system. Hence we find students of the moon at work, never asking what use might be made of their results, but seeking to determine the correct features of the moon and the nature of the objects on its surface; inquiring whether there is ever any change in its stony features, how its hieroglyphics are to be deciphered, and what sign posts we may discover on it that will direct us in our exploration of the great universe beyond.

Next to the sun with its dazzling light it is the full moon that chiefly attracts our notice in the sky.* The softer light of its surface allowed even the savage to see spots on it, and the slightest attention will show that these are permanent. They led the imaginative child of nature into speculations that were partly connected with his worship of the gods, partly framed on the experiences of daily life. Just as the Greeks read whole legends into the groups of stars to which they gave corresponding names, so the lively fancy of ancient races saw the outline of a hare in the full moon. The Sanscrit tongue calls it the 'hare-bearer.' It is a familiar practice to speak of the 'face' or the 'man' or 'man and woman' in the moon; and, of late the suggestion of a 'kiss' has

Fig. 1.—The imaginary 'kiss in the moon.'

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* Newcomb says that 'the entire amount of the light transmitted to us by the full moon, is, according to the latest photometric determinations the 570,000th part of the light of the sun.' On the other hand the moon sends us the 82,000th part, according to Rosse, the 185,000th part according to Hutchins, of the sun's heat! Cf. also the *Astrophys. Journal*, vol. VIII, pages 199 and 265; and Very's *Prize Essay on the Distribution of the Moon's Heat.*

FIG. 2.—Photograph of the full moon for comparison.

been humorously, and not ineptly made. All these things are only indications of the habit of reading some expression or other into the unknown.

But an explanation of the moon that went beyond all these imaginative conceptions, a physical explanation, was attempted by the ancient Greeks (Clearchos ?), when they conceived the moon to be, possibly, a concave mirror reflecting the image of our earth. The idea came from Persia. Anaxagoras regarded the moon as a sort of earth with hills and valleys, and was banished on account of the independence of his speculations. Plutarch very accurately compares the shadow of the high lunar mountains, as it is seen with the naked eye in the irregularity of the light-line or terminator, at the first quarter, with the shadow of Mount Athos, which sometimes reached as far as the island of Lemnos. Thus from the constancy of the design and its finer features it was possible to form a substantially correct idea of the nature of our companion's surface and a fair appreciation of lunar

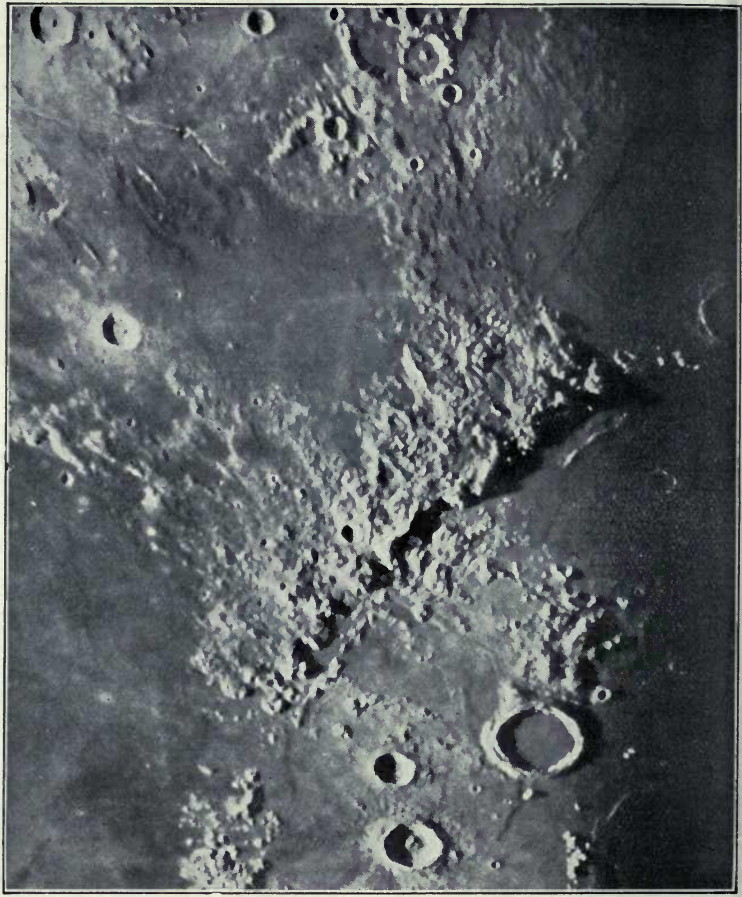

FIG. 3.—The Apennines and the walled plain of Archimedes.
(from A. Mang and Ph. Fauth's *Quadrantenfernrohr, &c.*)

forms, so that people began to speak of a round body with mountain-like processes on its surface. But neither the Greeks nor the Oriental races made any further progress, and the Romans failed to do anything in the matter.

The next step came with the invention of that wonderful instrument for bringing distant objects nearer to us, the telescope (1608)*. We can easily believe that, after the first gratification of curiosity on indifferent objects, the moon would be one of the earliest things in the heavens to attract the attention of the lucky inventor. But it took the great mind of Galilei to give meaning and name to the new spectacle. That he left only an imperfect sketch of the new world is due to the fact that the whole field of celestial observation was opened to him at one stroke; he was too overwhelmed with new discoveries to go thoroughly into any single one. The improvement of the telescope by Kepler confirmed Galilei's 'round mountains' on the moon, and Kepler expressed his astonishment at their number and structure. The burgomaster of Danzig, Hevelius, left behind him a series of drawings of the moon's phases, which he had obtained with a telescope magnifying forty times; we have also views of the full moon from him (1645), and one from Fontana (1630). We know also of a large general map by Langrenus (1645), and one by Grimaldi (1665), which was published by Riccioli†. But the imperfect instruments only gave very poor enlarged pictures of the moon, and at that time it was usual to compare our

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* On October 2nd, 1608, Jan Lapprey (Hans Lippersheim or Lipperseim) attempted to secure a patent from the States General of the Netherlands. On October 17th, Jacob Metius made another attempt; and in 1609 Galilei heard of the invention, and succeeded in making one. He was the first to shew how to prepare telescopes, and use them for astronomical purposes.

† Fontana's map may be seen in Flammarion's *La Planète Mars* (p. 10), and in W. Meyer's *Das Weltgebäude* (p. 94). Hevel's map also is given in the latter work (p. 95). Langrenus's map is reproduced in *Ciel et Terre* (vol. xxiv).

satellite to over-ripe cheese or pumice-stone. Further progress depended on the improvement of the telescope. The next step in this was the making of lenses of enormous focal length, which gave clearer images with less colour at the edges of bright objects. We can realise the action of these contrivances by using a spectacle glass (costing a few pence) with a four yards focus. A flat lens of that kind will give a focal image of the moon more than an inch large.

With instruments of this kind, Robert Hooke and Dom. Cassini did their work, the latter publishing in 1680 a map of the moon about twenty inches in diameter. His contemporary, Isaac Newton, sought to do away with the inconvenience of the long tube by using concave mirrors for producing the image, and the metallic mirrors that were made in increasing quantities towards the end of the 18th century did such good work that the lens was almost forgotten. Further advance in the manufacture of glass objectives was needed, and this was sketched by the mathematician, Euler, in 1747, in the sense that the colour-edge of the lens-images was to be got rid of in some way. In point of fact, the optician Dollond was the first to produce an 'achromatic' telescope by the combination of two lenses, in 1758, though as the result depends on the testing of many different combinations, these 'achromatic' instruments were far from perfect. Still they were successful rivals of Herschel's numerous 'reflectors,' which were very good of their kind. In England the heavier reflectors were generally used, but in Germany the smaller and more convenient Dollond-achromatics were more accepted.

What Herschel did with his mirrors for stellar astronomy in England, was done for the science of the moon by Schroeter in Germany He made a number of interesting observations; and, if his skill as a draughtsman had been at all equal to his power of observation, his pictures would still be valuable. But he was so far led astray by his possession of powerful optical apparatus as to go beyond the problems of his time, and occupy himself with ‘changes’ in the, as yet, unworked field, instead of laying the foundations of a sound science of the moon according to the power of his telescope. The distinguished astronomer, T. Mayer of Göttingen, who made careful measurement of the moon's surface and drew an eight-inch map of the moon, published a work (1775), that remained the sole accurate map until 1824. Schroeter's partial pictures could not be combined into a general map, because he had pursued a misleading purpose. Moreover, the means at hand were not very liberally used in the exploration of the moon. Apart from the comprehensive genius of Herschel—and even he only did so intermittently—no one used the best instruments of the day on the moon. There were greater problems to be attacked in the fixed stars, and hardly a single professional astronomer concerned himself with our nearest neighbour.

Once more progress depended on an improvement of the instruments. Fraunhofer's theoretic insight into the conditions of the making of achromatic lenses and his success in making glass combined in the nineteenth century to produce instruments far beyond Dollond's. On the 18th of December, 1817, glass was melted to make an ‘achromatic objective’ of unheard of dimensions—10 inches diameter and 14 feet focal length—and the telescope, afterwards installed at Dorpat, then at the beginning of its work, was regarded in England as something fabulous. Even when gigantic refractors of 13—20 inches aperture followed —to-day they exceed 40 inches—the poor moon was still neglected, and remained the field of wealthy amateurs. At Dresden, the geometrician, Lohrmann, worked so zealously in private at the task, that he formed a large map of the moon, based on his own measurements and drawings, and published it in four sections, with text, in 1824. In 1857 Beer and Mädler published an equally large map and a complete 'selenography,' most of the work being based on Mädler's private study in his friend Beer's modest observatory at Berlin. After these we find a number of people, such as Kinau, who, partly for their own pleasure, and partly for the advance of science, investigated the moon with the aid of the incomparable telescopes of Fraunhofer and his successors. The distinction between professional and amateur astronomers became greater during the course of the nineteenth century. The work of observing, drawing, and describing was left to the latter, and hence the physical features of the planets generally, especially of our moon, were generally taken up by industrious and able amateurs.

In the second half of the nineteenth century it was suddenly discovered that there was a new and far-reaching interest in our neglected satellite. A young enthusiast mounting his poor telescope on a lamp-post to get a glimpse of the wonders of the moon, was so profoundly impressed, that he continued throughout life to gather material. He became a 'selenographer,' went far beyond Lohrmann and Mädler, and about the close of his life (1878) published, at the public expense, a map, twice the diameter, four times the surface, and seven times as rich in detail, as Mädler's 'Mappa Selenographica'; though the plan of this gigantic map was very different in his mind from what he actually achieved, and the life of one man was too short for the work of mapping out the moon on the scale that the optic appliances of his time permitted.

Thus appeared the finest piece, as yet, of lunar research, the 'Map of the Mountains of the Moon,' by Julius F. J. Schmidt, but new circumstances arose that demanded a fresh attempt. The work to be done is not merely to ascertain the features that certain agencies have induced in the face of our satellite. It is equally necessary to have an elaboration and control of the material by many co-operating students. A very welcome advance in optics has provided the best instruments at a moderate price, and the spread of scientific education in the last few decades has stimulated interest in the observation and reproduction of the cosmic bodies. In addition, a series of observers of great merit have, by their example and teaching, created a school of good amateur astronomers, and the multiplication of scientific periodicals has contributed by announcing the latest news from the heavens, fostering investigation, and allowing even the amateur to have his say. The science of the moon became once more the province of amateurs with the work of Schmidt, and that is a circumstance of great influence on the attainments that we have made. At this stage of peaceful development and interpretation we find accomplishments that have greatly extended our knowledge. In California a great 36-inch refractor has been established by a private donor, Mr. Lick, and used in photographing the heavenly bodies, especially the moon*. A still larger (40-inch) refractor has since been set up at Yerkes Observatory, Chicago, through the munificence of another private donor. An immense number of negatives of all its phases have been taken and published, and we have every hope now that the riddle of the moon's sphinx-like face will soon be solved.†

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* (See 'Brief account of the Lick Observatory,' by E. S. Holden).

† See the Photographic Atlas of the Moon from the Lick Observatory, with 19 plates on the scale of Mädler's map. The figures vary considerably in fineness, but have a remarkably good tone.

With our more accurate knowledge of the topography of our satellite there has been no lack of attempts to interpret its peculiar condition. The resemblance of lunar structures to the craters of volcanoes, like those on our planet, was too great to resist the temptation of giving that name to them and endeavour to explain them as such ; in fact the almost circular shape of all of them seemed to demand some such explanation. Hooke long ago experimented with molten alabaster with the object of proving that the round mountains of the moon might have been formed by heated vapours issuing from its glowing interior, perforating it, and throwing up walls. We know now, however, that the cohesion of matter is not great enough to permit the formation and distension of bubbles of 60 miles and more in diameter. The volcanic theory of the formation of the lunar type of mountain was afterwards attacked by Kant. He would not hear of 'craters,' but believed that certain terrestrial districts, such as Bohemia, threw some light on the structure of the lunar rings. Kant, however, overlooked the fact that only a few terrestrial structures can be compared with the tens of thousands of ringed walls, and so the moon remains a different and very distinctive world.

Schroeter returned entirely to the volcanic theory in his search for 'changes,' which he believed he discovered on a gigantic scale. Herschel speaks of a fiery eruption on the dark side of the moon, which he followed with his own eyes ; no doubt the use of his great reflecting telescope, with slight magnification, might very well give the dull glow of a highly reflective spot the sparkling appearance of a star. Other extraordinary features have been attributed to the moon since Herschel and Schroeter, because it was not sufficiently known at the time how to distinguish recurrent monthly phenomena from accidental and momentary ones. Beer and Mädler, two industrious collectors of facts, went deeper into the knowledge of its features, in spite of their small instruments*, than their predecessors; and they knew nothing of 'changes.' Indeed, in view of the immature condition of 'selenography' they do not attempt to set up a 'selenology,' as they would have had a right to do. Humboldt also recognised that the volcanic theory does not apply to certain localities.

The sphinx-like face of the moon, its surface covered with hieroglyphics, remained unexplained for many decades. Then the cooler attitude of the founders of modern selenography was assailed by a new volcanic theory, worked out with great energy and conviction. Two English scientists, Nasmyth and Carpenter†, had gone deeply into the features of our moon with their large reflecting telescopes. They made some ingenious models, and at length reproduced the finest details of lunar relief in a preparation of plaster of Paris. When a vivid light was thrown on this model, it had a most deceptive resemblance to the lunar landscapes, as they are seen in the telescope. But the resemblance could only deceive the inexpert. The otherwise conscientious observers were not able to refrain from introducing their favourite theory of lunar volcanic energy into their model-relief. Thus we find them, in the second half of the nineteenth century, with a good deal of sagacity and technical and empirical knowledge, attempting to prove what they would like to see proved, yet completely failing in the end. Their

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* Mädler's Fraunhofer of 4 in. aperture and powers of 140 and 300 was a fine instrument; but we now use lower powers, and get clearer and better views. Mädler generally used a power of 300 with an objective of 4 in. aperture, but the present writer has worked for years with powers of 160, 176, and 210, with objectives of 6½ and 7 inches. Many of the peculiarities of the earlier science are due solely to excessive magnification. Lohrmann's telescope was larger, but perhaps not so good.

† 'The Moon, as Planet, World, and Satellite,' 1884.

scientific conscientiousness compels them to admit that their knowledge is imperfect here and there. They feel themselves that precisely those objects that are most distinctive and most in need of explanation do not find a place within the frame of their theory of the origin of lunar mountains, and that the largest and the smallest of the typical circular structures are not susceptible of explanation by it.

Yet all the contemporary and later 'selenologists' start from the same point of view. The less they know of practical observation of the moon in detail, the more they seem prepared to solve its riddle. Amongst a large number of attempts in this direction we may select three for notice. Meydenbauer (Figs. 4, 5, 6) began with the intention of explaining the origin of walled depressions by the fall of meteoric bodies, and really produced structures resembling those in the moon by letting small quantities of dust fall on a layer of dust. W. and A. Thiersch developed this aggregation theory in a special work; and there seemed the more reason to oppose it to the volcanic theory as we were learning more and more every day about the presence

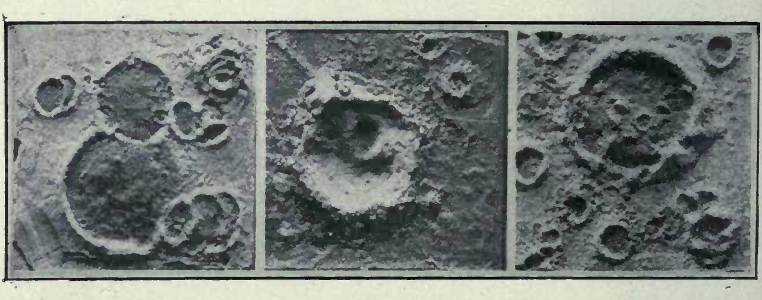

FIG. 4 FIG 5 FIG. 6

Imitation of lunar craters in ground felspar by Meydenbauer. Fig. 4: flat twin-crater. Fig. 5: strongly developed wall with secondary inner crater Fig. 6: locality rich in craters.

of countless meteoric bodies in space, and the extension of the theory of cosmic swarms of meteors to another province—the meteoric nature of Saturn's rings had been affirmed and proved — was supported by the leading authorities. Hence it seemed as if meteoric masses falling on the moon had led to a reaction of its crust—the formation of ring-mountains and the outpouring of the molten interior.

As if the volcanic basis of this view were not precarious enough, the theory of aggregation brought fresh difficulties. The chief objection to these speculations is that the tens of thousands of lunar structures demand that these meteoric impacts should be vertical, or in the direction of the moon's radius ; and we can demonstrate on mathematical grounds that a vertical impact is almost impossible in the case of a body that is without a buffer in the shape of atmosphere. It is therefore quite certain that these impacts did not occur in tens of thousands. It is much easier to speak of a bombardment of the moon's crust by meteoric projectiles than to prove it ; and it has certainly been forgotten that the sudden arrest of a cosmic movement at the rate of ten or twenty miles a second would cause an enormous generation of heat, so that a meteor would neither dig up the material of the moon, nor deposit its own material in a circular mound. The visible product of any such meteoric impact would rather be a spot molten with the heat and traces of the explosive expansion of the vapourised mass of the meteor—an indication of an explosion, but not a circular mountain. There is no reason whatever to suppose that larger and more numerous bodies dashed on the moon in former ages than in ours ; nor is it explained why the moon alone is so pock-marked, while the earth, which is far more active in attracting foreign bodies shows no trace of impacts.

No more substantial ground can be found for the views of geologists like Professor Suess or Toula.

Whether it was volcanoes alone that formed the moon's surface, or whether meteoric impacts were needed to relieve existing strains, or whether the ageing moon produced the mountains by the wrinkling and breaking of its crust, so as to release the molten matter within, which would remain visible in the round hills—in all these speculations there is at the bottom a disputable hypothesis, the Laplacean theory of the formation of the solar system. This theory has lost much of its prestige of late and we often find its untenability and the scantiness of its support in recent research openly admitted even in professional circles.* Loewy and Puiseux, it may be said, take their stand on the old ground in their explanation of the maps in their Parisian 'Atlas of the Moon.'

If we glance back at our historical survey, we find that there were two circumstances that hypnotised the founders of selenologies—of whom Nasmyth and Carpenter were the only ones with a real knowledge of the moon—so that they were incapable of paying attention to its real features. The first of these was the circular form of the so-called craters; though on closer examination, and on the confession of the theorists themselves, they are found to have a somewhat different complexion. The volcanoes of the moon are hollowed out like saucers, while those of the earth rise up like mountain cones: the former are of gigantic dimensions, the latter would be barely perceptible if they were removed to the moon: the former consist only of a circular mound, the latter almost always form a cone. The other circumstance was the general acceptance of the Laplacean hypothesis of the origin of the sun and planets. In the days of its founder this system was probable enough; now that our knowledge has so much increased, it not only fails in its older form to harmonise

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* See Riem's article 'Die modernen Weltbildungslehren' in the July number of *Glauben and Wissen*, 1905.

with astronomical truths, but it offends against fundamental laws such as the persistence of force and can render little help to cognate sciences, such as geology, meteorology, and palæontology. We are, therefore, in a stage of transition to-day—not alone in regard to lunar science—which must end in a rejection of Laplace's theory in its first form. Only when we have rejected untenable foundations will it be possible to pursue our task with any profit and read the language of the moon's surface.

The direct inspection of the moon with a telescope and the drawing of small parts on a large scale were not likely to lead to an abandonment of the old views. More confidence was felt in the impartial results of photography, in view of its fidelity and its effectiveness in two directions. In the first place the telescope only shows a small part of the disk at a time, and the varying illumination and the almost constant agitation of the air only allow us to examine particular spots. Once the opportunity is past it will be many months before the spot is illuminated in much the same way, and then clouds or other impediments may prevent us from examining it. Photography, on the other hand, would enable us to attain results in a short time that would have taken years at the telescope. Further, it is no longer the province of the astronomer alone, or even the amateur, to work up lunar experiences into a large scheme of another world. A whole crowd of specialists in different branches of science get pretty much the same view of the external features on which the theory and analogy are to be based. This had never been the case before, and so much was expected from the judgment of geographers and geologists.

The 'daguerrotype' had hardly been invented when an enterprising American, Dr. John W. Drayer, of New York, began a series of pictures of the moon on silver plates (1840). Ten years afterwards, the photographer Whipple, began, at the invitation of William C. Bond, director of the Harvard Observatory, to work with the Merz refractor of 15 inches aperture, and produced images more than two inches in diameter. Another American, Humphrey, obtained even better pictures of the moon with a two seconds' exposure, showing a good deal of detail ; and at Königsberg, in Germany, Barkowki secured negatives that would bear enlargement up to two inches. But a great advance was made by Warren de la Rue, at London, who began his work in 1852, especially when, in 1857, he caused his telescope to follow the movement of the moon by clockwork. His pictures were good and numerous, so that he could make a selection of them, and arrange them in pairs to produce stereoscopic effects and represent the moon as a globe. Dr. Henry Draper, of Hastings (on the Hudson), who united in himself the attainments of the chemist, physiologist, photographer, optician, and constructor, made a metallic concave mirror in 1860, and one of silvered glass in

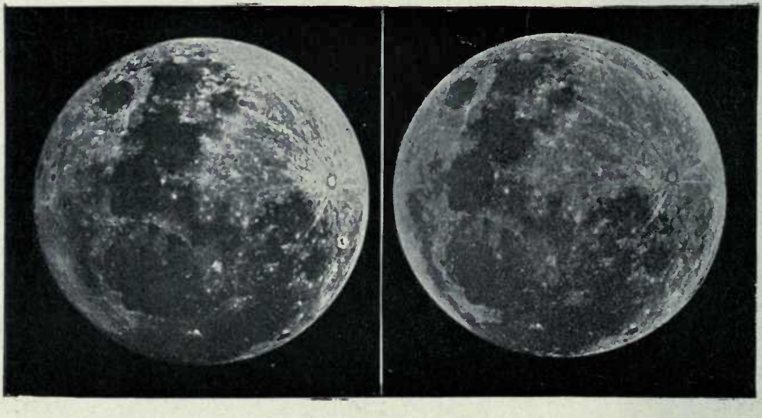

Fig. 7 Fig. 8
Two photographs of the full moon for the stereoscope.

1861, each 16 inches in diameter, and worked with unprecedented success. One of his photographs of the moon, an inch in diameter, taken in 1863, was enlarged to the size of Mädler's 3 foot map, and was still decipherable. In 1870, the indefatigable worker made a speculum twenty inches in width, but after 1880 he used—with more advantage—a refractor made especially for photographic purposes, with a 12 inch objective. Rutherfurd, of Cambridge (U.S.), had observed in 1857, that there was a difference of $\frac{5}{8}$ of an inch between the distance of the image for the eye and for the sensitive plate in his telescope.* Once this was taken into account pictures of the moon were secured that could be enlarged to five inches. He also constructed his first stereogram, independently of de la Rue. He further tried to increase the sharpness of the image by separating the lenses of his four-inch objective about $\frac{3}{5}$ths of an inch. A large objective (11 inches in diameter and of 14 feet focal length) gave in 1864 a picture of the full moon which showed details very sharply even when enlarged to seven inches. Another objective, specially corrected for chemical rays, gave him in 1865 a focal image of $\frac{3}{5}$ths of an inch, which could be enlarged with success to 21 inches; and after 1871 he used a 13 inch refractor. Beside these successes we need pay little attention to the work of Wolf and Rayet with a seven inch reflector or even of Ellery (of Melbourne) with a 4 foot reflector, which gave direct images of three inches diameter. But the Argentine astronomer, Gould, succeded at Cordova in 1875, with

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* Spitaler says that the lenses of a large refractor show a focal difference of about one inch between the optical and the chemical rays. 'The sensitive plate could be pushed $\frac{1}{5}$th of an inch to either side in the chemical focus without making any perceptible change in the quality of the photograph.' Even in six-inch telescopes the difference between the two foci may amount to more than $\frac{2}{5}$ths of an inch, so that for photographic purposes it is necessary to achromatise for the chemical rays or to use reflecting telescopes, which give colourless images.

the help of a pupil of Rutherfurd's, in producing original pictures of an inch and a half, which were enlarged to nineteen inches.

The year 1888 saw the beginning of the work of the great Californian telescope. For photographic purposes the great 36 inch lens is converted into an enormous camera of 33 inches aperture and 50 feet focal length. This gives a focal image of the moon's disk 5 inches wide. Unfortunately, the best results are not obtained with the full aperture, but with one shortened to 8 inches. Burnham, Schäberle, and Campbell, in particular have secured a large number of plates of all parts of the moon with this instrument. In the meantime, the brothers Paul and Prosper Henry had done good work at Paris with a 13-inch objective of their own make. They began to photograph the moon before the erection of the Lick telescope, producing a large original image by means of intermediate lenses. Other experiments were made by Prinz at Brussels, Pickering at Cambridge (U.S.), Spitaler at Vienna, and Wolf at Heidelberg*. But from 1890 onwards, the Henry's secured pictures that astonished all students. Still it was some time before the method of direct magnification of the image was generally preferred to focal photographs. The dry plates contain fine grains of silver precipitate in the film. Details finer than these cannot be shown, and when a negative is enlarged we see the crudities that result from this granular nature of the film. This defect marred the otherwise remarkably good Lick photographs. When Prof. Weinek put them under the microscope he could discover nothing more than was visible on a careful

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*For Pickering's work see 'Annals of the Astronomical Observatory of Harvard College,' vol. xxxii, part 1. Prinz used an aperture of 9 inches, and had an image of 4·13 inches : Pickering used a 33-inch aperture, and enlarged the full moon to 28·70 inches : Spitaler used the 27-inch Vienna refractor, Wolf his own 6-inch refractor.

mechanical enlargement of the plates. When he did fancy he had discovered further and finer details, it turned out to be an illusion, as it had been pronounced from the first by those who were well acquainted with the moon*.

Thus, for instance, the magnification of the round mountain Capella, and the small parasitic crater Taruntius C, shows a number of fine lines, which no expert now regards as 'rills.' We also see a large number of craters and fine bubbles which are in marked contrast, on account of their sharp definition, to the remarkable vagueness of all the large details that we know. It is a difficult task to interpret these details; and it is equally vain to attempt to-day to determine the causes that have been at work in the glass of the positive, the sensitive film, or the taking of the negative, to produce these apparently well-defined craters under the microscope. We have learned from Prof. Prinz's measurements that even objects twice or many times the size of those supposed to be found in the photograph under the microscope are altogether vague and indefinable on the same plates.

Meantime the Lick plates were enlarged very considerably, and an atlas of 19 plates was published, on the scale of Mädler's map, but the details are largely spoiled owing to a defect in the method of taking the originals. Then Prof. Weinek began his magnifications, and published an atlas of 200 wonderfully beautiful plates of the moon, which were evidently made with the utmost care from the Lick photographs. About the same time Loewy and Puiseux began to work at Paris with a particularly suitable instrument with a 24-inch objective and 60 feet focal length. They took focal negatives, which hardly needed one second exposure, and measured up to seven inches in diameter.

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* See 'Publications of the Lick Observatory,' vol III, 1894: with 16 plates, including 11 heliogravures.

Fig. 9.—Lunar landscapes. Theophilus, Cyrillus, and S. Katharina. Photographed by Ritchey.

From these large plates were prepared, on a scale of 80–90 inches for the full diameter of the moon. Some of these are the finest work that has yet been done in this department. Cambridge (U.S.) has also been busy, as the Atlas of 1904 shows; the object of this was to illustrate each part of the moon in five different stages of illumination. Setting aside this latter performance, which will not advance our knowledge of the moon's surface, we now have, the smaller Lick atlas of 19 plates, the Weinek enlargements in 200 plates, and the Paris atlas of 40 large plates (pictures 15 × 23 inches), which is the high water mark of our accomplishments so far both in form and content.

It is true that the latest photographs of the moon taken with the Yerkes refractor at Chicago are much finer, but the difficulties of taking them in the monster telescope are too great to allow of much being done there.

Now let us see what these most recent advances have done for us. It is clear that the chief merit of these great photographs is their unfailing accuracy. Such correct presentations of the mutual position, the size, and the shape of the moon's mountains could not be given by the most acute eye, most careful measurement, and the most practised hand; especially when we have thousands of individual photographs combined in a general picture. The second advantage is the equal goodness of the whole picture (apart from flaws in the negative), whether it is uniformly clear through having been taken in very favourable conditions, or uniformly dim on account of unfavourable circumstances. In either case the features are evenly presented to us. But, both these advantages, together with the third, the ease with which they are taken, only seemed to confirm the opinion of men who still take their stand on the ground which astronomy is just beginning to abandon. The man who pours the wine of fresh knowledge into old bottles, though he knows they have a bad taste, need not expect it to be of good quality. On this account the views of some of our geologists (Toula, Suess, etc.), and of the publishers of the Parisian Atlas (Loewy and Puiseux) and their school, are not likely to satisfy those who know the moon well from their own observations and deep studies.

It is a very different thing to study pictures and to observe the real moon in all its brilliancy and colour. On the moon we have light in every possible tone; there is a complete scale from the glowing white that dazzles the eye, to the coldest and deepest black, all

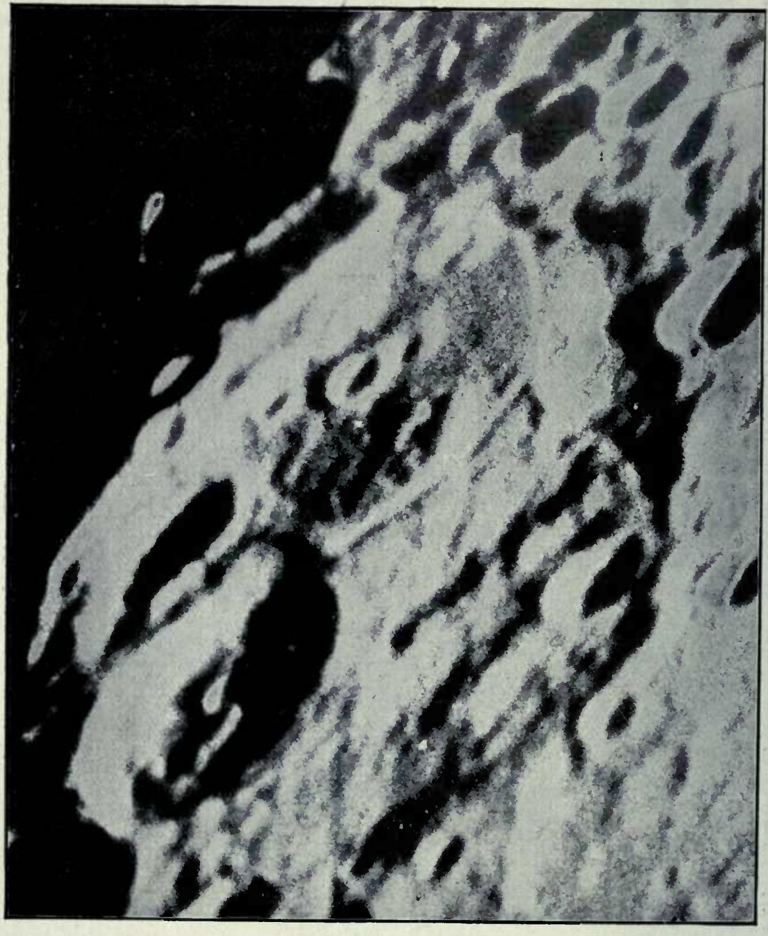

Fig. 10

The round mountains, Janssen and Fabricius (1 mm. = 1800 m.)

over the moon, unless it is examined at full. It need not be said that the finest pictures can only give a clear reproduction of the *middle* tones. What the eye takes in at a glance can only be gradually reached by the photograph. For every photograph that turns out 'good' with one second exposure there are two others, one of which perhaps needs a tenth of a second, and the other five or more seconds exposure. If the bright spots must not be over-exposed and the dull under-exposed; if they are not to be sacrificed to the spots of medium intensity, we should need three different and wholly impracticable photographs. Yet the human eye takes them all in at once, without any gradual adjustment.

Thus, selenologies that are based on photographs are open to question. If it is ever necessary to go into detail, this is certainly the case as regards the moon. Its riddles only begin to dawn on us when we turn from the broad features and general configuration to study the specific lunar peculiarities of the small structures and parts of the whole. We have realised that the circular shape and the walls cannot give us any satisfactory information of themselves, and we have seen that there are a dozen or more hypotheses framed on these purely external features, because a great number of different agencies might have produced them. The salient feature is not the 'crater,' but a different thing altogether, that can only be explained by a close scrutiny of the floor of the moon. Yet scarcely one eye in a hundred is directed to the *empirical* study of it*.

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* See, for instance, the work of expert lunar observers who have attained only moderate results with very large objectives I need only refer to Neison's, Pratt's, and Klein's pictures of the Hyginus district: Neison's four pictures in Meyer's *Weltgebäude*: Smyth's picture of Copernicus: Nasmyth's Tycho region (in which it is impossible to identify the score of large craters, or even Tycho itself): Secchi's Copernicus ('The Sun'): Neison's Godin-Agrippa landscapes, Copernicus, and two pictures of Plato: Trouvelot's landscape's of

Although photography has eclipsed the army of once active ocular observers, who think they have been superseded, there have been efforts made in the last two decades that seem to show that it is possible to do more than photography can do. With all our precautions we have not yet succeeded in taking plastic objects of about a mile in extent in photographs in a properly recognisable form†. It is not enough that we can just point out the features; in 99 cases out of a hundred we shall be wrong or uncertain. But the eye can, under moderately good conditions, perceive things and judge their size, posture and shape, when the photographs will give nothing but a hazy spot. In other words, ocular vision is clearer, truer, and finer, and is able to penetrate precisely into those regions which it is indispensable to explore if we are to have a sound theory of the moon.

Since Schmidt's large map was made (1878), Klein (of Cologne) has attained some moderate results in certain lunar districts with a 6 inch telescope, Gaudibert (of Vaison) was equally limited in his results with 8–10 inch silver reflectors, Elger (England) did some work in the same direction. All these efforts

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Parry, Arzachel, Gassendi, Eratosthenes, and Caesar: Trouvelot's Linné, and Herodotus: Nasmyth's Gassendi (in 'The Moon'): Stuyvaert's 50 lunar landscapes: Prof. Weinek's artistic pictures, &c. I say nothing of pictures of this kind in the *Bulletin de la Soc. Astr. de France*, and the *Memoirs of the British Astr. Ass.* In all these pictures, though they have appeared since the great 'Map of the moon' was published, you will look in vain for details that had already been charted, to say nothing of others. On the other hand our special maps give fresh material every time, even in reduced forms.

† See articles in *Ciel et Terre*, 1889, December, 1890, and January, 1891 Prof. Weinek himself writes in it as follows (February, 1891): 'Every competent student knows that the image seen in the lens is still more definite than that on the best photographic plates . . . The practised eye of the observer will *always* retain its rights; the two methods, optic and photographic, will not exclude, but complete, each other . . . Still, they [the negatives] have clearly proved to me that we must be very careful in discussing the smaller photographic details, and that it should only be attempted when we have two plates taken in the same night.' Other articles in *Ciel et Terre* are of November, 1892, and 1896: and the *Bulletin de l'Acad. Roy. de Bruxelles*, 1892 and 1895. See also Prinz's *De l'emploi des photographics stereoscopiques en sélénologie.*

have ceased with the recent advance in photography. It was left to amateurs to take up the moon as a welcome field when the plan of a fresh exploration, with the view of forming a new map, was formulated by the present writer.

Brenner (of Lussinpiccolo), using his 7-inch refractor in the unique climate of the Adriatic, discovered a number of very fine lunar features. Krieger set up an observatory at Trieste with the object of making a statistic collection of small details from copies of lunar photographs (the Trieste *Atlas of the Moon*). Others, such as D. Nielsen, of Copenhagen, and J. Meller, of Osterath, published drawings in colour or tone, with shadows of lunar landscapes. Then the observatory established on the hills, near Landstuhl, by the author, began the preparatory work for the projected new map of the moon. Maps were made on a scale of 10½–57 feet for the moon's diameter. They contain an amount of detail beyond any yet published, of which the photographs give no trace. We have lately heard from the astronomers of the Harvard, Lick, and Yerkes observatories of new observations*. It seems that they are now using their large visual instruments in the long-neglected systematic study of the moon, and are discovering details that had not hitherto been seen. That is very natural in view of the hundreds of thousands of details that are accessible to-day, and certainly a large telescope should show more than a smaller one; yet the transatlantic astronomers are hardly in advance of those of central Europe, as they seem to be unacquainted with what has been done over here for a long time.

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* Prof. Pickering 'Annals, &c., of Harvard College,' vol. xxxii. Also articles in *Sirius*, 1901, viii and ix; 1902, x; 1904, v and xii; and 1905, i and ii. E. E. Barnard writes in the *Astronomische Nachrichten* (nr. 4075, February, 1906), on 'Periodical changes in the size of the glow surrounding the lunar crater Linné.'

This is clearly seen from Professor Holden's application of the 36-inch Lick refractor to the regions of the Hyginus and Ariadaeus rills. The eight pictures obtained in November, 1889, are very faulty and poor in detail (as also are the enlargements from 270 to 600) in comparison with the large aperture and light-power of the telescope. In the last few years, Professor W. Pickering has explored the region of Messier with his powerful instrument, but, in the opinion of German selenographers, with just as little success. At all events his picture of the two craters is not of a nature to justify even the slenderest anticipations from such work. He had in the spring of 1893 examined the variations of dark spots at various points on the moon, using a magnification of 345 to 714 with the 13-inch Boyden telescope. The reader will see from the comparison of the Alphonsus spots, which we give later, how much he discovered, and how much the present writer had done with an instrument only half as large and a magnification of 160 to 210. It will give a good idea of the controversy about these spots.

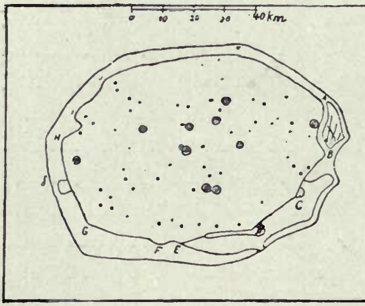

FIG. 11

Fig. 11.—Pickering's plan.

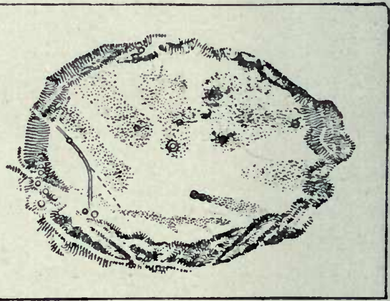

FIG. 12

Fig. 12—Fauth's map.

A little earlier Professor Pickering made a detailed study of the little craters in the depths of the circular plain Plato, which we reproduce here, indicating the wholly or partially certain, and the altogether uncertain positions, together with our own map of the interior of Plato. Most of the positions are illusory and do not correspond to real objects, for Pickering conscientiously used the results of even the most superficial of previous observers, such as Neison, Elger, Pratt, etc. It would have been wiser to separate the chaff from the wheat.

To sum up, we have some works of great value, especially three orginal maps of the moon (Mädler's, Lohrmann's, and Schmidt's), which reflect great credit on the conscientiousness and self-sacrifice of their authors, and three photographic atlases of the moon (Lick, Prague, and Paris), besides the Harvard atlas of lunar phases*. But the ultimate aim of all these efforts, the explanation of the processes that have left these traces on the surface of our satellite, has not yet been attained, chiefly because students have not yet succeeded in emancipating themselves from the deep-rooted but more and more untenable idea that the matter of our solar system is still in its youth. In this we sufficiently indicate the path and the duty of all future study.

If we wish to form a correct idea of the moon's mountains we must above all take into account the size of that body. The irregularity of the line of light at the first quarter suggested to the ancient Greeks a correct conception of the nature of the lunar surface, but two measurements had to be determined before there could be any proper appreciation of its mountains, and this could not be done until centuries afterwards.

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* We may also mention Neison's Atlas, which is an elaboration of the *Mappa selenographica*, giving more of the rills but less details in the mountains, and admitting many errors. There is a crowded map, 'La Lune,' by Gaudibert and Flammarion, about 25 inches in diameter. This is a rather schematic 'carte pittoresque,' and shows a number of rills. It contains 509 names, and costs about five shillings. There is also a map in Elger's, 'The Moon,' about 18 inches in diameter, and very clear. [Mädler's map is reproduced in Webb's 'Celestial Objects for common telescopes.']

The ancients succeeded in making a fair estimate of the moon's distance from the earth and of its diameter, by determining certain lines and angles between the stars. Aristarchus, of Samos (320–250 B.C.), found in this way that the distance of our satellite was 56 semi-diameters of the earth, and gave it a diameter of 2°, which is excessive. We now know that the figures are 60·27 semi-diameters and 0·52°. It has been said that Aristarchus was more successful in his difficult method of determining the distance than many in the easier method of measuring the angle between the horns of the crescent moon. As a matter of fact, he was quite ignorant how large the semi-diameter of the earth was in ordinary terms of measurement, so that his 56 semi-diameters only give a proportionate not an absolute, size. The insecurity of calculations at that time can be seen in the results of Eratosthenes, who allowed only 25 earth-radii. On the other hand Hipparchus (190–120) came closer to the truth with a distance of 59 radii and a diameter of 31′. But this again merely means the proportion to the unknown size of the earth, so that Hipparchus could only give a proportional estimate of the real size of the moon. Ptolemaeus (100–170 A.D.), again made the angle much too wide. Since the application of the telescope to lunar purposes, and since the insertion of a spider's thread in the lens to fix a definite point, and the use of carefully graduated instruments to determine small angles, students have approached nearer and nearer to the real size, and we now know that the moon revolves round us at a distance of 60·274 earth-radii (238,000 miles) and has a diameter of 31·1′ (minutes of an arc), or 2170 miles. According to L. Struve, the diameter, as determined by 42 stellar occultations in 1884, on the basis of the Hansen parallax (57′ 2·27″) is 31′ 5·29″; and according to J. Peters it is, as deduced from eight occultations of the Pleiades from

1840 to 1876, 31′ 5·18″. These determinations give the moon a diameter of 2162·4 and 2162 miles respectively. In this way we can give a positive value to all our arc-measurements and to parts of the lunar disk. If we imagine an equatorial line drawn round the moon, one degree of it must have a length of 19 miles, and must be seen from the earth at an angle of 16·6″ (seconds of an arc). Thus we get direct measurements of the true diameters of the circular ramparts on the moon ; only we must remember that nearly all circular structures are fore-shortened when near the moon's edge, and we must therefore always measure the longer axis of the apparent ellipse.

It is a more difficult matter to determine the height of the lunar mountains. It is true that, as the pictures of the moon show, they cast deep black shadows, long drawn out in some circumstances, toward the night-side of the moon ; but these must always be parallel to the equator, and their real length only tallies with the apparent one when they lie quite close to the middle of the disk. As the terminator (or line of illumination) is, like the parallels of longitude, more and more bent towards the east and west, in the higher latitudes the linear distances of an object will be smaller and smaller as compared with the angular distances expressed in their degrees of longitude, and towards the east and west the shadows must be optically fore-shortened on account of the rotundity of the moon. It is therefore necessary to bring the immediate findings of shadow-lengths, as determined by the micrometer in the telescope, into proper relation to their distance from the centre of the disk, before it will be possible to establish their real proportion to the moon's diameter and so express their length in miles. Even then we have not yet got the height of the mountain that is being studied ; but the first measurement will give the height of the sun above the mountain, and then we have only to find out what vertical height will correspond to the said height of the sun and the given shadow-length, and we have the latitude of the mountain. We need only say here that the results are more accurate in proportion to the smoothness of the floor of the moon below the point of the shadow, and the longer the latter is drawn out. On the real moon, as a matter of fact, the shadows are much deeper and sharper than on the pictures of it. Hevel established long ago, with poor instruments that only magnified from 30 to 40 times, the height of a lunar mountain of 17,333 feet, and there are much higher ones. Schroeter gave very reliable measurements of many others. Mädler determined the heights of more than 1,000, and Schmidt made altogether 3,050 measurements. We may say confidently of many of these determinations that they are much more accurate than most of the measurements of terrestrial mountains outside of Europe. Indeed Mädler's map was far more correct as a reproduction of the moon than any map of the earth was, even at the beginning of the twentieth century. The interior of Africa, of north and south America, Asia, and Australia—to say nothing of the polar regions—is not yet as well charted as the moon was in this 70 year old map. The reason is that we can see the whole moon at a glance, while the exploration of foreign lands involves costly and wearisome expeditions and innumerable dangers.

A closer measurement of lunar objects on the photographic plates has been undertaken for many reasons, but chiefly in order to secure new and better maps. An older theory assured us that the moon departed a little from a perfectly globular form, and presented to the earth an unusually flattish oval. Dr. Mainka,* of Breslau, has made a large number of

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* See his article in the 'Mitteilungen der k. Univ.-Sternwarte zu Breslau,' I, pp. 53-71.

measurements in this connection. His results did not establish the theory, but gave a number of interesting suggestions of support, from which we could infer the irregularity of the curved surface. These determinations of level show at least that extensive bulges and small swellings alternate with broad depressions, and that the whitish mountainous regions correspond pretty well to the plateau surfaces and the plains to the depressions. The map shows this very clearly.

Another peculiarity was discovered by Galilei in studying the design of our neighbour-planet, and can be seen with the naked eye at its greatest development. This is a variation in the part of the moon comprised in the disk, and is called 'libration' from the Latin *libra* (a balance). It is caused in the following way. The moon's orbit is inclined to that of the earth at an angle of 5° 8′, so that it occasionally stands to this extent north or south of the ecliptic. Moreover the moon's axis is inclined a good 1° 5′ towards it. Hence, if the moon comes, so to speak, right above the ecliptic, especially in the constellation Gemini, we can see a good piece of its south polar region, and its centre is a little north of the centre of the disk. Then, when it lies quite to the south of the ecliptic, especially when it is in the constellation Sagittarius, we can see a good deal of its north polar region; especially we who live in the northern hemisphere and occupy a particularly 'elevated' position in this respect. The two movements together make up what we call 'libration' in virtue of which we see, alternately to north and south, a crescent-shaped piece beyond the lunar poles.

We know further that the moon travels with unequal speed in its elliptic orbit. It goes more quickly when near the earth and more slowly when farther away from it; though it rotates on its axis with perfect regularity. This causes another displacement

Fig. 13.

Dr. Mainka's map, showing lunar levels.

of the moon's features, the lunar centre at one time outstripping the orbital movement and at another time lagging behind. Thus we get once more, alternately to east and west, a crescent-shaped piece of the other side of the sphere, which is generally invisible.

By frequent observation, therefore, we know, not exactly half, but 0·59 of the moon's surface; the remaining 0·41 remains completely invisible. These variations have, of course, been utilised by the photographer. Professor Franz has studied and reproduced several plains in favourably situated positions, that cannot be found on the older maps. Moreover, the libration is the best means of combining pictures taken at different times in the stereoscope so as to produce an astonishing effect of plasticity.

Finally, we must mention certain standards that should be within reach of every observer and that are easily handled. These refer to the position of the terminator in the lunar parallels of longitude. The charts assign 0° to the centre, and count up to 90° each way, eastwards and westwards; they also give the reverse, as seen in the astronomical telescope. The illumination begins on the left edge of the chart and proceeds as far as the right (full moon), then goes back from left to right. The lengths from the edge (or limb) to the centre are progressively indicated by the minus sign (–), corresponding to the fall in the number of the degree; the lengths from the centre to the other limb are indicated by the plus sign (+) with progressive increase of the numeration. Thus, – 32° means 32° left of the central meridian: + 17° means 17° right of it. The latitude distances of objects from the equator are indicated, as usual, as north, (lower half of the map) and south (upper hemisphere). There are tables that give the meridian of the terminator for each day. We may give a few, with an explanation, for the use of those who are interested, as it is often necessary to know the limits of the visibility of an object. In the present case we assume the year to begin with March.

Position of the terminator each day between the years 1906 and 1941.

1906	19·5°	1918	227·5°	1930	75·4°	March 1	6·1°
1907	249·9°	1919	97·8°	1931	305·8°	April 1	23·2°
1908	108·1°	1920	316.0°	1932	164·0°	May 1	29·7°
1909	338·5°	1921	186·4°	1933	34·3°	June 1	48·3°
1910	208·8°	1922	56·8°	1934	264·7°	July 1	54·9°
1911	79·2°	1923	287·1°	1935	135·1°	August 1	73·8°
1912	297·4°	1924	145·3°	1936	353·3°	Sept. 1	92·4°
1913	167·8°	1925	15·7°	1937	223·6°	Oct. 1	98·4°
1914	38·1°	1926	246·1°	1938	94·0°	Nov. 1	116·1°
1915	268·5°	1927	116·5°	1939	324·4°	Dec. 1	121·1°
1916	126·7°	1928	334·6°	1940	182·6°	Jan. 1	138·1°
1917	357·1°	1929	205·0°	1941	53·0°	Feb. 1	155·0°

(Progress of the terminator, 12·15° per day; 0·51° per hour).

How to use it.—From the meridian for the beginning of the year (March 1st) the angle is to be deduced that holds for the date—say July 16th, 1906. For 1906 we have 19·5°; for the 1st of June 48·3°, and so for the 16th of June 15 × 12·15°, or 182·2° more, or 230·5°. The latter figure is taken from the first, 19·5°, or from the meridian lengthened by 360°. We thus get 149·0° meridian. The figures between 0° and 90° indicate *western* meridians (on the left side of the map) of the *morning* terminator; between 360° and 270° their difference from 360° indicates the *eastern* position of the *morning* terminator; between 270° and 180° the excess over 180° indicates the *western* meridian of the *evening* terminator; between 180° and 90° their difference from 180° indicates the *eastern* meridian of the *evening* terminator. The result given above, 149·0° comes into this last category. The difference from 180° is 31·0°, and so the terminator after midnight on June 16th, 1906, is at 31·0° eastern meridian in the waning moon, and can only be conveniently observed about 2—3 o'clock in the morning.

CHAPTER II

Appearance and Reality

We have already mentioned the interesting fact that even the ancients were acquainted with the ruggedness of the moon's surface, as there are features near its centre which cast long shadows, and these are revealed by the irregularity of the line of illumination, or terminator. It is clear that a mountain-chain, stretching from the south-east toward the north-west, with a steep fall on the side that faces the sun, must cast long shadows toward the east (according to the orientation of lunar maps) as the sun goes down. Its eastern spurs will stand out prominently in the illuminated field long before the deeper-lying parts are touched by the sun. Such a situation, with long and broad shadows and illuminated peaks, is actually found in the Apennine range (see illustration on page 28), and was not unknown to the older astronomers. But the conjecture can only be converted into certainty by the use of optical instruments, and we shall now see how they render us this great service.

Magnification of a thing by means of the telescope is equivalent to bringing it nearer to us. Let us fix a normal range of vision for things that we can hold in our hand—say the letterpress of this book. We may take it, for convenience, to be 10 inches. If we now use a lens with a focal distance of 10 inches, we may say that its images (received on oiled paper or a ground-glass plate) seem to be in the normal range of vision, and are not *magnified*, whether the object is a landscape or a heavenly body. It follows that a flattish lens, with focal image at 20 inches, must make the object twice the original size ; and that with a spectacle glass of 160 inches focal length the distant object will be magnified 16 times, because the proportion of 160 to 10 is 16. Thus the glasses once made, especially in Italy, with very great focal length, give of themselves, without any additional lens, a magnification of 30 or 40 or more times.

If we now use a short-focal lens, so that the image to be examined lies behind the glass, we shall find that its power of magnification is equal to the number that we get on dividing the 10 inches by the inches of its focal length. Thus if a lens has a focal length of two inches, we have a power of magnifying 5 times. Such a lens in combination with the above-mentioned spectacle-glass (magnifying 16 times) would again magnify the focal image (at a distance of 160 inches) 5 times ; so that the eye, looking through the lens, would see the distant object magnified 80 times, or brought 80 times nearer. The effect is therefore just as if we were travelling toward the distant object—toward the moon, for instance. If we take an opera-glass that magnifies 2 times, and turn it on the moon, the effect is the same as if it now came within 120,000 miles of us instead of 240,000. We may fancy that we have lessened by one half the distance between us and our satellite. A modern prismatic telescope with a power of magnifying 5 times would bring the moon within 48,000 miles ; a terrestrial telescope, magnifying 20 times, will bring it to a distance of 12,000 ; an astronomical telescope, with a power of 100, to a distance of 2,400 ; and the workers with the very large instruments can at times—this is the most, but unfortunately, not the best, that art has yet done—indulge in the luxury of a power of 4,000, and they then see the moon at an apparent distance of 60 miles.

It must be remembered that when we make these comfortable journeyings towards our distant planetary neighbour, we really penetrate very far into the mysteries of its exterior. Those who have not themselves enjoyed the experience, sometimes shake their heads incredulously, and point out that this extreme approximation is impossible, and that Snowdon, for instance, would make a very poor and hazy appearance at a distance of 60 miles. It may be urged in reply that Mont Blanc can be seen at a distance of 153 miles, and the mountains of Corsica can be seen from Monte Viso, a distance of 160 miles. Moreover, seeing things in an horizontal direction, through the thickest and least pure layers of the atmosphere, is a very different thing from seeing things at an altitude. It is true that the height of the atmosphere is considerable, but it decreases rapidly in density, and therefore increases in clearness.

We can illustrate the point with a few simple figures. We have long known that at the sea-coast there is an atmospheric pressure equal to the weight of a 30 inch column of quick-silver. We also know that we must ascend about eleven yards in order to lessen the pressure by $\frac{1}{25}$th of an inch. It follows that if the atmosphere were of equal density at all levels, like a block of glass, we should only need to ascend 8,450 yards to reach the upper limit of it. Roughly speaking, therefore, seeing things vertically through the whole thickness of the atmosphere is almost equivalent to seeing things horizontally at a distance of five miles. We can thus understand how it is that mountains at a distance of 20 or 40 miles look such a watery blue, and are mere pale shades at a distance of 150 miles. But telescopic vision has not only the advantage of showing non-terrestrial bodies with comparatively little loss of light—taking into account the purity of the upper atmosphere, as well—it is much sharper in itself, and the limitation of the field of vision, and possibly of the object, allows an extreme concentration of one's attention on a small surface, so that it can be profitably studied in its smaller features.

It is astonishing to what a depth we are thus able to explore the lunar world. We can tell approximately whether an object that has an apparent diameter of only $\frac{1}{250}$th of an inch is round or oval, and the result is very interesting. The author generally works with a power of 200, and can therefore perceive things 200 times smaller than such an object. This would be seen by the eye at a visual angle of 1½ minutes of arc; hence, when it is magnified 200 times the size need only be 0·375″ (seconds of arc) for us to have a fair idea of its shape. But on the moon, in good conditions, 0·375″ means only 644 yards. Hence, with even moderate instruments and powers, hills of 640 yards diameter can be seen on the moon!

We must remember, moreover, that the lunar mountains sometimes cast gigantic shadows. A mountain 2,200 yards high may cast a shadow 60 miles long, and a hill only 22 yards high (as high as a four-storied house) may have a shadow 1,100 yards long.

These are things, therefore, that, in favourable conditions, fall within the range of my modest observatory at Landstuhl. I will only add for the moment that a trained eye would be able to see, in the larger telescopes, lunar structures of about the size of a modern town school. In comparison with this the detail that has been explored on the nearest planet, Mars, since Schiaparelli's epochal discoveries, is very scanty, as will be seen on an examination of the map of Mars here given. The naked eye can perceive on the moon at a distance of 240,000 miles, many thousand

FIG. 14

G. V. Schiaparelli, director of the Milan Observatory.

times more than the finer details on the tiny disk of Mars, which is, at its nearest, 135 times as remote. Hence if the surface forms of a distant world seem to be described in the following pages with some facility, as if it were a trifle to span the 240,000 miles that separate it from us, the reader will now approach them with confidence. Nothing is so unsatisfactory as having to take everything on trust in unfamiliar matters ; and nothing so much enhances our pleasant interest in facts as a knowledge of the way in which they are ascertained.

In default of a direct examination of lunar scenery by the telescope we must be content with the admirable pictures which we owe to the faithful camera (compare the picture of the Apennines, page 28). The hardness of the landscape, which is due to the depth of the shadows, will seem strange to us. We are accustomed to see every stage of illumination in one and the same object, from vivid light to deep shade ; absolute black

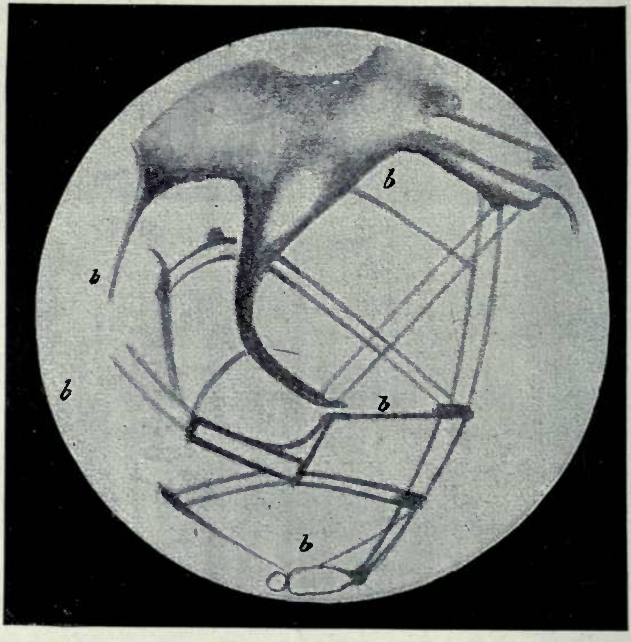

FIG. 15

Mars on June 5th, 1888 (central meridian = 300°), by Schiaparelli.

alone is wanting, because the diffused light penetrates into every corner and cleft. We speak of body-shadows, that help us to realise the contour and depressions of things, and of cast-shadows, which are more or less dark patches, of the same outline as the body itself, on the side away from the light. We do not find both these kinds of shadows in the usual form on the moon. The only shade beside the fully illuminated surface is a half-light, due to oblique illumination. All the rest is perfectly dark. There is practically no twilight. On this account pictures of the moon have a singular hardness and coldness of tone. We must further remember that the light portions of the pictures are not all as vivid, and the black not at all so intense, as the real shades on the moon. In the reality we find dazzling light and inky darkness in hard contrast.

On the other hand there is an exaggeration of the moon's plastic features. These have to be raised to such a high scale to give their real size, that we need figures and illustrations to help us to form a correct idea of the structure of the lunar mountains. The dominant forms look like the mouths of craters, or at least like deep cauldrons with very prominent walls. The first observers embodied this impression in their phrases, and so we still convey wrong ideas in the names we give these structures. The circular forms on the moon are not mouths, or cauldrons, nor even depressions of a disk-like character. When we do find considerable depressions, it is amongst the smallest structures that our pictures reproduce. Even the hollow of a flattish dessert-dish would convey an exaggerated idea of the character of the large and medium-sized circular structures on our satellite. To realise the difference between the popular notion and the real lunar landscape, we may take an instructive experiment of Nasmyth's and a few figures.

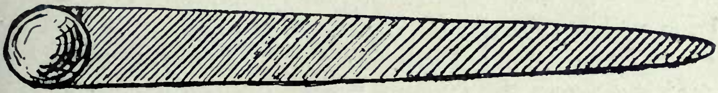

Fig. 16
The shadow of a split pea in a strong light.

Nasmyth photographed the shadow cast by a split-pea in a very strong light, and found it was six times the length of the pea's diameter. It is possible to make the shadow 20 times as long, or even more; so that we cannot take the length of a shadow as an absolute indication of the size of a body. In the same way the shadow seems only to fill the mouth of a lunar 'crater.' As a matter of fact the 'mouth' is in many cases so incredibly shallow that the eye of an observer on the crest would hardly be able to see the crest on the opposite side, because the depression is so slight that the curvature of the moon's surface covers the opposite wall. We must support this very curious fact by some figures and an illustration. One of the largest cavities (called Clavius) has a diameter of about 142 miles, while the wall has a peak (this is not the average height of the crest) to the west of a little over three miles (17,300 feet); on the east the altitude is generally greater than on the opposite side, also reaching more than three miles. Thus the proportion of height to diameter is 3 : 142, or about 2 per cent. Another so-called 'depression' (Ptolemæus) measures 115 miles, and rises to a height of 8,600 feet on the west and 4,000 feet on the east. In this case the proportion of height to diameter is 0·65 per cent. A third structure (Plato) is 62 miles in diameter, and rises to a height of 6,700 to 7,500 ft. in the peaks; its proportion is 2 per cent. A fourth (Copernicus) is 56 miles in diameter, and has peaks of 11.000 ft.: a percentage of

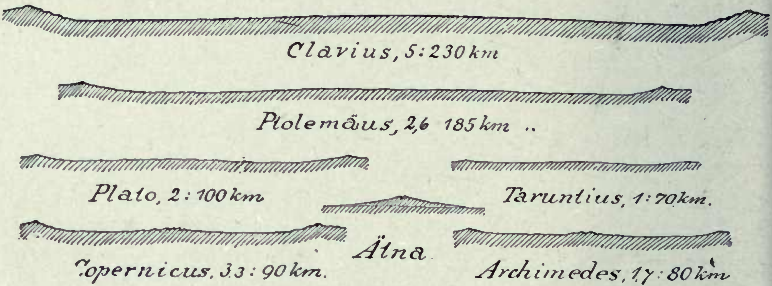

FIG. 17

Profiles of several craters in their real proportions.

3·66. Archimedes, a fifth, is 50 miles in diameter, and rises to an average height of 5,700 ft.: percentage 2·1. Finally, a sixth 'crater' (Taruntius) is 43 miles wide and has a western height of 3,300 ft.: percentage 1·4. A dessert dish five inches in diameter (without the border) and less than a quarter of an inch in depth has twice as deep a cavity, proportionately, as the deepest of these depressions.

The slopes are in proportion to this very slight absolute depth. Julius Schmidt made a study of these lunar features, and he tells us that 'there are very rarely acclivities of 60° or over; and they are in such cases confined to small stretches (that is to say, the highest crests). We find inclinations of 25° to 45° very frequently. Most of the craters have falls of 3°–8° on their outer faces, and 25°–50° internally. Isolated mountains, such as Pico and many similar ones, are about as steep as terrestrial volcanoes, but frequently enough they are less steep. There are no vertical precipices or crater-walls on the moon.'

The present writer has made a systematic investigation on this point, and has reached the following results. As Schmidt's conclusions were described by the great English selenologist in 1881 as very acceptable—he himself holding that 'an average inclination for the inner wall of 8–12° towards the foot and 15–25° near the peak seems to be the most correct expression'—the author determined to carry out some extensive observations in order to secure more reliable data*. In the course of several months 1065 measurements were made with the telescope, and when these were arranged and worked up they gave the details of 687 ring-structures. The classification of the angles of inclination discovered in the inner steeper walls of these structures gave an angle of over 17·5° in 112

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* See the author's article in the *Astronomische Nachrichten*, no. 3266.

cases, a little over 22·25° in 290 cases, just 23·5° in 256 cases, and a little less than 23·75° in 16 cases. In the rest (13 cases) the measurements were ordinary. In any case it can no longer be doubted that the average inclination of the interior walls of lunar ring-mountains—reckoned from the crest to the foot—is only 22—23°, a figure that will be found in our own terrestrial mountains. There are, of course, both on the moon and on the earth, conspicuous departures from this average, hence it was worth finding out, also, what is the proportion of the size of a ring formation to its depth, or to the steepness of its slopes. It was long known, from direct observation, that large rings have rather easy slopes, but there were no accurate figures. From the author's work, in relation to the diameter of the ring-mountains, the following results were obtained. Of the objects measured, those up to 6 miles in diameter had an inclination of 33·1°; those up to 12½ miles, an inclination of 34·2°; those up to 18 miles, an inclination of 33·8°; up to 25 miles, an inclination of 21·4°; up to 24 miles, an inclination of 15·5°; up to 60 miles, an inclination of 14·2°; and the largest (over 60 miles) an average inclination of 11·6°. The relation of the first three groups is striking and it is permissible to give ring-mountains up to 18 miles in diameter an average inclination of 33·5°. The two following groups also may be combined, and we may say that the walled rings of 18–30 miles diameter have an inner slope of 22·7°. The next two groups—diameter of 30–60 miles—have an inclination of 14·8°; and the group of the largest walled plains is distinguished for the least inclination of the inner walls, about 11·6°. We have thus not only a statistical confirmation of the appearance, but also a striking graduation in the relation of size and steepness, which should be carefully taken into account by those who would frame theories of the moon.

In connection with these investigations, a third was undertaken, with the object of distributing the lunar ring-structures according to their size. It could be seen at a glance that the largest structures were the flattest; they also seemed to have the gentlest slopes, and the above figures confirmed this; and, finally, they were the least numerous. There is an immense number of the smaller crater-forms. The question was, whether we could get statistics on this point also, showing, as in the case of inclinations, that there was a certain affinity between forms with like dimensions. The monotonous work of measuring was conducted in regard to 2,154 forms, and, after a good deal of classification, gave something like that result. From the first it was neither intended nor necessary to include the smallest rings ('craters'), which run into tens of thousands. The author set to work on those forms which measure about 3 miles across, and studied about 700 of them, as the following table shows:—

Diam.	miles 3	6	9	12½	15½	19	22
Number	700	630	268	144	75	62	45
Diam.	25	28	31	37	42½	53	62
Number	51	37	22	33	24	21	16

There are in all only 26 walled plains with a diameter of more than 62 miles. The absolute number of crater-like forms on the visible hemisphere of the moon increases very rapidly with the smallest; from 15 miles upwards the decrease in number is steady and constant. The variations in this last part of the curve are scientifically insignificant, but the transition from high figures to low ones is very significant. Something remains to be discovered here, as the matter cannot be due to chance. If meteoric impacts had been, as many suppose, the cause of the engendering of these features, there must have been falls of meteors on a colossal scale. Where are they to-day ? On the other hand, if they were due to volcanic action, this must have needed thousands of vents for the play of its forces. Thus the statistics seem to confirm the selenological theory hereafter advanced.

According to what we said previously, we should have a convenient and very instructive means of exploring the moon by reducing its distance from us by a half, a quarter, a tenth, or a hundredth, according as we use an opera-glass or a terrestrial or astronomical telescope. We must leave this enjoyable pursuit to those who possess the instruments, and turn to our pictures and maps, and examine the results of a hundred years' industrious observation of our satellite. The reader who wishes to learn the smaller features of its topography from maps and manuals, as we do in terrestrial geography, will find in Neison's work plenty of description and illustrations*. But for our present purpose we shall in our inquiries into the nature of the moon, and the peculiarities of its surface, prefer dry statistics to the examination of pictures and speculation on features that differ so widely from those of our earth.

At our first sight of the moon the eye sweeps over its surface and gets a general view of numbers of similar structures. We involuntarily select a few of these, so that the eye may fix its gaze and examine them more closely ; for the warty face of the moon seems to be sown with large and small rings. They seem to be circular in and about the centre of the disk,

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* 'The Moon, and the condition and configuration of its surface,' with an atlas of 726 maps, and 5 coloured plates, 1876.

but elliptical toward the limb, and their axis becomes shorter as they approach the edge of the disk. Compared with this ubiquity of the ring-forms, the elevated structures that we call mountains, on the analogy of terrestrial objects, are small in number, though of considerable height. The number of the round structures gives the unaccustomed eye of the layman the impression of an almost inextricable confusion of forms, so crowded together that they have to encroach on each other's space. There are a good many of these clusters and chains; and when the eye is a little accustomed to the sight, new and smaller craters come into the field of vision, so that in some places the floor of the moon seems to be perforated like a sieve. If there were not extensive and well-defined plains, and if the shoals of smaller rings did not cling like parasites to larger objects, so that we can eventually group our impressions, in spite of the confusing number and irregularity, we should doubt whether we could succeed in drawing up a good map of the innumerable wrinkles, holes, veins, and mountains. Our illustrations give only a feeble impression of the real aspect of the moon, because the much-reduced reproductions of photographs only include 'craters' of at least nine miles in diameter. And we need only glance at these pictures to realise that we have nothing on our earth to compare with such structures. In the true sense of the word, the moon is a foreign world.

The mountain-forming forces that created our own heights and crumpled the earth's external crust are not revealed in the corresponding mountains of the moon, quite apart from the rings. There is practically nothing analogous to them in our planet, especially if we consider their structure and their finer features; there is nothing like these on the earth. The first impression is very deceptive, and it is quite natural to take the name 'crater' in the terrestrial sense, as the mouth of a volcano ; particularly as in many cases there is a central elevation within the surrounding walls, and this is a common feature of terrestrial craters. As long as people had only vague ideas of the real extent and the plastic features of these ring-elevations the name of ‘crater’ could very well be retained. To-day, it ought to be at least used with reserve as a mere expression of general form, because on closer investigation there is as much difference as possible between terrestrial and lunar craters. (Compare the profiles of the two).

In order to identify one's position in repeated observation of the chaos of lunar details, and to explain one's discoveries to other observers, the practice came in with the invention of the telescope, of giving names to the chief structures. Between 1620 and 1640 Langrenus introduced the names of famous men into his map. But as his work was forgotten, Hevel of Danzig invented new names, taking a certain resemblance between the mountains of the earth and those of the moon as his base, and transferring our geographical terms to our satellite. Hardly four years had elapsed since the publication of his work (1651) when Riccioli of Bologna published a map. He returned to the plan of Langrenus, and again gave the names of distinguished astronomers and mathematicians to the spots on the moon. He left Hevel's title of ‘seas’ however, to the lunar plains, though he gave them names to indicate the various astrological influences that were supposed to emanate from the moon. But his substitution of ‘terrae’ for the names of the mountains was not maintained, and Hevel's geographical names (Alps, Apennines, etc.), have survived. It is clear that the early selenographers, with their imperfect instruments, did not penetrate very deeply into the mysteries of the outer crust of our satellite, and the names they gave were satisfactory in the then state of knowledge.

With the improvement of the telescope and the enlargement of our knowledge of details, it became necessary to form a new nomenclature. Schroeter had to extend the list, and Beer and Mädler introduced 150 new names—names of scientists for the ring-structures, and of terrestrial mountains for the new ones on the moon. They had also to develop Schroeter's other innovation, which consisted in giving the name of a large structure, together with a distinctive letter, to smaller forms in its vicinity. In this way a very extensive orientation became possible; simple elevations were indicated by Greek letters, depressions and craters by Latin ones. Capital letters notify that the object so named is a point of measurement. Later on a committee of the British Association, which dissolved after a brief activity, thirty years ago, contemplated the introduction of a new system, which was impracticable, but certainly would have allowed the classification of an immense amount of detail. The moon was to be divided into four quadrants, each quadrant into 16 sections, and each section into 25 special surfaces. The sections would have Latin, the surfaces Greek letters; and each object in the latter would be designated by a number. Thus, when a small crater was called I A o 16, it would mean object 16 in surface o (omicron) of section A in the first quadrant. It was intended to have a map of the moon 100 inches in diameter, on which the surfaces would be squares 2 inches in length. A similar plan of dividing the map of the moon has been mooted lately. However, English and other observers have continued to introduce new names on the old system, whenever it was necessary, and it is retained in Schmidt's large map.

It was necessary to have some unity in nomenclature, but it is certainly not necessary to have a rigid classification. We have already pointed out that the names that were given to the large and small ring-structures were mere descriptions of their form, and conveyed no idea of their real nature. When we hear a terrestrial structure called a ‘mountain-cone’ we have some idea of its shape. If it is called a ‘volcano,’ we do not of course associate it with a cone-shape, but we chiefly think of it as a special geological form of mountain, with a very distinctive origin and development. It is quite otherwise on the moon. In its case, seeing that we look at everything from a respectable distance, we cannot at once pronounce on the nature of things, but can merely say what they look like in a general way. Any layman who is able to appreciate size from the distribution of light and shade will at once describe a number of lunar forms as holes, mouths, peaks, etc. If in addition to his knowledge of them as depressions lying between some sort of walls, he is also aware that they are extraordinarily flat, he will not only describe them as depressions, cavities, dishes, flat dishes, and so on, but will seem to have a right to attribute definite characters to them. As we have mentioned several times that the word ‘crater’ very early came into use in selenography, and is still retained in it, we must now see how far the name is justified. We know from what we have already seen that it is, unfortunately, not an appropriate description of the lunar mountains. It was a hasty designation of them on the ground of their purely superficial features, and those who bestowed it were not sufficiently on their guard against deceptive appearances. Those who use the word ‘crater’ to-day must remember that it is merely a superficial description of an external form.

Following Neison’s classification,* we will now distinguish between a number of lunar structures that

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* ‘The Moon,’ ch. III.

have a certain resemblance. The entire visible surface of the moon may be distributed into three great classes, plains, craters, and mountains ; the term craters being used only in its usual conventional sense. The first class, which occupies more than half of the entire lunar surface, is divisible into the two great sub-classes of dark and light plains. The first includes the lunar Maria with the smaller formations to which the terms Palus, Lacus, and Sinus have been applied ; whilst the formations comprised in the latter class have received no distinct name, and seldom possess as definite borders as the former. Under the single term craters, in compliance with the conventional usage of the name, have been grouped the whole mass of the formations of the moon, which, when perceived with a low power and a small aperture, are supposed to bear some resemblance in appearance to the volcanic craters, though they are of the most diverse nature, and mostly without the slightest claim to be regarded as such. These formations will be divided into nine classes, namely, walled-plains, mountain-rings, ring-plains, crater-plains, craters, craterlets, crater-pits, crater-cones, and depressions; each of which possess distinctive features, though the lines of demarcation are of necessity somewhat arbitrary. Finally, the mountain-formations may also conveniently be separated into twelve classes, namely, the great ranges, highlands, mountains, and peaks, constituting the greater elevations ; and hill lands, plateaus, hills, and mountain ridges, forming the lesser elevations, whilst the numerous small irregularities of the surface are comprised in the four divisions of hillocks, mounds, ridges, and land-swells.

Neison's scale of names, taken together with the remark about ‘ craters,’ almost agrees with the principle of Dugald Stewart : ‘ Phenomena should always be described by names that involve no theory as to their causes. These are the subject of separate investigation and are best understood when the facts are considered impartially and independently of anything that must be regarded as unknown. This rule is particularly important when the facts are complicated to some extent.' This maxim (which Mädler took as his motto at the beginning of his chapter on 'Topography,' etc.) has not always been borne in mind; especially in regard to the 'lunar craters,' which were already considered to be volcanoes when people knew hardly anything about them except their roundness, and in regard to the 'canals on Mars.' It is true that there are certain slender lines and streaks of shade on Mars that give rise to the latter designation, but they can

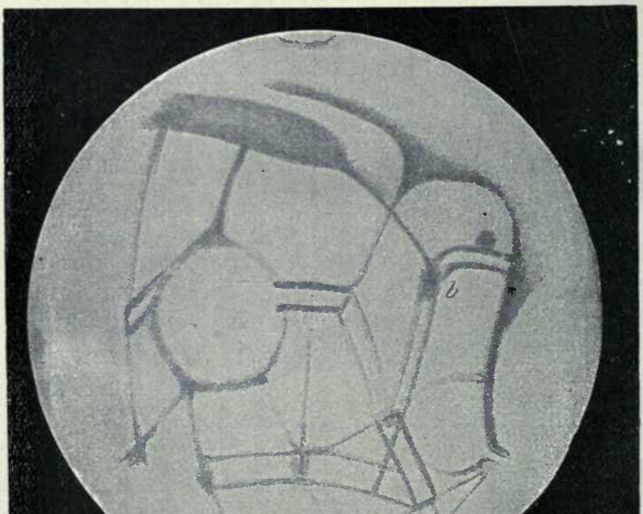

Fig. 18

Mars on June 12, 1888 (central meridian = 240°) by Schiaparelli.

only be regarded as ‘ canals ’ in our sense of the word by assuming a great many other conditions. Even Neison himself fell into a certain play with words, as we see in the expressions ‘ crater,’ ‘ crater-elevation,’ ‘ crater-pit,’ ‘ small hill,’ ‘ ridge,’ and ‘ hillock.’ If we avoid dogmatic ideas of real selenological value until we are in a position to give a proper explanation of *all* lunar forms, we may, with some convenience, apply phrases taken from terrestrial geography to our satellite.

CHAPTER III

Light and Colour

One can see at a glance in pictures of the moon the apparent extent of the 'plains' on this side of its surface. They are distinguished by their darker tone and less variety of form, though this is compensated by the considerable graduation of light and colour on their surfaces. Neison's observation, that they comprise more than half of this hemisphere of the moon, must not be misunderstood. We see the parts of the moon that lie towards its limb very much fore-shortened, because they are on a round surface. It is at all events true that the area of the gray plains, as measured on a map or photograph, covers 0·4 of the disk, but rather less than this in reality for the whole lunar globe. In this point, therefore, there is again no analogy between the earth and the moon, as the terrestrial oceans make up about 0·7 of the entire surface. Further, the oceans form the far greater part of our southern hemisphere, whereas the relation of depressions to elevations in the moon is quite different, the plains lying more northward and near to the equator. And, as regards the total proportion of lunar plains to the higher land, we must remember that we know nothing about the distribution of mountain and level plains on the other side of the moon.

These level plains, as yet little explored and very poor in detail, have been called 'seas,' though there is no ground for the name. It has stuck to them, however, as the map of the earth afforded a very deceptive analogy, and especially as the state of things seen on the moon in astronomical telescopes was supposed to show a similar distribution of heights and depths. But even our best optical appliances can discover no trace whatever of water, or the action of water. It is true that Chacornac (quoted in Neison) believed his powerful instrument revealed, on a close investigation of the moon's structure, much greater analogies with the earth than were generally admitted. Sir J. Herschel thought he discovered many traces of the former presence of water, such as the formation of diluvial deposits; and Professor Phillips* indicated several analogies between volcanic structures on the earth and on the moon and found many proofs of the action of a destructive atmosphere. We will only observe that these three astronomers cannot be regarded as authorities on the moon, because there are no results of any importance whatever in the science that we owe to them; in their case the wish seems to have been father to the discovery. If anywhere, the moon is the place for a man to discover whatever he wishes; and we must remember that in their time it was very little known.

The plains are characterised by all the *geographical* features that distinguish large terrestrial depressions, but they have not the same *geological* features. On our earth the water and atmosphere have mechanically and chemically softened the hard features of its earlier physiognomy and helped to level it. Generally speaking, the lunar plains, with their variations of colour and their bands of light, are seen under good

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* 'Notices of some parts of the surface of the moon,' 1868, with five illustrations.

illumination to be very much dinted, veined, granulated, and even torn. In many places isolated peaks and hills rise abruptly from the surface, without any gentle slopes at the foot; there are even small plateaux rising from the flat ground, and an incalculable number of large and small ring-structures are scattered over it. Taking them as a whole, these level plains follow the curvature of the moon, but there seem to be round protuberances of almost imperceptible slope and base-line, and flat depressions with indefinable 'shores,' that can only be perceived when the sun passes directly over them. These marks of slight inequality should be carefully explored, and can only be studied by one who is practised in lunar observation, because they do not cast shadows. The author is acquainted with some cases where flattish eminences lie much like thin disks on the floor of the moon. They generally have a little 'crater' inside them.

It is extremely interesting to study the borders of the large 'seas.' Especially round the *Mare serenitatis**, very clearly on the coast of the *Mare nectaris*, and to the experienced eye just as clearly on the south-west and west borders of the great *Mare imbrium*—we have already seen the meaning of these curious names—we can perceive lines of cleavage in the plains running parallel to the coasts in wide circles. This points to a repeated sinking inwards, with a secondary action toward the chief coast. The same traces will be found by those who can read lunar photographs in the isolated depressions of the *Mare crisium* and the *Mare humorum*. They are not, however, a peculiarity of the plains; there is quite a number of large ring-mountains or crater-plains with the same characteristics in their much smaller interior.

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*If the reader has not a special map he should consult the map in one of the large atlases or in an encyclopædia. For about six shillings one can get a very full general map by Flammarion-Gaudibert, with 509 names.

FIG. 19

The ring-plain Gassendi and *Mare humorum* with concentric rills and mountainous veins (1 mm. = 3700 m.)

F

In order to show the affinity there may be between the largest and smallest of isolated circular depressions on the moon, we will give a few names with the respective diameters: Mare imbrium, 750 miles; Mare serenitatis, 437; Mare crisium, 312; Mare humorum, 270; Mare nectaris, 187; ring-plain Petavius, 90; Posidonius, 69; Cyrillus, 56; Gassendi, 55; ring-mountain Taruntius, 43; Doppelmayer, 42; crater Lambert, 17; small parasitic crater Hesiodus, A 10; small crater Ramsden, 4 miles. All fourteen have the same features and lines of cleavage on the inner edge of their cavities, though these secondary phenomena, the outcome of a process that no expert has yet explained, have assumed the shape of concentric inner craters in the three smallest structures. Finally, it is only one step from these objects to the ring-plains and ring-mountains with finely formed terraces on the interior walls. We could again quote specimens of this type amongst objects of very different size—a further indication that selenology will have to include all the ring-formations, even the largest, in one general explanation.

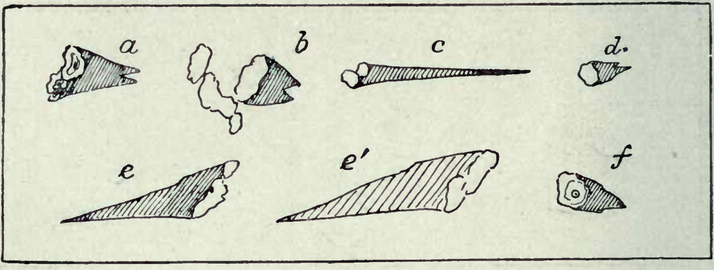

Fig. 20-26

Shadows cast by peaks; *a.* Archimedes, north: *b.* Archimedes, south: *c.* Pytheas, east: *d.* mountain on the rill of Hyginus: *e.* é Pico B: *f.* Cauchy, east.

Whenever we find a mountain rising abruptly from the level on our earth, it either is or once was a volcano. Take, for example, Vesuvius, or Kilima

Ndscharo, or Ararat. At the same time it always has some foreground with a gentle slope. It is only in a situation like that of Stromboli, which has its base at a great depth of the sea, or of the eruptive cone in the crater of the isle of Santorin, that we find a well-marked obtuse angle between the surface of the sea and the sides, or, in other words, a hard contour in section. There are plenty of these abrupt cones and hills on the plains of the lunar 'seas,' and they are just as devoid of 'foot' as Stromboli. This is not merely one species of structure there, but the *general rule ;* to such an extent that it is quite exceptional to find a hill of a different character. This is very striking and remarkable, and it is quite clear that the forces that have been at work on earth levelling the heights and curving the slopes have not acted in the moon. These agencies are water and the atmosphere, denudation and weathering. We cannot, therefore, assume when we see mountains 'sunk' in the plain, so to say, as well as ring-walls and 'craters,' that their feet are buried in diluvial deposits, because it would be a serious question where the material of the deposit came from. For this divergence between terrestrial and lunar phenomena there seems to be only one explanation, and we shall indicate this at a later stage.

The close relationship of the plains and the ring-formations is seen in their circular borders, their comparative or complete isolation, and the characteristic parallel lines near their edges. We might almost put it that the constructive agencies produced large, medium-sized, small, or very small circular forms, according to the intensity and duration of their action ; taking into account, of course, the quality of different parts of the lunar crust in advancing or retarding the work. In this respect we may very well introduce the meteoric influences suggested by W. and

A. Thiersch, at least in the sense that meteors may here and there have *initiated* the formation by their impact and, possibly, perforation of the crust; just as the flow of resin is started by boring a hole in the tree. In the same way the strain of the pressure on some material underneath the crust may cause it to work out, and this may depend on lunar conditions that have nothing further in common with volcanoes than the fact that it is an eruption from within—probably the only direction in which lunar forces can expend themselves.

However, that may be, there is certainly an affinity between plains and 'craters'; though the former are large enough to comprise in their area all the other peculiarities of the moon's surface. We find perfectly formed and rudimentary craters of all sizes, the purest specimens of the species being alongside ruins, plateaux, irregular masses of hill, precipices, wart-like or boil-like growths, long veins with a flat profile, and cracks. When the sun rises or sets over some parts of the 'plain,' it often looks as if the floor of the sea had a granular roughness, and this, in consequence of the innumerable minute shadows, gives it a dark appearance. In other places the smooth floor can be so clearly seen in a strong light that it is possible to pick out its finest features and distinguish the smallest elevations. In these cases it is especially advantageous if the ground is of a light colour in itself.

The mention of colour brings us to a fresh feature of the sunlit face of the moon. It is, of course, difficult to distinguish colour clearly in a field where one shade of light blends with another so closely, and it will generally be missed by an eye of little experience, on account of the flood of light that enters the pupil from a large telescope. Beyond an impression of yellow, white, and gray, shading into black, inexperienced observers can see no colour at all. But when one has learned,

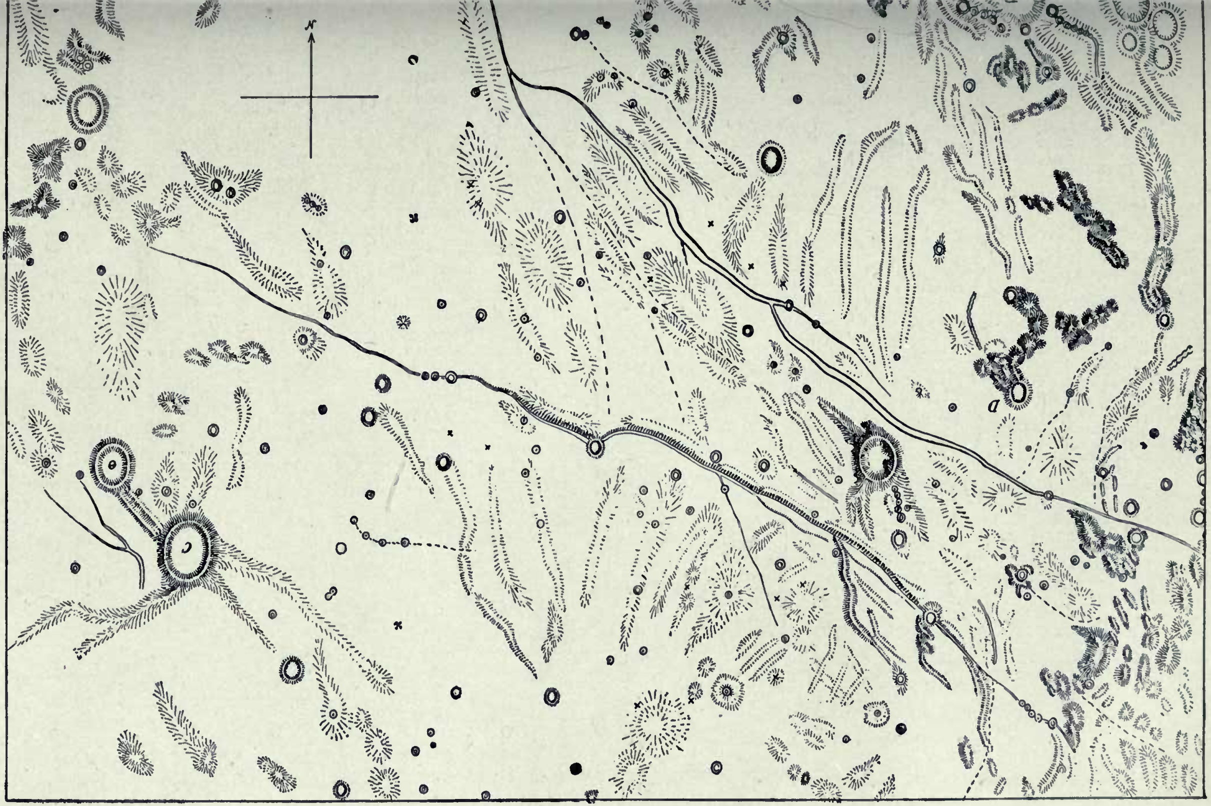

FIG. 27
Lunar landscape Cauchy in the Mare tranquillitatis, by Ph. Fauth (1 mm. = 2000 m.)

for instance, to compare certain localities of a bluish-green or yellowish-green with others, it is possible to recognise delicate shades even in a strong light. The naked eye can hardly see any difference in the intensity of the light on the illumined surface at the first quarter, full moon and last quarter, but we can see it in the telescope. The brilliancy increases and decreases almost with the progress of the phases of the moon.

At first one is inclined to ascribe the greatest brilliancy to the full moon, and to regard it as equal in the two quarters—apart from an inequality between the brighter mountains and the gray plains, which is included in the calculation. In reality it is somewhat different. The material composing the external shell of the moon has a peculiar property, that may be briefly defined as a bleaching under the rays of the sun. The elevated masses emerge almost gray and dull out of the 14 days long night into a day of equal length, and their creamy yellow changes into an almost pure white—at certain spots, at all events—and then loses its tone again as the sun passes away. The influence of the direct rays requires some time to produce the brightest tone, —and so it happens that the bleaching process does not reach its height at the beginning of full moon, but one or two days later. Then there is a very remarkable colouring of the disk towards the west, but the brighter rest of the moon only gradually loses its brilliancy. The lingering of the strong light thus causes the last quarter to be brighter than the first, in which the bleaching is only beginning. It takes some time for the bleached parts to lose all their light again, as we see in the maintenance of the brilliancy of crater-edges. If other round cosmic bodies consist of the same or similar material at their surfaces, and so exhibit similar retardations in the process of illumination, it will be impossible to determine their illumination by a simple formula for each phase; there will always be a difference that the formula does not cover. Astronomers have experienced this in the case of many bodies, and so each law has come to have its ‘anomalies.’ Nature does not proceed according to pure formulae.

We have already pointed out that all the colours do not attain equal brilliancy, hence it is that we see a ‘man,’ a ‘face,’ or a ‘kiss,’ in the full moon. We might say that the disposition to bleaching is fairly even among the different tones in the moon’s surface, with the exception of certain blackish and whitish parts, which do not become very bright on the one hand, or increase in brilliancy almost to a pure white on the other, and would give us very much more contrast in the full moon if the deep shadows had not disappeared. The meaning of the full moon is that we are looking at our satellite almost parallel with the sun’s rays, so that it is impossible for it to cast any shadows; we see it under a vertical sun. All that formerly looked warty and rough is now smooth and without relief. If it were not for the half-tones and brilliant points and mountain-ridges that remain, it would be impossible even for the expert to identify regions in the full moon; and the difficulty is still further increased by the appearance of bright bands and spots of light that have, as a rule, nothing to do with the moon’s relief. To look for the map-details on the full moon is like looking for a needle in a load of hay. We find the same confusion of light lines and thousands of spots on the new moon, that is to say, at the phase in which the moon is invisible except for a few seconds during a total eclipse of the sun. But although the new moon phase is almost useless for telescopic investigation, the small crescents just before and after new moon afford an interesting glimpse of the condition of the ‘dark’ part. If we examine it with a low power on these occasions we find that the night-side of the moon has, generally speaking, the same features as the full phase. By choosing favourable periods—for instance, the spring for the waxing, and the autumn for the waning moon—periods when the narrow crescent is best placed as regards twilight and the vapour line of the atmosphere very minute features can be observed on it. The light is, however, exceedingly delicate, as it is merely the light reflected on the moon from the earth, bringing the night-side within the range of visibility for the naked eye. Many a reader will have seen the 'new moon in the old moon's arms,' as popular phraseology puts it. It may be noticed that the waxing moon is a little less bright than the waning crescent. The reason of this is that in the one case it is the western hemisphere, with America and a great expanse of ocean, in the latter the eastern hemisphere, with Asia and Africa and less ocean, that reflects the sunlight on to the moon. Our satellite therefore has its earth-shine just as we get moonshine.

Chief amongst the features that strike the observer of the full moon are the rays of light. Here selenology has still a problem to face, and all its finest combinations have broken down before the phenomenon of the bundles of rays or lines that stream out from certain very brilliant ring-mountains. It is a pity that the observers who believe they have made themselves acquainted with these enigmatic systems of rays have allowed themselves to be hypnotised by the purely external feature of the radial position of the lines, just as they stopped at the circular form of most of the elevations and at once pronounced them 'craters.' What is called a ray or streak of light is not one continuous object when seen in the telescope, but the effect of an accumulation of spots and lines—dots and dashes—of light. It is the arrangement of these in a longitudinal direction and their concentration on the region of a ring-mountain that gives rise to the appearance of a 'system of rays.' Refraining from any speculation as to how these pencil marks may have arisen on the rough surface of the moon, our first task will be to determine the nature, connection, and extent of the various constituents of the radiating crown. It is possible that here again a mass of detail will give a clearer idea than the broad impression made by an entire system.

From pictures of the moon at advanced phases and from observation we know that the rays have a certain breadth and extend over enormous regions. Hardly has the sun passed over these particular districts than the first trace of the brighter streaks appears on the illuminated surface. The structure, therefore, is already there, and is generally clearly recognisable in the earthshine of the new moon at the times we have stated. As the sun advances, or as the radiation of the sun increases, a streak of light is defined more and more against the different tones of the lunar floor, and finally shines almost a pure white, remaining visible, and paling but little, until it sinks into the lunar night. Even at the very terminator, where the flattest hillock, with no measureable slope, is at least indicated by half-tones, the floor of the moon that bears these rays does not show any elevation. This does not mean, of course, that the heights may not in places be as bright as the rays; but the material of these streaks passes over all sorts of country, hill, valley, and plain, and without any deviation, and clearly does not of itself imply any elevation of the ground. It is just as if one made pencil marks on a pale-cream globe with features in relief, leaving the marks of the pencil against the white ground over all the ridges and those parts of the plains between them that are lightly touched by the pencil. Hence the lines are series of shapeless spots and groups of spots; there is not a continuous pencil mark. This is the real structure of the streaks. They do not exactly 'radiate' from one point, even where they are found in their most perfect form; and they may be most irregularly crossed, bent, serpentine, interrupted, or varying in width.

Let us take two striking specimens of the different species of rays. One of these lies about Tycho, near the southern border of the moon; the other about Copernicus, in the north-eastern quadrant. Their rays are as different as possible in structure, detail, and extent. Tycho throws out its rays all round like the centre of an explosion, so to speak. Copernicus is surrounded by a veritable network of lines—straight, curved, and serpentine. In each case the point of unity, as it were, lies in the common centre.

As regards the Tycho type of rays, which we find in just the same form about the small-ring mountain Kepler, one of its most distinctive features is that the separate rays reach out far from the centre, and, quite differently from our experience of the explosive scattering of matter, run to fine points at the end. Others have the lines of the same width throughout. Their contact at the point of departure, the base of the streaks, must not be understood in the sense that the geometrical centre of the ring-mountain in question (Tycho, Kepler, Aristarchus, Proclus, Anaxagoras, the small crater A to the north-east of Furnerius, the still smaller one to the east of Stevinus, a crater to the east of Cavalerius at the extreme eastern limb of the moon, etc.) is the exact starting-point of all the rays. In the case of Tycho itself, the largest and most extensive centre of rays, the three finest lines (to the north-east, south, and south-east) run rather at a tangent to its eastern and south-eastern walls, and many sheafs of rays that run toward the west take their rise in the direction of the southern wall. In number there must be about fifty lines, without counting fine

FIG. 28

Systems of rays and streaks round Tycho and Copernicus. (Tycho is at the top of the illustration, Copernicus a little below the middle to the right ; the dark 'eye' some distance below it is Plato).

brush-like ramifications which even the practised eye would find it no easy task to separate in the strong light of the moon. In the Copernicus type also some of the lines start from inside the ring-mountain, and some from its encircling wall. As to the length of the Tycho rays, for instance, which determines the area of the system over which Tycho dominates, in a sense, we may say that an error in calculation has led to an enormous exaggeration in this respect. Until a very recent date the streaks that belong to the crater Bessel in the Mare serenitatis have been put to the account of Tycho. In this way the longer streaks were made to cover fully half the face of the moon, if not more. It is impossible to assign a limit to them, as they have a considerable strength at the very edge of the disk, and cannot be traced beyond. This part of the corona, therefore, with its 3,000 miles long rays, would reach twice as far as the longest of the other streaks, which is difficult to conceive. In fact, the Bessel-streak forms a distinct angle with the radiants from Tycho, and, if it has any connection at all with other rays, points rather to the north, where it is met by one from the other side.

There are many conjectures as to the nature of these mysterious appendages of the ring-mountains (and many others). They remain one of the greatest riddles of the moon ; and this is largely owing to the reason we stated previously—the obstinate retention of the Laplacean theory of the formation of the heavenly bodies and the volcanic theory. Mädler paid little attention to the opinion of Herschel and others that the streaks may possibly be streams of lava ; and he dismissed the theory of a real and literal radiation with the brief remark that the rays are clearly seen while the centre of the supposed radiation still lies far within the unillumined part of the moon. 'It only remains,' he said, 'to suppose that, through some natural process or other, the *internal structure* of the floor of the moon at the points where these lines are seen has experienced some change that has greatly enhanced its power of reflecting light. What kind of a process this was is at the most a matter of conjecture, but there can be no doubt that it was most closely connected with the formation of the ring-mountains, which are clearly the central point of these streaks, especially as these ring-mountains are the only conspicuous objects in their regions on the full moon.' With all respect for the authority of the great master of selenography, his successors have pointed out the untenability of the view that glowing gases issuing from beneath the lunar floor may have brought about a partial glazing of the strata. Why did not the gases escape from the numerous vents that already existed ? What made those vents, if gases with an obvious explosive character could not do so ? And why was the matter only melted in patches (especially on the elevated parts) and not along the whole length ?

If we turn to the meteoric hypothesis, which would explain the colour and length as a sort of splash of the matter of the falling body, which has been resolved into its elements and spurts outwards with explosive speed, we have a serious difficulty in the length of the rays. Experts speak of rays 3,000 miles long. There is also a difficulty in the form, as the rays are not of an indefinite breadth, but run out to a fine point, giving the impression of a force that gradually spends itself. Hence Nasmyth's attempt to illustrate the form, at least, of Tycho's rays from the analogy of a glass globe full of liquid that bursts with radial cracks when it is heated is so striking that we find his illustrations still often reproduced in popular works. But what a brittleness and cohesion the idea postulates in the comparatively thick shell of the moon ! And why should the seams be interrupted so often and make their appearance further on? The heights usually show traces of these light lines, and so the 'seams' must have overcome some great obstacles, and yet they are often not to be found just where we should expect them more easily. Finally, even if a meteor was capable of throwing up a ringed wall of the size of Tycho, it would never have had the force to break in so large a part of the shell of our satellite, and Tycho is less in size and mass than a good many other ring-mountains. Moreover, Tycho lies on the surface, and must, as the surviving rays indicate, represent a relatively recent form of lunar activity. If 'the thick encrusted moon' had received the impact of a projectile at this time it would hardly be likely to be broken.

Thus the failures of selenologists teach us that it is impossible to read the hieroglyphics of the moon with any of the hypotheses as yet offered to us. The crowns of rays spread out over the face of the full moon, and seem to mock at all explanation. Possibly we have only to abandon the earlier ground and the current theory of the formation of the heavenly bodies, and substitute for their acute forces and processes such as will allow more time for the moulding of the moon's features; to regard as the outcome of a steady activity what we cannot explain by explosions and collisions. Such explanations are quite feasible, but it is not our place here to enter upon a study of these possibilities. As every theory of the formation of cosmic bodies must be tested on the moon, the future will decide which of them affords the simplest explanation.

Before we go on to describe the mountain-formations in detail, we must say a word about the general outlines of the moon. Within the disk the elevations offer us very much the spectacle that meets the eye of an aeronaut when he looks down on a hilly country from a great height in the morning or evening. He looks down on top of the hills, but the oblique illumination of the scene by a sun that is low on the horizon brings out the various inequalities of it. It is otherwise at noon, when all shadows and profile disappear. It is much the same in observing the moon; though the mountains, either peaks or ridges, that lie very near the limb, can be seen at any time in their true shape, height, and slope, as we are in the position of an aeronaut passing over them when we examine them in the telescope. At certain parts of the disk, which vary slightly in virtue of the process of 'libration' that we have already described, we perceive the very marked profile of mountains, and this gives a lumpy appearance to our satellite. This unevenness of the limb unfortunately interferes with our measurement of the moon's diameter. It must differ in extent according as there are mountains or plains at the limb at the moment of measuring. Strictly speaking, therefore, all measurements of the moon must vary within certain limits. The average diameter is something between 2172 and 2150 miles. There are, it is true, other causes of variation. There is, for instance, a fairly wide region about the equator where the moon is strikingly flattened, on account of the presence there of what Professor Franz has called 'Mare Smythii' (237 miles broad). There is also a 'Mare marginis' (Professor Franz) within the selenographic range of the Mare crisium near the limb, of only slightly smaller dimensions, so that the scanty upland between the edges of the two stands out at an obtuse angle. These divergences from the globular form often cause mistakes in a certain class of lunar measurements and eclipse-observations, and these must be corrected by paying attention to the libration at the time, and its influence on the curvature of the moon's surface. Of recent recent years Hayn has determined and published the corrections for the departure of the limb from the standard.

Near the moon's limb we see the profiles of the mountains at a glance. Towards the middle of the disk we can at most only find them when the summits are illumined by the rising sun, and then the slopes slowly emerge out of the night; or when, on the other hand, the successive parts disappear at the setting of the sun. We often see whole chains of peaks, the outlying points of an irregular ring-wall, flash out on the torn terminator like so many pearls, gradually growing more and more numerous, until the loose string gets thicker and thicker, and reveals itself at last in the form of a solid ring. The magnificent spectacle of the lunar sunset in the ring-mountains is further enhanced by the sharp contrast between the deeper parts still lying in the black night and the brilliant row of the pearl-like peaks. With mysterious and measured pace the illumination passes down the slopes, and embraces gradually the seemingly unfathomable mouth, black as a pit. Suddenly a point in the centre creeps into the light. The phenomenon began with a soft light as of the dawn; the eye can follow its increase step by step; and in a few minutes the rays proclaim that the sun has reached the central peak. It grows clearer and clearer, and rises with ever-broadening base from the encircling night, like an island emerging from the sea at the ebb of the tide. A few hours later the light penetrates into the seemingly fathomless depths, and then the ring is revealed in all its glory to the gaze of the observer, who can follow the structure of the curious lunar mountain with perfect ease. The ridges that were first lit by the sun bleach slowly in the light, the later illumined parts follow with a yellowish tone, and with them is mingled the deep black of the shadows. As the hours go on the shadows become smaller, and what they had revealed in sharp angular outline, as if a practised hand delineated them in thick strokes, grows softer in the lingering half-tones, as in a crayon drawing. The relief is so far lost in the waxing sunlight that we can at length only trace a faint plan of it in white lines.

For a few days we have this vague harmony instead of the initial contrast of height and depth. Then the play of light begins afresh in the reverse order. Within the lengthening shadows, stage after stage of the hill sinks into the darkness. The last peaks disappear, and the fourteen-day night sets in, relieved only by the earth-shine which our 'full earth' now casts on the new moon, just as the gentle brilliance of the full moon illumines the earth at night. But the earth is much larger; it has a diameter 3½ times the size of the moon's. Hence it stands out in the nocturnal sky of the moon like a great disk thirteen times as large as the moon seems to us. It illumines the moon almost in the same greater proportion to the moonshine reflected on earth, and so allows terrestrial telescopes to recognise even small features in the earth light, and teach us for certain that the distribution of bright and dull spots on the moon is essentially the same during the long lunar night as in the lunar day. Yet the belief that there is a slight alteration of tones is not wholly groundless. It will be one of the pleasant tasks of the future to study the phenomena of the 'ashy-gray light,' at least three or four days before and after new moon, and this will be done best in southern climates.

CHAPTER IV

THE RING-MOUNTAINS

At a time when it was impossible to calculate exactly the size and steepness of the round lunar structures, they were all, from the largest to the smallest—and the very small ones were not known then—comprised under the general heading of 'craters.' The name has now become a merely formal expression, but we must show on what ground it came into use at all, so that it may be properly understood. Their appearance, as will be seen even on small pictures of the moon, shows how the name would be quite satisfactory for naive observers, and its convenience as an expression of at least one aspect of the objects justifies the continued use of it. But it is more interesting to study the radical differences in structure between terrestrial and lunar 'craters,' quite apart from the enormous size of the latter.

A mountain that has been formed from the plutonic matter of the lower levels of the earth, under volcanic conditions, will have the distinct form of a cone, because its mass, which is generally very considerable, has been gradually ejected, during long spaces of time through a comparatively small opening in the earth's crust. The dome-shaped curve of a mole-heap is hardly ever seen on the moon; though there are objects something similar to them, which we have already called small bosses ('boils') with craters on them. There is a number of them on our map of the Cauchy region. The typical form of the objects that the geologist calls an elevated or eruptive crater is a cone. At its summit we find a trace of the opening from below, though this is sometimes partly closed, sometimes pierced by another crater of smaller dimensions, which still preserves its opening, and in active volcanoes ejects sulphurous gases and ashes. Lava-streams usually break through the side of a volcano.

An eruptive cone of this type would hardly be visible in the largest telescopes, if it were transferred to the moon. A lunar crater is a fundamentally different type of structure. In the first place the plan of its construction is quite the reverse to that of a volcano. Its 'crater' does not lie on the summit of a cone (see the profile map); it is merely a wall, generally composed of a ring of elevations, within which there is a more or less level surface, often strewn with mountains, hills, bosses, cavities, small craters, ridges, and bridges, and so *deeply excavated* that it lies far below the general level of the moon. Lunar craters, therefore, are cavities or depressions, not elevations. In order to reach a terrestrial crater one has to ascend mountains thousands of yards high, and then to descend only a moderate depth; to get into the depths of a lunar crater one would have first to ascend a broad upland of moderate height (the wall), and one would then look down from a ridge on a succession of terraces, leading down with fair steepness, steeper as a rule than the descent from the higher plains of Mexico to the coast. To form a just idea of it we may picture the scene in this way. Put a flat dish floating in water. The water will represent the general level of the plain without; the deeper interior of the dish gives an idea of the interior of the lunar crater. If we then put the same dish—assuming it

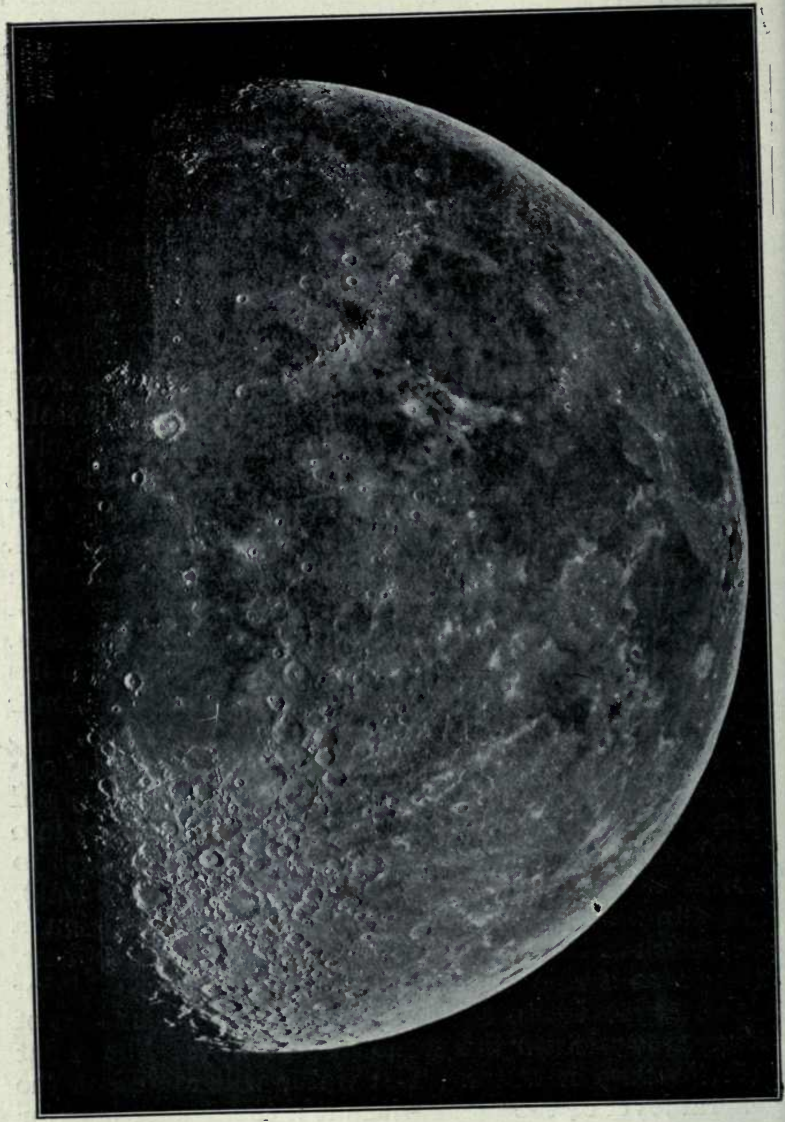

Fig. 29

The Half Moon

to have a raised curve round the bottom—upside down on the table, it will illustrate the depression that we sometimes find in a high district; say, the Wan Sea, or the Göktscha Sea (Ararat region). In the terrestrial case we have a slight depression at a great elevation; on the moon a moderate elevation and then a deep cavity (compare the profile picture).

We may plausibly generalise from these characters and say there is so great a contrast between terrestrial and lunar craters that it becomes easy to doubt whether volcanic energy is responsible for the latter. We are well acquainted with Neison's view that there are some 'real craters' on the moon. 'It is difficult to discover these crater-cones on account of the smallness of their mouths, and they are easily confounded with the bright peaks of mountains.' Klein, also, who spent thirty years in observing the moon, says somewhere of the half-sunken round formation Stadius, near Copernicus, that the small craterlets on its level stand on a high substructure, so that they look like needles when the sun is low. Both these ideas of a certain sort of small ring-structures must be modified. There are no objects at all that will bear a direct comparison with terrestrial cones. The plains in Stadius and to the south of it have only a slightly rougher relief than many others, as we can easily see in a strong light.

In point of size the walled plains occupy the first position on this hemisphere of the moon. They are depressions of a marked or a moderate character, such as Clavius or Grimaldi, clearly showing the curvature of the lunar globe, especially when they are very close to the limb, and when their floor is flat. The finest specimen is Clavius, with a diameter of 145 miles. Its depth is just as striking to the eye as it is proved by measurements, and it has a whole range of formations of the second and third rank within it. Its high border is pierced by large crater-rings. It is larger than Wales, and is remarkable for the purity of form of its 'crater-cone.' It is in this and its subsidiary forms that we best see the weakness of the volcanic theory.

At the south-east edge of the moon we find the partly obscured plain of its rival Schickard, a long-drawn ellipse 125 miles in length. Its floor looks like the convex bulge of a shield, and clearly shows the curvature of the moon's surface. Its surface, moreover, is not much broken by subsidiary features, but comparatively flat, though perhaps a little lower to the north and south than in the centre. Schickard has also an outwardly more independent wall with numbers of ridges and passes, which is a general character of these larger structures. Hardly less in size, but with a very different border—massive hills at one point and flat shore-banks at another—is Grimaldi on the eastern limb, with a diameter of 120 miles, and very little appreciable detail on its curved and very darkly-coloured floor. Owing to its position amongst bright uplands and its own darker shade it might almost be included amongst the 'seas.'

Humboldt in the south-west and Bailly equally close to the limb on the south-south-east measure 112 miles across. The former resembles the two already described; the other is like a field of ruins, strewn with ridges, hills, and craters, all enclosed in a common border. In the centre of the moon's disk there is only one giant-structure, the typical Ptolemaeus, with a diameter of 100 miles, and strewn with details of all sorts. As this is well exposed to view in all phases the author has discovered and charted no fewer than 78 craters of the second rank, 8 depressions without walls, and 10 seams within the huge circle, as well as 90 hilly ridges and 16 craters on the wall.

Another that is almost as large and rough in detail as Bailly is J. Herschel in the north-east. A little smaller (93 miles) is Gauss, an almost empty plain, with merely one fine and prominent central elevation, to give a clear impression of a ring-mountain of the crater-type. About the same size we have Petavius in the south-west (in the vicinity of Humboldt) with a very distinct wall, divided into parallel sections, and a fine central mountain 19 miles in diameter. Hipparchus, also about 93 miles in diameter, in the nighbourhood of Ptolemaeus, has a good depth and a pentagonal outline. Its steep inner wall is pierced by gigantic passes and set with subsidiary crater-forms; its floor is strewn with veins, hills, and a 19-miles wide ring-mountain.

These huge objects complete the list, if by walled plains we wish to understand only the larger of the round structures. Neison does not take the word in this exclusive sense, but includes structures down to 40 miles in diameter. Besides a few objects which we have not yet mentioned, this definition will bring in structures of the type of Archimedes (51 miles) and Plato (60 miles) on the one hand, and of the type of Tycho (52 miles), Copernicus (57), and Arzachel (64), on the other. The former may very well be described as walled plains, as the name is as literal a description of them as one could wish; but the latter are well-formed 'craters' with a central elevation. In these it is not the plain that chiefly catches the eye, but the terraced slopes and the central mountain. It is best to take into account the general impression of an object in giving it a name, and so we must classify even much smaller structures as walled plains (such as Kies, Lubinietzky, Billy, and Herodotus), as these cannot very well be given a different name except under the influence of some theory or other.

We must not be understood to take exception to the lunar nomenclature in these remarks, as it can be worked up into a formal system without doing any harm. We wish to show merely that the various types are to be found in all sizes and all stages of their characteristic features. Neison restricts himself so little to the ground he chooses for division that he puts the 'ring-mountains' immediately after the walled plains. From the following description of the characters of the best-known forms we can understand how the group is arranged. First there is Copernicus, its floor, 57 miles in width, scantily encircled with walls of a partly undulatory and partly broken-up character. To the west of Copernicus lies Stadius, 31 miles wide, its horse-shoe shape clearly being the remainder of a once complete circle, and its low walls pierced with many holes. To the east and west of the small crater Wichmann there are other ruins of the same kind ; and not far from them there is a crown of isolated peaks near Flamsteed, which strikingly mark out a circular space 65 miles in diameter, and must be regarded as the outstanding heights of a sunken structure. Finally, there are many levels with low ridges belonging to the group which only catch the eye when the sun is low, as we find to the west of Copernicus and round the 'long wall' of Thebit, where the region so defined measures 112 miles in diameter. The more specimens of this sort we consider, the clearer it is that any description that suits the chief characters of a lunar form will suffice, as long as it does not involve any theoretical conception or any idea as to their origin.

However, Neison goes further, and describes in succession 'ring-plains,' from 56 to 20 miles in diameter, in which the area of depression is very large in proportion to that of the wall ; 'crater-plains,' 20 to 12 miles in diameter, which appeal to the eye as craters in spite of their vast size ; 'craters,' in which the inner surface is much smaller in comparison with the well-formed mass of the enclosure (4–12 miles); and finally, 'small craters,' of still less roughness and of such dimensions that they are only seen on close observation.

A walled surface large enough, for instance, to enclose the whole of Manchester, seemed to the earlier observers to betray a 'volcanic origin.' Neison does not hesitate to describe depressions of 4–12 miles in width as 'the real lunar craters.' It is always the volcanic theory in the rear that influences research and description in this way.

Besides the four classes we have enumerated he gives also 'crater-pits,' from a few hundred yards to 6 or even 11 miles in width, with very scanty or totally unrecognisable walls and 'crater-cones'—'perhaps the only real representatives on the moon of our terrestrial volcanoes'—with a comparatively small opening in their lofty and steep summits. We have already pointed out that there are no such objects anywhere on the moon. The first glance at elevated craters of sugar-cone form may be deceptive, but the experienced observer must have restraint enough to take into account the low and one-sided position of the sun, when he sees the remarkably long and pointed shadows. It will always be found that both the curve and the absolute height of these 'elevations' or 'eruptive craters' are very considerable. Certain structures of this class in Stadius cast shadows 20 miles long with the sun at 2°, yet they have a base averaging two miles broad to a height of only about 550 yards, and so do not justify the comparison. Moreover, these structures are very rare. We must bear in mind, too, that the smallest and the largest ring-formations are all composed of the same material. If this is of such a nature that it does not present knife-like ridges, but seems to round off the edges and angles, the depression on a small elevation must naturally seem narrower and flatter than if it had a broad base for its development. As the author has not felt compelled to admit volcanic forces, he has never found any necessity for introducing a finely graduated nomenclature. Any student who bears in mind the details of the size of lunar structures in describing them will be sure to avoid misunderstanding.

We cannot refrain from mentioning at this stage a peculiar form of ring-structure that is found in a few, but well-formed specimens—the sunken walled plains on the edge of the sea. They have sunk more or less sympathetically in connection with the subsidence of the sea-floor, and they reveal the destructive influence of their neighbour, either in obvious undermining of their wall, which has become invisible at some points and entirely sunk in at others, or in the disappearance of a large part of the area, at least as far as certain peaks. To show how we find the phenomenon in all its stages we will describe a few more lunar forms. On the north-west border of the Mare serenitatis there is the walled plain Posidonius, some 62 miles in width. To the east the wall has become very thin and low, and a mile and a half of it has disappeared altogether, so that the level of the Mare and the interior surface is almost the same. This is the case of slight deformation. On the diametrically opposite side of the disk is Gassendi, at the edge of the Mare humorum, 56 miles wide, with the whole of its southern wall submerged with the Mare; the latter, in fact, seems to have penetrated it by a wide breach, as a broad patch on the inner wall is dark coloured. But the rest of the wall is intact, as we also find in the object Pitatus on the south shore of the Mare nubium; about one-fifth of its area slopes strongly towards the sea, and there is a wide breach that shows the equality of level on either side. A fine example of this type is found in Fracastorius on the south shore of the Mare nectaris. This huge ruin has lost a full quarter of its enclosure, only a few groups of peaks and dams remaining to show its former position. Its interior bristles with hills, craters, bosses, dykes, and breaches, and the part of the wall that remains at its full height is pierced by a good many secondary craters. Almost exactly like this immense horse-shoe of 56 miles diameter is the half-crater on the southern edge of the Oceanus procellarum of still larger dimensions, Letronne, which has lost quite a third of its northern wall, not even a single peak now rising out of the Oceanus. The inundation has not entirely destroyed the two central elevations, but there is hardly any other detail inside it beyond a few flat ridges. Another structure that has lost fully one half its wall by subsidence and inundation is Lemonnier on the western shore of the Mare serenitatis, of which only a few ruins are left on the eastern side. There are also smaller objects of the same class, such as Hippalus, which has lost a third of its ring-wall, and is full of ruins. Not far from this, on the eastern side of the sea, there is Doppelmayer, which has merely suffered a considerable subsidence, like Gassendi in the north. We could enumerate a good many of these smaller objects, as well as others that have more or less subsided *inside* the walls. Of this nature are one to the east of Encke, two mountain-circles to the west of Letronne, Stadius to the west of Copernicus, a horse-shoe structure to the north-west of Aristarchus, a flattish form named Kies, Beaumont, near Fracastorius, some scanty remains of a ring-mountain on the northern area of the Mare nectaris, the mountain-circle round Torricelli, two sunken forms in the Mare crisium, etc.; to say nothing of the numerous bays which either run into the highlands or seem to be relics of former crater-cavities. In these we see the same effects as are found at the edges of extensive submerged areas on the earth, but without the accompanying phenomenon of the violent storms that bring the land to a common level. That is a specifically lunar feature.

There are three other sorts of lunar forms that are very interesting and are fatal to the current volcanic theory. The first category contains the double and multiple objects with a common interior. We have a fine specimen of this class in Torricelli, whose 12 mile broad ring has an appendage 6 miles in width, giving rise to a pear-shaped structure. To the north-west of this, on the edge of the heights, there is a still larger specimen; and to the east of Torricelli there is a flattish, elongated depression called Hypatia. To the south of Copernicus there is a double structure (*see illustration*), with common interior; on the outer edge of the walled plain, Albategnius, there is a triple one, known as Airy d, which looks as if it had a double

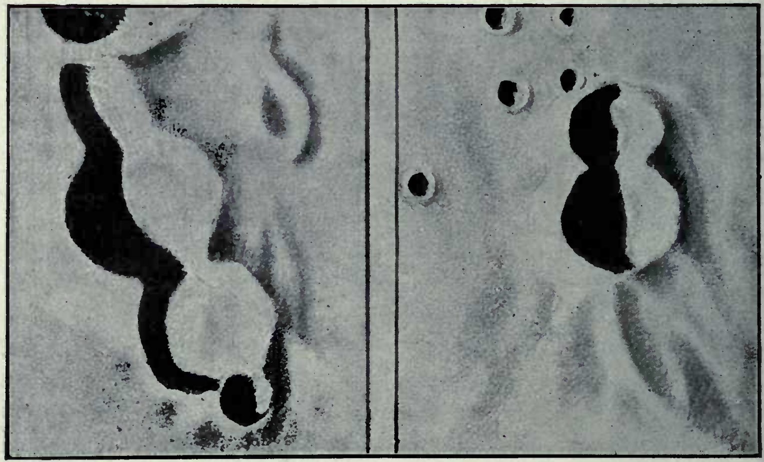

Fig. 30. Airy d. Fig. 31. Copernicus A.
Multiple craters

constriction. There is a very similar triple structure, though the division is less advanced, called Reichenbache, with a length of 42 miles and an almost smooth floor. But these objects are insignificant beside the large double structure in the extreme south-east that has the name of Schiller. It measures 112 miles and consists of a smaller half, which is filled with hilly ridges, and a larger half with a smooth floor. It is very difficult for the volcanic or the meteoric hypothesis to explain structures of this kind in any intelligible way.

The other sort of lunar mountains also is unique, and is not like anything on the earth. These are the connected ringed-walls, which may be fairly concentric, or may merely overlap, but cannot very well be regarded as twin craters, like the form Copernicus A. One of the two is always intact, and looks as if it had eaten its way into the wall of the other. One of the most characteristic examples of the class is the pair Theophilus—Cyrillus (*see Fig.* 9). The first crater-plain is quite round; but if we were to complete the northern wall of the other, its crest would extend some 12 miles further, and the rings would overlap to the extent—they are about equal in size—of one-fourth of their area. At first glance we should say that the complete object must be the more recent, the imperfect one the older. That is certainly bound to be the opinion of the volcanist, but it is quite wrong. In details the volcanic theory has always proceeded on speculation rather than on research, and here at least it breaks down. When we take into account the phenomena of fragmentary craters, sunken ring-mountains, multiple structures, and the extraordinary flatness in proportion to the diameter, it is more reasonable to suppose that, in a way we will not attempt to explain just yet, the imperfect object has grown on to the other, much as outlying walls in a fortress are built on to the main wall. This growth cannot have been one-sided in the present case, or in Thebit, or Zagut and Guttenberg and Hainzel, but must have been mutual, the two ring-walls embracing each other as it were. In other cases the walls are concentric, but these are more easily explained by the operation of central agencies.

The third kind of lunar peculiarities are the almost square area in Aristoteles, the similar square of vast proportions, W. C. Bond, an enclosed square space in Eratosthenes, another in Theophilus (north-east), and several others. These can hardly be volcanic in origin, even if other forms were. At every step we meet structures that militate against the theory.

We have spent some time in these observations, although one must admit that the small maps that the general reader can consult in an atlas or encyclopædia are very imperfect guides through the labyrinth of lunar forms, and the names of all the objects we have described will not be found in them. But there are so many writers at work to-day popularising scientific knowledge on the old base of the Laplace theory that it is absolutely necessary to draw attention to a source of facts on the moon that does not tally with it. This source is the rigid face of the moon, unchanged for countless ages, whose stony features contain the secret of its origin. It is our work to find the solution of the enigma, just as, some decades ago, we found the key to the cuneiforn writings.

At a time when lunar science was in its infancy and observers had quite enough to do in the work of collecting facts, it was possible for speculation to make bold ventures, without the risk of their being contradicted by actual observations. But for the last twenty years or less, selenography can boast that it has discovered abundant evidence to refute the old idea that the moon is an off-shoot from the earth. Every attempt to read lunar hieroglyphics on the theory that it is of a volcanic nature and was composed of material directly similar to that of the earth could not get beyond the most superficial characteristics. It only remains, therefore, to pour our new wine into new bottles, to remember that our companion has only a specific gravity of 3·5 and gives no indication whatever of volcanic character, and base our speculations on its peculiar and distinctive features rather than on the ambiguous and too general characteristic of the circular form of the mountains. We can only say as yet that there is some prospect of success in that direction.

The number of the ring-structures arose from a few dozen on the older maps to several hundred on Tobias Mayer's map. Schroeter added many objects, but it was chiefly Mädler and Lohrmann that increased the number. Mädler's 'Mappa selenographica' indicates 7,735 crater formations, and Lohrmann's valuable and independent, though almost contemporary work gives 7,178. The difference is that, though Lohrmann had a larger instrument, Mädler used a somewhat finer one in Beer's observatory, and perhaps had better conditions in the Berlin Tiergarten. It must be remembered, too, that Mädler's fine 'pits' are often misinterpreted, whereas Lohrmann's work is very faithful and objective. Schmidt indicated no less than 32,856 of these ring-structures—disregarding the others for a moment—on his six-foot 'map of the mountains of the moon.' The revisers of the map were in a position to add more, and the present writer has himself contributed 4,590 'craters' in regions on which he happened to be working. Schmidt threw out the conjecture more than a quarter of a century ago that there would prove to be 100,000 of them when it became possible to apply a power of 600 to the moon. He was quite right, and the author has found that half that power is sufficient. The best instrument is an experienced eye. The wealth of form that is immortalised on Schmidt's map can only be appreciated by those who make use of it, but if the above estimate is right we should find ten craters to every part of the map that could be covered with a farthing. The number of other lunar features is legion. It could not be expressed in figures, and could not possibly be crowded into Schmidt's map,

Let us now transport ourselves in imagination to the three-mile high peak on the western wall of Clavius. We are looking eastwards over the depression of the plain, at a time when the sun has passed over the spot some days before. Our elevated position enables us to trace an almost closed ring round the depression. But the eye cannot reach the further side, because even at a height of three miles on the eastern wall we cannot look over the hills that fill the interior of the plain and limit the horizon. Before us is, at a distance of 43 miles, a large crater 17 miles in diameter that at once catches the eye. Its rough outer slopes have numbers of wrinkles and off-shoots, that merge gently into the plain. Its crest has no lofty peak, like those that line the crest of Clavius itself to our right and left. In front of the circle we see flat banks and rough bars scattered across the scene. They are the flat ends of the rugged spurs from the north of a second giant crater, which lays its mass against the inner wall of the ring. It is nearer to us, and we can see its deeply furrowed north-west side, which is turned towards us, glittering in the sun, or darkening in its deep clefts, or still, in places, casting its black, hard, and angular shadows. The space between this mass of rough contours and the western wall of Clavius itself, which spreads out at our feet, is milder and milder as it nears us. On our left it is like the colossal ruin of mountain spurs that have run into each other, and immediately below us they have arranged themselves in a parallel series of descending terraces. Our eye cannot reach the foot of our wall, which is some nineteen miles away, because in front of us the inner side of it rounds its great slope like a deep-breathing breast. After a few rough stages a wide cavity opens its gaping mouth behind the sharp crest of the last barrier, and we seem to look down into an abyss. Its depth may be judged from the impression on the observer of the plain that rises beyond it, like the surface of the sea seen from the coast. On our right also we recognise a giant-crater, with the crest of Clavius hanging vertically over its ring, and showing that there has been a wide breach in the main wall of the crater. The great structures that we see rising to the south and the north-east cover the larger part of the main crest. In the east-south-east there is a narrow opening through which we look out on masses scattered like ruins over a distance of 47 miles, and catch the jagged line of the south-east wall 106 miles away. To the east-north-east also we see the outline of the great wall as a gleaming white on the black background of the heavens. Right behind the first-named crater, which bars the prospect toward the east, we catch a glimpse of another large one at a distance of 70 miles, also covered with small undulations.

If we look behind us we see no great gulf yawning, but the eye is dazed by the flood of sunlight that pours on us and the brilliant white of the strongly-reflected slopes near us. The eye is hurt by the contrast between the brightness all around us and the deep black shadows of the depths below and the equally dark sky above. The brain is bewildered if we attempt to cover the chaos of inequalities that stretches out before us in terraces, interlacing rings, craters, precipices, and myriads of other forms. We should need a much more lofty position to get a clear view of all the structures that crowd together. And we terrestrial observers have indeed the advantage of taking up a supremely elevated position and getting a perfect bird's-eye view of the scene—we look on it from the earth through the telescope. But if

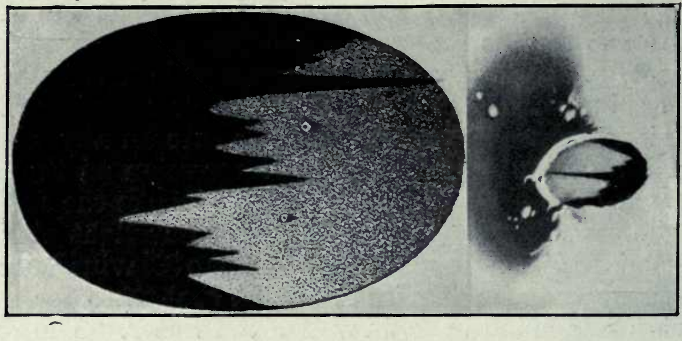

FIG. 32 FIG. 33

Shadow-figures in the walled plain Plato

FIG. 32 by Fauth (morning illumination); FIG. 33 by Weinek (evening illumination).

we have the advantage of height we pay dearly for it in the matter of distance. We have already explained that even with the highest powers the moon remains at a considerable distance.

If we mount the highest western peak of Plato (60 miles in diameter), and contemplate the situation of this gigantic theatre, more than a mile deep, we find a quite different spectacle from the preceding one. The wall at our feet, both in front and behind, is very impressive. Here it seems to descend almost without gradation into the bottomless deep that spreads out like the surface of an ocean toward the east: there it breaks into a wild and craggy landscape. But both the course of the wall and the plain it encircles are quite different from Clavius. The crest vividly recalls the jagged line of an Alpine range in the far horizon (see illustration).* On the western side we have a series of

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*One must remember, of course, that the real aspect of the line of peaks and crest, as seen in a horizontal direction, would present far less difference in altitude than the long shadows cast in a strong light would lead one to think. At the same time these 'magnified' profiles enable us to make much more accurate measurement of the heights.

Alpine peaks, the three highest reaching 1,722, 2,166, 2,445 yards. Between them are at least seven others of less altitude that are distinctly Alpine in their contours. One of the passes between the steep-rising peaks is at a height of 555 yards above the inner surface, another at a height of 1,000 yards. The conspicuous notches in the shadow line show that in the western quarter of Plato's enclosure there is a high peak about every four miles.

If we look toward the east we see before us a real plain with no important details. It spreads out almost to the horizon, and is encircled by an undulating wall of which we cannot see the foot in the extreme distance. One huge peak in it rises to a height of 2,445 yards: a straight peak, flanked by two hills in the south, and one in the north, of less proportions. Twenty-eight miles in front of us is a flattish boss, which the telescope would

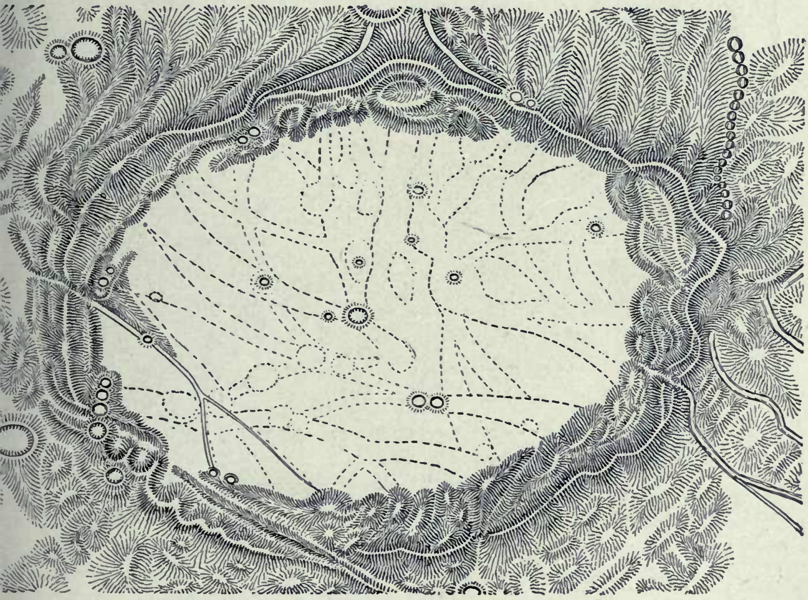


FIG. 34.—Map of the walled plain Plato, by Ph. Fauth (1 mm. = 3,030 m.).

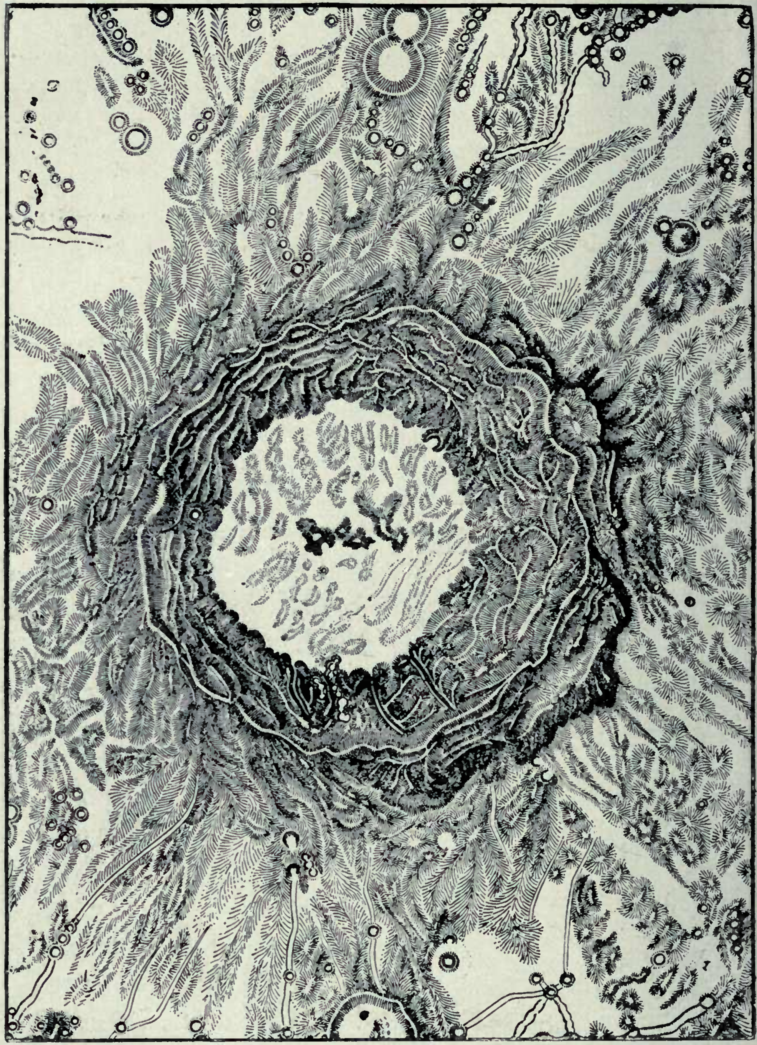


Fig. 35—Map of the ring-mountain Copernicus, by Ph. Fauth (1 mm. = 1,540 m.).

show to be a small crater-form about two miles in diameter. Another one comes into view on the right, and if we look closely, we can discern with the telescope half a dozen very flat breaks in the great desert plain of Plato. The only relief is afforded by a few vague grey spots and the broken slopes of the wall. There are few of even the most modest ‘ crater ’-structures scattered over the almost smooth floor here—but we will return later to the subject of Plato's inner surface—whereas there are dozens in Clavius, and the largest of them measures 17 miles. The comparative level of the plain shows that the cavity, which was certainly more concave at one time must have been filled up from below ; though it is not necessary to bring in the familiar molten material of the moon's interior to explain this.

We have a different spectacle in a well-formed crater like Copernicus, which I reproduce here in a greatly reduced print of my map. Unfortunately the reduction has much interfered with its clearness ; the original is on a scale of 1 : 450,000. Here, with a diameter of 56 miles, we have in the western summit A of the chief crest an excellent position at a height of 3,777 yards, from which we can survey both the cavity and the entire wall. In front of us a number of almost isolated peaks rise out of the middle of the hollow, the one to the east reaching a height of 750 yards ; the nearer one, on the west, is about 673 yards high. The whole group looks like a heap of loosely tumbled ruins, and is *totally unlike* what we would expect in a volcanic cone, though the term ‘ central mountain ’ is usually applied to it. From our eminence A we can not only follow the further limits of the plain beyond these hills, but can also detect a great difference between the northern and southern halves. The former is covered with extremely flat and long undulations, generally running from south-east to north-west ; the latter has a large number of peaks and bosses, which seem to be

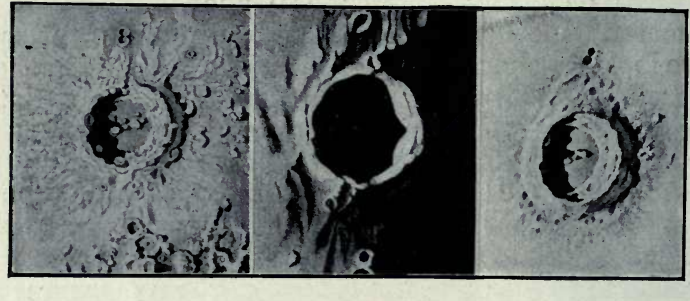


FIG. 36 FIG. 37 FIG. 38

Copernicus according to Tempel, 1860; Hefti, 1882; and Weinek, 1884 (original size).

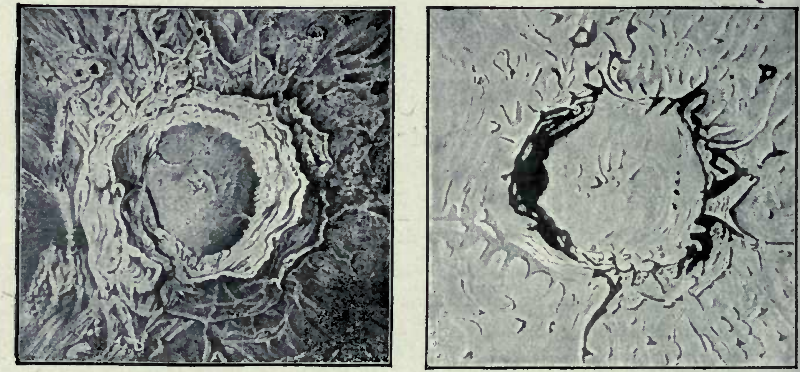


FIG. 39 FIG. 40

Copernicus according to P. A. Secchi and E. Neison. (Half original size).

scattered irregularly, though they can really be grouped together, much as if a number of clods had been washed into heaps and strings. The generally flat interior of Copernicus seems to indicate that its level was formed in a fluid state; but once more the 'central mountain' and other characters forbid us to introduce plutonic forces.

All round the eye sweeps over a terraced landscape on the inner and outer walls, filled with an enormous number of topographical forms. It is a chaos of parallel and transverse valleys, eminences, ridges, and peaks, alternating with gorges and crater-cavities. The crest of the wall itself, which is much deformed and broken by independent lunar forms, as in the case of Clavius, departs very considerably from the circular shape. There are about 11 distinct angles; some stretches of the crest are straight, while others are curved, with the bend inwards. As in the case of Plato in the east, where a sort of landslip has broken the line of the enclosure, and caused a good deal of the wall to fall into the cleft made, so in Copernicus we find—or at least, seem to find—similar masses broken away from the main crest in two places. In fact, the structure of the complicated terrace-system of the most perfect 'lunar crater' that the telescope reveals is one of the greatest difficulties for any explanation of the action of constructive agencies. It is impossible to solve the riddle of its mountainous structure on the lines of the plutonic theory; perhaps just because the features—as strange as is their origin—have remained in their original condition.

There are many other features of the moon's face that we might dwell upon. From the peak of Copernicus, for instance, we need only sweep the landscape to the west with the telescope, or look out over the neighbouring shore of the Mare nectaris from the western wall of Theophilus, and we find shoals of tiny craters giving the place the appearance of pumice-stone or sponge. Other regions, as in the mountain Argaeus, would look like a broken coat of ice. But the forms are innumerable, and we must be content with the pictures we have given.

There is one other peculiar class of structures that we must mention, because for some time they gave the chief countenance to the theory that changes are still

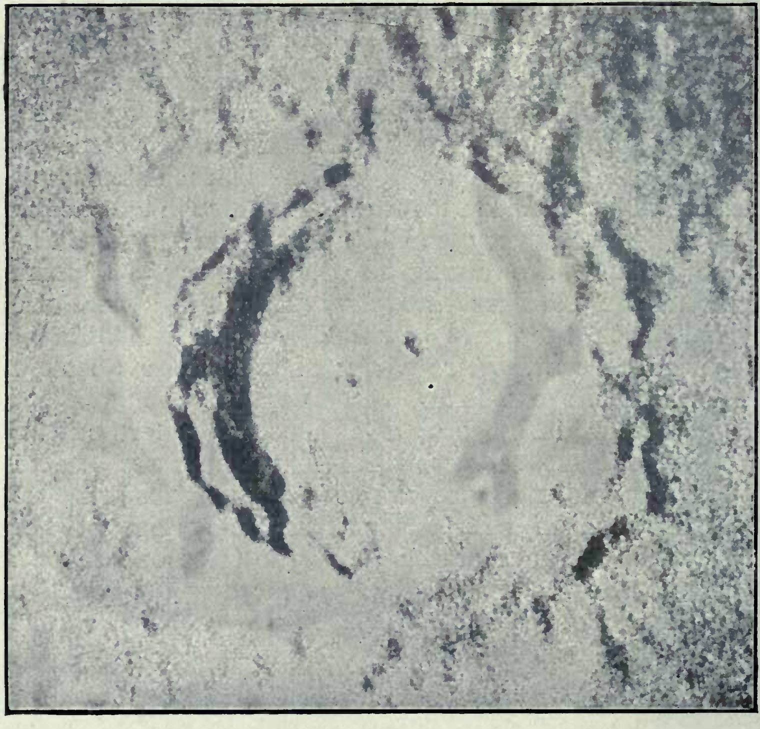


FIG. 41. Copernicus, from Prof. Prinz's enlargement. (Half-size.)

taking place, and they are, as a matter of fact, the most recent constructions of the lunar forces. These are dark, almost black, spots. It was thought that they represented the outflow of masses of dark lava, accumulating in hollows. But there are few cases in which cavities have been recognised, and there are others where we have reason to think the ground is elevated. There are spots of this kind, almost circular in shape, in the hilly ground to the south-west and to the north-east of Copernicus, in the plain near Gambart C, on the eastern shore of the Mare nectaris, in

Fig. 42
The Alphonsus-spot (Klein.)

Fig. 43
Alphonsus (photograph)

Atlas, Alphonsus (*see illustration*), Petavius, Schickard, Riccioli, etc. Crüger, Billy, Endymion, Vendelinus, and Grimaldi have a smooth dark sea-surface generally, and are only one step removed from the Mare crisium. From these we can draw certain conclusions with regard to the processes that produced the ring-formations with smooth floors, or have left in other walled plains certain marks of recent action in the shape of blackish spots. We often see small craters in the middle of, or at least inside, the spot—they can also be seen at the borders—and these are regarded as the natural outlets of the dark matter. But, once more, there is no need to assume any 'dark-coloured lava' or a thin layer of 'dark ashes'; if that is done, we may well ask how it is that the five walls of the little craters and hills have remained *white*. But we know from what we have already seen that no physical problems of the moon can be solved on these antiquated plutonic lines. We shall afterwards describe a way in which the question can be answered much more simply, and from which side-paths branch off toward the solution of many cognate problems.

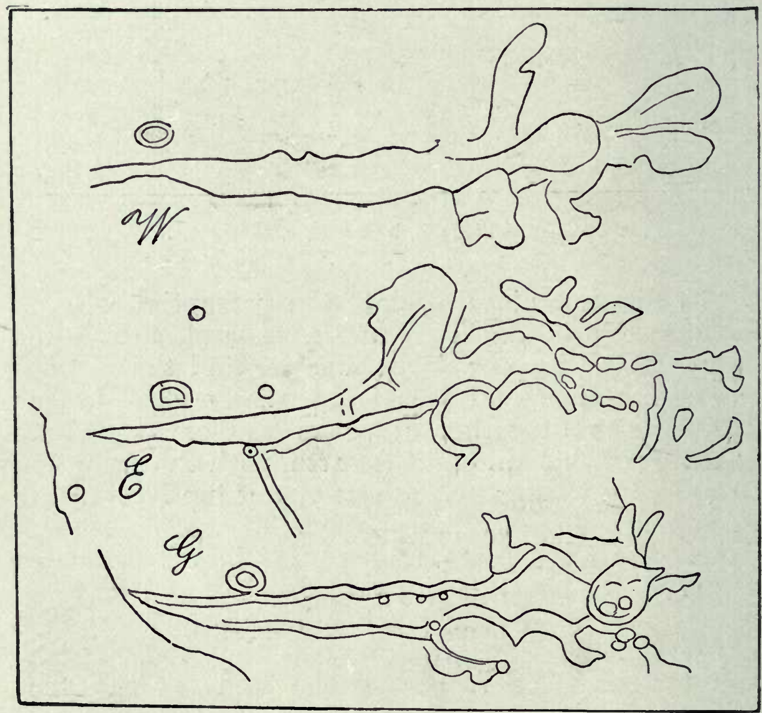
CHAPTER V

THE REMAINING ELEVATIONS AND THE RILLS

The solid mountains on the moon form a special class, although they seem, on a superficial examination, to resemble closely those terrestrial mountains which have an extensive surface. But we should conduct our task of exploring a foreign world very poorly if we were content with a superficial analogy, and did not make a more searching examination of our phenomena. Doubt is one of my best leaders into the unknown: the most effective impulse to fresh work. In the present instance it is greatly aided by the facts themselves, which are by no means easy to ascertain. We may say, without hesitation, that the typical specimens of lunar mountains—The Apennines, Alps, Caucasus, Hæmus, Carpathus, Riphæus, etc.—are as little as possible like terrestrial mountains in structure. If we wanted to give a proper and instructive description of the lunar highlands, we might say: The Apennines (see Fig. 3) form a conglomerate of elevations and depressions (or 'intermediate spaces') on a base that is slightly bent towards the south. We must regard the base as a piece of the earlier shell of the moon (we deliberately avoid the word 'crust'), which has been broken off by some remote agency and has been lifted up together with a colliding piece to the north, that was at first submerged and then reared up once more (but pushed a little more toward the west). Thus, if we regard the base of the Apennines as an obliquely raised surface and the ring-formations of the Mare imbrium as incomplete elevations, or elevations inundated by lunar matter (and partly filled up, as in the case of Archimedes), and explained on the analogy of the rest—'explained,' that is to say, on the lines of the theory that substitutes for the 'magma' (for which there is no place on the moon), another fluid with similar properties of expansion and solidification—we shall find increasing evidence in favour of this new material.

Figs. 44-48—a, á Pico ; b, b′ Piton ; c, Lambert, N.W.

In the first place, besides the perceptible rise on the Mare-side in the Apennine base, and, to a small extent, in the base of Carpathus, we find that all the solid mountains, and this is especially clear in the Alps, consist altogether of peaks and crests. There is nothing of this kind on the earth, with the exception of the Greek islands, which rise out of the level of the Aegæan sea like so many warts, bosses, hills, and peaks. We have something similar in the shoals of islands off the coast of Norway, Sweden, and Finland. The sea makes an even level from base to base ; the hills do not slope gently upwards, but rise straight from the surface. It is just the same in the vast region occupied by the lunar 'Alps.' Here isolated mountains and groups of hills are scattered over a light-coloured surface, and rise like islands out of the ground; it is only at the eastern bluffs of the mass that we find large masses heaped up, but these are not connected together like terrestrial mountain-masses—especially bearing in mind that the Swiss Alps are not shown on our maps in their original form, but weathered and worn by the action of water during thousands of years, while the lunar topography remains in its virgin freshness. Further, the lunar Alpine mass is burst at two places; at its main outcrop on the east, where the high peaks and steep bluffs are, and again, transversely, at the point where we now



Figs. 49, 50, and 51. Situation of the valley of the Alps, according to Webb (W), Elger (E), and Gaudibert (G). (A slightly enlarged reproduction).

see the great 'valley of the Alps.' 6 miles broad and more than 80 miles in length*. The slight depth of these broad gaps and their level floor countenance the idea that the bursting of the mass allowed the fluid to rise almost to the edge of the breach. The cleft

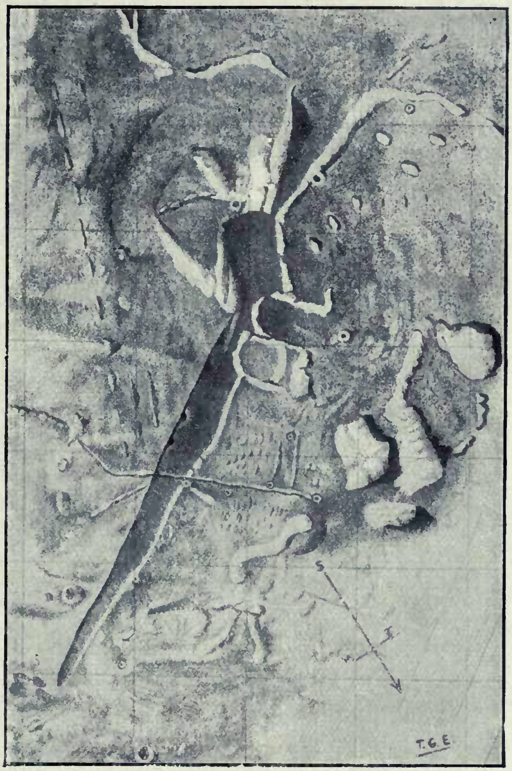


Fig. 52. The great valley of the Alps. (Drawing by Th. Gwyn Elger, January 25th, 1885).

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* The author's own map, which is also given, represents the actual condition of our knowledge, and includes the greater part of what Perrine regarded as rills. After the block had been prepared the author added a western continuation of the Perrine-rill, three crater-like enlargements, another branch of the rill toward the north-east border, and a pit at the eastern end of the broad floor of the valley, so that the American discovery is now fully confirmed at Landstuhl.

failed to close again toward the eastern end, partly on account of displacement and partly on account of being stopped up with debris, and the difference in specific gravity of the solidified and the liquid matter prevented the halves of the mass from sinking down to the level of the fluid, which was also hindered on the east by the fragments pressing underneath them. The Carpathian hills also exhibit elevated surfaces,

Fig. 53. Fauth's map of the valley of the Alps (1 mm.=960 m)

steep bluffs, and broken edges on the Mare-side; inland we see hilly debris scattered loosely and wide around.

There are some instances of even greater elevations of mountain-masses. The Apennines seem to exhibit this formation, and also the Caucasus. But when we examine them in good light they are merely regions in which the parts fail to be connected, or are only connected by secondary hills. The general level of the moon appears throughout, and forms what we call the valley or the plain on earth, though on the moon it would be more correct to call it the common basis of the heights, often only seen as a space between them. We can learn from a further instance on our satellite how we may picture to ourselves this catastrophe of the forcing upwards of parts of its shell. The comparatively small Mare nectaris is encircled in a wide circle by the seemingly gigantic parallel lines of the Altai mountains, with an inner fall from Piccolomini to Tacitus, though the expert can trace it much further. Here one can almost see at a glance that the whole of the inner surface subsided at one time or other, and—relatively to lunar dimensions—remained at a slightly lower level. Was it the same process in the Mare imbrium? Was it the case with the Mare serenitatis—with the 'seas' generally? Yes and no. The seas in general are flat, because they have remained flooded. The first inundation from below has, however, been followed by others in the Mare nectaris, and this has given it its actual character. We may extend the principle with the necessary reserves and enlargements to other objects. The transition to Grimaldi, Clavius, and similar gigantic walled plains is obvious; but it will not be easy to say where 'eruptions' must be substituted for depressions in order to explain the plastic features of the moon's surface.

There are still two very distinctive and therefore important lunar forms that we commend to the notice

Fig. 54. The Mare nectaris, and the regions to the north of it. (Cf. figs. 9 and 33.)

of the reader who has a good map of the moon or a telescope. These are the isolated plateaux and mountains. A few of the chief examples of the former are: a mass with many inequalities and depressions to the north of Copernicus and the west of Gay Lussac; a still more sharply defined mountainous mass to the north of Euclides, quite distinct from Riphæus and rising out of the *mare* with a smooth border; an equally large mass to the north-west of Fra Mauro, which has clearly been broken from its wall and forced to one side; a large triangular island to the east of Hippalus in the Mare humorum, and many others. The common features of them are that they emerge sharply from the smooth plain and are quite separated from the neighbouring heights. They look like plates laid on the ground, or rather, like flat islands embedded in a fluid and solidifying in it.

When we turn to consider the size of these parts of mountains, we find some that have more resemblance to groups of hills, such as the Harbinger mountains in the Sinus iridum, or the long lines to the south-east of Plato. We might also adduce the scattered plateaux and mountains to the south of Archimedes or the southern end of Caucusus, and other similar structures. But we shall see the character of these elevations more strikingly if we take them in the following order: The mountains to the north-west of Aristarchus, Pico and Piton on Plato, Lahire, to the east and the peak to the west of Lambert, and others (see figs. 21–27, and 47–51). In these cases a single peak, or a mountain split into several peaks, rises straight up, and casts enormous shadows at the rising or setting of the sun. Some of the central mountains inside the large ring-formations are of the same character. We must not, of course, trust the superficial appearance too closely, because, in spite of their remarkably pointed shadows, all these 'peaks' are really very flat, as the following figures will show. Pico is 12–15 miles broad at its base, and rises to a height of 2,676 yards, so that the proportion of height to width at the foot is 1 : 8 or 1 : 10; Piton, 15 miles in breadth and 2,333 yards high, has a proportion of 1 : 12; Lahire, 1,611 yards high and 11 miles wide, has a proportion of 1 : 12·4; and the peak Gamma, on Lambert, is 1,166 yards high and less than four miles broad, and so has a proportion of about 1 : 6. The sharply defined uplands and the isolated peaks with their white tint look to us as if they once floated in a fluid, with the greater part of their mass below the surface, and then with the solidification of the sea only showed their upper parts above the surface. The whole of the lunar Alps consists of peaks of this kind, and they are relics of the mass that lies in the fluid below.

We will now consider a last category of lunar features that are often found on the map, and still more frequently on the moon itself, and that will give us a new light on the solidity of the material of our satellite. These are the breaches, clefts, or 'rills.' They have nothing in common with river-courses or anything of that description. They are quickly recognised by the practised eye on account of their reversed relief. Whilst the heights are bright on the side that lies nearest the sun, and dark on the opposite side, it is, of course, just the reverse with depressions. The rills may, it is true, run in such an unfavourable direction as regards the sun's rays that they show hardly any trace of light and shade; in that case one needs prolonged research before forming an opinion as to their real nature. They have been compared to terrestrial gorges, to the valley of the Rhine between Bingen and Coblenz, to ravines like the Via mala, or to the cañons of Colorado. But, on the strength of an acquaintance with several hundreds of well-placed rills we hold that these comparisons are quite unjustified especially when they are based closely on the *apparent* features, which are so deceptive on the moon. If we take the Rhine-valley *below* Coblenz and the whole plain of the upper Rhine as extremes, taking account of both depression and flatness, no doubt the lunar rills will come somewhere between the two. Whether the finest of the rills in the moon's shell are still steeper and deeper we cannot say; we are fortunate to perceive them at all.

There are, however, two quite distinct types, the flat and broad rills, and the narrow ones that we can hardly tell the depth of. The 'great valley' near Herodotus and the 'valley of the Alps' are the largest and earliest known of these objects. There are also the 200-mile long rill of Ariadæus, the Hyginus-rill, the wide canal at the foot of Plinius, the three chief rills near Hippalus, the 170-mile long cleft between Hesiodus and Capuanus, the great valley inside Petavius, etc. The narrow ones are the most numerous, they are sometimes very long, sometimes short, like fine cracks. The system of rills about Triesnecker, the clefts in Posidonius, Gassendi, and Ramsden, are so many examples. What makes the rills so interesting from the selenological point of view is that they so often make their appearance round areas of subsidence or inside them (Gassendi ?). It is evident that this phenomenon has occurred round the borders of the Mare humorum and the Mare serenitatis. Where they seem to be lacking, we find a cognate structure, the long and flat mountain-veins, which are clear signs of earlier cleavage-lines in the Maria serenitatis, humorum, and nectaris, they run more or less parallel to the shores. Further, the ranges of hills that run in bold, S-shaped, flat curves from the ring-mountain Lambert towards the south-west, north, and north-east, are nothing more than earlier ruptures, filled up to overflow with a fluid that issued from below and solidified. In this case we

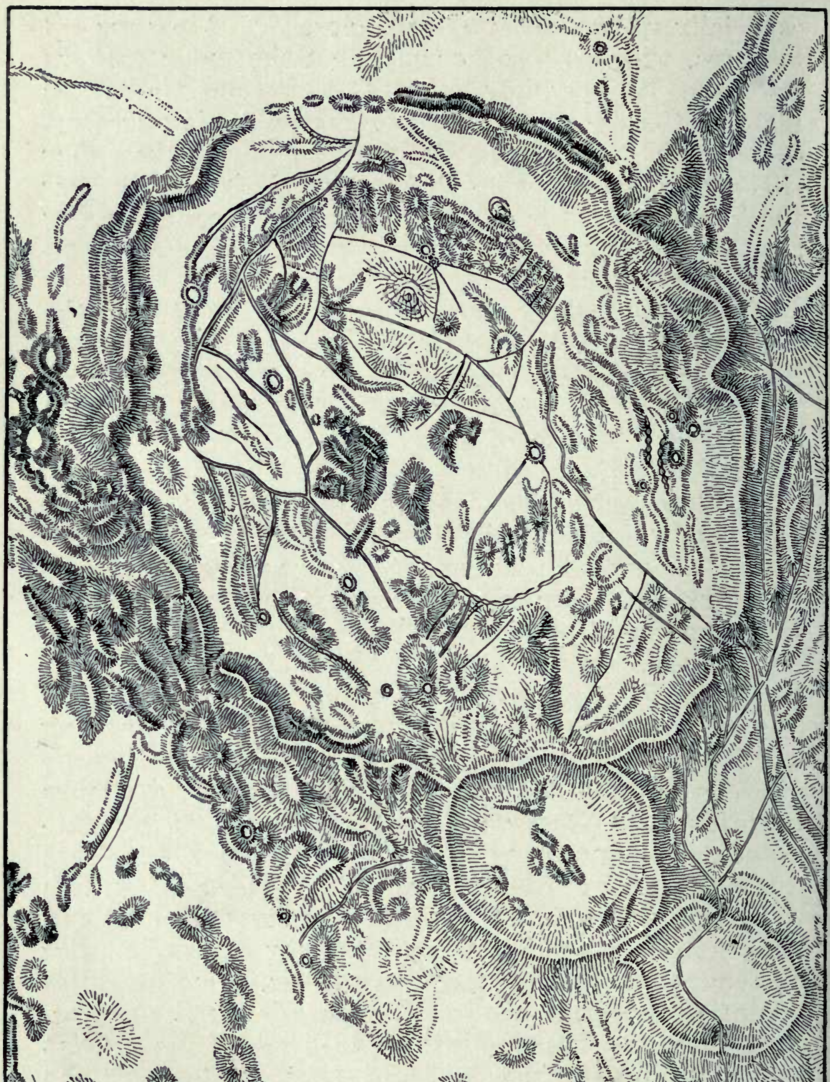

Fig. 55. Map of the ring-mountain Gassendi, by Ph. Fauth.
(1 mm = 940 m.)

willingly endorse the Meydenbauer-Thiersch theory of meteoric impact, which may have been the cause of the bursting of the moon's shell. Since Prof. Prinz proved* by many experiments and illustrations the reality of the apparent features, and showed that brittle masses split generally in three different directions at the place of impact or of least resistance, the frequent occurrence of three rays on the mountain-veins and the frequent triangular and hexagonal form of the ring-structures (Godin, Ptolemæus, and many others) are no longer very puzzling. Rills must generally be regarded as secondary and subsidiary formations, and they help us to appreciate the brittleness of the solid matter of the moon.

In this connection it would not be out of place to recall the abrupt gradation of the plains, as we find in Thebit, where it is known as 'the long wall' (78 miles) or (in England) 'the railway.' The steep fall lies toward the east, so that it only casts shadows in the first quarter of the moon. The author has on careful examination, recognised at the foot of the wall the line of rupture and some remarkable details; Gaudibert also detected the rupture. There is a similar case on the western edge of the chief rill near Cauchy, and something like it, though without a rill, is seen to the west of Cassini. In order to appreciate these details we must carefully bear in mind what we saw above as to the possible origin of these terraced falls.

We have already observed that the broader valleys were the first to be discovered. Schroeter found 11 rills, and with the improvement of the achromatic telescope and of our knowledge of the character of the rills the number increased. Mädler has indicated 77 of them; Lohrmann, with rather better instruments, 99; Schmidt gives on his map no

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* *Esquisses sélénologiques.* See also his *L'échelle réduite des expériences géologiques.*

less than 348 of these very elusive objects. Schmidt did not think the number was exhaustive, and conjectured that they would prove to be about 500. His successors have added a few, though there was little choice in reproducing them. Gaudibert gives 324 (partly new ones) on his map of 1885, and Neison gave 366 in 1881. But we shall only get reliable and very desirable information about the number of the rills in particular, and the centres of rupture in general, from some such study of the moon's topography as L. Brenner is making, in small tracts, at Lussinpiccolo, where some 360 new rills have been discovered, or as the author is making on a larger scale with the object of producing a map 11 feet in diameter. The author has discovered a further 1,258 rills in a small portion of the moon's surface, and these make up 1,600 with Schmidt's indications.

CHAPTER VI

SOME CONCLUSIONS

From what we have now seen the reader will understand how difficult it is to penetrate the mysteries of lunar processes, and it will seem, at first sight, very remarkable that we should speak at all about air and water on this distant body. Here, however, we are assisted by our knowledge of the physical properties of fluid, which are unchanged even in the very singular circumstances of the moon; these are the refraction of light and evaporation. A lunar atmosphere in the remotest degree like ours in extent would have revealed itself on the moon long ago by rendering deep cavities vaguer, by toning down the blackness of shadows and the outlines of things, and by causing a very perceptible twilight. Moreover, the aqueous vapour which would then certainly be present would become visible in the form of mists or clouds, especially at the very spots where we find details quite devoid of haziness and wonderfully clear—on the terminator. We must also remember that water-surfaces of even moderate extent would be directly visible. Some of the communications of earlier observers, which must be taken with reserve, related the discovery, in certain cases, of a nebulous haziness or traces of a twilight at certain points. These are not strong enough to survive the objection that arises from the well-known imperfection of their lenses; and there is a certain sort of twilight, as the author knows from his own experience, that can be explained without any atmosphere. Haziness of one kind or other can be found very clearly any month, namely, when the sun has passed over brilliant-white and deep crater-plains. Thus we see the sun-lit interior of the deep Theophilus, Tycho, or Copernicus, entirely lost in light, and even the experienced eye finds it very difficult to recognise degrees of brightness within the brilliant part. On the other hand, it is well-known that many large structures cannot be detected in the full moon, or rather, at the time when the sun's rays are almost vertical, even if the localities are quite familiar. We will return to this fact later on, and make a closer study of it.

However, all these tests are very coarse in comparison with the investigation of the refractive power of an atmospheric envelope. The comparatively large disk of the moon passes over a number of bright fixed stars in the course of its monthly tour of the heavens. They disappear at its left limb, and reappear at the right. We know from physical experiments that an atmospheric mantle refracts the light of the stars, so that a star seems to remain for some time on the edge of a cosmic body after we know it has been really occulted (or eclipsed), and that it seems to be delayed for a time in making its appearance at the other edge, though we know it has passed the edge. Now we have calculated the 'occultations' of a number of stars from their known positions in the heavens and the pretty accurately known diameter of the moon, and we find no ground for supposing that the moon was under-rated in measurement owing to a refraction of the light of the stars; we discovered no trace of a departure of its body from the circular form, or of what we call flattening in the other planets.

The test is, therefore, so far conclusive; and if careful experts still, taking all considerations into account, speak of an atmosphere 300 times (Neison) or 1,000 times (Bessel) thinner than our own, there are several ways in which we may philosophically examine the result of their calculations. In the first place this tenuity would amount in the deepest cavities on the moon to a barometrical pressure of from 2 to 0·75 mm., which is equivalent to what is called the vacuum under the glass bell of an air-pump; in the second place it seems as if some experts are straining the evidence to retain an atmosphere at all costs on the moon, because they take their stand on the plutonic theory of its origin, and this involves the formation of a gaseous mantle about the cooled globe.

Johnston Stoney has lately communicated an important piece of knowledge in regard to the assumed atmospheres on various large cosmic bodies. It has been shown that the earth cannot retain free hydrogen and helium permanently in its atmosphere, and that aqueous vapour cannot be found permanently in the atmospheres of Mercury and Mars. Probably none of the moons in our planetary system, except perhaps that of Neptune, has a relatively thick atmosphere. In our moon the expansive property of the gases preponderates so much over gravitation that any atmospheric mantle must have been dissipated into space long ago. Finally, it will follow from our subsequent positions that we can, for a fresh reason, dispense with this atmospheric mantle, and in fact show that there *probably* never was such a thing on the moon. We will only add that the finest tests, including the eclipsing of Jupiter, Saturn, and the sun by the moon, confirm the absence of a lunar atmosphere.

How does the matter stand as regards water? Any man who is well acquainted with its physical, and especially its thermodynamical properties, will know that it cannot exist where there is no air. At the sea-level water must be raised to a temperature of 100° C.

for it to boil; on a moderately high mountain-summit it boils at 95° C., in conditions that correspond to a barometrical pressure of 640–630 mm. The less the pressure exerted on the surface of the water, the less heat is required to bring it to the boiling point; under the bell of an air-pump it does not need to be hot at all, and will even boil at a temperature of 0°. Hence on the air-less moon ice-cold water would boil. In other words, there cannot be any fluid water on the moon.

But the lack of air leads to another and more important feature. We know that the thicker layer of the atmosphere on the level ground amounts to a sort of reservoir for the solar radiation, which is converted from light into heat. On the summits of the Alps, or at a great height in a balloon, the air can no longer retain this heat, so that ice and snow remain unmelted in spite of an increased solar radiation in the purer air, that burns the skin. If we go a step further in imagination, and fancy ourselves at the indefinable limit of the atmosphere, we shall be exposed to the unmitigated ardour of the sun, yet surrounded on all sides by the appalling cold of space. This cold, the so-called absolute zero, lies 273° C. below the freezing point of water. Now, as the moon has no atmosphere, there will be no mitigatlon of radiation, or storing up of heat on it, and its surface must possess in the highest degree the conditions of our loftiest, glacier-covered peaks. *The moon is covered with a thick layer of ice*, and exposed to the intense cold of space—273° C.

Nearly twenty years ago a similar conclusion to this was reached by Dr. P. Andries (*Sirius*, 1887, VII). According to Langley's observations with the Violle actinometer, as amended by him, the solar radiation on Mount Whitny (3,935 yards high) was 31·7° C. above the temperature of empty space (*in vacuo*), and

Violle found a difference of 29·8 C. on Mont Blanc (5,344 yards). When we take into account the real value of the 'solar constant' (the amount of heat that the real solar radiation communicates to 1 ccm. of water in one minute) these figures go up to about 48° C. The basic temperature in the moon must be only −273° C., and its surface cannot, in the best conditions, rise above −225° C. Ericson suggested the complete glaciation of the moon in *Nature* (vol. 34, No. 827) before Andries did so, and gave an explanation of lunar forms on these lines that differs in many respects from that of Andries. Lord Rosse was enabled by his measurements to appreciate the differences in temperature on the moon's surface during full radiation and by night, and found them to be over 300° C. But the temperatures cannot be determined with any accuracy. Lord Rosse's results have often been questioned, but they are supported by the recent investigations of Very. Very believes that at the moon's equator, when the sun is at its highest, the ground increases its temperature by more than 100° C. (which would be −173° C.). When the solar radiation ceases the temperature must fall enormously, and probably approach that of space, which is believed to be −273° C.' (Newcomb).

The objection will be raised, of course, that if the moon has no water, it cannot have any ice. The objection is quite wrong. Ice is certainly the same material as water; but the matter that we express by the chemical formula H_2O, may exist either in the form of solid ice or of gaseous vapour, in conditions where the liquid state is impossible because the degrees between freezing and boiling point are not found. Many terrestrial phenomena, especially the dreaded heavy hail-storms with blocks of ice 4 inches thick, which still puzzle meteorologists, point to an accession of ice from outer space; and the moon with its coat of pure ice is an eloquent witness to the existence of ice in the solar system.

We now come to the question of colour. Aristarchus and various other spots on the moon are lit up so strongly, almost to a pure white, in the solar rays, that even the seasoned eye of an experienced observer is dazed by it, and the inexperienced observer feels pain. Other landscapes look as if they are covered with hoar-frost. Most of them bleach very visibly, forming and depositing a light hoar-frost during the 14-day lunar 'day,' and are dull when they pass away into the lunar night. No material exposed to sunlight shows a similar change of colour, so as to be visible even in the dark. In certain circumstances, which we cannot explain in detail in the present brief survey, the surface may be darkened instead of bleached; it is very remarkable that the deep and isolated circle of Plato has often been made a subject of investigation in this respect*. But the finest indication is the brightness, claimed by the author to be hoar-frost, and increasing with the height of the sun on the crests of the ring-walls, ridges, and mountains, that reflects the strongest light when the radiation is almost vertical, and grows darker as the sun sinks. Many observers, like Majert, think they see the 'snow line' or glacial cap on these peaks, and it is an observation that can be repeated in hundreds of instances. If others have, like the author, seen unillumined parts of ring-mountains glow as if in a faint twilight, this must have been due to earth-light, often in conjunction

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* See pamphlet of W. R. Birt, 1869, another in 1873. Also Neison, *The Moon*, p. 172: *Sirius*, 1887, VII (article of Stanley Williams on Plato): *Sirius*, 1901, VIII (article on 'Pickering's observations of Plato.') The author's observations of the colour of the interior of Plato, which were greatly enhanced on March 6 and 7, 1906, go farther than any other in this department. The map given (Fig. 34) shows this. It must be taken as a general survey, as the visibility of particular details depends on the height of the sun above Plato. The work of showing the ring-mountain in the various phases of illumination yet remains to be done.

with the reflection of sun-light from illumined walls into the lunar night, or at the close of the 14-days' radiation, which may have caused a phosphorescence or luminescence, as has often been observed on glaciers (so Professor Maurer, of Zürich, informs me).

The blackish spots we described in a previous chapter are just as easily explained if we regard them as pure ice. Ice naturally assumes a crystalline and transparent form, as can be seen in any pond. Why these interesting localities do not engender hoar-frost under the 14-days ardour of the sun, as the other parts of the moon's shell, consisting of amorphous white ice, do, may be explained by the fact that smooth surfaces reflect light almost as well as a mirror, and change very little under the action of heat, and so do not form hoar.

Eyes that are sensitive to colour have discovered on the moon regions of every shade of white from yellow and gray to black, as well as greenish and faintly reddish localities. But if wide stretches of the earth's surface may be tinted by meteoric (ferruginous) dust, where atmospheric influences are constantly changing and weakening the colour, it will be much easier for traces of this kind to remain visible on the moon. Here again we may have recourse to the meteoric hypothesis, and regard the meteors, which occasioned the breaches and overflows that we now look upon as 'seas,' as the causes of the colouring of this or that Mare. The shell of the moon must have a mantle of ice; but underneath this, there is, perhaps, an ocean, the waves of which, have at times, broken through or been pressed through the ice. The mass of water, however, could not rush out in an explosive vapour, because there was no air to take it up and convey it. This breaking of the icy shell would probably take place with massive effects on the intensely cold surface, and the fact of the repetition of the catastrophe enables us to understand the overflows that we call ‘ seas ’ and the gradual construction of the remarkably flat walled plains with hollow interior, which would be washed out, so to say, by the ebb and flow of warmer water from below. Lakes of water in depressions of that kind evaporate freely before the freezing or the retreat inwards of the overflow. This vapour must be frozen into ice-dust immediately after its formation ; and the longer and more frequently the hollow is filled with the water in its ebb and flow, the more would this vapour, turned into a cloud of ice-powder, be pressed out by its own weight through holes and passes in the encircling wall. Here it would not be blown to either side by currents of air, and would gradually sink outwards, and *cover the district round with radial streaks.* Thus we would get a corona of rays ! The formation of such very long streaks in some circumstances by the ice-dust may be explained by the persistence of the phenomenon and the slight gravitational influence of the moon on the icy particles.

These suggestions as to how the glacial character of the moon's shell will enable us to solve its greatest problems are all that we need give here. We may now point out that we are calling into question only the plutonic theory of the moon's *surface*, not of the moon itself. Its nucleus, the real body of the moon, which we look upon as covered with the ocean we have suggested, must lie in it like the yolk in the white of an egg. If we assume for this globular nucleus—which we take, on terrestrial analogy, to be metallic-earthy—an average specific gravity of 4·5 (the earth's is 5·5), we need, as a very simple calculation will show, an ocean 115 miles deep (or a round water-shell of this thickness) in order to give the well-known average gravity of 3·5.

We will say just a few words on the remarkable consequences of this theory. The cosmic rain of ice, of which we have previously pointed out one trace, must have acted for ages on the smaller moon of former times, even when it was in the period of incandescence and must have gradually brought it 'under water.' From this point of view we can understand that the enclosed and isolated nucleus would, in consequence of the ever-increasing hydrostatic pressure, not be in a position to evolve gases at its surface from its mineral interior, and so the moon would have no atmosphere. Its ocean naturally accumulated more on the tidal side facing the earth, and formed a huge tidal mountain on that side ; on this account the nucleus must be eccentric, or displaced toward the other side, and so those astronomers are right who place the centre of gravity of our satellite beyond the absolute centre of the sphere*.

Dr. Mainka, also, is right when, on very careful measurement, he can find no trace of the suggested oval curve of the moon's surface in the direction of the earth. The tidal mountain, which remained on the side turned toward the earth, was bound to alter by friction the original rotation of the moon, and thus we get the present situation of relative rest, and the moon only rotates once in the course of its four-week revolution.

These are a few instances showing how questions as to the appearance, light and colour variations, specific gravity, centre of gravity, and shape of the moon are readily answered if this theory of a complete glaciation of the surface of our planet, which we will establish further in some future work, is made the base of lunar exploration.

We cannot conclude our historical account of lunar science without saying a few words about the

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*See Prof. Franz, *Ueber die Figur des Mondes* (1900) ; Dr. Mainka, *Untersuchung über die Verlängerung des Mondes nach der Erde zu* (1901). Cf. also Neison, p. 12.

'changes' which various observers have tried to prove on the moon during the last hundred years. We will not deal with Schroeter's fantastic expectations or Gruithuisen's precarious speculations—such as his discovery of an 'artificial wall' to the north of the ring-mountain Schroeter. Mädler, who had great authority in this direction, was more than reserved in regard to their ideas. Later on comparisons were made between Mädler and Lohrmann's and Schmidt's maps, and from certain discrepancies here and there it was concluded that there had been real changes in lunar objects. But a few examples will show that the first accomplishments in selenography, though they brought an immense amount of fresh detail into the science, were bound to suffer from many omissions and other defects. Indeed, we cannot directly compare our present topographical knowledge with that of our predecessors, who had to acquire very laboriously the information that we gather so easily to-day from maps and photographs.

The defects of the earlier exploration, the instruments and magnification employed, and possibly the influence of suggestion, can be seen very well in Mädler's repeated study of the small craters Messier and Messier A. He thought that they were absolutely alike in detail, and reproduced them as simple ellipses. Schmidt then wrote an exhaustive monograph at Athens, and gave them a characteristic form—also indicated by Lohrmann—on the map, yet we find them reproduced on Klein's map (1884) in the older and inaccurate version of Mädler. We may add that Gruithuisen had given a more correct presentation of their size and shape in 1824. To-day the craters are as different as possible. A peculiarity in the eastern wall was first discovered by Schmidt, and since then the author has detected many interesting details, as will be seen on the map we have given. The original map is on a scale of 1 : 200,000, or half the size of the new German national map.

The question of 'changes' first came to the front when Schmidt in 1866, failed to find the crater Linné indicated on the older maps. It at once excited a heated controversy, the only useful result of which was that at last a large number of astronomers—not very expert in lunar exploration, it must be said—

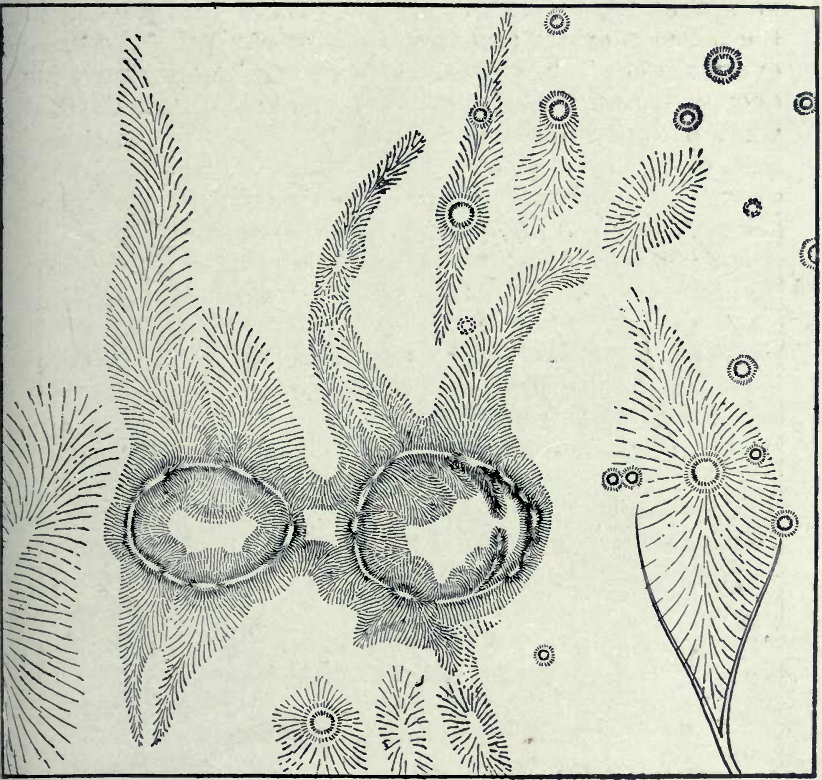

FIG. 56

Map of the crater Messier and A, by Ph. Fauth (1 mm.= 650 m) were induced to turn their large telescopes on the object, and so a number of finer features were detected. We know these details much better to-day than the plan shows; but the older communications show quite plainly that there cannot have been any change in the object. We can now say confidently that Schmidt contended much too rashly and obstinately for a change. Klein, it is true, refers us to Mädler's original drawings, which he has studied, but one can gather as little from this as we could in the case of the Messier crater and the Hyginus cavity. We have every reason to know that Mädler and Lohrmann were deceived, and that Linné never looked different from what it does to-day.

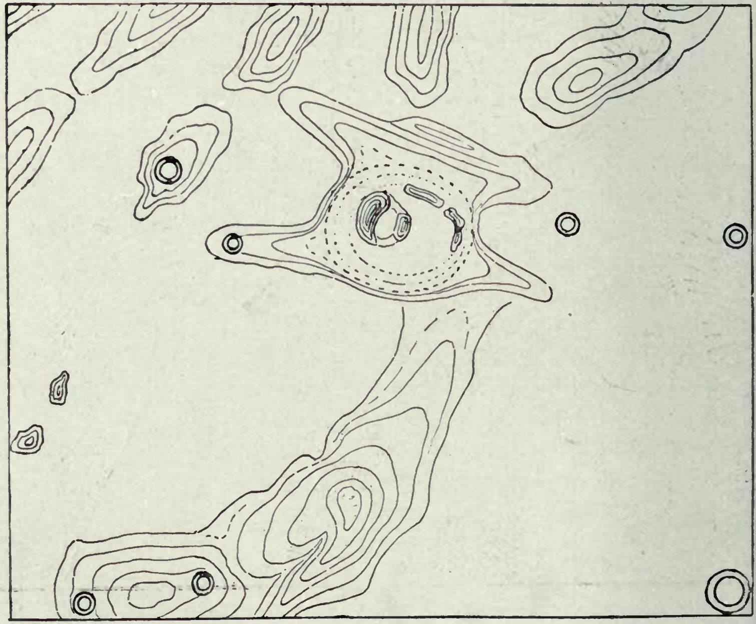

Fig. 57

Plan of region round Linné, by Ph. Fauth (1 mm = 450 = 450 m.)

The question is not yet abandoned, but it may be said that the whole literature of the supposed changes in the last forty years turns on Schmidt's fateful conclusion. Professor Prinz and L. Brenner have made more extensive investigations of the object*. Among the many opinions expressed on the subject in the last few years we will quote only three, as in these cases powerful instruments were employed. In the first place Professor Pickering noticed at Arequipa (1897–8) changes of size in the white spot of Linné (see note, page 42), which is given in punctuated lines on our chart. The spot was large when it emerged from the night, decreased rapidly until a day after greatest illumination, and then slowly regained its proportions; and during the eclipse of the moon on October 16, 1902, the diameter increased in the shadow. The same thing was observed by Dr. Wirtz with the Strassburg 18-inch telescope during the eclipse of April 11, 1903. Professor Becker rightly remarked that there was probably a fault in the observation, and we may support his objection with the following explanation:—At first Linné was probably measured too small in the glaring light, as the unseasoned eye of the observer would sustain some strain, and the spot is not very sharply defined. When the light diminished in the eclipse, and the eye had grown accustomed to the milder tones, the dim outline of the spot was measured again, and larger dimensions were found. An eye that is less sensitive to lunar light can trace the outline of the white spot at other times. Now, Dr. Wirtz has made

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* See Prinz in *Ciel et Terre*, 1903, ix: 'y a-t-il eu des changements dans les cratères lunaires Messier et Linné?' Also *Sirius*, 1877, viii, for Schroeter's observations; and *Sirius*, 1893, xii. Brenner writes in the *Naturw. Wochenschrift* on 'Changes in the Moon,' and in the *Astr. Rundschau* (no. 71) on 'The crater Linné.' See also Fauth 'Linné and lunar changes' in the *Astr. Rundschau* (no. 73), and in *Sirius*, 1877, v and vi: also Klein's *Durchmusterung* (p. 160), and article in *Sirius*, 1884, iii (with map), and Schmidt's *Ueber die Mondlandschaft Messier*, 1882.

continued measurements of it during a lunation, and found that 'the diameter of Linné varies in the course of a lunation, and the formula is that, after a lunar day has begun for it, at about the seventh day of the moon's age, it increases about 116 yards each succeeding day, until it passes into the night again, when the moon is about twenty-one days old.' This formula must be taken with great reserve.

Professor E. E. Barnard has discussed a number of measurements of Linné taken with the 40-inch telescope at the Yerkes Observatory from December, 1902, to November, 1904, and found surprisingly little of interest in them (see note, page 42). In general, he believes that the spot decreases as the illumination increases, and is reduced to nearly half its diameter

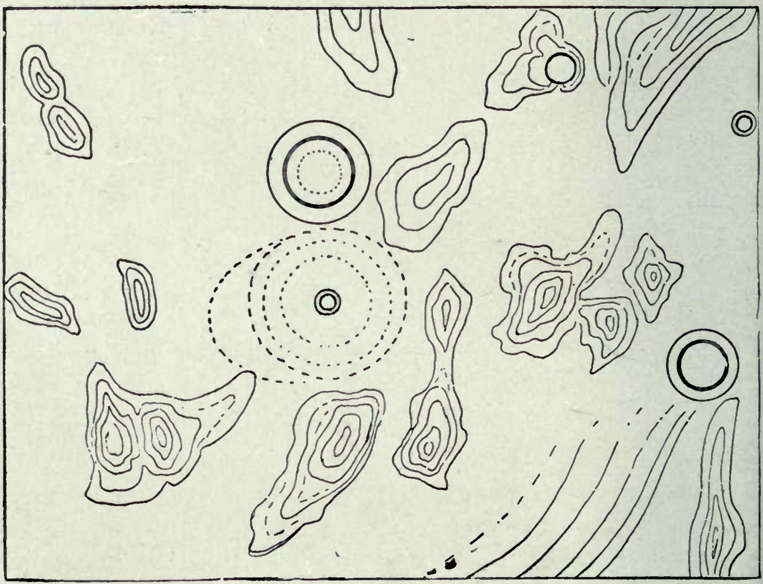


Fig. 58

Chart of the region about Alpetragius, by Ph. Fauth (1 mm.=460 m.)

in a strong light. Professor Pickering has attributed this change to a deposit of hoar-frost, and we can thus welcome his explanation as a support of our theory of the icy character especially of the white spots on the moon. No progress has been made in determining the topography of Linné beyond the chart given here, but the question is whether there has been any change in the crater. We do not believe there has. We may add that Mädler made the same topographical mistake in two other cases (Parry B and Alpetragius D); he thought there was reason to regard white spots as flat craters. Lohrmann avoided that mistake, but fell into others in describing flat mountain-tops as the craters. In this respect it is noteworthy that Schmidt, startled by the threefold repetition of the case, only expended his zeal on Linné, and not on the other quite analogous cases. He must have felt himself that he had gone too far in the first case.

The progress of lunar research has taught us that we cannot swear to any single one of the thousands of details on the early maps. Even Schmidt's map, which was completed fifty years later, has serious defects here and there. The present author himself has had to strike out a 12 mile wide crater ('Melloni,' section XIX), which does not exist at all. And on testing the two older maps, we found the following surprising results:—On half the surface of the map (not counting the chaotic mountainous districts) for instance, to the south, and without the border districts) Mädler has omitted 17 craters of such dimensions that they ought not to have escaped him; and on the other hand, he gives 337 pits and small crater-structures that are not found on the moon at all. We can easily recognise Mädler's conscientiousness in taking white spots for craters. Lohrmann also has not seen many craters that were certainly within the range of his telescope, and given 95 craters that did not exist. These instances warn us not to draw general conclusions from the small crater-forms given on these two maps.

Further support to the theory of physical changes was found in the groups of rills on Aristarchus and Ramsden. The author, who has prepared two exhaustive maps of these, and has spent 21 years in lunar observation, can only express his surprise that any changes or 'disturbances' were claimed here. At Landstuhl there has never been any ambiguity about the details. The idea of the possibility of extensive changes in the appearance has sometimes occasioned the most curious results. Specialists announced, for instance, that Lohrmann's great gray spiral structure in Triesnecker, had disappeared; yet one can see it well enough in any moderately successful photograph, and it is perfectly clear with the telescope in a good light. The blackish spots in Alphonsus are supposed to have changed; as if there had ever been any special attention paid to them. Even Dr. Klein's special map (*Sirius*, 1882, IX) shows how little people expected in

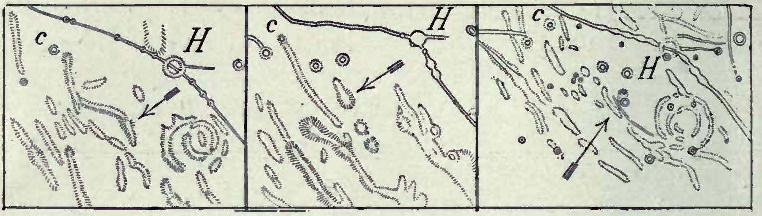
Fig. 59
Pickering's map.

Fig. 60
Fauth's map.

The dark spots in Alphonsus.

these things formerly (compare our maps in Figs 42 and 43). In further illustration of our point we may take Pickering's and the author's reproduction of the Alphonsus spots. Two darkly outlined small craters in the Mare nectaris could not have been overlooked by Mädler and Lohrmann, it is said ; as if the former had not overlooked 17 others, and the latter had not indicated a cavity at the very spots ! They did not look for dark spots, nor are the craters in question of such a nature that they would be likely to catch the eye of early observers. From Schroeter and Gruithuisen we have nothing to expect in this direction. In the same way a number of novelties of more considerable dimensions have been signalised at different places. They have proved quite groundless and can generally be traced to the observer's unfamiliarity with lunar matters.

We repeat that if lunar experts had not been stimulated by the futile problems of Messier and Linné, many of the more recent statements about other localities, particularly about the region of Hyginus, near the centre of the moon, would have had a cooler and more judicious reception. There is not only the cavity, Hyginus N, first announced by Klein in 1877, but also a broad flat valley (between the Schneckenberg and the crater of Hyginus), 19 miles long and two miles wide, and between the two a very small crater, 'Hyginus N 1,' according to Krieger, and a group of 8 or 10 very small pits in the vicinity, in which Brenner found changes. In view of the obstinacy with which 'Hyginus N' has for nearly 30 years been maintained to be a new formation, it is advisable to emphasize the fact that the deep shadows of the cavity are due entirely to its western edge with a longish dome, that the so-called 'crater' only has the appearance of a cavity at sunset, and that Mädler himself described the dome, the cause of the 'black crater,' and the



Figs. 61-63

The region of Hyginus. Sections of Mädler's and Lohrmann's maps (natural size.) Klein's map (slightly enlarged.)

crater lying between it and Hyginus (describing the latter as a hill); he also clearly reproduced the elevations to the west of the latter in the form of a longish hill, as correctly as was possible with his instrument.* Lohrmann, again, has reproduced with great fidelity the district to the west of 'N,' and especially the hill in question. If we suppose, as we are entitled to do, that both these older masters recognised the hill as casting a shadow, and they needed only a single observation at sunset to convince themselves that the cavity is not dark then, and that the eastern appendage of the hill shines white—they would not have had the least occasion to give a crater on their maps. A hill was quite enough—and a hill they gave.

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* Cf. Rand Capron's remarks in *Sirius*, 1886, i, where he wrongly describes this hill (crater ?) as Hyginus N. Klein speaks in the same periodical of the details of Mädler's map, which he certainly could not identify. The hill in question is the larger crater to the east, marked 78 on Brenner's map (*Naturw. Wochenschrift*, 1896, x). Cf. also *Sirius*, 1879, iv, where Klein speaks of sketches made with Lord Lindsay's 15-inch. 'In the second sketch one recognises a hill there,' he says. Neison says (*Sirius*, 1879, vi): 'there was no trace of a bright edge;' and in regard to a drawing of Edgcomb's, who had observed with a 9·3 inch like himself, he says: 'there was no wall to be seen.' Klein further remarks: 'some English observers have pointed to the fact that the new object N in Hyginus is not a crater, but a concave depression, or a spoon-shaped marking of the ground.' In *Sirius*, 1893, i, Roger Sprague declared N to be a shadow of the western hill, which is in part correct.

Fig. 64

Map of the Hyginus region, by Ph. Fauth (1 mm. = 1,050 m.)

As to the large valley near Hyginus, that is plain at sunset, but soon becomes invisible; it is said that Gruithuisen's observations make it clear that he must have seen it and reproduced it especially on November 28, 1824, at 5.30 in the evening, if it had then been visible. In order to study the matter properly the author has used 36 drawings with the shadows, in addition to his own observations, and compared with them Gruithuisen's drawing, taken when the terminator was 1° to the east. The result was as follows. In the first place at this stage of illumination the valley is only vaguely, and not definitely, shadowed; in the second place, on Gruithuisen's drawing, which was only made for the sake of the finer rill of Triesnecker and two fine 'circlets,' this object comes on the extreme left, and actually touches the edge of the drawing. Klein's comparative sketch is incorrect in the position of the valley, in blackness and in the distance of the valley from the edge of the paper. It is thus clear that Klein has failed in his proof. That Gruithuisen, moreover, was not too accurate in things that he did not wish to emphasise is clear from the omission of the shadows in the craters A and B, and the mountain to the north of them, though even these are well characterised and much easier to recognise than the 'circlets.' They were not recognised by Krieger with a 10-inch refractor. Schmidt himself, who drew the valley on February 18, 1869 (*Sirus*, 1882, I), and added further details on March 28, 1871, *overlooked* it on June 5, 1870, and December 7, 1872, when it was particularly visible. On June 5, 1889, V. Nielsen discovered a flat pit, running from the cavity 'N' toward the valley on the south-east, and this is omitted on four drawings by Stuyvaerts and those of observers generally. The author was the second to notice it, on March 17, 1891, during his fourth or fifth observation of the Hyginus region—the 6½ inch refractor had only

FIG. 65. Map of the vicinity of the cavity Hyginus N., by Ph. Fauth (1 mm. = 505 m.)

been established nine months—and it is really an easy object. Yet Krieger made a drawing of the district on April 12, 1894 (*Atlas of the Moon*, Pl. 8), with a 10-inch telescope and powers of 175 and 520, and failed to see this easy depression. We must conclude that there has not been sufficient discrimination, and that new foundations have been assumed too readily. The belief in these changes in the Hyginus region seemed to be a better position than the belief in a collapse of the ‘ former ’ Linné, and so the author thought it well to enter more closely into the matter. Students may be invited to consider the details within the cavity, as we give them on Fig. 65.

The object N also is not a new formation. It was given by the author on a special map in July, 1893, and afterwards claimed by Krieger to be a ‘ new structure.’ The pits which Brenner regards as newly-formed are objects of such delicacy that it took all the work of that observer and the present writer to establish their existence. The very fact that these and others have only been gradually detected shows that with practice and perseverance we may discover many things still in the middle of ‘ known localities,’ yet they will not be ‘ new formations.’

The author has no wish to enforce his view of these things on other selenographers ; but as a student of the moon for the last 20 years, and as probably one of the few living investigators who have kept in practical touch with the results of selenography, he is bound to express his conviction that no eye has ever seen a physical change in the plastic features of the moon’s surface.

It is fortunate that the investigation of ‘ changes ’ has been directed in another direction, namely, to the study of the alterations of light and colour that recur in almost the same way every month. This is the proper quarter for enquiry. Besides the particular works we have mentioned on certain dark spots, there are earlier and recent researches on the plain of Plato and the interior of Alphonus; we have already given illustrations of these. In addition, Professor Pickering has made the characteristic ring-mountain Eratosthenes the subject of a searching enquiry, and has published pictures of it with which we must deal briefly*. The evil star that has ruled lunar observation in a transitional period has wrought its mischief here also. In a word, it is improper to speak of the lines and spots that Pickering saw on the walls and in the vicinity of Eratosthenes during the advance of the illumination as 'canals' and 'seas.' These ideas have introduced error enough in the case of Mars. We may say, in fact, that the object depicted by Pickering does not exist in that form. The American astronomer only shows that he has approached a difficult task without proper preparation, and that he is not well acquainted with the topography of the ring-mountain. The details he gives are sometimes so sharp that they are found on moderate photographs.

There is not much to be done on negative grounds, without positive proof. On this account we have commenced a series of observations of brightness on the basis of a thorough topographical detail-map, and in the course of 1906 we intend to reproduce the light-tones during a whole lunation, in order to prove to those who are interested what the real nature of these mysterious new formations is. Up to the time of writing, the observations have only confirmed the judgment we expressed above. We will only add that

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* *Sirius*, 1902, x, and 1904, xii (with drawings and photographs). See also the recent communications of J. Deseilligny (*Bulletin de la Soc. Astr. de France*, 1906, iii), where the variations of the spots in Flammarion, and to the south of Archimedes are described, according to observations with a 4-inch Bardou telescope with a power of 160. The variations are a normal phenomenon, as in the case of all particularly dark lunar spots; they are repeated in much the same form every month, because they depend on the duration and angle of incidence of the solar radiation.

the lines and streaks are almost always the least direct gorges, valleys, depressions, cavities, etc., that are only gradually exposed to the sun-light, and bleach more slowly; and these can be followed in a much finer form in the much-terraced slopes of Copernicus. We may repeat that the recent announcements from America, which usually command such confidence on account of the size of the instruments employed, have not yet made any appreciable contribution to our knowledge of lunar conditions of the monthly variations in the appearance of the finer features. It is very important to bear well in mind all that was discovered by German observers, so that further investigation may build on this, instead of losing itself along a false path. The first epochal works on the moon came from German writers, and the greatest map of the moon was constructed in Germany.

Our study of the nearest and most accessible of cosmic bodies would hardly be complete if we did not say a final word on the question of its habitability. It is not necessary to say much. Even if many of our measurements of objects on the surface of our satellite were incorrect; it remains at least, indisputable, that it has no atmosphere, in the ordinary sense of the word, and no water. Hence we need not indulge in speculation about living inhabitants. It is true that gills or tracheae, as well as lungs, serve the purpose of breathing at the bottom of our aerial ocean, and that bacilli, for instance, can endure an intense cold, comparable to that of space without perishing. In this way we might grant that living things of unknown organisation might subsist on our satellite. But the only question of great interest for us is whether beings approaching the human type could live there.

Sometimes we find imaginative writers seeing traces of ‘vegetation’ in the moon’s colour-changes.

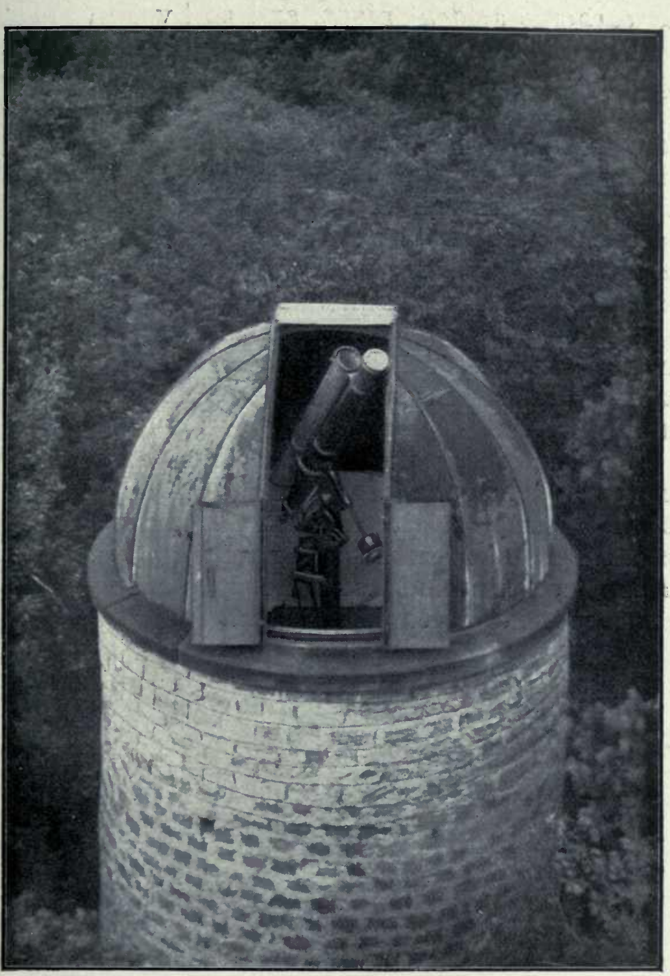
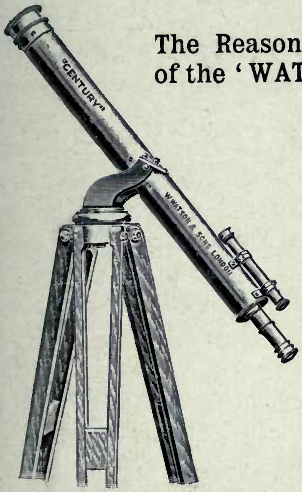


FIG. 66. The author's observatory at Landstuhl, with 6½-inch and 7-inch refractors, at an elevation of 450 feet.

But vegetation gives off oxygen during the day-time and carbonic acid at night, and so lives in 'air.' It is, therefore, unmeaning to speak of inhabitants or organisms of any kind intelligible to us on a planetary waste without air or water. The largest telescopes in the world and the most laborious research cannot yield this result. But work that yields us a more accurate knowledge of those localities that are found to be most effective in bringing us nearer the solution of the moon's hieroglyphics, is sure to lead to general cosmic as well as specifically lunar results. How much material may be gathered in such research by either professional or amateur astronomer may be judged from the small maps given in the present work and the perspective opened out on page 20.

We come back therefore, to the starting point of our work. The cuneiform writings on the moon's surface are destined to give us fresh and clearer ideas as to the natural development of our solar system, provided our astronomers understand the signs of the times and do not let the opportunities be lost.



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