The Origin of Our Moon

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A NUMBER of years ago, Professor George H. Darwin propounded the view that the Moon was originally a part of the Earth, and had been separated from it by centrifugal force. His conclusions were supported by a mathematical analysis which has since become classic and are accepted at the present time by practically all the astronomers of the world. To understand his line of argument and conclusions we must first consider the mutual influence that the Earth and the Moon exert on one another at the present time. We all know that the Moon raises a double tide upon the ocean, by means of which large masses of water are transported over the surface of our globe. This motion causes friction, which uses up energy. The Earth may, in fact, be compared to a grindstone revolving between two brakes. This action retards its rotation, so that every day is a little longer than its predecessor. The effect is so slight, however, that the day is only a fraction of a second longer now than it was at the time of the Christian era.

The interior of the Earth is now known to be solid, but in the early geological times this was not the case, and the Sun and Moon acting on the molten interior of the Earth, there generated tides that were much more efficient than those now in existence. In those days the terrestrial day was much shorter than it is at present.

But, if the Moon is constantly retarding the rotation of the Earth, since action and reaction are equal and opposite, the Earth must be constantly accelerating the motion of the Moon. If its velocity in its orbit is increased, the centrifugal force will be increased also, and it will tend to fly away from the Earth. As a consequence the Moon is farther from the Earth to-day than it was a thousand years ago, and it will be still more remote a thousand years hence.

Carrying our thoughts back by means of this reasoning several hundreds of millions of years, we come to a time when the distance of the Moon from the Earth was only a few thousand miles, and when its revolution was accomplished once in four or five hours, instead of once in thirty days. Darwin has shown by computation that at this date the Earth would also by a curious coincidence have been revolving on its axis once in four or five hours, so that the Moon would have constantly remained over the same point of the Earth's surface. Now by another coincidence it can be shown that at this speed the centrifugal force at the equator would be so great that portions of the surface would be liable to crack off and fly away from it. Darwin concludes that the coincidence in time of these three facts is not due to mere accident, but at this early period the planet actually did separate into two parts to form our present Earth and Moon.

Going back for a moment to a still more remote period, we find that the Sun, Earth, and Moon originally all formed one gigantic nebula. Until within a few years it was supposed that the nebulæ were intensely hot bodies. It is now believed that they are generally cold, shining by electric illumination. As they condense into stars, however, they become hot, and at the time the united Earth and Moon separated from the Sun, it is thought they were so hot that much if not all of their material was in a molten condition. The temperature could not have been so high,

For a more detailed and technical account of this subject, see papers in the *American Journal of Geology*, 1907, XV., 23, and in the *Memoirs of the American Academy*, XIII., Part IV., by the author.

however, as to disassociate steam into its component parts, otherwise the hydrogen would have escaped, and we should have had no oceans at the present day. It is likely that much of the steam that at this time formed part of our Earth has since escaped into outer space.

When the nebula consisting of our Earth and Moon separated from the Sun, it was given a rapid rotation on its axis, and as it condensed it may be shown that this rotation must necessarily have become still more rapid. Finally, when the speed had reached a sufficient velocity, it split in two parts. This is substantially Darwin's statement of the method by which our Moon came into existence.

We have, indeed, countless illustrations of this same process going on before our eyes in the heavens about us, only on a much larger scale. Reference is here made to the case of the short-period variable stars. It appears that certain stars have a tendency to split in two, the components revolving rapidly in small orbits around their common centre of gravity, but so close together that they appear as a single star, even in our most powerful telescopes. The tidal disturbances they produce on one another cause the fluctuations of light by means of which we are enabled to determine their period of rotation. At the time that the actual separation occurs a considerable amount of energy must be liberated, and it is possible that this may be related to the celestial phenomenon known as the appearance of a temporary star or *nova*.

Returning now to our Earth-Moon planet, Darwin has shown that at the time the division took place it could not have been much larger than the Earth is at present It must, therefore, then have been largely in the solid or liquid condition. It is possible that the condensation of our ocean from the atmosphere of steam furnished the impulse required by Darwin to start the Moon upon its way. However that may be,

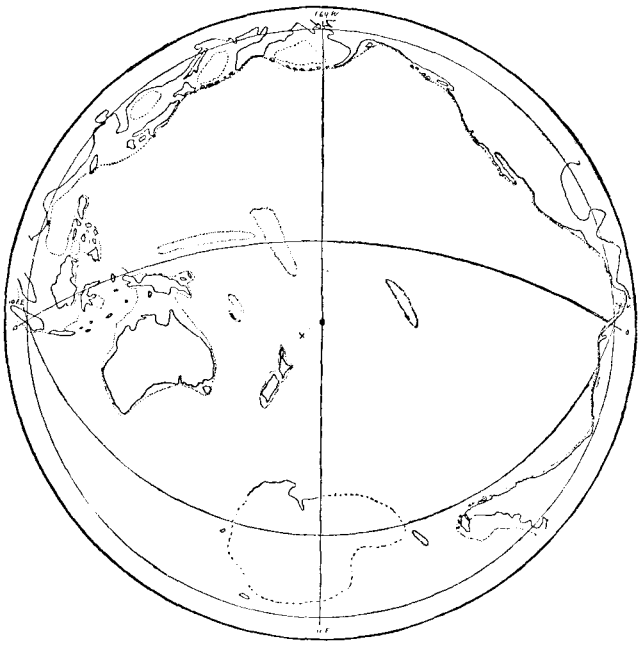

FIG 1.—View of the earth from a supposed perpendicular erected about one thousand miles northeast of New Zealand

something started it, and it now becomes a matter of interest to determine, if we can, from what part of the Earth it took its flight.

If the entire surface of the Earth were liquid at this time, such a search would obviously be hopeless. But such a hypothesis is highly improbable, since, as we have seen, the temperature could not have been extremely high, and so diverse are the substances of which the Earth is composed, and so high the melting-points of many of them, that it is not likely all would have been liquid at the same time. The force of this argument is still further increased by the varying pressure to which they would have been exposed in the Earth's interior. This pressure would affect their melting-point materially. It seems probable that our globe, from the time that it first came into existence as a sphere until the con-

densation of our oceans upon it, must, owing to radiation into outer space, have at all times presented a solid exterior surface.

Assuming, then, a hot, solid Earth, with an interior more or less liquid, revolving on its axis once in about four or five hours, we have a picture of our as yet moonless planet as conceived by the astronomer. If the crust was solid when the Moon escaped from it, it is almost certain that some sort of scar would have been left to indicate its birthplace, and it is the object of our present study to see if we can find it.

The specific gravity or density of the Earth as a whole is 5.6—that is to say, if we could put it in a giant pair of scales it would be found to weigh 5.6 times as much as an equal volume of water. The specific gravity of the Moon is 3.4, while that of the surface material of which the Earth's crust is composed averages about 2.7. If we were to dig down from the surface, we should find the specific gravity of the material removed gradually but steadily increasing with increasing pressure, until the denser core of our Earth had been reached. It is therefore evident that the Moon must be composed of material scraped off from the Earth's surface, and that it does not contain those heavy materials, doubtless metallic masses, which are to be found towards the Earth's centre.

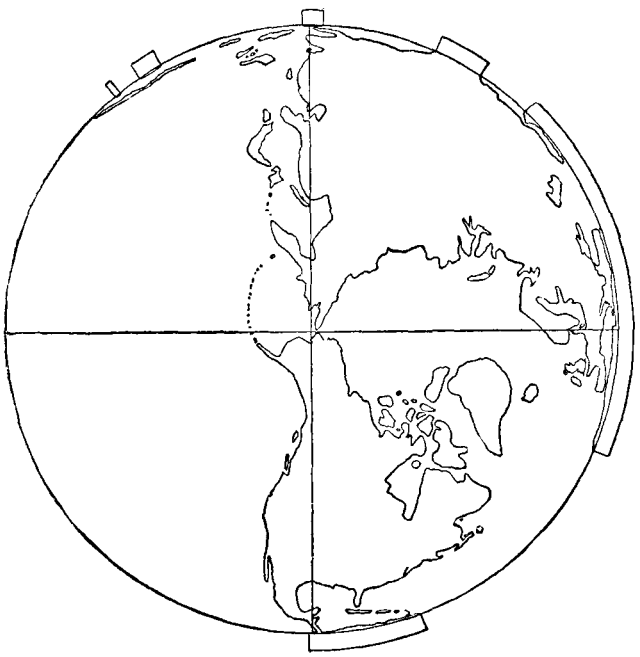

FIG 2.—View of the earth from a supposed perpendicular erected in the vicinity of Bering Strait

Turning now to our own geography, it is a well-known fact that our land and water are very irregularly distributed. If we erect a perpendicular about a thousand miles northeast of New Zealand, and view the Earth from a distance in the prolongation of this direction, we shall find it to present the appearance shown in Fig. 1. This map is so drawn that distances in a radial direction are not distorted, and the outline of the Pacific is therefore shown in its true form. Comparatively little land is visible, and the outline of the ocean is nearly that of a great circle. Near the centre, indicated by a little ×, is one of its very deepest portions.

If now we travel due north from the centre, one-quarter of a circumference, till we reach the vicinity of Bering Strait, and erect another perpendicular, we shall find an appearance somewhat like that shown in Fig. 2. In this figure the continents have been allowed to project outside the circumference of the globe, so as to show more clearly where they are located.

The centre of gravity of the Earth is the centre of the circumference, but it is clear that the centre of gravity does not coincide with the centre of figure. In other words, the material forming the continents is lighter than that forming the ocean-beds. If the oceans were drawn off, this difference would be still more marked. The centre of gravity would then be slightly raised in the

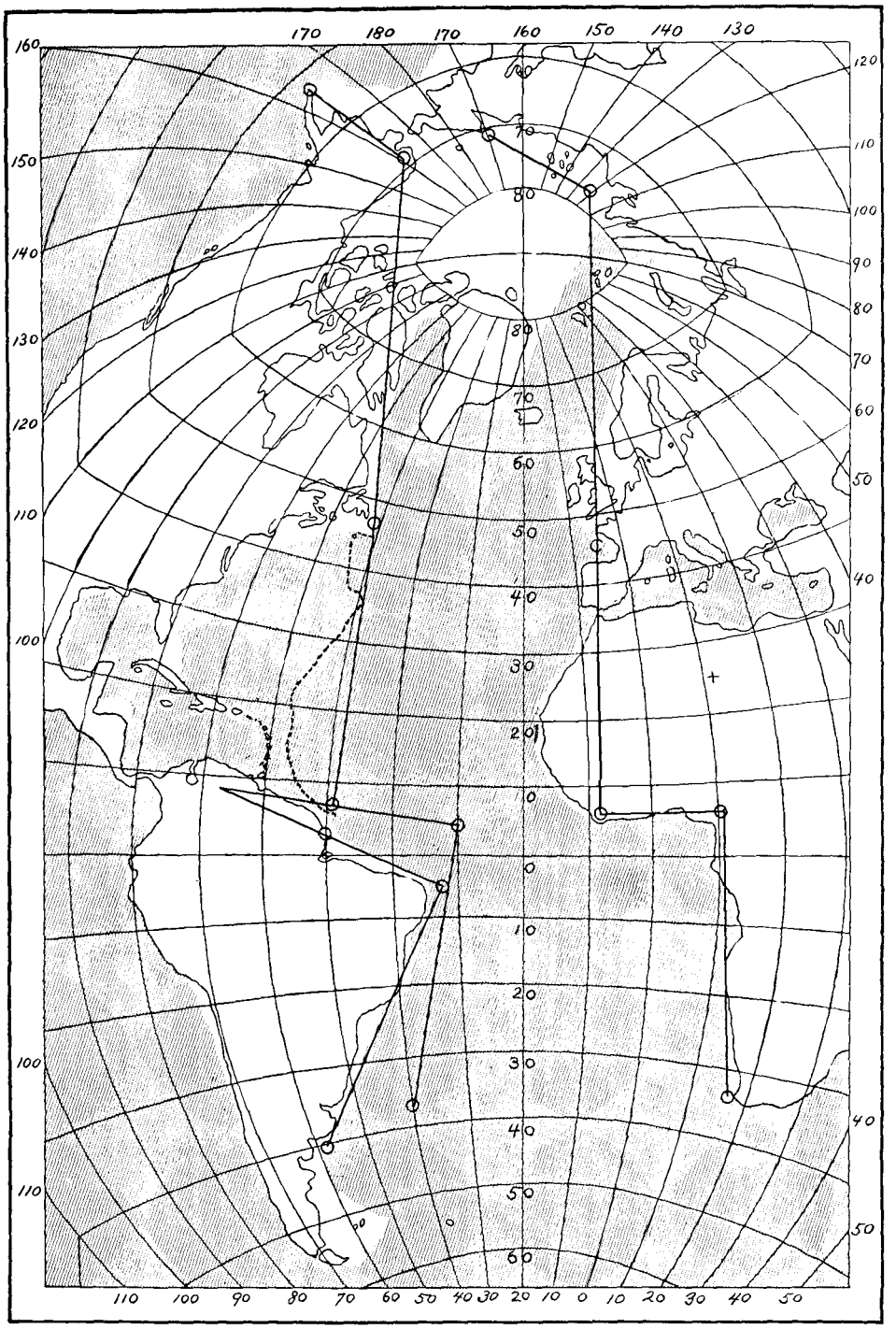

FIG. 3.- Map of eastern and western sides of the Atlantic Ocean. The straight lines joining the small circles show how the earth's crust, now forming two continents, is supposed to have been split in two and dragged apart when the crust formerly covering the Pacific Ocean was carried away, according to present theory, to form the moon

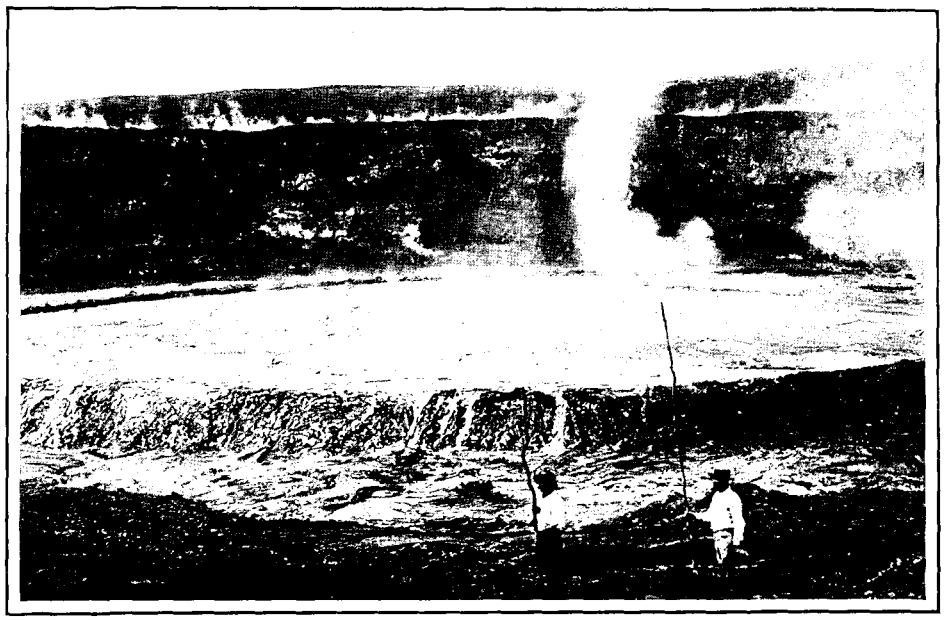

FIG. 4.—ENGULFMENT CRATER OF THE CRATER-RING CLASS IN PROCESS OF FORMATION

sketch, and the centre of figure still more so.

Practically all geologists agree that the continents are permanent surface features of our globe, which have existed from the earliest geological times. When the Earth was originally formed, the lighter material must have been distributed nearly uniformly over its surface. How is it, then, that we now find all the light material on one side only? Moreover, we find a mass of light material of about the same density up in the sky, which we have strong reasons for believing once formed part of our Earth. It does not seem probable that all the light material now forming the Moon was originally heaped on top of the light material forming our continents. Admitting the premises therefore, the only probable conclusion seems to be that the material of the Moon came from the other side of our globe, and that in the bed of the Pacific Ocean we see the scar formed at the time of the birth of our Moon.

If we examine Fig. 3, we shall find that the outlines of the two sides of the Atlantic bear in some places a striking similarity to each other. This is shown more clearly by the two heavy broken lines which indicate where they might be fitted together. It is suggested that when the crust formerly covering the Pacific was carried away, the remaining crust forming our present continents was split in two, and dragged apart to form the bed of our present Atlantic Ocean. If so, South America must have been also partly rotated about a point to the east of Panama, as shown in the figure.

The action that took place was then somewhat as follows: As the part of the Earth's crust near the present islands of New Zealand began to rise, in obedience to the centrifugal force developed by the Earth's rotation, the crust on the opposite side cracked and split in two, forming the bed of the Atlantic Ocean. Before the crack could widen more than two thousand miles the pull became so intense that a huge, roughly circular piece, forming nearly three-quarters of the Earth's whole crust, was taken out of the middle and carried away to form the Moon. This left a continent on each side of the Pacific. Thus the Atlantic bed was formed only a few moments before that of the Pacific, and the necessity for two chief oceans instead of one is made fairly apparent.

The point exactly opposite the centre of Fig. 1 is indicated by the little + in northern Africa.

If we examine the coast-lines of our great oceans, we shall find that of the Pacific bounded by a nearly continuous row of active or recently extinct volcanoes. These volcanoes frequently lie in curves, sometimes existing as islands, but nearly always convex towards the ocean. (See Fig. 1.) The Atlantic, on the other hand, is obviously of different structure. The coasts are low and flat, usually non-volcanic, and the general sweep of the outlines is as frequently concave as convex. The only convex chain of volcanoes existing is that of the Lesser Antilles. This is also the only place where the two sides of the Atlantic do not match satisfactorily, and it is possible that here, too, the Earth lost a small piece of its substance to the Moon. The geologists also tell us that it is certain that a continental area, narrow at the north and widening at the south, formerly existed to the eastward of the United States. This area they believe to have sunk beneath the ocean in more recent times. One or the other of these two explanations is probably correct, and perhaps they both are true. Either would account for the greater breadth of the Atlantic at this point.

As compared with our own terrestrial achievements, the lifting of an area covering an ocean-bed to form a new planet, and the splitting apart and transportation of two continents through thousands of miles across a fiery ocean in the space of a few minutes, seem impossible of conception. Yet to the great celestial forces, whose effects we see in daily operation in the heavens about us, not only such a result as this, but even the crushing and utter annihilation of our tiny Earth, would be a mere bagatelle—an affair that might be accomplished in a few seconds. Even the flash of our funeral pyre would hardly be noticed from the nearest star.

Dealing with the subject now from the quantitative standpoint, the volume of the Moon is equivalent to an area equal to that of all the terrestrial oceans and having a thickness of thirty-six miles. We must conclude, therefore, that at this time the Earth had a solid crust thirty-six miles in thickness, supported on a liquid or potentially liquid interior. By potentially liquid is meant that if relieved from the enormous external pressure to which it was exposed, due to the weight of the matter above it, the solid interior would at once liquefy.

The ocean floor has been found by soundings to consist of an enormous

FIG. 5.—NEAR VIEW OF A PORTION OF THE CRATER RING

plateau, situated at an average depth of about three miles below the continental surface. The continents must then have

FIG. 6.—Two crater rings on the moon, Schickard and Phocylides

floated like two huge ice-cakes in this ocean of molten matter. Since their density was the same as that of the Moon, 3.4, since also they were thirty-six miles in thickness, and rose three miles above the surface of the liquid, the density of the latter must have been 3.7. We know little of the density of the material lying beneath the ocean floor, but in some places it has been forced to the surface, as in the Hawaiian Islands. Tests made by E. D. Preston, of the United States Coast Survey, have shown that its density is very high—higher, in fact, than the density of any other region yet tested. The result found was 3.7, or exactly the value we have just reached based purely on theoretical grounds.

Geologists at the present day speak of the crust of the Earth, as distinguished from the material existing at greater depths within its interior. Both are understood to be solid at the present time, but the difference consists in a sudden change in the kind of material existing there. The thickness of this crust has been estimated by different methods. The rate of increase of temperature as we descend has led Bonney to believe that lava is usually forced up from a depth of twenty to thirty miles. Owing to reduced pressure on reaching the volcanic vent, the lava is supposed to liquefy at that depth. Computed from the speed of travel of earthquake waves, Fischer and Milne have placed the thickness of the crust at about thirty miles. Judged by the amount of radium contained in the igneous rocks of the Earth's surface, and the total quantity which the Earth can be assumed to contain, Strutt has computed the thickness of the crust to be about forty-five miles. It is interesting to note that the thickness that we have found dependent on the volume of

FIG. 7.—Lunar crater of the terrestrial type, recently discovered at Harvard on a lantern-slide made at the Yerkes Observatory

the Moon—thirty-six miles—lies well between these values. It is certainly gratifying that four computations based on

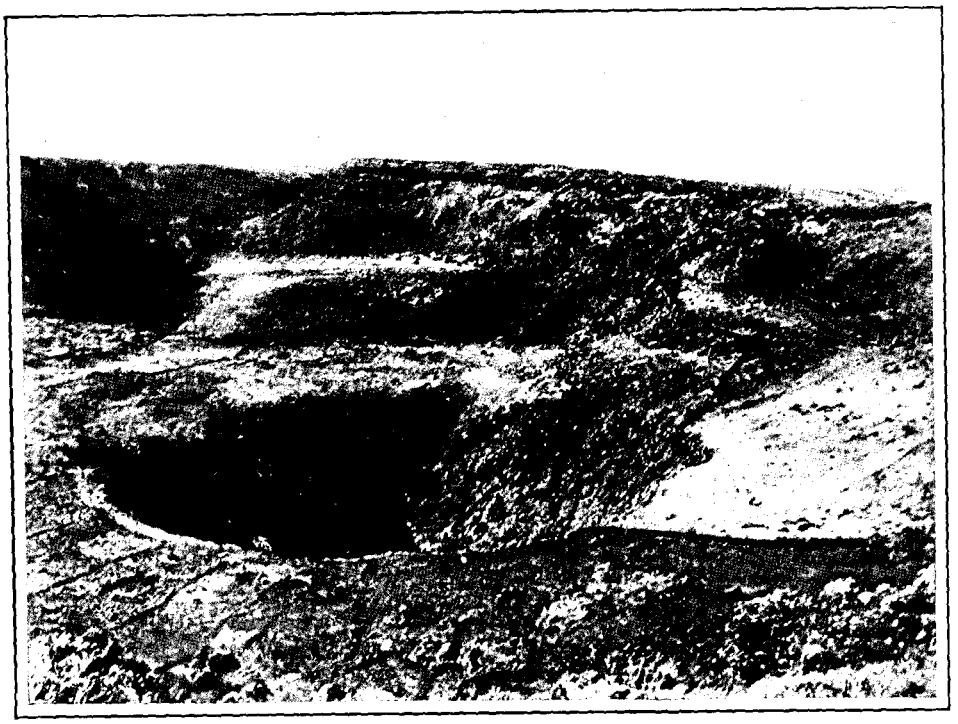

FIG. 8.—PIT CRATER OF KAUHAKU, MOLOKAI, HAWAIIAN ISLANDS

such dissimilar data should all lead to so nearly the same result.

If it is true, as here suggested, that we owe our continents and ocean-beds to the Moon, then the human race owes far more to that body than we have ever before placed to its credit. If the Moon had not been formed at all, or if it had carried away the whole of the terrestrial crust, our Earth would then have been completely enveloped in its oceans, as may be the case with the planet Venus at the present time. Our race could then hardly have advanced beyond the intelligence of the present deep-sea fish. If, on the other hand, the Moon had been of but a fraction of its present bulk, or if it had been a little larger than it is, our continents would have been greatly diminished in area, and our numbers decimated, or our lands overpopulated.

When the Moon first separated from us, it doubtless broke up into numerous irregular pieces, which later coalesced, when they had reached a suitable distance from the Earth. The Moon could never have existed as a uniform ring revolving about us; neither could it have existed as a huge sphere just clearing our surface. When the various parts of which it is formed finally united, they may have completely liquefied, and it was at or soon after this time that the larger lunar craters were formed.

It used to be supposed that all terrestrial volcanoes were of one kind, and that all volcanic activity was due to explosions of steam. It was found impossible to explain the origin of the lunar craters on this hypothesis, and numerous other suggestions, such as the fall of huge meteoric masses, were proposed as a solution. Latterly it has been found that there is a second kind of terrestrial volcanic crater, which belongs to what is known as the engulfment type. These craters are found in various parts of the world, but at the present day all are extinct save two, located in Hawaii, and these are active for only a part of the time. One of the largest of the extinct craters is known as Crater Lake, in Oregon, and meas-

ures five by six miles in diameter. It is now found that the lunar craters closely resemble some of the terrestrial ones of the engulfment type, and were doubtless formed in the same manner.

In Fig. 4 is shown an engulfment crater of the crater-ring class in process of formation. The lava rises in the opening or vent and overflows, gradually building up a circular raised dam. A near view of a part of this dam is shown in Fig. 5. Later the lava is withdrawn from below, leaving behind it a large ring-shaped formation with a depressed central cavity, having a flat or even slightly convex floor. The larger lunar craters are all of this type. Two that are found near the limb or smooth edge of the Moon are shown in Fig. 6. Lunar craters near the centre of the disk are seen at a high angle, and appear very much deeper than they are in reality.

The characteristic difference between the lunar and terrestrial types may be briefly expressed by saying that the terrestrial volcano consists of a high cone and a small crater, while the lunar formation consists of a very large crater and an insignificant cone. It had always been supposed, until recently, that the terrestrial type was nowhere to be found upon the Moon, but a few months ago, while a lantern-slide made at the Yerkes Observatory by Professor Ritchey was being examined at Harvard, a thoroughly typical crater of the terrestrial type was found upon it. This crater is shown a little to the right and below the centre of Fig. 7. The cone measures nine miles in diameter at its base, and is 2000 feet in height. The crater is half a mile in diameter. For purposes of comparison we may say that the diameter of the base of Vesuvius, including Monte Somma, is eight miles, and its height 4000 feet. The diameter of its crater, which varies with every eruption, rarely exceeds a quarter of a mile, although it is said at present to be somewhat larger. The large crater of the lunar type shown just below and to the left of the centre of the figure is known as Kies, and measures twenty-eight miles in diameter. Craters of five and six times this size are found in certain parts of the Moon.

Most of the smaller lunar craters with which we are acquainted, and these probably number more than ninety-nine per cent. of the whole, have smooth, rounded, concave floors. Many examples of this class also are found in Hawaii, upon the

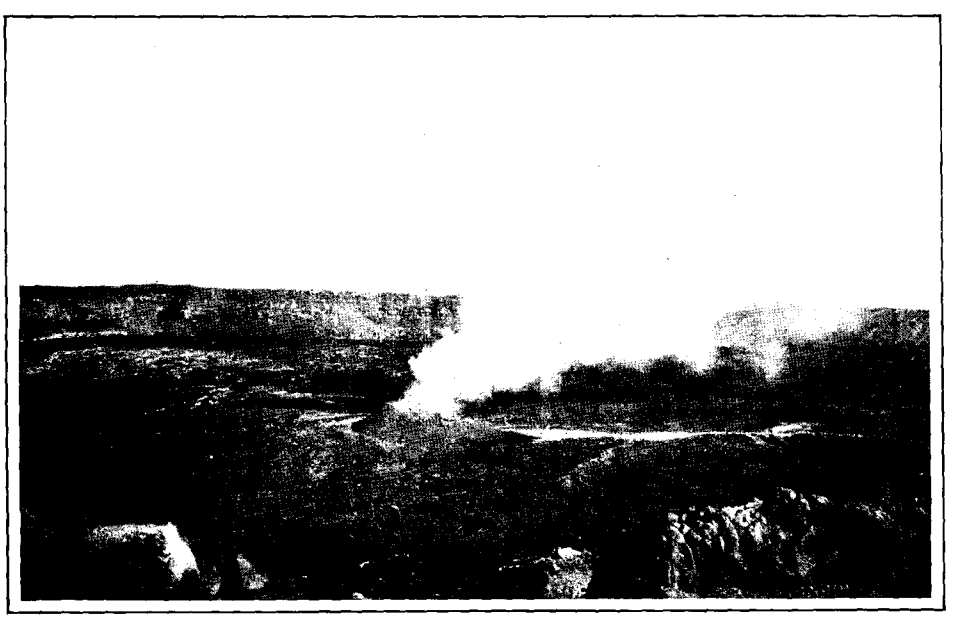

FIG. 9.—DAYLIGHT VIEW OF THE 1903 ERUPTIONS IN THE SUMMIT CRATER OF MAUNA LOA

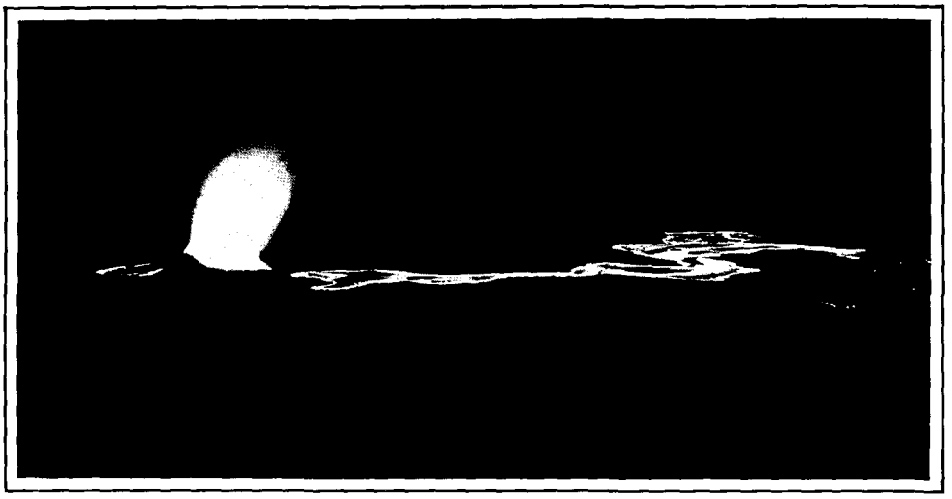

FIG. 10.—NIGHT VIEW OF 1903 ERUPTIONS IN THE SUMMIT CRATER OF MAUNA LOA

slopes of Mount Hualalai. Still another kind of lunar crater, of which only very small specimens are to be found, rarely exceeding a mile or two in diameter, has absolutely no outside cone at all, and is known as a crater pit. Fig. 8 represents a Hawaiian volcano of this type. Its name is Kauhaku, and it is situated near the leper settlement on the island of Molokai. It consists simply of a hole in the ground and nothing more. It once was brimming full of lava, but the lava has long since withdrawn, leaving nothing but the empty hole—an object very unlike our ideas of a volcano. Numerous other curious formations seen upon the Moon are now found to exist also in Hawaii, and there is scarcely a lunar feature which does not have its counterpart somewhere in this interesting newly acquired possession of the United States.

The Voice of the Rain

BY CHARLES BUXTON GOING

THE wind calls like a spirit—
  The sea, like mystic song;
But the falling rain is like a voice,
  Murmuring all night long.

For the wind's way none may follow,
  The sea no man may bound;
But the rain is gentle minister
  Between the skies and ground.

Rising, mist-clad and silent,
  From land and sea, it bears
The offering of their fragrances—
  The perfume of their prayers.

Then, with its myriad blessings
  For the myriad-praying plain—
Each drop an answer to a call—
  Earthward returns the rain.

The wind is like a spirit
  And the sea a mystery,
But the blessed rain is a living voice
  That speaks through the night to me.