MARS

AS

THE ABODE OF LIFE

BY

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To

MY BROTHER

PROFESSOR ABBOTT LAWRENCE LOWELL, LL.D.

WHO AS TRUSTEE OF THE LOWELL INSTITUTE

PROPOSED THESE LECTURES

THIS PRESENTATION OF THEM

IS AFFECTIONATELY

INSCRIBED

PREFACE

In 1906 Professor Lowell was asked by the trustee of the Lowell Institute to deliver a course of lectures there upon the planet Mars. Eleven years had elapsed since, at the invitation of the former trustee, he had done the like. When the time came for their delivery unusual interest was manifested, the course proving the most thronged of any ever given before the Institute. So great was the demand for seats that the hall could not contain the crowd, and the lectures had to be repeated in the afternoons, to audiences almost as large.

The eight lectures were then published, with slight changes, in six papers in the *Century Magazine*, and were subsequently wanted by Macmillan and Company for issuance in book form.

Though dealing specifically with Mars, the theme of the lectures was that of planetary evolution in general, and this book is thus a presentation of something which Professor Lowell has long had in mind and of which his studies of Mars form but a part, the research into the genesis and development of what we call a world; not the mere aggregating of matter, but what that aggregation inevitably brings forth. The subject which links the Nebular Hypothesis to the Darwinian theory, bridging the evolutionary gap between the two, he has called planetology, thus designating the history of the planet's individual career. It is in this light that Mars is here regarded: how it came to be what it is and how it came to differ from the Earth in the process.

The object of the founding of the Observatory at Flagstaff was the study of the planets of our solar system; a subject it has now for fourteen years made its specialty, the site, chosen for the purpose, enabling it to prosecute this study to more advantage than is possible at any other observatory at present. From the data thus collected, light has been thrown upon the evolution of the planets as worlds, resulting in a thesis of which the present book is a preliminary presentation.

As in all theses, the cogency of the conclusion hangs upon the validity of each step in the argument. It is vital that each of these should be based on all that we know of natural laws and the general principles underlying them. Their truth can only be adequately appreciated by those able to follow the physical and mathematical processes involved, and for this the general reader has not the necessary technical education. Yet there are many, professional and unprofessional alike, capable of comprehending provided the steps are made sufficiently explicit. It has seemed, therefore, worth the trying to attempt to write for both classes of the community in a single volume. To do this, the general text has been printed complete in itself, while the demonstrations of the several steps have been collected in a part by themselves with reference to the places in the text where they severally should occur. All illustrations of the planet Mars are by Professor Lowell.

May, 1908.

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FOREWORD

UP to the middle of the nineteenth century, astronomy was busied with motions. The wanderings of the planets in their courses attracted attention, and held thought to the practical exclusion of all else concerning them. It was to problems of this character that the great names of the past — Newton, Huygens, Laplace — were linked. But when the century that has gone was halfway through its course, a change came over the spirit of the investigation; with the advance in physics celestial searchers began to concern themselves with matter, too. Gravitational astronomy had regarded the planets from the point of view of how they act; physical astronomy is intent upon what they are.

One outcome of this more intimate acquaintance is the new study with which the present papers deal: the evolution of the planets regarded as worlds. Such research has to do not merely with the aggregation of material, but with its subsequent metamorphoses after it has come together. Planetology we may call this science of the making of worlds, since it concerns itself with the life-history of planetary bodies from their chemically inert beginning to their final inert end. It constitutes the connecting link in the long chain of evolution from nebular hypotheses to the Darwinian theory. It is itself neither the one nor the other, but takes up the tale where the one leaves off, and leaves it for the other to continue.

CHAPTER I

THE GENESIS OF A WORLD

SO far as thought may peer into the past, the epic of our solar system began with a great catastrophe. Two suns met. What had been, ceased; what was to be, arose. Fatal to both progenitors, the event dated a stupendous cosmic birth. Catastrophic origin.

It is more than likely that one or both of the colliding masses were dark bodies, dead suns, such as now circle unseen in space amid the bright ones we call the stars. Probable this is, for the same reason that the men who have been far outnumber the men who are. It is not to be supposed that the two rovers actually struck, the chances being against so head-on an encounter; but the effect was as disastrous. Tides raised in each by the approach tore both to fragments, the ruptured visitant passing on and leaving a dismembered body behind in lieu of what had been the other. That the stranger continued on its way is shown by the present moment of momentum of our system. For it is very small, and the fact can be proved to mean that after the encounter its matter still lay massed for the most part in a single centre.[1] Thus, what had been a sun was left alone, with its wreckage strewn about it. Masses large and small made up its outlying fragments, scattered through space in its vicinity, while a shattered nucleus did it for core. So much of its history we learn from the tiniest of its constituents now: the meteorites. To meteorites thus attaches a peculiar importance; for they are Rosetta stones for the decipherment of what went before.

Meteorites.

From time unreckoned, rocks have fallen out of the sky upon the Earth. Most of them are of stone, but some are nearly pure iron, mixed with a small amount of nickel. They are called meteorites. Twenty-six known elements have been found to occur in them, and not one element that is new. They thus betray a constitution cognate to the Earth's.

In size these visitants vary from the grain-like bodies known as shooting-stars up to ponderous masses weighing many tons. Coming from space, they enter our air at speeds of from eleven to forty-one miles a second, and friction, due to their great velocities, fuses their exterior, and eats the holes with which is pitted what remains of them when they strike the ground.

Meteorite worship.

Recorded meteoric falls date from a far past, and were deemed miraculous by early men. A stone that fell in Phrygia in pristine times was adored as Cybele, "the mother of the gods," and later, about 204 B.C., was carted with great ceremony to Rome. The famous Diana of the Ephesians was probably none other than a meteoric stone, enshrined and worshipped as a goddess. Adoration of such arrivals from heaven was not of local observance only, but common to peoples over the whole Earth. There was a stone so worshipped at Mecca, and another in Tatar, Siberia, to which homage was paid; while even in our own country a large mass of iron found in Wichita County, Texas, was set up as a fetich by the Indians, who revered it as a body not of the Earth, but sent to it by the Great Spirit.

Meteoric constitution of solar system.

A certain poetic justice invests this worship with a grandeur of its own; for these things are probably the oldest bits of matter we may ever touch, the material from which our whole solar system was fashioned. They mark the farthest point in its history to which we can now mount back. The time of day at which they commonly fall — the afternoon rather than the morning — points curiously to their oneness with the rest of the solar system; for in the afternoon the Earth looks backward over its traversed path, and their descent then proves that they follow and overtake it, and therefore that their movement has the same sense as its own. Still more conclusive of their relationship to ourselves is the speed with which they arrive, or, to be precise, the lack of it. For, did they come from the depths of space, were they ronins of the sky owing attraction's allegiance to no one lordly sun, they would have velocities exceeding forty-five miles a second, and these should often show, not an instance of which has ever been remarked.[2]

Just as, chemically and gravitationally, they stand confessed our kith and kin, so, physically, they betray the character of their origin; for they bear in them occluded gases, which could have come there only under great pressure, such as would exist in the interior of a giant sun. Thus they proclaim themselves clearly fragments of some greater body. To the sometime dismemberment of this orb, from which disintegration our sun and planets were formed, the little solitary bits of rock thus mutely witness.

Analogy of cataclysm to new stars (Novae).

Of the cataclysm that thus occurred far down the otherwise unrecorded vista of time, we have an analogue in the Novae that now and then blaze forth in the sky to-day, startling us from out the depths of space. These new stars, that suddenly appear, grow in brightness, and then slowly fade to nebulosity, speak by such action of a like catastrophe by which they were born again. Not otherwise was our own birth heralded in heaven.

The meteorites gravitate together, generating heat.

Strewn thus about the scene of the encounter, the pieces of the disrupted sun would begin to gravitate together. The several subsidiary swarms of these fragments were of different sizes, but of much the same substance, because of the general similarity of their origin. Cooled by contact with the cold of space, so soon as the meteorites started to fall together, they generated heat, warming one another, just as the rubbing of two sticks strikes fire. The amount of heat produced depended upon the number of particles concerned, or, in other words, upon the mass of the body the particles were busied to form.

THE MOREHOUSE COMET AS PHOTOGRAPHED AT THE LOWELL OBSERVATORY, 1908
By E. C. Slipher.

Amount of heat depends on the mass of the body.

Approximately we can compute what this heat would be. If the body be supposed homogeneous, and to contract under its own gravity from an original extended condition to an eventually compressed state, the work done, converted into heat, would be proportionate to the square of the mass divided by the radius attained. The same would be the case if the body were heterogeneous and composed of concentric spherical shells, only that the numerical amount would be greater according to the distribution of the mass. However the body were constituted, its caloric would be spread through the mass, and the resulting heat on each unit of it would therefore be as its mass divided by its radius. The internal temperature of the particular planet would therefore depend upon the amount of material that collected together. Thus each body was subjected to a different heat as well as to a differing pressure, according to its mass from the moment it began to form; and to its mass alone, for that determined the radius to which it finally stood compressed.[8]

Substances vary with heat and pressure.

Now, all substances behave differently according to the temperature and the pressure under which they exist, both as to physical state and in their display of chemical action. Diverse results ensue from diverse conditions. The same element melts or remains solid, combines with another eagerly to form a third utterly unlike both, or coldly stands aloof from all association, solely as the temperature or the pressure constrains it to that end. Each, too, is a law unto itself, and acts unlike its neighbor as these compelling causes change.

To them, therefore, diversity is due; and they in their turn are conditioned by the mass.

Mass, then, is the fundamental factor in the whole evolutionary process, the determining departure-point, fixing what the subsequent development shall be. Though the bodies were in essence the same at the start, their initial quantity would change their very quality as time went on. What started like would become different; for the gathering together of the particles into a single body was the preface to that body's planetary career. **Mass the fundamental factor.**

Not until the internal heat began to abate did what we call evolution set in. Up to then the growing temperature induced a devolution or separating into simplicity of what had been complex. The time taken by each planet to reach its maximum bodily heat differed as between one and another. The larger the body, the slower it attained the greatest temperature of which it was capable, both by reason directly of its mass, and indirectly of the pressure to which that mass gave rise.

At its heat-acme the picture each planet presented was all its own. Some may have been white-hot, some certainly were red-hot, some were merely darkly warm; for one differed from another in self-endowment of warmth or light, each with a glory of its own. **Cooling.**

Radiation had, of course, been going on from the time the impact of the particles began. At first the heat gained by contraction surpassed that radiated away, but at last a time came when the depletion exceeded the generation of heat, and the planet began to cool. By parting with its caloric into space, its surface fell in temperature. Unlike in amount of acquisition, the bodies were no less unlike in the manner of their loss. Each acted according to its kind. Those that originally had little, lost that little fast; for volume is a matter of three dimensions, surface of but two, and as through their surfaces their volumes cooled, the smaller got rid of their heat with relatively greater speed. Just as if two stones be put into the fire and then taken out, the smaller will turn cold while the larger is yet warm. With the

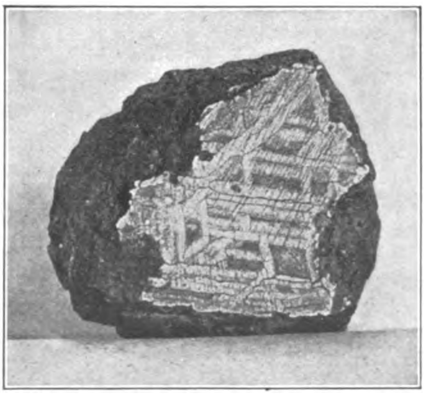
METEORITE FROM CAÑON DIABLO, ARIZONA

Pitted by fusion in traversing the earth's atmosphere.

planets, contrast in performance was accentuated from the fact that the big ones were intrinsically hotter at the start. Thus, for two reasons, the large lingered in the race: they had more to lose, and they lost it more reluctantly.

Life-history depends on size.

In consequence the life-history of a planet was long or short in proportion to its size. If little, it ran through its gamut of change fast, and that gamut was itself brief; if large, it tarried in its several stages, and those stages were themselves drawn out. But, in addition to this, the larger knew states the smaller in their heating had never reached. Diversified age, both in length of years and in breadth of experience, was thus the first result of size.



METEORITE FROM CAÑON DIABLO, ARIZONA
Surface polished. Showing method of crystallization.

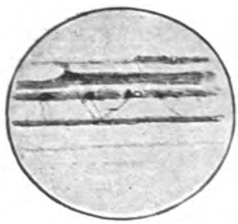
Planetologic eras.

Six stages may conveniently be distinguished in the progress of a planet from sun to cinder, all of which will be traversed by the body, if it be sufficiently big. If it be of asteroidal size, it virtually knows none of them, remaining meteoric from first to last. The six periods may be designated:—

I. The Sun Stage. Hot enough to emit light.
II. The Molten Stage. Hot, but lightless.
III. The Solidifying Stage. Solid surface formed. Ocean basins determined. Age of Metamorphic rocks.
IV. The Terraqueous Stage. Age of sedimentary rocks.
V. The Terrestrial Stage. Oceans have disappeared.
VI. The Dead Stage. Air has departed.

Present aspects of the planets our guide.

Though we cannot in our own ephemeral life watch any planet pass through these several phases of its career, we can get a view of the process by studying the present conditions of the various planets and piecing together the information we thus obtain. It is, in the end, as conclusive as in botany would be the study of a wood by carefully noting the condition of the individual trees in their various growths from seedling to patriarch. Thus, at the present moment, in Stage II are found Neptune, Uranus, Saturn, and Jupiter; in Stage IV, the Earth; in Stage V, Mars; and in Stage VI, the Moon and the larger satellites of the other planets.



CLOUD EFFECT ON JUPITER
As observed at the Lowell observatory in 1907, indicating that Jupiter is in the second planetologic stage.

Each planet's internal heat was its initial motive-power, and cooling the mode by which this energy worked, first, to the fashioning of its surface, and then to all evolution upon it. While still in the molten state the mass was a seething chaos but little differentiated from any other equal agglomeration of matter. Yet even here the several substances had begun to segregate, the heavier falling to the bottom, the lighter rising to the top.

Geologic part of planetology.

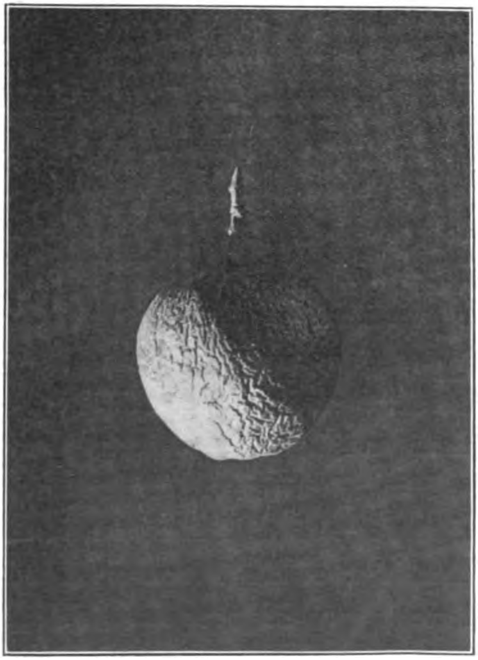
With Stage III we enter the part of a planet's career with which, on our Earth, geology is concerned. Though specifically the story only of our Earth, that science has analogues elsewhere, and to be best understood needs to be generically considered. Local as many Earth-happenings are, with increasing light from the heavens it is becoming clear that the main events are of cosmic occasioning, and that astronomic cause presides over their manifestations. Initial instance of planetary action occurs at the first stage of the Earth's history to which geology mounts back — that in which a crust began to form over the molten mass. The liquid metal in a furnace upon which the solidifying slag has begun to float gives us an idea of this early state of things. Our metamorphic rocks were in action akin to the furnace slag, rising to the surface because of their lightness. Proof of this lies in their present density, which is only about one-half of the average density of the Earth, 2.7 times that of water instead of 5.5. Their constitution furnishes further evidence that such they were. The gneiss, mica, and hornblende of which they are composed show by their crystalline form that they cooled from a once molten state, and their foliation indicates that they were crumpled and recrystallized in the process.

In Stage III the body first acquires a physiognomy of its own. Up to then it is a chaotic mass as unstable and shifting as clouds in the sky; but at the advent of surface solidification its features take form — a form they are in fundamentals ever afterward to keep. Its face is then modelled once for all; and its face is the expression of its character. Our knowledge of this stage and of the two subsequent stages IV and V is derived from study of three planets of our system, the Earth, the Moon, and Mars. The others contribute nothing to our information of these mid-phases, either because, like Mercury and Venus, they are too advanced, or because, like the major planets, Jupiter, Saturn, Uranus, and Neptune, they are not advanced enough.

Landscape the result of cooling.

Landscape is simply the sculpturing due the fashioning cause of planet physiognomy. As the substances composing the mass cool, some of them expand; but most of them contract, and in consequence of this the crust finds itself too large for what it encloses.

To fit the shrunken kernel it must needs crumple into folds. These folds are what we know as mountain ranges — long, low swells while the crust is yet thin, abrupt and broken fractures when it has become thick. The valleys between mark the down-folds of the squeeze. Wrinkles are thus as inevitable a consequence of planetary aging as of man's, only that while they are thought a disfigurement in him, they are regarded as beautiful in a world.



AN APPLE, SHRUNK TO SHOW THE EFFECT OF CONTRACTION

Mountains in proportion to mass.

Such crinkling of its cuticle is most pronounced where the heat to be got rid of is greatest, and the surface to radiate it is relatively least. Both conditions are fulfilled the more completely the bigger the body. The larger the planet, therefore, the more mountainous its surface will be when it reaches the crumpling stage of its career.

Volcanic phenomena.

In like manner is volcanic action relatively increased, and volcanoes arise, violent and widespread, in proportion; since these are vents by which the molten matter under pressure within finds exit abroad. This is shown in their positioning. They occur where the crust is most permeable; and so are found along the edges of continents, as these are weakened by dipping down into the sea.

Relative roughness of Earth, Moon, and Mars.

Three bodies exist near us in space where the working of this inevitable action stands displayed, and its comparative effects may thus be studied: the Earth, Mars, and the Moon. With the accidented character of the Earth's surface we are all familiar. Its mountains, its volcanoes, and its hills go to make up its loveliest and its grandest features. Its mass fashioned them, and fashioned them as they are because its mass was large. This mass is nine times that of Mars, and eighty-one times that of the Moon. Being greater than that of the Moon or Mars, our globe should have crumpled more, and those other two bodies should have smoother contours than the Earth shows. The general order of their roughness should be Earth, Mars, Moon.

No mountains on Mars.

Now, when we come to scan Mars with nicety, we are gradually made aware of a curious condition of its surface. It proves singularly devoid of irregularity. The more minutely it is viewed, the more its levelness grows apparent. Finally, calculation shows that heights, even of very moderate elevation, should be visible if such existed, and none show. Thus we are confronted by the fact that there are no mountains on Mars.

Slant illumination.

Second only in interest to the fact itself is the method by which that fact has been found out. To appreciate the problem, we may recall the appearance of a road lighted by electric arc-lights placed at such considerable distances apart that the illumination falls aslant. All of us who, on dark nights in the country, have trudged along such pikes, have started at the mammoth sharp-cut shadows of its ruts, so that we have lifted our feet to surmount what threatened to stub our toes, only to find the obstacles not there. To such delusion were we led by the monstrous length of the shadows thrown with unexpected vividness across our path.

Important to astronomers.

Now, the fact of such projection, — as Cowper puts it of his legs under the rays of a rising or a setting sun, "spindling into longitude immense," — bothering as it is to the midnight pedestrian on arc-lit roads, proves to the astronomer of inestimable use. For without its aid he had forever remained incapable of gaging the inequalities of the terrene of the heavenly bodies to any fine precision.

When an object stands on the sunrise, or the sunset, edge of a planet, the slant illumination it then receives throws its shadows to a great distance from its foot. A tapering finger searching the plains as the sun changes position, it may be a hundredfold the height of the object casting it. The effect is well seen in photographs of the moon.

Deprived of this natural kind of magnification, the astronomer would be forced to measure the object itself for just what it was, as it showed in profile on the limb, the fully illuminated rim of the planet where the sight-line of the observer grazes horizontally the surface, and shows heights for just what they are. With shadows he has a vernier to his hand. For the derived may be any number of times longer than the original.

On the same principle, by noting the distance off the general sun-lightened edge at which some fortunate peak first catches the rays of the rising sun, or holds latest his setting beams, its loftiness may be found.[4]

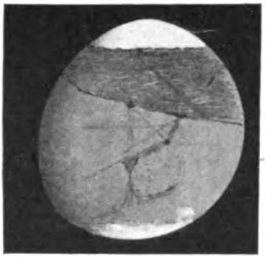
The principle has been employed to determine the heights of the mountains in the Moon. By the help of trigonometry the shadows and the star-like tips of peaks, standing isolate beyond the general edge of light, have been made to tell their tale of elevation. In consequence, we know the heights of crater walls there, to within a few hundred feet, as accurately almost as we know them on Earth by our aneroids.

Applied to Mars.

The same procedure applied to Mars results in a negative outcome. While the sunrise or sunset edge of the Moon is palpably notched, even to the naked eye, as any one may see who scans it carefully a

Phase View of the Moon, showing the Effect of a Mountainous Surface on the Terminator (the Dividing Line between the Illuminated and the Obscured Part of the Face)

few days before or after the half, the similar edge of Mars is wonderfully smooth and even. One may gaze, armed with the most powerful glass, night after night, and never detect the least irregularity in its elliptic outline. Commonly, at most, he will notice slight flattenings here and there where a dark area happens at the moment to be passing over the boundary of sunlight and shade. So rare is it to perceive any other indentation or excrescence upon the smooth rim of its disk where the light fades away, that to do so is something of an astronomic event. The very rarity of the phenomenon — there has been but one good one at each of the last three oppositions — proves the projections not to be due to what causes them on the Moon, an accidented surface. In short, they cannot indicate mountains, for a mountain is a permanence, which under similar conditions should either always or never show. Now, for many nights in succession, indeed for weeks together, Mars presents us his disk under substantially the same conditions night after night; so that if the obstacle that caught the light were part and parcel of the surface, however it might tower above that surface's customary level, it should be seen as regularly as the planet's rotation brought it round. The fact that it fails of such continuity of expression is proof conclusive that it is of no such origin.



PHASE VIEW OF MARS, MAY, 1907, SHOWING A SMOOTH TERMINATOR (THE CURVED LINE AT THE LEFT), WHICH INDICATES THAT THERE ARE NO MOUNTAINS ON THE PLANET

View of the Earth, showing the Proportion of Land and Sea

Sporadicity, then, far from raising the slightest presumption in favor of mountains, or indicating their uncommonness, is absolutely fatal to the observed phenomenon being a mountain at all. Now, as none of these projections seen on Mars are of permanent appearance, we perceive that there are no mountains on Mars. Such impermanence testifies not only negatively but positively to their character. For, from the fact that when detected two nights running they prove to have changed their place in the interval, we Not indicative of mountains.

have witness that they are unattached. Thus they come from something floating in the planet's air; to wit, clouds, and, furthermore, from their color, clouds of dust.

Dust Storm on Mars, from a Drawing, May 28, 1903

Two or three thousand feet limit of elevation on Mars.

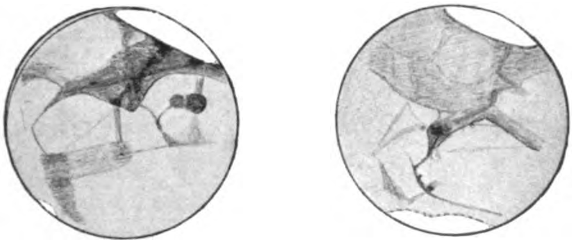
From the evidence as to scale afforded by the Moon, we can tell what height we ought to be able to detect in this manner on Mars. We find it by calculation to be two to three thousand feet. Nothing, therefore, higher than this modest elevation exists there, which leaves us for contemplation a surface singularly flat, according to the idea with which our Earth has furnished us. A Martian landscape would

From "Old and New Astronomy," by R. A. Proctor, Longmans, Green & Co.

Two Views of the Earth, 180° apart, showing the Polar Caps and General Features as seen from Space

seem to us remarkably peaceful and tame, — scenery chiefly noticeable for the lack of everything that with us goes to make it up.

Contemplating now the Moon in the light of what we have thus learned, the first thought that strikes us is the glaring exception seemingly made by it to the theoretic order of smoothness, Earth, Mars, Moon, above laid down. The lunar surface is conspicuously rough, pitted with what are evidently volcanic cones of enormous girth and of great height, and seamed by ridges more than the equal of the Earth's in elevation.



Two Views of Mars, about 180° apart, showing the Polar Caps and General Features for Comparison with the Earth (as above)

Many lunar craters have ramparts 17,000 feet high, and some exceed in diameter 100 miles; while the Leibnitz range of mountains, seen in profile on the lunar limb, rises nearly 30,000 feet into space.

Internal heat of the three bodies.

On the principle that the internal heat to cause contraction was as the body's mass, — and no physical deduction is sounder, — this state of things on the surface of our satellite is unaccountable. The Moon should have a surface like a frozen sea, and it shows one that surpasses the Earth's in shagginess. To perceive this more definitely we will make that not uninteresting thing, an evaluation of the heat evolved by both the Moon and the Earth, supposing their origin the same. We will express it in terms, if not in figures, that are comprehensible. The result is startling. Unaccountable at a first view, the event proves actually impossible when we subject the heat evolved by a like genesis to numerical computation. If the Earth contracted homogeneously from an infinite expansion to its present state, and none of its heat were lost meanwhile by radiation, calculation shows that the energy evolved would be sufficient to raise the temperature of its entire mass to 146,000° F., if that mass were composed of iron, which represents about its present density and is probably not far from the fact. If it were composed of other material, the temperature of that material would be different, according to its capacity for heat. Thus quartz has a capacity nearly twice that of iron (sp. ht. 0.20) and water one of five times as much (sp. ht. 1.00). The temperatures would be reduced in proportion.

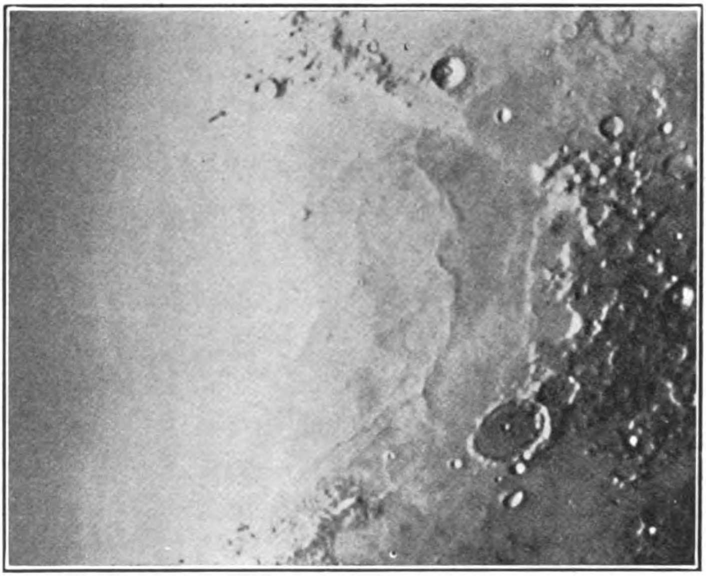
If, instead of supposing the body homogeneous, we consider it heterogeneous, as indeed it is, and treat it by the simplest law consistent with physical principles and an approach to fact, to wit, that the density increases from surface to centre and that it resists compression in proportion as it stands compressed,—the formula assumed by Laplace,—we get an even greater amount of heat generated.

We do not know the law of parting with this heat, though the greater portion of it was certainly radiated away in the process. But we may make some approximation, at least as between the several planets concerned, by assuming the heat near the surface to have been, at its maximum, what a body contracting from the density of its constituents, the meteorites, to its own eventual density would generate. We do this because the heat thus begotten proves in the case of the Earth to have been more than sufficient for all the volcanic and orogenic phenomena displayed. Now, as it is common physical knowledge that a small body cools quicker than a large one, we shall not err on the side of making Mars' internal heat too small if we apply the same principle to it. When we so evaluate the heat for the Earth and Moon,[5] we get results as follows:— 23,000° F. and 80° F.

Here, then, we are landed in a quandary. If the Moon was generated on its own account, as the Earth and Mars were, the internal heat it was able to amass was never anything like the amount sufficient to provide for the features which its surface shows. It could not even have kept itself from freezing amid the terrible cold of space. Now, it will be noticed that we said "if its genesis was like our own"; that is, that it came into being by itself alone. In this saving "if" will be found the explanation of the dilemma.

Darwinian theory of lunar origin.

Some years ago Sir George Darwin showed analytically that the action of the tides in the Earth-Moon system, when traced backward, lands us at a time when



From a photograph taken at the Lowell Observatory.

A Part of the Moon's Face, showing Ancient Sea-bottom

the Moon might have formed a part of the Earth's mass, the two rotating together as a single pear-shaped body in about five hours. His analysis pointed to what might have been. Now the pregnant point in our present heat inquiry is that the face of our satellite indicates that the might-have-been actually was.

Confirmed by lunar surface.

The erupted state of the Moon's surface speaks of such a genesis. For in that event the internal heat which the Moon carried away with it must have been that of the parent body—the amount the Earth-Moon had been able to amass. Thus the Moon was endowed from the start of its separate existence with an amount of heat the falling together of its own mass could never have generated. Thus its great craters and huge volcanic cones stand explained. It did not originate as a separate body, but had its birth in a rib of Earth.

Far from disproving the law, the seeming lunar exception, therefore, really upholds it.

Probable comparative internal heat of earth and Mars.

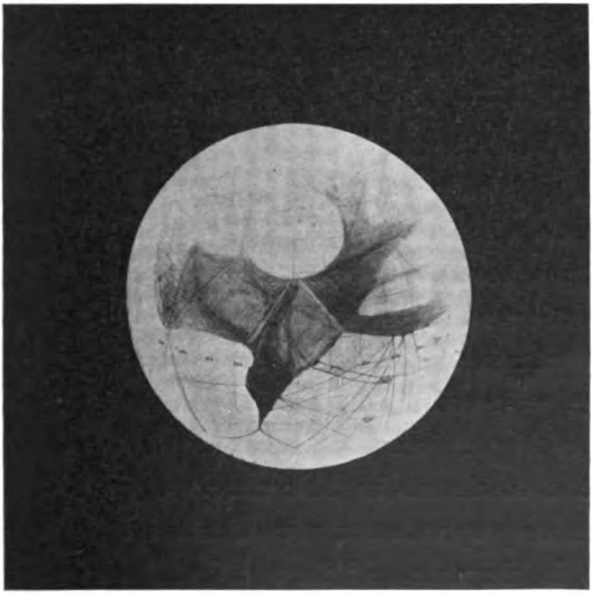
We may now go on to apply the principle to no less interesting a determination—the case of Mars.[6] If, taking into account the radiation which has ceaselessly gone on from the time when first the matter started to collect, we allow 10,000° F. for the effective internal heat of the Earth, we shall be making it a liberal allowance. Now, computation shows that an internal heat of 10,000° F. for the Earth would correspond to about 2000° F. for Mars. But the melting-point of iron is 2200° F., so that iron would not have fused, and we should have in consequence virtually no volcanic action. Furthermore, there could have been but little crinkling of the crust. For, first, the direct pressure was less, and then the heat, its indirect effect, was correspondingly small; so that Mars cannot have contracted much, and so must largely have escaped crumpling. What the contraction was may be inferred from comparison of its density with that of meteorites. The mean density of meteorites which are mostly stone with some iron is 3.5, that of Mars 4., and that of the Earth 5.5, water being unity. The planet should show, therefore, a remarkably smooth and level surface; and this is precisely what the telescope reveals.

Continental and oceanic areas formed.

The crust, to the folding of which a planet's physiognomy is due, was forming during all the time the planet took to cool on its surface from the temperature of the fusion-point of gneiss to the boiling-point of water, or from about 2000° F. down to 212° F. In some places it gathered thicker than in others; and inasmuch as it floated, stood up higher, to which height crumpling contributed. Up to the time when its liquefaction-point was reached, water existed only in the form of steam, but on the fall of the temperature to 212° F. the steam fell with it, condensing into water. Into the troughs already there the water, as soon as it formed, proceeded to run. Thus the oceans came into being.

Their distribution determined.

We may apply this to the Earth and consider an important consequent detail. The fashioning cause of the depressions that gave rise to the distribution of what we know as continents and seas is of great interest, for it seems to have been determined in a general way by cosmic considerations. If we scan a map of the globe, we shall mark a significant fact: that in all the continents a certain apexing to the south is discernible. Witness North and South America,



View of Mars, showing the Proportion of Dark and Light Areas

The dark areas are probably old sea-bottoms, and the light ones, desert land. Mars is here given of its true relative size as regards the Earth on page 21 — so that the actual surface of its former seas as well as their relative proportion to the land areas may be compared with those of the Earth.

Greenland, Africa, and India. Blunt-based to the north, they all terminate in a tip southward. Australia is the only one of the great continental masses that fails to show the peculiarity at first glance. But a bathymetric chart reveals the fact that the platform on which it stands does indeed do so, Tasmania being really a part of it and making the detached tip.

True Martian message.

Nor does the Earth alone present us with such curious conformations, for Mars has a word to say on the subject. On casting one's eye over a map of that planet, one is struck by the triangular projections of the dark areas into the northern hemisphere. The Syrtis Major is the most conspicuous instance; but the Margaritifer Sinus, the Sabæus Sinus, and the Trivium Charontis exhibit a similar propensity. Now, when we reflect that the dark regions take the place of seas on Mars, this apexing of them to the north stands as the negative aspect of the positive picture presented by the Earth. Reverse the relative ratio of depressions to plateaux in order to get the seas and continents in their earthly proportions, with the oceans preponderant, as on Earth, instead of, as on Mars, in abeyance, and the two distributions are seen to typify the same action.

Their relative size on different planets.

The amount of surface the oceans covered on any particular planet was again a consequence of the particular planet's size. If the material forming the planetary bodies was of the same general character throughout the fields they severally swept clear, which, to a certain extent, is probable, and the more so as the planets stand neighborly near, the amount of water each possessed would be as its mass, and when it collected into seas, these, if equally deep, would cover more of the surface in the larger planet, since it

VIEW OF THE MOON AT THE FULL, SHOWING THE PROPORTION OF DARK (SO-CALLED "SEAS") AND LIGHT AREAS

Only the darkest patches are thought to be sea-bottoms.
Moon of true relative size to Earth (page 21) and Mars (page 29).

has less cuticle for its contents. We have seen, however, that this cuticle would be more crinkled and of greater accentuation in the larger body, owing to a greater contraction in the kernel within; the folding we may perhaps take as being roughly proportionate to the radius of the globe. The larger body would, therefore, begin life with larger oceans, even if it were born with but its share of water; but, as a fact, it would have more than its share because of being better able to hold on to its gaseous elements, and thus retain more of what was to condense to water when the time arrived.

Now the three bodies, the Earth, Mars, and the Moon, have, or had, in all probability, judging from their present look, oceans in this order of size, the Earth having the most in amount, Mars the next, and the Moon the least.

In the case of the Moon the matter is complicated by the fact that when it left the Earth it took probably not only a greater amount of light constituents than a solitary genesis would have permitted, but even a greater proportion than the Earth retained since it was born of the outer and therefore lighter layers of the Earth-Moon mass. It thus started more profusely endowed with the wherewithal to oceans than its size warranted.

Earth's oceanic basins unchanged.

On all three planets their primeval topography has proved persistent. On both the Moon and Mars the dark areas are apparently the lowest portions of the surface, while their character points to their having held seas once upon a time. With Mars it is their present occupancy, though by something other than water, that tells the tale; with the Moon the fact that rays and rills run athwart them discloses it, bespeaking their age.

Turning to the Earth, according to the best evidence we possess, the great ocean basins have remained unchanged in place from the period when they were laid down. Not that the areas marked out as land and water at any epoch have not greatly altered since the beginning of geologic time; but the abyssal depths on the one hand, and the continental platforms on the other, have not substantially varied during all these ages. If we examine a bathymetric chart of our several oceans, giving their body by registering their depth, instead of a superficial one which marks simply where the water laps the land, and consider the one hundred-fathom line, the ocean bottoms and the continental plateaux stand well differentiated from each other. It is then seen that each continent is set on a shelf wider in some places than in others, but at its edge falling abruptly to the marine abysses, which, though themselves uneven, stand, with the exception of a few islands, projecting and submarine, at a generally much lower level. This indicates that they have always held such attitude.

But the character of these ocean bottoms furnishes the best testimony that they have not changed during geologic time. Their flooring is organic ooze or inorganic clay, globigerina, radiolarian, or diatom ooze, Their flooring attests it.

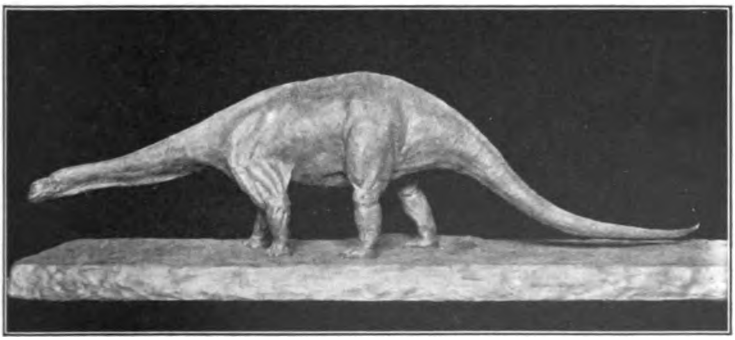
according to locality and depth, and red clay formed of the decomposition of volcanic stuff. In this ooze and clay, spherules of metallic iron, identified as similar in substance to that of falling stars, are still recognizable in perceptible amount, and as they must accumulate with exceeding slowness, their patent presence asserts the absence there of sedimentary silt from any shore. These abysses, then, have always been abysses from the start. That astronomy should tell us this is strikingly suggestive, while of peculiar planetologic interest is it that meteors again should be our informants of the fact.

CHAPTER II

THE EVOLUTION OF LIFE

UPON the fall of the temperature to the condensing point of water, occurred another event in the evolution of our planet, the Earth, and one of great import to us: life arose. For with the formation of water, protoplasm (the physical basis of all plants and animals) first became possible, what may be called the

The origin of organic life.



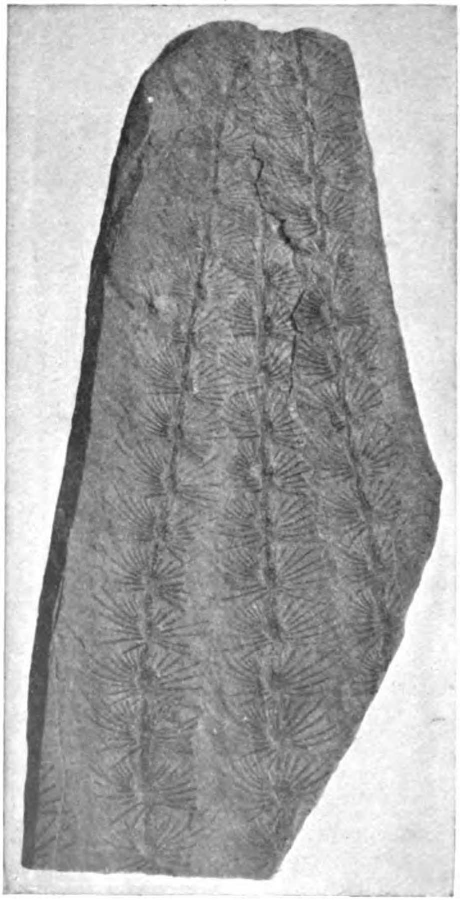
MODEL OF A BRONTOSAURUS, A FIRST POSSESSOR OF THE EARTH'S LAND, IN THE AMERICAN MUSEUM OF NATURAL HISTORY*

The fossil skeleton is 15 ft. and 2 in. high and 66 ft. and 8 in. long.

life molecule then coming into existence. By it, starting in a simple, lowly way, and growing in complexity with time, all vegetable and animal forms

* This illustration and those succeeding it to page 41 were kindly furnished the author for the purpose, by Professor Osborn.

have since been gradually built up. In itself the organic molecule is only a more intricate chemical combination of the same elements of which the inorganic substances which preceded it are composed. It is thus carrying on the building-up process begun by the inorganic before it. Between the organic and the inorganic, increasing knowledge, by pushing back to greater and greater simplicity the forms of life discovered, has tended to break down the barrier man had assumed to exist. There is now no more reason to doubt that plants grew out of chem-



PLANT LIFE IN THE COAL MEASURES

From a fossil specimen in the American Museum of Natural History, found in Illinois, here shown two-thirds its size.

ical affinity than to doubt that stones did. Spontaneous generation is as certain as spontaneous variation, of which it is, in fact, only an expression.

But it is not spontaneous generation in the popular sense. By that term many persons think of flies suddenly born of decaying meat, and this they know has been shown impossible. But this is simply because flies are far too advanced a product to be thus suddenly evolved. For them to be so produced would as directly controvert all we know of evolution as that, given the proper conditions, the lowest rudiments of life would not arise. That even the latter may nowhere be evolved on earth at the present time does not invalidate such origin for it when the conditions were other than they are to-day.

Life an inevitable phase of planetary evolution.

From all we have learned of its constitution on the one hand, or of its distribution on the other, we know life to be as inevitable a phase of planetary evolution as is quartz or feldspar or nitrogenous soil. Each and all of them are only manifestations of chemical affinity resultant on condition, and considering the oneness of the stuff, it is the conditions alone we have to investigate if we would learn what is to come.

Virtually only six so-called elements go to make up the molecule of life. It is the number of its constituent atoms, and the intricacy of their binding together, that give it the instability to produce the vital actions.

Carbon, hydrogen, oxygen, nitrogen, phosphorus, and sulphur are practically all that are required. If a planet be capable of furnishing these under suitable temperature conditions, it seems as inevitable that life will ensue as that the two elements sodium and chlorine will unite to form common salt when the heat and the pressure are right. Now, on its face, it is suggestive of the universality of life that the elements that go to form it are of all elements the most widespread. Oxygen, the chief factor in all organisms, makes by weight one-half the substance of the earth's surface; silicon, a large constituent of shells, comes next in

PLANT LIFE OF THE UPPER DEVONIAN

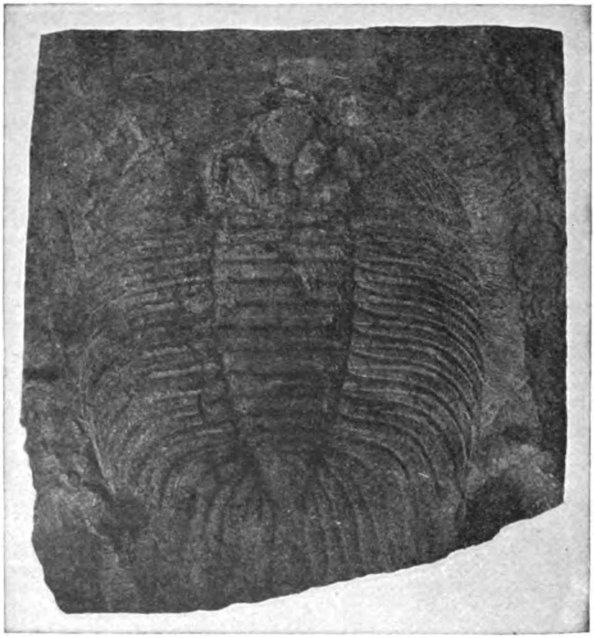
From a fossil specimen in the American Museum of Natural History, found in New Brunswick.

amount; and the others follow in the constitution of life about in the order of their natural abundance. For proof of the continuity of the processes of both structure and change in the inorganic and organic alike, nothing at once more conclusive and more interesting can be recommended than the books of the great Haeckel, couched in language every educated person can understand.

Of all the conditions preparatory to life, the presence of water, composed of oxygen and hydrogen, is at once the most essential and the most world-wide. For if water be present, the presence of other necessary elements is probably assured because of its relative lightness as a gas. Furthermore, if water exist, that fact goes bail for the necessary temperature, the gamut of life being coextensive with the existence of water as such. It is so consequentially, life being impossible without water. Whatever the planet, this is of necessity true. But the absolute degrees of temperature within which life can exist vary according to the mass of the body, another of the ways in which mere size tells. On the earth 212° F. (100° C.) limits the range at the top, and 32° F. (0° C.) at the bottom in the case of fresh water, 27° F. (− 3° C.) in the case of salt. On a smaller planet both limits would be lowered, the top one the most. On Mars the boiling-point would probably be about 110° F. (43° C.).[7] Secondly, from the

Water essential to life.

general initial oneness of their constituents, a planet that still possesses water will probably retain the other substances that are essential to life: gases, for the reason



A TRILOBITE, ONE OF THE EARLIEST FORMS OF ANIMAL LIFE PRESERVED
From the fossil specimen in Niagara shale, in the American Museum of Natural History, here shown two-fifths natural size.

that water-vapor is next to hydrogen, and helium the lightest of them all; and solids because their weight would still more conduce to keep them there. Water, indeed, acts as solution to the whole problem.

Water plays a protagonist part in the origination and the development of protoplasm by constituting at least nine-tenths of its substance. But, to begin with, it actually furnished the stage-setting for the drama of life by providing a medium in which it could evolve and function. This all-important use of water by living organisms is shown both by the present state of all animals and plants and by what science is discovering of their past history. There never was a time, and there apparently never will be a time, when plasm can do without that indispensable ingredient of life. At first, in the lowest unicellular plants and animals, it forms the whole environment, completely enveloping the organism. Thus the simplest cells are found in the sea, in ponds, and even in hot-spring geysers nearly at the boiling-point. In fact,

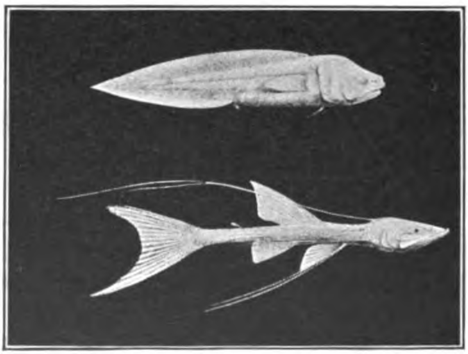
Fossil Footprints of Amphibia

From a slab reproduced in Professor Edward Hitchcock's "Report on the Sandstone of the Connecticut Valley."

far from this last habitat being peculiar, it is in such warm baths that plasm undoubtedly took its rise. Protophyte and protozoa lived in a sea that to us would have been fatally hot.

Seas the earliest home of mundane life.

Here is the reason for the contemporaneous appearance of oceans and of life: the one was the necessary home of the other. That it was so in fact geology states. The geologic record proves that life originated in the oceans, and lived there for long eons before it so much as crawled out upon the land. Seas were the nurseries of mundane life. Whether life might have generated on land we do not know; on earth it certainly did not, possibly because seas were intrinsically the better habitat in place and in time for the uniformity of the conditions they offered; possibly because they were all the home there was. For the land was a sorry spectacle in those days. Granite fringed by mud-flats pictures but an inhospitable sight. The seas were much as they are now,



SPECIMENS OF DEEP-SEA FISH

These specimens were obtained by the *Challenger* Expedition from a depth of about 500 fathoms (3000 feet). They illustrate life formerly thought impossible.

only warmer. Their equable temperature for wide localities and their slow accommodation to climatic change rendered them places of easy livelihood to simple organisms. In addition to which, food, inorganic at first, was floated past the baby plants or animals, and as constantly renewed. To its seas and oceans our planet, then, is actually, if not necessarily, indebted for the life which now teems everywhere upon its surface.

Life, once started, continued the course of advancement thus aquatically begun just as itself was the continuance of the inorganic development which had gone before. And the *deus ex machina* was the same — a gradual lowering of temperature. Cooling was what occasioned increasingly high forms of life, and in two ways this was simultaneously brought about — by preparation of habitat and by prompting of the organism to appropriate it.

The record written in the rocks of our own earth permits us to trace the history of the spread of life. With the gathering of the waters into their place began a new stage in the world's physiographic career — the stage of sedimentary formations. Until the seas were, no strata could be laid down; but with their advent both motive force and suitable sites were present, and, in consequence, what the welkin-born torrents tore down of the naked earth was deposited over the edges of the continents, now here, now there, according as upheaval or subsidence slightly changed the continental altitude toward the sea-level. One bed after another was thus made, until they were several thousand feet thick in places, each being tucked into its long repose by later coverlets superposed upon it.

Entombed in these strata are the skeletons of all those animals that a not too flimsy structure permitted to survive the casualties of flood and commotion or the long disintegration of time. The softer ones have necessarily vanished, leaving as a rule no trace. The rocks are thus vast graveyards of life that once inhabited the earth. They give us the only direct record of the past, and a record which from the necessities of the case is perforce imperfect. Especially are the earlier chapters effaced for the gelatinous character of primeval protoplasm and the forms it first built up. Thus the earliest preserved remains of life are already somewhat advanced types, crustacea in the shape of trilobites being the most primordial specimens that have come down to us in unquestionable state. From this lowly start the line can be followed upward, unfolding through the strata, the marvellous thing being not the paucity, but the fulness, of the record thus written by the animals themselves. For animals and plants, too perishable to endure, have left their stamp behind, and even footprints of past reptiles confront us, legible still on the hardened sands of time, as if made yesterday in the spots they traversed hundreds of centuries ago.

Uniformity of paleozoic fossils.

According to their age, the rocks are designated by geologists as primary, secondary, or tertiary formations, representing paleozoic, mesozoic, and cænozoic eras, meaning the old, the middle, and the new lifetimes, so called from the remains embedded in them.

For our purpose, the most remarkable characteristic of the primary rocks consists in the world-wide uniformity of their contemporary life as exhibited in these fossils of the far past. In the earliest beds existent species prove to have been coevally widespread. In the Cambrian, the lowest of the primary strata exhibiting unmistakable organic remains, we find identical species of seaweeds and trilobites appearing, regardless of latitude, in France and Siberia; and indifferently on both sides of the equator, in the Argentine Republic, as in Europe and North America. In the beds above these, the Silurian, it is the same story. Some of the genera and even some identical species have been found alike in Europe and North America and in Tasmania, Australia, and New Zealand. Evidence of a like latitudinarianism is forthcoming in the Devonian deposits that followed them and in the early stages of the succeeding Carboniferous.

The fauna so distributed was a warmth-loving one, an attribute betrayed by the fact that their nearest relatives now extant live wholly within the tropics, huddled as it were about the equator. Coral reefs, now not found outside of the warm equatorial seas in a temperature not less than 68° F., were reared then in spots now covered with perpetual ice, within eight degrees of the pole. A species of polyp coral, Lithostrontion by name, has been found as a fossil between Point Barrow and Kotzebue Sound, and others in Grinnell Land in latitude 81° 45′ north.

At first the fauna was wholly marine, but gradually the land grew less impossible. Wings of insects have been found in the Lower Silurian, and in the Upper, insects themselves, scorpions both aquatic, apparently, and terrene. Vestiges of plants in the Devonian foreshadowed the superb plant life of the Carboniferous.

Carboniferous plant life.

The flora of the coal measures corroborates the testimony of the animals of that day to the climatic warmth which then existed. Gigantic ferns, fifty feet high; others, more lowly, thirty feet in spread; marsh-loving calamites, horsetails, and club-mosses, dignified to the dimensions of trees, spread their incipient leaves from well-nigh woodless stems, and grew, flourished, and decayed with almost Jack-and-the-beanstalk rapidity between 33° and 70° of latitude. Only a warm, humid foothold and lambent air could have given them such luxuriance and impressed them with such speed.

In the vast marshes which constituted so large a portion of the continents this vegetation was singularly same. Not pretty, but profuse; dense, but not varied, cryptogams composed its greater part, attesting by the habit of the ferns of to-day to the shady half-light in which they must have lived. Grotesque rather than beautiful, no flowers touched with color the sombre stems. No birds made the air about them half sentient with song. Only shade-affecting insects, May-flies of mammoth wing, flitted through the gloom of those old forests, accentuating a heavy stillness they were powerless to dispel.

The twilight their character thus reveals is shown by the details of their structure to have been continuous. No seasons diversified the work of wood-making, as the uniform stems of the few gymnosperms then present attest. No annual rings of growth encircle them, witnessing to intermediate times of rest. They minded not extraneous things, but grew right on; not to delight the world, but to make coal measures their industrious end, to which in their own blind way they excellently conformed. Blind in their habit they may be said to have been, for they were flowerless and much restricted of leaf.

Two attributes of the climate this state of things attests. First, it was warm everywhere with a warmth probably surpassing that of the tropics of to-day; and, second, the light was tempered to a half-light known now only under heavy clouds. And both these conditions were virtually general in locality and continuous in time. For such vegetation as existed the climate was ideal. No enforced hiemal torpor brought on by stalking delegates of frost compelled the workers constantly to stop. It is their less fortunate descendants only that are limited by nature's imposings to labor but six months a year.

Light less and heat more than now.

Thus the records of the paleozoic rocks bespeak two seemingly incongruous things — both less light and more heat than is the Earth's lot nowadays. Many hypotheses have been invoked to account for this warm dawn of the early geologic ages. Some of them are locally geologic, some broadly astronomic, advanced by geologists. But of the two kinds all alike fail.

Thus, merely a different distribution of land and sea will not explain it, because it was general, not local; and, secondly, because this leaves untouched the problem of less light. Equally impotent is a change of position in the axis of the Earth; for were the axis so far changed as to point directly toward the sun, this would not do away with the seasons, but would accentuate them. Nor will an altered eccentricity in the Earth's orbit, which has also been suggested, prove more effective.

Not less impossible is the suggestion due to M. Blondet, and to which De Lapparent has lent the weighty indorsement of his name, that the sun was then so large as to be able to look down on both poles of the Earth at once, and so to give our globe equal day and night everywhere and, as he supposes, a substantially even temperature in consequence throughout. Here the beauty of that to many people deterrently austere and awe-enshrouded subject, mathematics, comes in. For it enables us to do that most important thing for any line of investigation — to subject it not simply to qualitative, but to quantitative, reasoning. When we thus calculate what this paleozoic sun must have been and what its effects, we are brought up on both counts against impossibilities.

The first impossibility relates to the sun itself. For it to do as desired it must have filled all the space inside the orbit of Mercury. For a sun of such stupendous size there is no place in modern cosmogonies. On the other hand, it would have been of incredible tenuity, only one-fifth as dense as hydrogen gas. Nor is this all. It must have been thus uncondensed at a time when the Earth had already solidified. The conception evolutionarily is quite incredible.[8]

Effect on the Earth.

Matters are not bettered for the theory if, passing by the results consequent on the Sun, we calculate those ensuing to the Earth.

We perceive, in the first place, that the exposure to the Sun's rays in the arctic regions would have been by no means uniform, but would have varied greatly with the time of year. At latitude 82° N., for instance, the exposure would have been virtually nothing at midwinter; 25 per cent of what it would be now at the equator, at the vernal equinox, and 1.24 per cent of that, at the summer solstice. So that the play of the seasons would have been much as now.

Secondly, we find that at the arctic circle the solar heat in midwinter would equal that at present in latitude 60° N., and even at the equinox 82° N. in those times would be no more heated than is now 46° N. in midwinter. A Quebec winter six months long does not quite supply an adequate temperature for the bringing up of a polyp coral family within ten degrees of the pole.[9]

So that, when subjected to mathematical treatment, the supposed paleozoic sun turns out to be quite impotent to the work demanded of it. The theory fails as regards the Earth as much as it does with reference to the Sun.

Earth itself responsible for paleozoic heat.

Planetology, however, can offer us a clew to this beclouded hothouse state of things. The Earth's own heat, not directly on the crust, but directly on the water, and thence through its atmosphere, might well be responsible for paleozoic conditions. For consider the warmth we know must have existed while the recently precipitated seas still were hot. Their temperature would furnish an agreeably heated habitat for organisms such as even the tropics fail to supply to-day, and one which from its genesis would be much the same from the equator to the poles. Simultaneously, a vast steaming must have gone up from the still warm waters, resulting in a welkin of great density. This would act in two ways to explain the phenomena. First, the welkin would keep the Earth's own heat in; and, secondly, it would keep the Sun's heat and light out. We should have a sort of perpetual tropical summer in a twilight of cloud; a climate superior to seasons because screened from direct dependence on the elevation of the sun. This is perfectly in accord with the half-light the vegetation vouches for, while the luxuriance of that vegetation testifies to the warmth and even suggests a further, though not the chief, reason for it in the great amount of carbonic dioxide its existence establishes as then present in the air.[10] For carbonic dioxide is a great bar to the passage of heat. So is water-vapor. It was dank and dark in those old carbonic forests because so seethingly steamy overhead.

That the oceans should have retained their heat so long is not surprising when we reflect upon the great capacity that water has for heat. Its specific heat, which means the relative amount needed to raise it one degree in temperature, is five times that of stone, and ten times that of iron. So that it would have more to part with than its surroundings, and would still be warm and steamy after they had cooled.

Earth, not sun, the motive force in evolution in the paleozoic era.

In paleozoic times, then, it was the Earth itself, not the sun, to which plant and animal primarily stood beholden for existence. This gives us a most instructive glimpse into one planetologic process. To the planet's own internal heat is due the chief fostering of the beginnings of life upon its surface. Thus a planet is capable of at least beginning to develop organisms without more than a modicum of help from the central sun. We talk of the sun as the source of life; and so it is to-day in the sense of being its sustainer; but the real source was the Earth itself, which also raised it through its babyhood.

A once cloudy Mars.

Something of the same history probably fell to the lot of Mars. Several circumstances render this likely. If its initial surface temperature was in the neighborhood of 2000° F., it was well above the production-point of steam. So that a cloud canopy would be possible when a general volcanic fervor of the surface was not. Then the apparent presence in those early days of seas would furnish the wherewithal of clouds. Thus Mars would seem to have possessed the necessary substance to its veiling, and the requisite conditions to that end. If a planet be big enough to bring forth life, it may well provide a set of atmospheric swaddling-clothes in which that life goes through its early days.

Life outgrows the sea.

Under such paleozoic conditions life passed the first eons of its earthly existence. Gradually life outgrew the need of such careful housing, water within the organism remaining as necessary as before. Organic development proceeded from amœba to fish, attaining no mean height in the process. But at last a better habitat offered itself, and was speedily appropriated. Weathering of the land and constantly changing chemic processes prepared the continents for organic use. Plants, as we have seen, at last found foothold, and insects an abode. Then came the exodus from the sea. We may picture some adventurous fish, spurred blindly from within, essaying the shore in preference to the main. Tentatively at first he must have ventured, as became such bold endeavor. Finding the littoral not inhospitable, the pioneer reported his exploit and was followed by others whom mutation had specially endowed. This impulse toward the new, from the promptings of altered character, which we call spontaneous variation, is the motive principle of life. It probably derives from the instability of the plasmic molecule, forever rearranging its constitution afresh and finding itself thus adapted to novel relations. Thus arose the amphibia in the Carboniferous era, visitors only to the solid ground. From them came the reptiles, their descendants, in the Permian, who, from the temporary sojourners their fathers were, developed into permanent denizens of the new abode. From this aboriginal crawling out upon terra firma the organism progressed until finally it came to stand erect and call itself a man.

Changed habitat made all the later strides in intelligence possible. The very sameness that rendered the sea so inviting a habitat to simple souls, made evolution beyond a certain point difficult, if not impossible. Change might develop in the organism, but it would find little encouragement to survive in its surroundings.

Effect of environment upon evolution.

It was the variety of conditions possible on land that gave rise to varying environment, and this in turn that conduced to organic differentiation. Life would have remained forever of a low, cold-blooded order if it had been constrained to continue in the sea. What made the broad ocean so excellent a nursery curtailed it as a field for action later on.

To appreciate how unsuited to high development of organism the sea was, we need only think how poor a place it is for bringing up a family. Fishes cast their spawn upon the waters, and leave the hatching of the eggs to chance. If one in a million survives this unparental treatment, it is all that nature expects. The fish has done well, and its tribe increase. This is taking but little thought for the morrow. The poor little egg is homeless as well as parentless from the start, lacking even that attenuated appreciation of home surroundings Gallicly expressed as *mal du pays*, since one tract of ocean so dishearteningly resembles another.

Very different is the care of their young exhibited by the higher land inhabitants, the mammalia. With them the mother begins by carrying the egg in the safest possible way, as a part of herself, until it has become to all intents and purposes an animal on its own account. It then sees the light, but not the limit of fostering care. She keeps it by her, suckling it till it is able to procure food for itself. Even then its guardianship is not in the highest forms foregone. In man parental help continues up to the point when the young is full grown, and even after that, on through life, till the next generation has become the dominant one of its day.

To say the least, life was an arduous, adventurous career amid the inhospitable homelessness of the sea. And this is shown not only by the leaving it at the first opportunity by those who could, but by only degenerates returning to it again. Only the poor relatives of the mammalia — the porpoises, dugongs, and whales—are now to be found there, having taken to it through stress of circumstances, elbowed off the better ground by their stronger associates.

That the outcasts still exist, however, proves the tenacity and adaptability of life. It goes everywhere, takes up with what it can get, and turns the least propitious *milieu* to its own ends. For life is more universal than is our usual conception of it. Our limited personal experience we take as measure of the whole, and say, "Thus far and no farther." But nature knows no such limit to her own possibilities. And we are gradually, one may almost say reluctantly, learning them of her. Go where he will upon the earth, man finds life of some sort there before him. He discovers new continents or seas merely to find out that they had been discovered by some poor relatives long ago, and appropriated by them. From burning Saharas to polar snows no spot is exempt from colonization, though some teem with immigrants more than others. In altitude it is the same story as in latitude. If man ascends, he meets with forms of life that rise with greater facility than he, and inhabit, too, what they explore. In descent it was until recently thought otherwise. One region was supposed free of such intrusion and to have remained as virginly azoic as when originally formed—the unstirred abysses of the vast oceanic basins, all that constitutes the great deep beyond the immediate vicinity of the shore and below the hundred-fathom line. No life existed, man was sure, in the depths of the sea.

Fifty years ago the absence of both flora and fauna from the deep seas was not only taken for granted, but believed on the most conclusive grounds to have been proved inevitable. The first of these was the enormous pressure to which any organisms resident there would be subjected. From the weight of the superincumbent water the pressure would increase at the rate of one ton per square inch for every thousand fathoms of descent.

Deep-sea life thought impossible fifty years ago.

Consequently, at the bottom of the Atlantic, it would be from two and a half tons to three and three-quarters tons per square inch, and in the greater depths of the Pacific from three and one-half to nearly five tons. On bodies at the earth's surface, living only under the ocean of air, it is but fifteen pounds to the square inch. From fifteen pounds to ten thousand is a far cry, and one it staggers imagination to understand. It was only too easily argued as prohibitive to life. Any organism there, it was thought, would simply be crushed out of existence.

The second bar was the total extinction of light. Below two hundred fathoms no sunlight could possibly penetrate. So it was calculated from the rate at which light is absorbed at lesser depths, and the calculation was amply borne out by observation. Experiments by Fal and Sarasin have fully demonstrated the unassailability of this deduction. On a

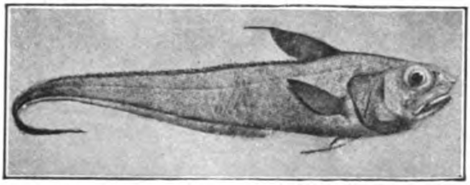
Extinction of light.

sunny day in March they exposed bromo-gelatin plates for ten minutes at a depth of two hundred fathoms without a trace of reaction. To those who know by experience how quickly plates fog in a dark-room, this immunity speaks for the more than Stygian darkness which must there prevail.

Now, the lack of light is distressing enough to any fauna, but to flora it is absolutely preclusive, since light is the necessary stimulus to chlorophyl reaction, and thus to the growth of the plant. But if all plants be absent, animals, it was confidently concluded, must be absent, too, since they could not live without plants, being unable to fashion their food out of inorganic substances. They must eat plants or other animals that have eaten plants. Therefore, after the stronger inhabitants of these abyssal depths, supposing any there, had eaten the weaker, they must themselves die of starvation.

These arguments seemed unanswerable, to say nothing of the abyssal cold. For the temperature falls as the thermometer descends until at a depth of a few hundred fathoms in the unbarriered ocean basins it reaches a temperature of 34° F., whence a slow falling further brings it to 29° F., or actually below the freezing-point of fresh water.

Deep-sea life. When it had thus been conclusively proved that no life could exist at the bottom of the sea, deep-sea dredges were invented, and no sooner were they let down than, behold! they came up teeming with life. Fish and crustacea, mollusks and echinoderms — life, in short, of all the usual pelagic kinds from protoplasmic molecules to marine monsters — were found to inhabit the abysmal depths. What could not be, just was.



SPECIMEN OF A DEEP-SEA FISH

This specimen was obtained by the *Challenger* Expedition from a depth of about 500 fathoms (3000 ft.) and illustrates life formerly thought impossible.

The abyssal fauna thus disclosed proved to be in comfortable circumstances, in spite of the supposed impossibility of its existence at all. It had, it is true, no visible means of subsistence, but it subsisted, nevertheless. It was as widespread as it was abundant, enjoying a distribution unknown on land. The same species were found off the coast of Europe and about New Zealand, in the arctic seas as well as under the tropics. This was because of the uniformity of the habitat. Only seven degrees of difference in temperature distinguished one part of its huge domain from another. There was therefore no bar to migration; indeed, the sameness of the surroundings must have insidiously led the inhabitants on. A species was thus induced to become world-wide, while on land, even supposing a pathway to exist, the journey from one hemisphere to the other involved enduring a shift of 100° F. or 150° F. of temperature, made as it would be from winter in the one to summer in the other. No such temporalities as seasons disturb the abyssal pelagic denizens, nor can locality have meaning to them, even though they be associated with the bottom, which is only ooze or mud — ooze, the burial-ground of protozoa, and mud, the siftings of volcanic lava mixed with meteoric dust. One place is like another, bearing no earmark, and a fish returning to the very spot of its nativity would not know it again. Time and space are alike annihilated there, and both to sense made limitless. If any creatures can feel infinity, it must be these abyssal denizens of the deep sea.

Blindness. The supposed impossibilities of their abode Nature has contrived to surmount. The pressure permeates them, and their parts are constructed to stand the strain. Yet so little change has been needed to adapt them that it is virtually imperceptible to the cursory eye. In another way Nature has accommodated them to the illumination of their habitat. She has let them get on without seeing or she has provided them with lamps. By supplying senses other than the eye, and allowing the animals to become blind, crustacea and fishes alike, she has made them independent of the darkness. Or she has done for them what man has accomplished for himself — supplied artificial illumination. That a blind fauna should exist in a vast domain with not so much as a one-eyed specimen for king, is interesting and suggestive of what Nature can contrive to do without, but that she should undertake to light the region, and that by means of the creatures themselves, is yet more surprising.

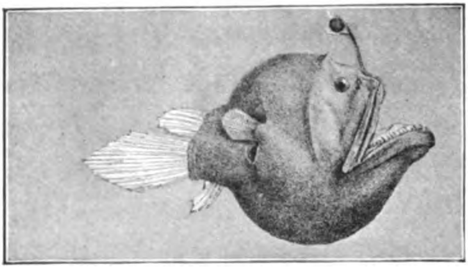
Phosphorescent organs.

But this is precisely what she does, and with something akin to electricity, each animal carrying with it its own machine. Whole tracts are brilliantly lighted up by the inhabitants till they must resemble London or Paris seen by night, only that in these thoroughfares of the abysses of the sea the passers-by provide the illumination, each, as it swims about, swinging its own lantern as in old Japan, though better — a phosphorescent arc-light, as one may say. These devices are evident even when the fish, no longer living, reaches the surface in the dredge; much more brilliant they must be in their native wastes of abysmal water, where all is cold and dark and silent round about, as impressive as a mountain top at midnight, standing confronted with the stars.

Lesson of the fishing fishes.

How thoroughly the living by artificial light is now a part of their everyday existence, the occupation of angling practised as a means of livelihood by certain of the fish themselves — fish that fish and are known in consequence as angler-fish — will serve to show.

On the surface the genus given to this profession are furnished with a long tentacle which, rising from the back, curves over by its weight till the end, which is lobed into a red bunch not unsuggestive of a tempting worm, dangles right in front of the fisher's mouth.



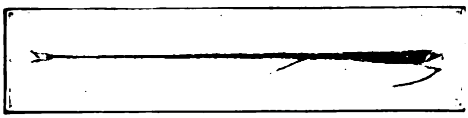
SPECIMEN OF A DEEP-SEA FISH

This globular specimen is an angler-fish, which has kept to the habit of angling, but has changed its bait. From the *Challenger* Expedition.

Smaller fry, attracted by this bright bait, dart forward to gulp it, and are themselves snapped up by the expectant jaws.

Now, of these angler-fish one species proves to inhabit the abyssal zone; and this relative of the anglers above, instead of the red worm-like bait at the end of its rod, which would be useless in the Stygian darkness thereabout, has replaced it by a brilliant, phosphorescent light, which lures as certainly to destruction. Adaptation could offer no more expressive example of the insistence of life, even to the preservation of the very type, than this keeping of the fishing habit with only a change of bait.

After such an ingenious transformation, the substitution of lungs for gills when the aquatic animal changed into the terrestrial one, seems a forthright step in comparison. The swim-bladder, discarded when the descendants of the upper relatives of these animals emerged, leads to some curious experiences at the bottom of the sea — ones that induce new outlooks on life, and yet are the result of conditions alone. To us who live upon the solid crust, pulled downward constantly by gravity, danger lies in falling over precipices or down holes. Abyssal fish are exposed to no less a risk, but of precisely the opposite character — that of tumbling upward. Within limits, the fish has control of his swim-bladder, but if in the excitement of the chase he gets carried by impetuosity farther up than he intended, he may reach regions where, for the lessened pressure, he can no longer control its distention, and is swept against his will higher and higher till his organs burst from the released strain. The fish tumbles upward, and is killed by the fall.



Specimen of a Deep-sea Fish
Obtained by the *Challenger* Expedition.

As for the flora, it simply does not exist. Nevertheless, the absence of a local food supply is not fatal to these denizens of the deep. It would seem that what descends to them from the waters above is enough, meagre as it may be. They feed off the crumbs that fall from the better-spread table of their littoral relatives, as is shown by their being the descendants of emigrants thence. For most of them have relatives still living in shallow water, the oldest abysmal species not dating farther back than Cretaceous times.

Cosmic character of life.

From such world-wide distribution of life over the Earth under conditions which are antagonistically unlike, we realize its essentially cosmic character experimentally, if we may so put it, as well as theoretically. Modifications of it follow any and every change of environment, but nature strives to the last gasp to bring forth this, her highest product.

Each planet sets a different stage for the play of spontaneous variation. In no two is the scenery the same, but this is not essential to organic origin and growth. Nor are many of the environmental circumstances prohibitive, though at first they seem fatal to our particular species of life. Because a man, if suddenly transported to Mars, would gasp and die, is as beside the point in any inquiry into the existence of life there as the fact that no woman ever was the mother of a monkey is irrelevant to a discussion on the origin of man. We have here been evolving in keeping with the shapings of a certain environment. To suppose that we could instantly prove adapted to another quite diverse is to mistake the process upon which life depends.

Indeed, our most commonplace actions would there seem phantasmagoric. Personal experience of Mars, on the surface of which gravity is only three-eighths the Earth's, would take on a character akin to the grotesque. Everything there would become unnaturally light: lead would weigh no more than stone with us, stone than water, each substance appearing to be transmuted into something other than itself. It would prove at once a world imponderable, etherealized. Our actions would grow grandific. For with little effort we should accomplish the apparently impossible, endowed with an effectiveness increased sevenfold. Lastly, everything would take its time. Water would flow with hesitant and lazy current, and falling bodies sink with graceful moderation to the ground. After our first paranœac wonder, it would certainly impress us as a world as slow as it was flat.

Our very senses would seem estranged. Sight, indeed, and taste would be the only ones not to be shifted in their point of view. Touch, hearing, even smell, would all suffer a space-change and prove quite other than we know them now. We should be anything but at home. But this does not imply that life of some form would not. For consider how our own world must seem other than we know it to every animal upon its face. To the ant it stands a very different habitat from what the elephant conceives it. The grass-spires which tower as trees to the one are trodden unnoticed underfoot by the other. Nor is it matter of mere magnification alone. The former feels both strength and limitations the latter quite ignores. The ant scales his grass-stem with an ease and assurance we should not know on trees, and falls off to the ground, if need be, completely unscathed from a relative height that would terminate our careers forthwith.

But though modified in feeling by size of habitant and modified in fact by size of habitat, life would go on superior to such detail were the planet only sizable enough to furnish it with its necessities.

So far as we have evidence, life is an inevitable outcome of the cooling of a globe, provided that globe be sufficiently large. For life did not reach this earth from without. No fanciful meteorite bore it the seeds which have since sprouted and overrun its surface. Meteorites gave it life, indeed, but in the more fundamental way in which all nature's processes are done, by supplying it with matter only from which by evolution life arose. Of this we may be absolutely certain from the fact that while meteors were falling upon it in any numbers, they were forming its mass, the full heat of which had not yet been evolved by their impact and subsequent condensation. The heat that thence ensued was excessive, many fold greater than sufficed to kill any germs that might have come to it housed in the meteorites themselves. Thus the action due the meteorites after they came must have annihilated any organic possibilities they may have brought with them. Those arriving after the heat had waned enough to make survival possible found life already started, since protoplasm formed the moment cooling permitted of it.

The proof that life was here spontaneously evolved appears at every stage in its history, not only in its origin, but at every step of its progress upward where a marked departure occurs from its previous course. It and the environment are observed to have changed together. Two short parallel columns, the one showing the changes that have occurred in the habitat, the other those supervening in the habitant, will make this not simply clear, but striking. As effective as the well-known deadly parallel of oratorical utterances, this life-giving one reaches the same certainty through the probabilities disclosed.

Occasion of this vital parallelism occurs at the very start. Indeed, we may go back of this and note agreement before the start. For until the conditions were such as could support life, no life appeared. This is the first coincidence. Another follows on its heels with the dawn both of conditions fit for some existence and of that existence itself. The waters were its birthplace. No other portion of the surface could then have offered it a home, and nowhere except in the sea is it then found.

The simultaneity of each new birth and each new cradle crops up again when a new field arose by the making of the land. As soon as this was suitable, plants appeared to take possession of it, and from that time on neglected more and more the sea.

The fourth parallel is found in the significant fact that the edible plants and the plant-eaters made their début on the scene together in Miocene times, the world having got along without both before that epoch. This entry, hand in hand, so to speak, De Lapparent, the great French geologist, does not hesitate to link logically, and to regard the one as the necessary complement of the other. If this were not the case, there is certainly no reason why they should appear at the same instant of time. Food evokes its eater in fact as definitely as in phraseology.

The last of this procession of coincidences, man, came on the scene at the time when the cooling of the globe rendered his own extension possible at the least expense to himself. His brain allowed him to take advantage of conditions less intrinsically favorable than other animals could endure. His mind clothed his body and gave him fire, and with these two products he sallied forth into a world where antagonists were chiefly climatic, with which he was fitted to cope.

Thus all along the line we perceive that life and its domicile arose together. The second is necessary to the first and the first is always sufficient to the occasion. The coincidence of the possibility and its seizure, of the *posse* and the *esse*, seems to be a general principle of evolution. Endless variation is constantly in progress, and this variation takes advantage of any opportunity so soon as it occurs. Life but waits in the wings of existence for its cue, to enter the scene the moment the stage is set.

CHAPTER III

THE SUN DOMINANT

Transition. The passing of the supremacy of its own heat, and the entrance of the Sun upon the scene as the dominant power in its life, mark the next stage in a planet's history.

On Earth the transition from self-support to solar dependence began with the first symptoms of atmospheric clearing in the time of the great reptiles. The clouds that had veiled the whole Earth in the paleozoic period then began to dissipate; though it was probably not until much later that the sky approached the pellucid character we know. The Earth's own cooling thus first let in the Sun.

That such must have been our Earth's history we gather from the other planets; that it actually was so we discover from the records of the Earth itself. For from the fossils embedded in its rocks we learn that when the Triassic strata, more familiarly known as the New Red Sandstone, were laid down, gymnosperms, cycads, and conifers had replaced the cryptogams of the primary age. These plants require more light than ferns. Though technically called flowering plants, they yet lacked flowers to catch the eye. Still, they demanded more sunshine than their predecessors, and thus testify to the purifying air caused by the gradual cooling of the surface and the consequent less abundant generation of cloud. That the Sun had not grown more insistent, but the Earth more open-eyed, the latitudinal character of the cooling shows. For it was not the absolute lowering in warmth, but the zonal differentiation of temperature that then set in, which is the noticeable thing. The tropics were as before; the climate was changing slowly toward the poles. Climatic zones began to belt the Earth.

In the next mesozoic division, the Jurassic, the corals, by dropping down the latitudes as time went on, speak of continued refrigeration. Tropic, temperate, and frigid regions began to belt the Earth. But zones were not yet well established, as the presence of the same cycads in Mexico and Franz Josef Land suffices to attest. Corals still grew in latitude 55° N.

With Tertiary times came in the seasons. Before this the Earth knew them not, though its axial tilt was the same as now. Their advent is registered for us in the changed vegetation they induced. For their presence is witnessed by the coming in of deciduous trees, which make their first appearance in its preceding strata, the lower Cretaceous, and spread and

The sun asserts itself.

flourished in the Eocene, Miocene, and Pliocene eras. The northern zones had now grown so cold that vegetation had to hibernate in the winter months. Meanwhile we mark the palms successively descend the parallels in search of heat. In the Eocene — the dawn of the recent — already they are lower than in earlier epochs; in the Oligocene, the next age, their northern limit is the smaller fifties; they become rarer there in the Miocene; and in the Pliocene they have virtually disappeared from northern Europe. With increase in light went hand in hand decrease in warmth, which shows that the Earth had been the source of the earlier torrid climate. Its seas and continents were both cooling off.

The Sun was slowly asserting his position as the great giver of both light and heat, and the world as we know it was beginning to be.

This change in dependence from Mother Earth to distant Sun ushered in the reign of beauty in the world. We live in the colored supplement of our globe's history, the time when the pigments were put on; and this because as fashioner the Sun has replaced the Earth. Though they bear no relation to us, the gorgeous tints of blossom, butterfly, and bird that so delight the eye were called into being by the sunbeams themselves; while the descendants of the plants that were beholden chiefly to the Earth — the fungi, mosses, and brakes — are sombre browns and greens, and flourish only in the shade. A few indeed have adapted themselves to the new conditions, but the greater part still pathetically cling to the world in which they were brought up — a world (except in corners) long since passed away.

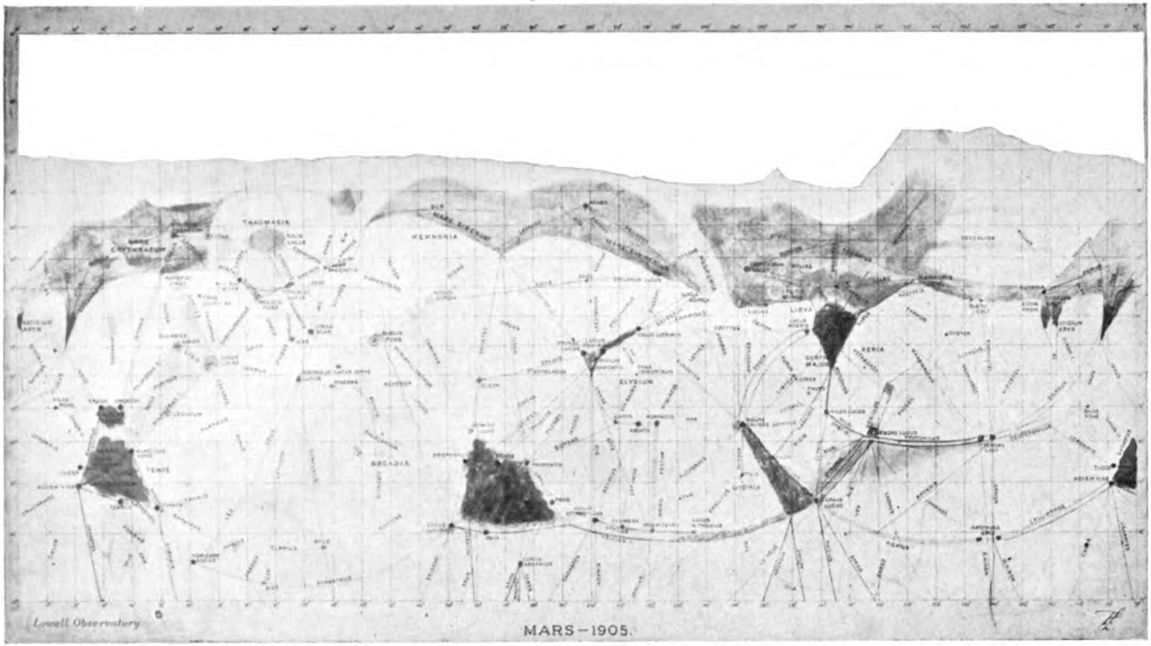
Mars betrays the same evolution.

Since a general clearing of its sky is a regular step in a planet's development, we should expect to find a cloudless, transparent air in the case of a planet as relatively old as Mars. For thus a body opens its eyes to the cosmos. Now, this is precisely what we do find. The aspect of Mars shows that it has thus waked to the universe about it. In fact, such was the very first of its characteristics to be made known to the earth, being the one by which the others were revealed. Without it we had never made acquaintance with this other world in space.

Viewed under suitable conditions, few sights can compare for instant beauty and growing grandeur with Mars as presented by the telescope. Framed in the blue of space, there floats before the observer's gaze a seeming miniature of his own Earth, yet changed by translation to the sky. Within its charmed circle of light he marks apparent continents and seas, now ramifying into one another, now stretching in unique expanse over wide tracts of disk, and capped at their poles by dazzling ovals of white. It recalls to him his first lessons in geography, where the Earth was shown him set ethereally amid the stars, only with an added sense of reality in the apotheosis. It is the thing itself, stamped with that all-pervading, indefinable hall-mark of authenticity in which the cleverest reproduction somehow fails.

In color largely lies this awakening touch that imbues the picture with the sense of actuality. And very vivid are the tints, so salient and so unlike that their naming in words conveys scant idea of their concord to the eye. Rose ochre dominates the lighter regions, while a robin's-egg blue colors the darker; and both are set off and emphasized by the icy whiteness of the caps. Nor is either hue uniform; tone relieves tint to a further heightening of effect. In some parts of the light expanses the ochre prevails alone; in others the rose deepens to a brick-red, suffusing the surface with the glow of a warm, late afternoon. No less various is the blue, now sinking into deeps of shading, now lightening into faint washes that in places grade off insensibly into ochre itself, thus making regions of intermediate tint the precise borders of which are not decipherable by the eye.

Superimposed upon its general opaline complexion are now and then to be seen ephemeral effects. At certain times and in certain places warm chocolate-brown has been known to supplant the blue. Often,

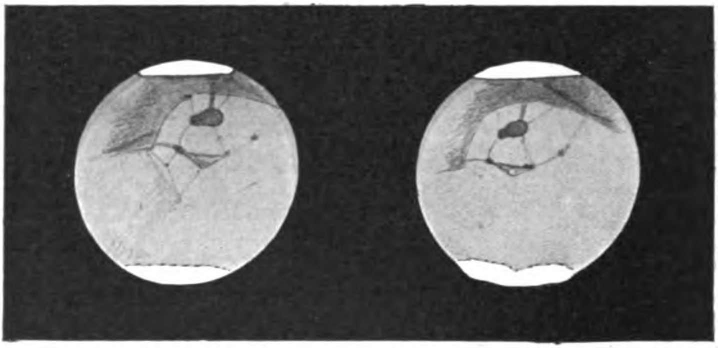


THAUMASIA
MEMNONIA
ARCADIA
TEMPE
ELYSIUM
LIBYA
AERIA
Lowell Observatory
MARS—1905.

too, cold white dots are scattered over the disk, dazzling diamond points that deck the planet's features to a richness beyond the power of pencil to portray. So minute are they that good seeing is needed to disclose them. It is at such moments that color best comes out. To those who know the sun only as golden and the moon as white, even in its color scheme Mars would stand forth a revelation.

It is easy to travel in thought over the strange land thus displayed below you. For though you gaze up into the sky, you still look down upon its ground, and follow consciously or unconsciously the configuration of its surface with cartographic eye, now led by some apparent bay to run with it up into the continent, now witched by the spirit of exploration toward some island, as it seems to be, set remote in the midst of the sea. But whether you purpose it or not, nature, taking the matter out of your hand, decides it for you. For presently you perceive your point of view not to be quite what it was. The bay in question, as well as the island, has slightly changed its place upon the disk, while the two have kept their mutual relation unaltered. A few minutes more and the shift has increased, and then you become aware of what is taking place: this other world is turning on itself, as turns our own, rotating from west to east as it rolls along its orbit about the sun.

Up over the rim of the disk rises a marking, to swing in time across the centre, and then on out of sight round the other limb. The one horizon marks the sunrise-line upon the planet, the other the sunset one, and in its course between the two the place has



Two Views of the Solis Lacus Region of Mars, One Hour apart, July 26, 1907 (the One to the Left the Earlier), showing the Rotation of the Planet. North is at the top

had its Martian day. Unsuspectedly, but no less potently for that, the act of such withdrawal only whets curiosity the more. What perchance might have wearied had it remained forever there, gains an added glamour from the fact that it is gone. But, more than this, it gives an earnest of yet further fields to be explored. From the circumstance of turning comes promise that other regions will later be displayed, and as the observer watches, the predicted comes to pass. One longitude after another turns the corner, rounds into view, and slowly swings into the meridian plane.

Objects, grown familiar, give place to others that are new. Sitting alone in midnight vigil in his silent dome, the astronomer thus mutely circumnavigates another world.

The cloudlessness of the planet's sky alone makes such travel possible. Were it not for the unobstructed view, exploration of the sort would be out of the question. Were Mars not an old planet, corroborating by absence of cloud the general course of planetary development, our knowledge of it had been slight. To begin with, its lack of covering enables us to mark the permanency in place of the planet's features, and from such permanently to time the planet's axial rotation. This gives us knowledge of the planet's day and furnishes means to measure it. This day proves to differ in duration little from our own, being 24 hours, 40 minutes long, instead of 24 hours. In the next place its scantiness of atmospheric apparel discloses the tilt of the axis to the planet's orbital plane, a relation which causes the seasons of the year. Now the Martian tilt, as well as the Martian time of rotation, turns out to be singularly like our own, being, in fact, 24° * as against 23½° for the Earth. Thus the Martian seasons counterpart ours. The year of

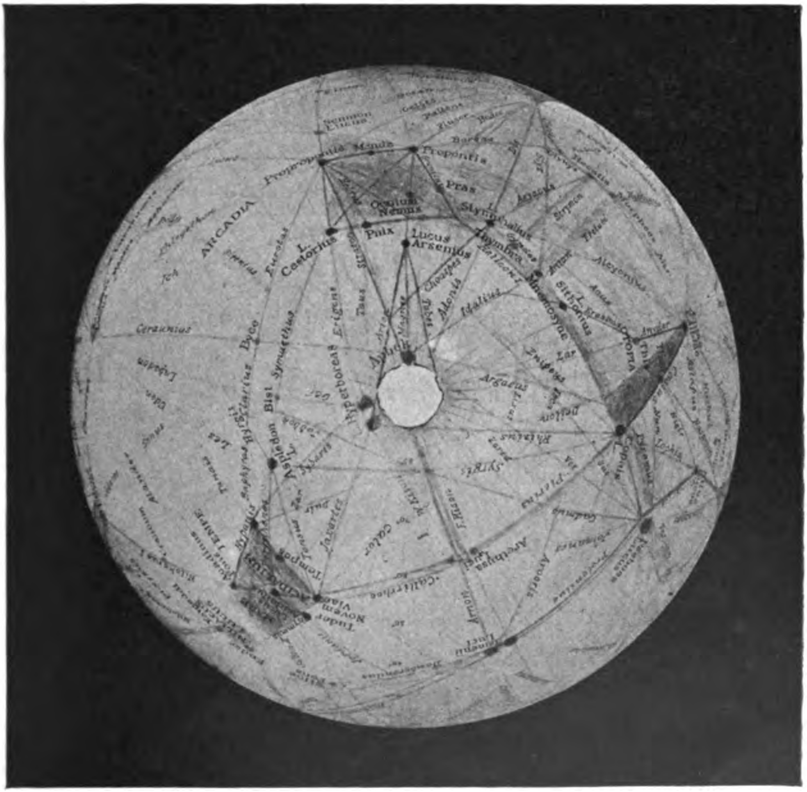
* Still later measures at Flagstaff make this even smaller, 23° 13′, — or actually a little less than ours. (See note 18.)

Mars, however, is twice ours in length, which, joined to great eccentricity of orbit, gives it diversifiedly long seasons. Thus, in the northern hemisphere, spring lasts 199 days, summer 183, autumn 147, and winter 158, while in its southern hemisphere the figures stand reversed. The numbers have more than academic importance, for absolute length is as vital a factor in a season's influence as the fact of the season itself. Much may be brought to pass in twice the time which could not develop in the shorter period. And it is not a little interesting that precisely this possibility actually turns out to be vital in the vegetative economy of the planet's year.

The thin atmosphere of Mars.

Absence of cloud speaks, too, of the thinness of the planet's air,[11] of which we have other evidence as well. Perhaps the best proof of a relatively thin air is the lack of intrinsic brilliancy of the Martian disk, its "albedo," as it is called. This is only 27 per cent of absolute reflection, as against 92 per cent for Venus. Now, a thick air, even if clear, — indeed, because clear, — would cast a luminous veil over the planet's face due to dust or vapor, as it does with Venus, dimming its features. Such is not the case with Mars.

Of twilight, therefore, there should be less, and certain observations made at Flagstaff in 1894 seem to prove this. The refractive medium of air which on Earth calls the Sun earlier in the morning, and keeps



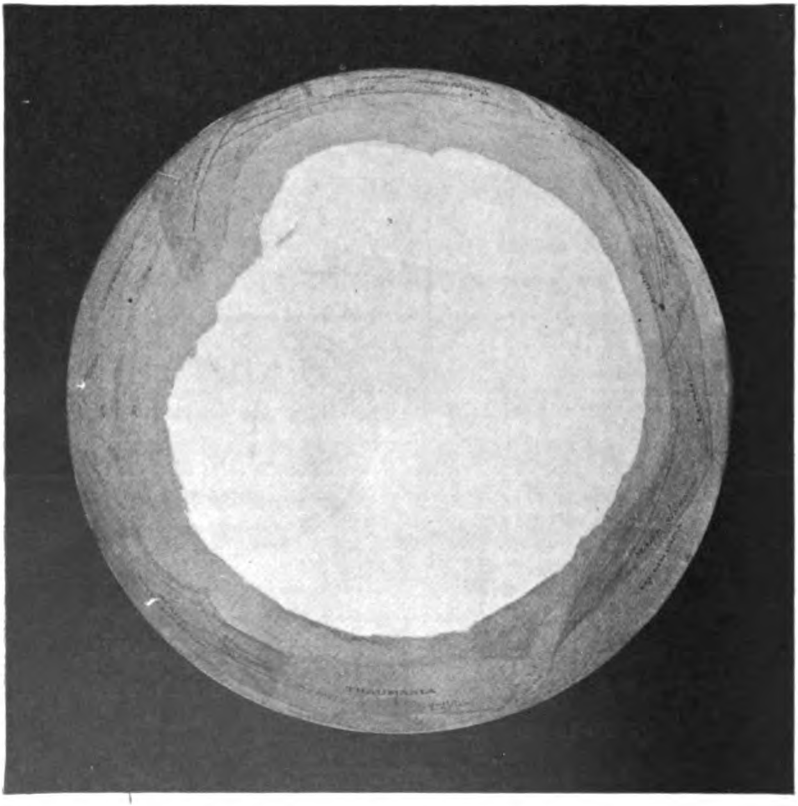
THE NORTH POLAR CAP OF MARS AT ITS LEAST EXTENT

him up later at night than would otherwise be the case, is not so potent on Mars. Day there enters with greater abruptness, and lapses into more sudden dusk. Then comes a night when the stars stand forth with an insistency unknown on earth.

That some air exists is, however, patent, both directly from the limb-light that fringes the circlet of the disk and inferentially from the changes that we mark in progress on the planet's face. For change of itself implies an atmosphere.

The polar caps of Mars.

First of the phenomena to betray this air were the white caps that bonnet the Martian poles; for in the person of these patches transformation was first recorded upon the Martian disk. Their position, together with

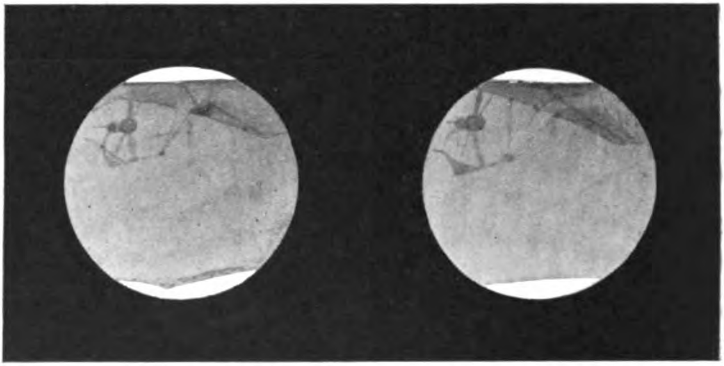


THE SOUTH POLAR CAP OF MARS AT ITS GREATEST EXTENT their seasonal wax and wane, pointed them out for polar snows gathered during the Martian winter and melting with the Martian spring.

That the polar caps are composed of snow, or, rather, hoar-frost, suggests itself to any one who carefully scans the planet. But to prove it was not so easy. Fortunately, a phenomenon which accompanies it turned out, when rightly reasoned on, a touch-stone to its character. As the cap melts, it is seen to be girdled about by a dark-blue band, deeper in tone than any other blue-green area on the disk. This belt developed the peculiar property of retreating with the cap as the latter shrank, maintaining throughout its attendant post. The phenomenon was first seen by Beer and Mädler, but it was not till 1894 that its significance was seized.

Drawing of Mars, April 8, 1907, showing the Dark Belt that girdles the Snow During its Melting

Clearly the outcome of the melting cap, it disposed by that fact of the suggestion that the caps might be solid carbonic acid that freezes at 109° F. into a substance not unlike snow. For carbonic acid, under pressures of one atmosphere, or less, such as would be the case on Mars, passes instantly from the gaseous into the solid state. Not so water-vapor. Here, then, was a telltale bit of behavior. The blue belt proclaimed the presence of a liquid. Thus carbonic



From drawings, July 20 and 22, before and after the event.

EARLY WINTER SNOW-STORM IN THE NORTHERN HEMISPHERE OF MARS, 1907 (NORTH AT THE BOTTOM). MARTIAN DATES: OCTOBER 22, LEFT-HAND DRAWING; OCTOBER 23, RIGHT-HAND DRAWING

acid could not be concerned, and the substance composing the caps was therefore snow. For no other, that we know of, dons their snowy aspect with change of state.

The behavior of the cap thus affords intrinsic proof of its constitution. Since this was determined, another line of argument has given extrinsic evidence of the same thing. This is the evaluation of the surface temperature of the planet recently made for the first time with any approach to precision.

The question of temperature on Mars.

The stronghold of doubt as to the habitability of Mars has always been the difficulty of accounting for a temperature there high enough to support life. From its own bodily heat at the present time the planet itself, like our own earth, can contribute to the surface temperature no appreciable amount. The necessary caloric must all come from the sun. Now, because the planet was half as far again from the sun as the earth, and because light and heat diffuse inversely as the square of the distance, — a candle two feet away giving only one-fourth the light of one a foot off, — it was supposed that Mars must receive only four-ninths the warmth that the earth gets, which would render its temperature terribly low.

But the receipt of radiant energy is not so forthright as this. To begin with, the bundle of rays from the sun striking the planet is subject to two adventures at the very threshold of its planetary career. A part of it is at once reflected back into space from the body it strikes — from the air first, then from the planetary surface. But the reflected light or heat does not go to warm the body at all. Strange to say, this important fact had never been taken into account until the present investigation of the subject, which led to a completely different outcome from what had previously been supposed. Too technical for exposition here, one or two points in it may be mentioned. First, the proportionate amount of the reflected light-rays which reach an observer stationed on another planet measures the relative brightness of that planet as seen by him. This per cent per square unit of surface at distance unity is what is called the planet's albedo. Now the albedo of the different planets has been found by more than one observer from investigations unconcerned with our present subject, the only gap in the series being that of our own earth. The latest determination by Müller is: —

Mercury	0.17
Venus	0.92
Mars	0.27
Jupiter	0.75
Saturn (Struve)	0.78
Uranus	0.73
Neptune	0.63

Our own earth's albedo is lacking from the table because we cannot see ourselves as others see us, and are consequently somewhat in the dark as to our own appearance. By suitable deduction, however, from the brightness of sunlight at different altitudes above the surface of the earth, it is possible to get some idea of it, and from this a modest estimate puts it as at least .75. So that we are not so dull as we thought.

Thus we get the amount of radiant energy received from the visible part of the sun's rays. There are also rays too long to be perceived by our eyes, and these must also be considered in a determination of the whole. The bolometer invented by Langley enables us to do this, and so to obtain the fraction of the total incident energy which goes to warm the body. In the case of the earth it proves to be 41 per cent of the whole; and in the case of Mars, 60 per cent. Here, then, we have at once a serious modification of a calculation based on distance alone.

The clear skies of Mars.

But this is not all. The clearness of the Martian sky comes in to abet the greater transmission of its air. From dawn till dusk, day after day in the summer season, and largely in winter, the sun shines out of a heaven innocent of cloud. No shield of the sort, and only a little screen of air, tempers its beams to the soil held up to it. Such an exposure far exceeds anything we have on earth; for with us, even in the tropics, clouds gather as soon as the heating grows excessive, and cool the air by plumps of rain.

How much this means to a planet as far away from the sun as Mars, will appear if we consider what in this respect is the condition of the earth. Over the earth as a whole, the proportion of actual to possible sunshine for the whole year is 50 per cent. That is, the sky is such that the sun shines only half the time it might were there no clouds to screen it.

On Mars the spring mistiness at the borders of the polar cap is the only veiling the surface knows, with the result that the percentage of sunshine throughout the year is 99 per cent of the utmost possible. This is somewhat reduced by the fact that some light and heat of course is let in by the clouds — and is kept in better, too.

Taking these different data, and using the most recently determined relation of radiation to temperature (that of Stefan, which has been independently deduced theoretically by both Boltzmann and Galitzine), we find that the mean temperature of the surface air of Mars should be about 48° F. We must not place too much credence in the actual figures, for our knowledge of the laws of atmospheric retention of heat is very uncertain, but the research is enough to show that the above result is much nearer the truth than the terribly cold ones. That of the earth is only 60° F.; so that the mean climatic warmth of the two planets is not very unlike, and far within the possibilities of life for both.[12]

But the circumstances are even more favorable to Martian life than this. For man does not live by mean annual temperatures alone. In fact neither he nor other animals in our temperate zones pay so much heed to yearly averages as is sometimes supposed. Much more to the point with them is the mean summer warmth they experience.

Summer and winter temperatures.

Now, in the summer-time, — that is, all the way from some months after the winter solstice to some months after the summer one, — more heat is absorbed daily from the sun than is radiated out to the stars at night. The surface temperature is then constantly rising; a fact patent when one stops to think of it in this way, since June is warmer than March, but that this means that the day's gain exceeds the night's loss is commonly lost sight of. The fact is pertinent to our present inquiry. For the daily increment continues for half the year, and the Martian year is twice our own in length. Its total gain in summer over the mean would, other things equal, rise to something like twice our own. Instead of a temperature lift of 30°, as with us, on Mars it might well be 50°, in spite of the thinner air.

That a thin air is compatible with great surface heat the latest and most authoritative measures of the heat of the moon's surface during the lunar day interestingly corroborate. These measures are those of Professor Very. With great care and thoroughness this excellent investigator experimented on the amount of heat radiated by different parts of the moon at different times of the lunar day. He continued the work Langley had begun to a much finer point of precision. It used to be thought that even at lunar midday the temperature of the moon's surface must be below freezing because of its lack of a retaining blanket of air. Very's latest conclusions in the matter put a quite different aspect upon it. In a letter of his to the writer he sums up his results as follows: —

> When the sun rises, no matter in what latitude, it is cold. I do not venture to say how cold, but below the freezing-point. Not until the sun has reached an altitude of 15° in middle latitudes does the temperature get above freezing. Then the heat mounts rapidly until at the end of the first week of sunshine in dry regions near the equator the rock surface is as hot as boiling water. As midday approaches at the end of the second week, the scorching rocks attain a temperature full 80° centigrade above the boiling-point of water in regions under a vertical sun (356° F.). Having once become heated, the rocky surface retains its heat to a great extent far into the afternoon, the curve of falling temperature being perhaps a day and a half of our time out of symmetry. Toward the end of the lunar afternoon the fall of temperature is very rapid, and before the sun sets, frost prevails, or at least temperatures which produce frost wherever there is water-vapor to make the article which we call "hoar-frost."

And this great heat occurs where there is virtually no blanket of air; and, what is even more striking, its temperature maximum is not attained till a day and a half after its greatest receipt of sunshine.

Now, when we turn from deduction to the picture the planet presents, which, after all, is entitled to some consideration in statements about itself, we confront what certainly seems a body in fairly easy circumstances of temperature. In its summer the surface lies fully exposed to our gaze, and it assuredly is not suffering from wholesale glaciation. On the contrary, the phenomena point to something quite the reverse. For weeks its arctic regions up to 86° and 87° N. latitude are certainly above the freezing-point, since the snow disappears. Probably they are far above it, for in the polar caps we then behold a shrinkage much greater than anything we similarly experience on earth, part of which is due to less depth of snow, but showing also that it is relatively warmer there than here. Lower down the disk, toward the equator, great dust-storms, like the simooms of our Sahara, sweep over portions of it at times, hundreds of square miles in extent, conveying to the onlooker anything but a sense of chill.[13]

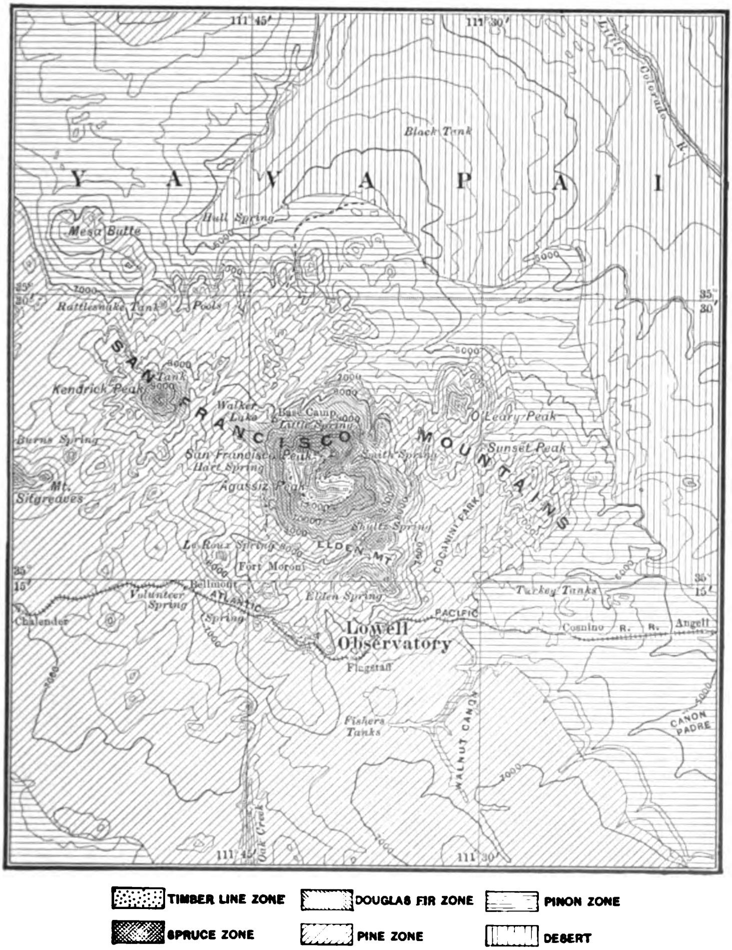
Aspect of Mars corroborative.

In winter the opposite state of things prevails. A good sixth of the whole surface goes into winter quarters as each autumn draws on. It stays so, too, for some eight of our months on end, not to emerge till the next Martian spring. A winter on Mars in high latitudes has a polar complexion to it not wholly pleasing to contemplate.

But the idea that such a winter's counterpane betokens more than hibernation, and in any sense hazards the existence of life, a moment's thought on our own conditions of living will suffice to dispel. The great nations of the earth, with scarce an exception, live half the year in the earth's north polar cap, buried in snow and hidden the greater part of the time from visual communication with outside space. If Martian philosophers are of the pattern of some earthly ones, they must incontrovertibly prove to their own satisfaction the impossibility of our existence. Nevertheless, from the fairly successful way in which we manage to survive in open contravention of philosophy, we see that it is not necessary even to suppose hibernation, feasible as nature finds that to be with insects, fishes, and beasts, in order to tide an animal over from one period of warmth to the next. An organism with or without what we are pleased to call human intelligence is quite capable of submitting to conditions which would, if permanent, prove destructive to life, and of biding its time to a more propitious season.

Summer the life season.

For, thanks to recent research, we now know that with animals generally it is the summer temperature, not the winter one, that decides the question as to whether life shall exist. An able investigation of the United States Government Zoölogist, Dr. Merriam, made upon the region of the San Francisco peaks, in



MERRIAM'S MAP OF SAN FRANCISCO MOUNTAIN AND VICINITY, ARIZONA

Published in "North American Fauna, No. 3."

1889, brings this point out with great acumen. Its pertinency to the problem before us commends it to reference here.

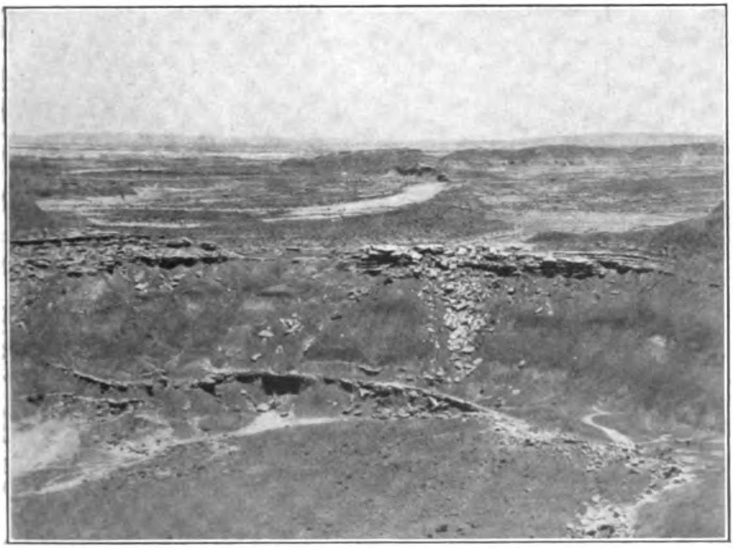
In geographic and climatic position combined the San Francisco Mountains of northern Arizona are among the most interesting animal and vegetal habitats

THE SAN FRANCISCO PEAKS

of the globe. They are what is left of a great crater of Tertiary times, which, rising out of the plateau north of the Arizonian desert, tower to 12,630 feet of altitude. The massif of this once volcanic cone supports now many square miles of forest on its flanks, and its plateau base is clothed with pine; while girdling it about, and cutting it off like an island from other vegetation, stretch the arid wastes of the great American desert.

This floral island is remarkable for being banded by successive zones of trees, each distinctive and exclusive, and giving place the one to the other solely according

Zones of vegetation of the San Francisco Mountains.



Arizona Desert View

to elevation. Starting from the desert forty miles away, where sage-brush and cacti alone succeed in managing an existence, the traveller enters at an elevation of a mile and a quarter above the sea the initial zone of scrub. Stunted at first, clumps of dwarf juniper — cedars, as they are locally called — make their appearance, and grow in size and vigor as he continues to ascend. With them are soon associated another form of juniper and the piñon, a small tree from twenty to thirty feet in height. At about 7000 feet he encounters the *Pinus ponderosa*, to which the juniper and piñons then give way, and the whole aspect of the

THE DOUGLAS FIR

tree vegetation changes. Here the stately pines possess the land alone, save for a few white oaks on the edges of the mesas. At 8500 feet the yellow pines disappear, to be succeeded by the Douglas fir, the Rocky Mountain pine, and the beautiful trembling aspen. At 9500 feet this set of trees gives place to yet another, and the traveller enters the western white spruce zone, associated with which is the fox-tail pine, the needles of which startlingly suggest a fox's brush. At 10,500 feet these trees dwindle to dwarf specimens of themselves, until at 12,000 feet they entirely lapse, and naked rock stretches supreme to the summit. A climb of 8000 feet from 5000 to 13,000 of elevation has carried the observer through six zones of absolutely distinct tree life, counterparts of the tropic, the temperate, the Canadian, the Hudsonian, the Arctic, which he would have traversed had he journeyed from the foot of the mountains northward to the pole.

To the higher slopes of the mountain every summer deer troop from the lower plateaux where they have passed the winter, to stay at these heights until October's cold drives them down again; while upon it all the year round are to be found bear, which also go up and down with the change in seasons. In addition to these are wildcats and mountain lion, besides a host of smaller mammals, squirrels, gophers, and the like.

Summer temperature determinative of life.

Merriam camped upon the peak in July, 1889, and studied the habits of the animals at high elevations during the summer months, comparing the various genus and species found there with those known northward in the world. Among other interesting results he found that the survival of species is determined not by the mean annual temperature of the locality or by the winter minimum, but by the maximum temperature prevailing during the short summer months. It is in this season that the animals bring forth their young, and his study showed that if they were sufficiently warm during the reproductive season, cold during the rest of the year mattered not. At the worst they hibernated. Here, then, the fact of a few warm weeks made life possible, outweighing the impossibility of all the other long, cold, forbidding months. Furthermore, what is important to our present discussion, Merriam found that temperature was more potent than humidity, so long as they had any water at all.

This point in animal history has immediate bearing upon the habitability of Mars; for the Martian summer is twice as long as ours, and, as we have seen, the probable acme of warmth attained in it is by no means small. It is by these attributes of its climate, and not by its mean annual temperature, or by the great cold its surface very possibly experiences in winter, that its ability to support life must be judged.

Another point the presence of the animals on the San Francisco Mountains serves to bring out — their indifference to thinness of the air. The creatures which dwell on the peak, or which visit it as a summer resort, are members of the same species whose natural home is at sea-level farther north. The deer are such as one finds in the northern part of the United States; the bear are the same as those inhabiting the forests of

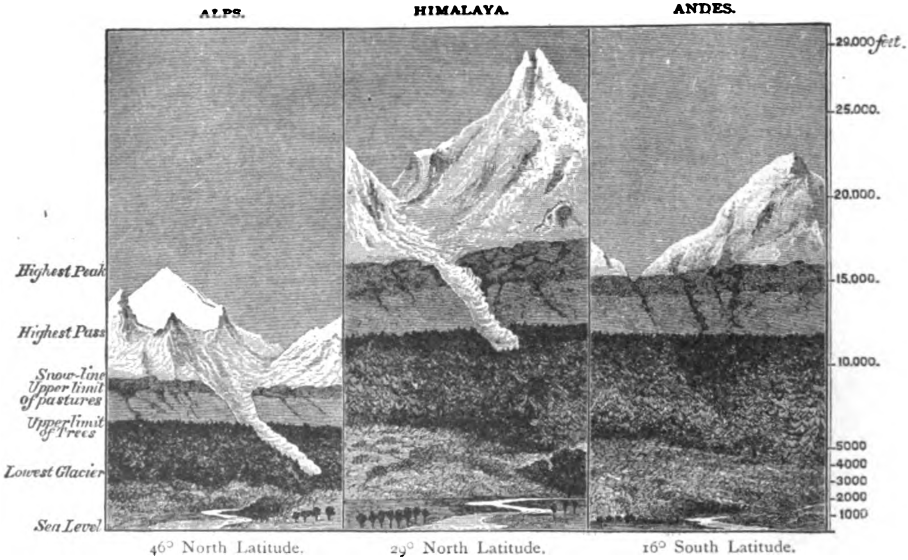
Canada and Labrador. Altitude takes the place of latitude in sufficiently cooling the habitat to their accommodation. But it does this at the expense of air. On the peak they dwell at elevations of 10,000 feet, where the barometer marks only 18 inches, instead of the 30 to which their relatives are accustomed. Yet, in spite of living in atmospheric penury on the mansard roof of the world, — for the mountain here is steep, — they suffer no inconvenience, and seem totally unaware that they are doing anything peculiar. Nor have they seemingly changed in organic or even in functional development. With the deer the lack of special adaptation is equaled only by the lack of conscious absence of it, and the animal is as much at home as in the timber of the Minnesota woods.

That thinning of the air proves no bar to a species, provided other conditions are the same, is further shown on the high lands of the western United States. The meadow-larks of the great plains rise with the surface into the parks of the Colorado Rockies, with an altitude of eight thousand feet, and are there as much acclimated as at two thousand in the Kansas prairies.

Now, if such a barometric range can be borne semiannually without special modification by the organism, how much more may not be accomplished by accommodation, given a sufficiency of time? Men who first pitiably gasp, learn to endure, and finally, embrace, a life of elevation. Quito, at ten thousand feet, has a population who live as easily as their relatives at sea-level.

Plateaux hotter than peaks at a like elevation.

Owing to the thinness of the air, it has been customary to liken the conditions on Mars to those upon

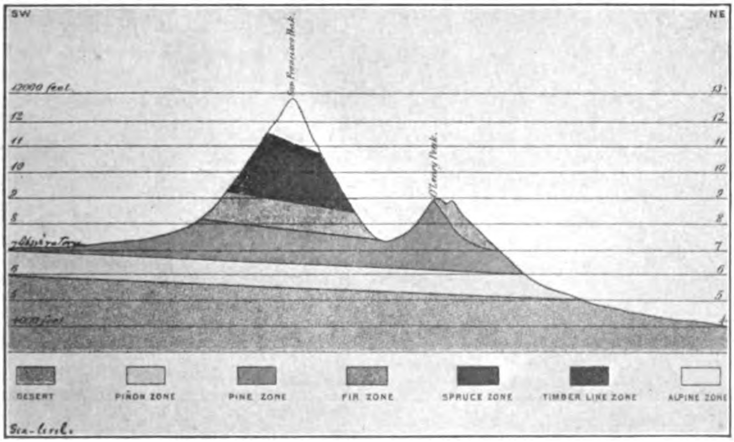


From Geikie's "Elementary Lessons in Physical Geography." (The Macmillan Company.)

VERTICAL DISTRIBUTION OF CLIMATE ON MOUNTAINS, SHOWING HOW LAND-MASSES RAISE THE TEMPERATURE

our highest mountain tops, where life finds it impossible to exist. But the analogy is misplaced. Mars, with its level surface, is more like some vast plateau. Now, that the temperature of a plateau exceeds that of a peak at the same height, table-lands on the earth make evident. Humboldt cited the Himalaya. On the north side of this great range, both snow-line and timber-line are three thousand feet higher than on the south side, a climatic lift brought about by the Tibetan table-lands on the north; and this in spite of the contrary effect of slope exposure.

But we may get instances nearer home. In scanning Merriam's chart Lowell was struck by a fact

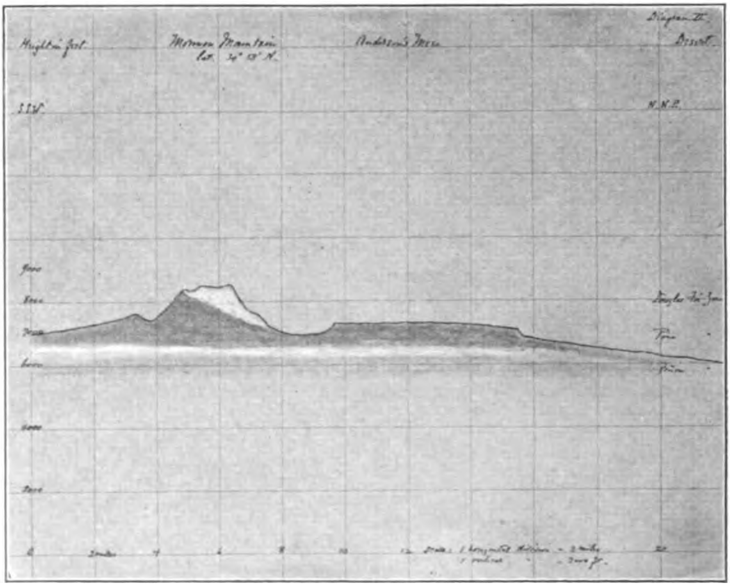


After a plate in "North American Fauna, No. 3," U. S. Dept. of Agriculture, Division of Ornithology and Mammalogy, by Dr. Merriam.

DIAGRAMMATIC PROFILE OF THE SAN FRANCISCO AND O'LEARY PEAKS, FROM SOUTHWEST TO NORTHEAST

The diagram shows the several life zones and the effects of slope exposure, but also shows what is unnoticed by the monograph, the effect of a plateau upon life. The location of the Lowell Observatory is indicated by the star.

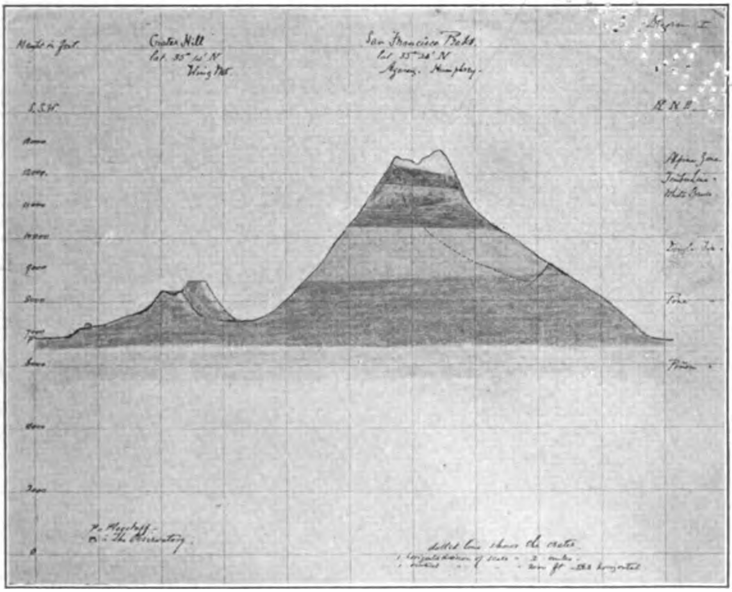
unmentioned by Merriam. Superposed upon the more evident dip of the zones down from the southwest to the northeast a divergence in this dip may be recognized, the dip increasing as the zones mount. It at once occurred to him that this must be due to the mass of land upon which each rested. That, in short, the isoflors rose relatively to the north because of the



SHOWING EFFECT OF PLATEAU ELEVATION ON TREE ZONES—LESS ELEVATION

higher plateau base there. To test this he made a series of camping trips this last summer, 1907, on and about the peaks, measuring, with an aneroid checked by trigonometric survey, the heights at which the several species of trees grew and from his data laying down the isoflors. The outcome was more striking when thus carefully done than it had been in Merriam's map, and quite conclusive as to cause. It is here presented to the reader in a series of charts.

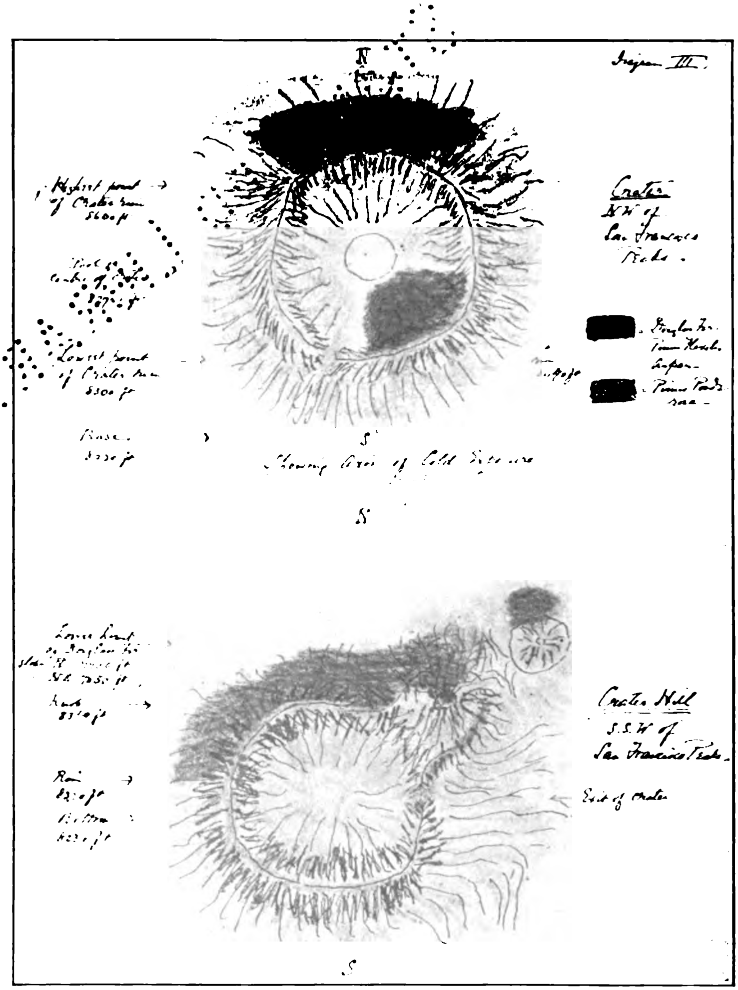
In these charts not only does the dip decline less the nearer the tree zone stands to the plateau, but in



SHOWING EFFECT OF PLATEAU ELEVATION ON TREE ZONES — GREATER ELEVATION

the nearest of all, the pine zone, the influence of the northern plateau is actually sufficient to counteract the opposite effect of slope exposure and cause the isoflor to rise toward the north.

The explanation of the matter is not far to seek.



DIAGRAMS OF TWO CRATERS SHOWING GREATEST COLD N.N.W.

Each bit of plateau helps warm its neighbor, and so keeps a heat that else had radiated away. So much for the effect of but a small plateau. If even a limited area of high ground can so far ameliorate the temperature, how much more would be accomplished were it to become world-wide?

That we do not find animal and vegetable life at the tops of our highest mountains is due to other cause than elevation; namely, to the restricted nature of the habitat upon the pointed needle of a peak, separated by impassable gulfs from other equally limited areas. The animal has no range of forage and no chance of commerce with its kind. This is one reason for the absence of life upon isolated pinnacles. Yet even so its presence proves surprising. On the very pinnacle of the San Francisco peaks, at 12,630 feet, the tracks of a chipmunk showed clearly in the snow on the occasion of its ascent upon October 15. Another exterminating cause is the wind that of necessity always draws over a peak at the slightest provocation. The consequent drain upon an animal's own heat when made under low temperatures is fatal to life. Man can endure 70° below zero F. if the air is still, but perishes at 40° below under the least wind. Even a breeze, therefore, is equivalent to a fall of 30° F. in the temperature.

Water-vapor in the air of Mars.

By both temperature and appearance, then, water-vapor proves a constituent of the Martian atmosphere. Now, the vapor of water is a light gas, the lightest of the constituents of our own air, and, in consequence, by the laws of gases, among the most difficult for a planet to retain. Its presence, therefore, in a planet's gaseous envelope is of the nature of a guarantee that less volatile associates are also to be found there. These, in an increasing order of weight, are nitrogen, oxygen, and carbonic acid gas. So we may conclude that these are probably also to be found on Mars.

But we are far from having to rely upon such inference, well founded in principle as it is, for our knowledge of the existence of these important gases in the atmosphere of the planet. Modern observation of a quite unrelated class of features puts their presence there upon a secure footing — a planting on the premises of both feet instead of one by the logical body of fact; and that, too, by reason of a descent from the air to the solid surface of the ground. It is the now recognized constitution of one of the two great classes of markings that diversify the disk which has given us the necessary information. The blue-green regions have proved themselves the sibyls in the case.

In form first, in color subsequently, the blue-green areas commended themselves as seas and oceans to the mind of the early areographers. Even Schiaparelli so considered them. Nor at that stage of acquaintance was the characterization at all far-fetched. But as these seeming seas were better scanned, differences of tint became apparent in them. This should have shaken belief in their character, but so tenacious is an idea when once it has taken root that the discovery awoke no doubt. The oceans were merely spoken of as shallower in some places than in others, as if thousands of square miles of water so few feet deep that the bottom showed through did not of itself need explanation.

Next, these very differences showed variation. Areas as large as Great Britain, and often very much larger, would lighten in the course of a few weeks in a perfectly unmistakable manner. Indeed, the greater part of the whole southern hemisphere of the planet would thus doff one tone, and even tint, to don another at surprisingly short notice, and this without anything approaching a correspondingly sizable darkening elsewhere.

When we set ourselves to consider the matter in the light of what was seen, we perceive that such absence of reciprocity is fatal to the theory of a liquid film. For were the transformation some subtle shift of substance, what one part lost, another must have gained. Either transferred as water elsewhere or wafted away, to be deposited as snow about the pole, the thing should still be somewhere in the planet's aqueous economy. Yet neither of these counterbalancing effects was perceptible. As water it had vanished, and the polar caps were not increased.

Vegetation of Mars.

Left, thus, without a marine character to their name, we are led to inquire what these patches, which both in form and color ape water, can in reality be. If the great blue-green regions be observed at intervals of a few weeks, and the aspects they successively present be recorded in drawings, intercomparison suffices to make evident that the metamorphoses they experience are periodic, and the period that of the planet's year. The changes, then, are seasonal in cause. That is, they depend upon the sun. And in proof of the relation, their fading out is found to occur in winter, when the sun is least operative, and their greatest evidence in midsummer, when the sun is locally most potent.

Now, there is only one thing, so far as we know, thus obedient to the sun and indicative of its subserviency by a change of hue from blue-green to ochre, and that is vegetation. Both colors are self-accusatory. The first speaks of verdure in its prime, the second of the change of the leaf to the sear and yellow stage, just as it takes place in our own foliage on the approach of autumn's frosts, indicating that its course is run. Not otherwise could we observe it from space, should we mark our own familiar earth change color when its season's work was done.

Vegetation thus vouched for, the constitution of the air becomes more certain. Besides water-vapor, oxygen and carbonic acid gas must both be present, and undoubtedly nitrogen, too, since in the matter of density it holds an intermediate position. To find that the Martian air is made up of our old familiar friends in the matter of gas is an important step to acquaintance with what goes on upon that other world. Though we are indebted for our knowledge of its existence to the vegetation, which is visible while the air is not, it is in fact the vegetation that is indebted to it for being able to show at all.

Mode of manifestation of life.

Of organic existence there the main, or natural, features of the planet's face could not be looked to for more disclosure. Indeed, the surprising thing is that they should have disclosed so much. That the coming and going of vegetation should be visible across the thirty-five million miles of space to which at its least the gap separating us from Mars is reduced, is little short of marvellous. As for a direct view of any animal life the planet might support, it would be out of the question. In a very different manner would this reveal itself. Not through its body should we be ware of it, but *through manifestation of its mind.* By the material changes in the surface of a planet wrought by the dominance of his mind over matter would the other world-worker stand confessed. This we shall realize if, from the point we have gained in establishing the probable existence of such life, we go on to consider its probable character. Such can be done by reviewing the experience of our own planet.

From what has taken place on earth, we see that cooling and complexity of organism have advanced together. Life originated here as soon as the temperature fell below the boiling-point, and it started in water, the liquefying of which out of steam gave it at once an essential factor of its substance and an environment of the most easily satisfying kind.

An upward step in evolution occurred when life stepped out upon the land. While less directly favorable to life, the land was fraught with more possibilities for organisms capable of turning them to account. Brain was needed, and brain evolved.

Brain, indeed, now became the chief concern of nature. The character of the habitat undoubtedly brought this about through the prizes it offered the clever, and the snuffing out to which it consigned the crass.

For long the animal remained thus the creature of its environment, its view restricted in both time and space. Greater possibilities came in with man. Doubtless his was no very dignified entry, though something better than on all fours. Brain now finally distanced brawn, and even in his savage state man became a being that others feared. From thus standing *primus inter pares*, he soon developed into first, "with the rest nowhere." Fire and clothes raised him to some independence of his surroundings, and slowly he began to take possession of the earth. His breeching, the putting on by the race of the *toga virilis*, was both an incident of his rise and part cause of it as well, for it made him superior to climate. But the fertility of brain, however humble in its beginning, which suggested the means of protecting the body, devised the methods by which he was to subjugate the earth.

For some centuries now this has been his goal, unconscious or confessed. The true history of man has consisted not in his squabbles with his kind, but in his steady conquest of all earth's animals except himself. He has enslaved all that he could; he is busy in exterminating the rest. From this he has gone on to turn the very forces of nature to his own ends. This task is recent and is yet in its infancy, but it is destined to great things. As brain develops, it must take possession of its world.

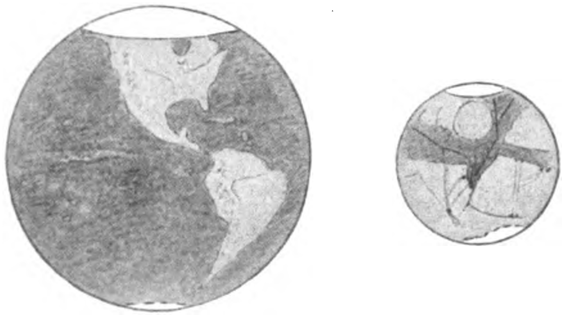
Subjugation carries its telltale in its train; for it alters the face of its habitat to its own ends. Already man has begun to leave his mark on this his globe in deforestation, in canalization, in communication. So far his towns and his tillage are more partial than complete. But the time is coming when the earth will bear his imprint, and his alone. What he chooses, will survive; what he pleases, will lapse, and the landscape itself become the carved object of his handiwork.

Equally applicable is this deduction to planets other than the earth. Instead of its being true, as a recent writer remarked, that "we cannot expect to see any signs of the works of inhabitants of Mars if such exist," precisely the opposite is the case. Until the animal attain to dominance of his world, his presence on it would not be seen. Too small in body himself to show, it would be only when his doings had stamped themselves there that his existence could with certainty be known. Then and not till then would he stand disclosed. It would not be by what he was, but through what he had brought about. His mind would reveal him by its works — the signs left upon the world he had fashioned to his will. And this is what I mean by saying that through mind and mind alone we on earth should first be cognizant of beings on Mars.

CHAPTER IV

MARS AND THE FUTURE OF THE EARTH

STUDY of Mars proves that planet to occupy earthwise in some sort the post of prophet. For, in addition to the side-lights it throws upon our



COMPARATIVE SIZES OF THE EARTH AND MARS WITH THE POLAR CAPS OF BOTH IN THEIR SPRINGTIME.

past, it is by way of foretelling our future. It enables us to no mean extent to foresee what eventually will overtake the earth in process of time; inasmuch as from a scrutiny of Mars coming events cast not their shadows, but their light, before.

It is the planet's size that fits it thus for the rôle of seer. Its smaller bulk has caused it to age quicker than our earth, and in consequence it has long since passed through that stage of its planetary career which the earth at present is experiencing, and has advanced to a further one, to which in time the earth itself must come, if it be not overwhelmed beforehand by other catastrophe. In detail, of course, no two planets of different initial mass repeat each other's evolutionary history; but in a general way they severally follow something of the same road.

Mars has lost its oceans.

It is in the matter of water that Mars stands forth as a prophet, and this in two ways: as polar ice and as oceanic expanses.

The first of these has reference to our own glacial epoch, a geologic phenomenon the strangeness and seeming unaccountableness of which has grown as scientists have contemplated it with more care. That vast areas of the earth's northern hemisphere, and of the southern, too, were at times covered by a continuous ice-sheet is a fact remarkable enough in itself, but grown still more curious from the difficulty experienced in assigning it adequate cause. Cosmic cooling of our planet will not explain it, certain as that cooling is; for the refrigeration was partial, and recurrent as well. Croll tried to account for it, but ingenious as his idea was, it will not hold water — in the shape of ice — in the form in which he put it, and it is now virtually abandoned by geologists, although it contains considerable truth.

Now, it is not a little interesting that Mars should have something to say upon the subject — something which throws light upon the phenomenon as a general planetary process, and specifically upon its occurrence on our earth. It is because Mars happens to present precisely the astronomic conditions which form the basis of Croll's theory, and at the same time shows the exact opposite of the prescribed results, that its evidence is valuable.

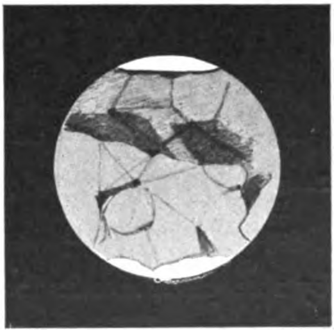
The relative length of a planet's seasons are determined by the elliptic orbit the planet pursues. If the axis be so tilted that summer of one hemisphere occur when the planet is nearest to the sun and therefore also moving swiftest, that summer will be short and hot, while the corresponding winter will be long and cold. This hemisphere will have seasons of extremes; the other reversely will have long, cool summers and short, warm winters or seasons of means. The greater the eccentricity of the orbit the greater the accentuation between the two hemispheres.

Glaciation would result from a greater deposition of hoar-frost or snow in winter than the succeeding summer's sun could melt. A lengthening of winter at the expense of summer would seem, therefore, able to bring it about. Now, a greater eccentricity in the orbit of the earth than is the case to-day existed in the past, and would produce just this effect. So Croll argued that it had done so. Unfortunately for the theory, Mars moves now in an orbit more eccentric than that of the earth ever can have been, and the nearest approach of the planet to the sun occurs, too, not far from the summer solstice of its southern hemisphere, yet that hemisphere which should show glaciation not only does not, but comes farther from doing so than the other. For while the northern cap diminishes from 78° across to 6°, the southern dwindles from 96° to nothing. This shows that while for various reasons the longer winter results in a greater deposition, the shorter but hotter summer of its hemisphere more than melts it away.

Now, if we increase pro rata the precipitation over the whole planet, we perceive that the extent of the southern cap at its greatest will still more outdo the northern one, and as the melting capacities of the two summers are approximately constant quantities, a time will come when the remains of the southern cap will surpass that of the other, and glaciation ensue.[14]

Such passing by one cap of the other in the race toward glaciation is bound to occur, whatever the eccentricity, if it be anything at all, provided the precipitation be sufficient. On the other hand, not only no glaciation can result unless the precipitation exceed a certain quantity, but in want of it the ice-cap is actually less in the hemisphere where we should expect it, that of extremes, than in the other. Whatever the cause of increased snowfall, the effect is the same. It is, then, the amount of precipitation, however it be brought about, and not increase of eccentricity, essential as eccentricity is, which is the determining cause of an ice age.

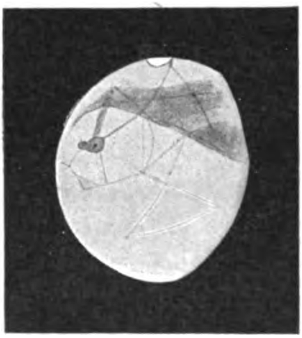
To perish by wholesale glaciation is not therefore the inevitable doom of a planet. Unless water be in abundance, secular cooling will not necessarily bring it about, and Mars shows us that a planet may wholly escape such a termination to its career by having previously parted with sufficient moisture, and actually enjoy an anti-glacial state in its old age.



LINES IN THE DARK AREAS OF MARS, SHOWING THAT THE LATTER ARE NOT SEAS.
From a drawing made July 11, 1907.

The thought leads us to the second matter in which the present state of Mars foretells the future of the earth. Not only does unhampered age [15] preclude the possibility of a death by frost; it tends to a death by thirst by deprivation of water. As we saw when reasoning upon the blue-green areas, Mars apparently had seas in the past, though it possesses none to-day. To the student of the planet the question at once arises, how this not wholly regrettable deprivation was acquired, since it was not congenital.

There are two ways in which a planet not only may, but inevitably must, be robbed of its water supply — from without and from within. It may lose its oceans



November 5, 1907.

September 1, 1907.

PARING ON THE TERMINATOR (RIGHT-HAND EDGE) OF MARS WHERE DARK AREAS CROSS; INDICATING THAT THEY LIE AT A LOWER LEVEL THAN THE REST OF THE SURFACE, AND WERE ONCE SEAS.

by absorption into its interior and by a slow depletion into space. While a body is yet molten, the continuity of its substance bars entrance to aught else; but as it cools and shrinks, fissures and crevices open in it, and into these the surface water sooner or later finds its way. As a planet ages, its very wrinkles must cause it to dry up. This is one drain upon its surface seas that is sure to occur. The other is equally scheduled to happen. It depends upon the fact that gases are composed of particles called molecules travelling at great speeds. Temperature is the expression of this energy, varying, indeed, as the product of the square of the speed by the mass of the particle. Such motion it is that causes gases to expand. In their journeyings the molecules collide, and thus give and take velocity. In consequence, some are moving swiftly, some slowly. The molecules are flying about in all directions, and as long as they do not go too fast, the planet about which they act as atmosphere continues to control them by its gravity. This it can continue to do up to a speed called its critical velocity, which is the velocity the planet can impart to a particle falling freely to it from infinite space. For the planet can annul just the speed it is able to cause and no more. But if, in their give and take of motion, a molecule gets to going faster than the critical velocity, it will escape into space and start on interstellar travels of its own. These molecules will never return to the body they have left, and as such desertion is constantly going on, it will eventually deplete the planet of all the gases it once possessed.

Now, from any liquid surface evaporation is perpetually taking place; so that an ocean is being slowly and silently lifted into the air. Ordinarily its particles fall again in the shape of rain, but not those which by collision gain sufficient speed. These from their tiptoe vantage-point take final flight into interplanetary space. The smaller the body, the sooner must it lose its seas, for the less can it hold on by its lesser gravity to its water-vapor. Three stages in the inevitable parting with its hydrosphere are exemplified to-day by the earth, Mars, and the moon. On the earth the sea-bottoms still hold seas, on Mars they only nourish vegetation, on the moon they contain nothing at all.

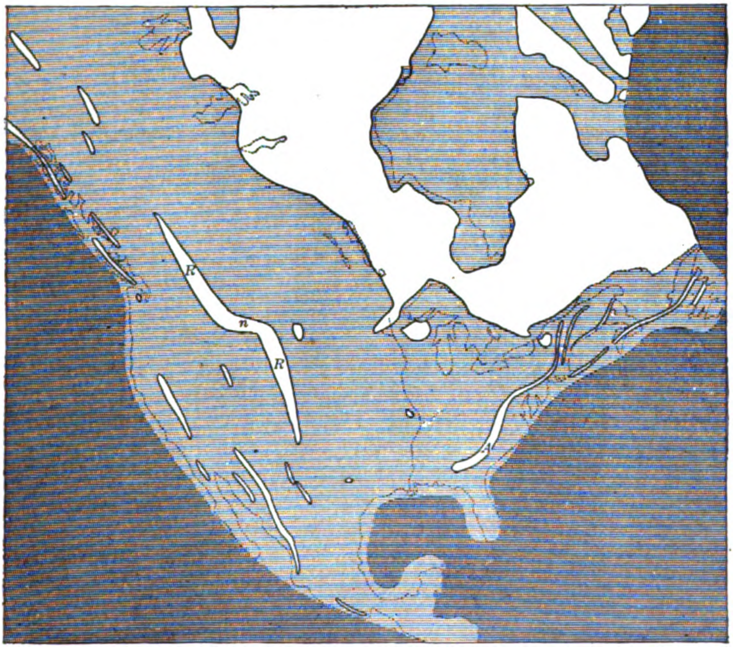
Parity of reasoning points to the road the earth must follow. Sharpened by science, we actually perceive the progress along it that our world has already made.

The oceans of earth are disappearing.

Attention shows that loss of water has been going on through the eons that have passed, and that the process is taking place under our very eyes to-day. Once laid down, the earth's oceans have been slowly disappearing since. The reason they have not wholly departed is partly because there was so much to go, partly because its greater mass has helped the earth to hold on to them the better. The speed of departure the earth can restrain is more than double that for Mars — 6.9 miles per second instead of 3.1 miles. Thus the way by the skies is less available. On the other hand, the greater initial heat of its interior has kept the water from sinking in to a degree beyond what is possible in a smaller globe. The earth has thus lagged in its losings, but it has lost, for all that.

Gain of land in North America and Europe.

Withdrawal of water should show in a diminution of the surface of the planet covered by the sea. Observation proves this to be a fact. With research we may assure ourselves that the depletion is in process.



From Dana's "Manual of Geology." (American Book Company.)

MAP OF NORTH AMERICA, SHOWING APPROXIMATELY THE AREAS OF DRY LAND (INDICATED BY THE WHITE SPACES) AT THE CLOSE OF ARCHAEAN TIME.

The late Professor Dana of New Haven constructed maps of North America from the evidence afforded by the geologic sedimentary strata, showing what of it had been terra firma in the successive periods of geologic time. A comparison of his charts gives most interesting and conclusive proof that the land in North America has been gaining at the expense of the sea from the time the sea first was.*

But North America was not alone in its natural territorial aggrandizement. Europe exemplifies the same generally steady, if temporarily fluctuating, conquest of terrain. As in North America, the land started at the north, and encroached upon the ocean farther and farther southward. What we commonly regard as Europe was, in paleozoic times, under the surface of the sea. Only the north of Scotland and Scandinavia protruded. Had the present great navies of the world been in existence then, they would have found ample scope for their operations, but would have missed their present bases of supply, since they could have sailed over the sites of London, Paris, or Berlin.

Wherever geologists have studied them, the strata tell the same tale. The land has spread, the ocean shrunk from the time they first partitioned out the surface. Now, a general universal gain of the sort can mean only one of two things. Either the oceans have been deepening or disappearing. If crumplings of the crust have caused increased depression in the ocean basins, they should have been equally busied in

* See "Mars and its Canals." Macmillan.

elevating the continental plateaux. There is no evidence of any widespread raisings of the sort. For though mountain-chains have been pushed up, they are effects of local crumpling, not of broad buckler-like embossment. From the very fact that they are fractures, they relegate long, low upiifts to the past. We are left, then, with the alternative that the seas have been slowly reduced in volume.

Lowering of the sea-level

Testimony to this same effect keeps cropping up. Only the other day the Chagos Archipelago, a little-known congeries of coral reefs south of the Maldives, was studied by Mr. Stanley Gardiner, of the Sladen Expedition, who concluded, from the appearance of the atolls, which, like oases in the desert, dot the waste of waters, that an alteration of level has been universal throughout the Indo-Pacific coral-reef region, from latitude 30° N. to latitude 25° S. From the fact that it was so widespread, there being evidence of many local upheavals throughout the zone, he inferred it to be due to a withdrawal of water rather than to a change of level in the ocean floor. The amount required to account for the appearance varied from five to thirty-five feet. Thirty-five feet may at first sound small, but occurring over hundreds of thousands of square miles, it means a good deal of water lost.

Inland seas.

What is exhaling in the oceanic areas may be gauged by what is transpiring in the smaller cut-off bodies of water, such as the Caspian, the Sea of Aral, and the Great Salt Lake. For the drainage basins of these inland seas are not only comparable with, but actually larger in proportion than, those of the oceans. Consequently they are fed the better of the two. Nevertheless, they are all with one consent evaporating at a very perceptible rate. Most of them are below the level of the sea, which in itself speaks for the depletion undergone since they were left behind by the retreating main body of water. Marine shells, fishes, and seals, persisting in the Caspian still, testify to its abandoned character. Seals, indeed, witness to its now distancing its greater prototype in its haste to be gone, in spite of the huge fresh-water drainage it at present receives. For in the great Kara Bugas Gulf, on the Caspian's eastern side, the evaporation is so rapid that while a current sets into it from its narrow opening, with no compensating outward one, it is becoming so salt that seals can no longer live there. The Caspian is disappearing before our eyes, as the remains, some distance from its edge, of what once were ports mutely inform us.* Even so is it with the Great Salt Lake, the very rate of its subsidence being known and measured.

The earth, then, is going the way of Mars. As

* See Huntington, recent examination of the shores of the Caspian.

there now, so here in time will be ushered in a phase of planetary evolution to which the earth as yet is stranger — the purely terrestrial, as opposed to the present terraqueous, character of its surface. Much must surely follow such a change of scene. What it will be like we must study Mars to know, since Mars presents us the picture of a world that has reached that pass. To all of us this cannot but offer a certain exploratory incentive — one concerned not with space alone, but with time. For while we directly scan the planet for what it has to say about itself, we are indirectly reading a story which has something to tell of our own future career. If we can succeed in separating in this the particular from the generic, what is local to Mars from what is cosmic in character, we shall do on a broad scale what the early astrologers thought to do on a narrow one, and instead of reading in the skies the fortunes of individuals, decipher there the fate of the whole earth.

Terrestriality succeeds terraqueousness.

Something further of this sort we may indeed do, and this by help of the same principle that led us to the loss of seas. The drying up which causes their extinction is no less active on the land. Being a general deprivation common to the whole planet, the two kinds of surface must suffer synchronously. The effects, however, are much less bearable on terra firma. What in the withdrawal of water lowers oceans to affluence, reduces tracts of vegetation to penury. The once fertile fields become deserts.

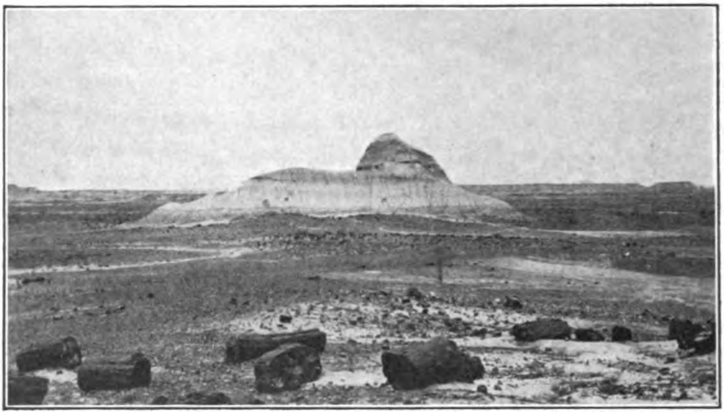
Deserts. Deserts already exist on the earth, and the nameless horror that attaches to the word in the thoughts of all who have had experience of them, or are gifted with imagination to conceive, is in truth greater than we commonly suppose. For the cosmic circumstance about them which is most terrible is not that deserts are, but that deserts have begun to be. Not as local, evitable evils only are they to be pictured, but as the general unescapable death-grip on our world. They mark the beginning of the end. For these deserts are growing. First steps they are in the long retreat of water. What depauperates the forests to grass-lands, and thence to wastes, must in turn attack the sea-bottoms when they shall have parted with their seas. Last of the fertile spots upon the planet because of the salts the streams have for ages washed down, and of the remnant of moisture that would still drain into them, eventually they must share the fortune of their predecessors, and the planet roll a parched orb through space. The picture is forbidding; but the fact seems one to which we are constructively pledged and into which we are in some sort already adventured.

Girdling the earth with what it takes but little personification to liken to the life-extinguishing serpent's coils, run two desert-belts of country. The one follows, roughly speaking, the Tropic of Cancer, extending northward from it; the other, the Tropic of Capricorn. Arizona is in the northern band, as are the Sahara, Arabia, and the deserts of central Asia.

Now, these desert-belts are widening. In the great desert of northern Arizona the traveller, threading his

PETRIFIED FOREST OF ARIZONA.

way across a sage-brush and cacti plain shut in by abrupt-sided shelves of land rising here and there some hundreds of feet higher, suddenly comes upon a petrified forest. Trunks of trees in all stages of fracture strew the ground over a space some miles in extent. So perfect are their forms, he is almost minded to think the usual wasteful wood-chopper has been by and left the scattered products of his art in littered confusion upon the scene of his exploit. Only their beautiful color conveys a sense of strangeness to the eye, and leaning down and touching them, he finds that they are — stone. Chalcedony, not carbon! Form has outlived substance and kept the resemblance, while the particles of the original matter have all been spirited away. Yet so perfect is the presentment, one can hardly believe the fact, and where one fallen giant



ANOTHER VIEW OF THE PETRIFIED FOREST OF ARIZONA.

spans a barren cañon, one almost thinks to hear the sound of water rushing down the creek.

The petrified forest of Arizona.

But it is some millions of years and more since this catastrophe befell, and the torrent, uprooting it, left it prone, with limbs outstretched in futile grasp upon the other side. A conifer it was, cousin only to such as grow to-day, and flourished probably in the Cretaceous era; for the land has not been under water here since the advent of Tertiary times.

Nowhere near it, except for the rare cottonwoods along the bank of the Little Colorado, grows anything to-day. The land which once supported these forests is incompetent to do so now. Yet nothing has changed there since, except the decreasing water-supply. During Tertiary and Quaternary time the rainfall has been growing less and less. Proof of this is offered by the great pine oasis that caps the plateau of which these petrified forests form a part, and is kernelled by the San Francisco peaks. The height above sea-level of the spot where the chalcedony trunks are strewn is about 4500 feet; the lower present limit of the pine in its full development is 6500 feet. Two thousand feet upward the verdure-line has retreated since the former forests were. And this is no local alteration, for upon the other side of the plateau petrified remains of trees are similarly found.

The line of perpetual green has risen because in desert regions the moisture is found most plentiful nearest to the clouds from which it falls upon a parching earth. Streams, instead of gathering volume as they go, are largest near their source, and grow less and less with each fresh mile of flow. The brooks descending from the Anti-Lebanon, in Syria, water the gardens of Damascus, and, thence issuing upon the plain, lose themselves just beyond the threshold of its gates. So in the Arizona desert, though in a less degree; and those who live there know it but too well. It is desert craft for Indians or cow-boys to seek water on the mesas, not at their base. To ascend after it is one of the footnotes of their trade.

Egypt and Carthage.

The evidence here brought before us of a secular parching of the land is not wholly confined to western North America. Crossing to the other side of the world, we come upon like remains. Upon the plateau above the Nile, near Cairo, the traveller goes to see another petrified graveyard of trees. It is prehistoric, yet contemporaneous with man; for paleolithic and neolithic implements have been found not far away, showing that in the morning of his race man lived and hunted in these forests, where neither hunter nor hunted could exist to-day.

Upon the southern coast of the Mediterranean, at the edges of the great Sahara, are to be seen to-day the ruins of vast aqueducts stalking silently across the plains. Fallen into decay now, they attest something more than the passing of the force of those who built them from the scene they once made great. Carthage has crumbled again to earth, and these sentinelling arches alone remain to show what tentacles of sustenance it formerly thrust out. Still architecturally impressive, they span not space alone, but time. They testify to something to be carried as well as to a city to which to carry it. This, now, has disappeared as completely as its drinkers. At the present day the streams are incompetent to supply the aqueducts, the very presence of which attests that in the past this was not so. The land has parched since times so recent as to be historic, recorded by the monuments of man.

Nor are we left to monuments for sole light upon the subject. The very fauna has changed. Animals that once inhabited the land are unable to live there now because of the increasing aridity of the habitat. Thus they add their testimony to that of the mute purveyors of water whose occupation is gone. The surprising thing is that it should all have happened so recently. In a startling manner it brings before us the speed with which the desert is gaining on the habitable earth.

Palestine tells the same story. The land which once flowed with milk and honey can hardly flow bad water now. Nor is this because the folk who made its greatness have since been scattered over the face of the earth. Much goes to ruin when the master hand is stilled, but no rich country ever lapsed to desert for this cause unless its fertility was irrigation-made. Conclusive and convincing is here the evidence that the land itself has changed.

Palestine.

Upon comparing the places where this desertism appears, it will be found that all occur in a band about the earth not far from either tropic, and extending

Subtropical regions chiefly affected.

north or south from it according to the hemisphere concerned. Now, when we turn to the tables of the rainfall for different parallels, we find this localization explained.

It is precisely in these belts that the average rainfall is least, except, indeed, far north, where the steppes attest to like aridity. The occurrence of the deserts is thus an affair of the circulation of the atmosphere, and from that fact is lifted at once into the region of general planetary evolution. For atmospheric circulation is a necessary consequence of a body having an atmosphere and being exposed to the action of the sun. The general effects of it are as follows: The equatorial region being the most continuously heated by the solar beams, the air above it rises and flows over at the top, necessarily poleward. The air about the tropics flows in to take its place. Meanwhile the lower portion of the equatorial emigrant, finding the space below less occupied, descends to earth in the forties, causing the prevailing winds in those regions. The upper part proceeds more or less spirally round the pole. This general circulation is independent in its main action of the character of the ground. Areas of sea and land modify the motions, but do not negative the results.

Now, keeping this circulation in the mind's eye, we note that, other things equal, those winds that descend from colder regions to warmer ones must be dry. For, on being heated, air becomes capable of taking up more moisture than before, and is by this restrained from depositing the water it already contains in the form of rain or snow or dew. It thus keeps with it such moisture as it has or as it acquires, and instead of being a bountiful dropper of fatness from its clouds, courses over the surface a scorching sirocco. Such is the fundamental, uncomplicated process, and, in consequence, desert-belts are bound to form in time, and just where we find those of the earth to-day, barring exceptions locally explained. For adventitious bodies of water over which these winds pass may supply them with water which mountain-chains may precipitate again on their windward side by the cooling of the winds due to rising up their flanks. Either of these accidents of surface may thus modify the effect without affecting the principle.

Planetary change far advanced on Mars.

Turning now to Mars, we find what is but in its infancy on earth, there in full control. Not only are the desert-belts in existence, but the whole surface, except for the sea-bottoms, has gone the same way. Five-eighths of it all is now an arid waste, unrelieved from sterility by surface moisture or covering of cloud. Bare itself, it is pitilessly held up to a brazen sun, unprotected by any shield of shade.

That such is the case with our neighbor certain points about it indicate. The first of these is hue. The fiery color from which Mars was named turns out in the telescope to be an ochre dashed with red. This is just the tint our own deserts show when one looks down on them from a mountain peak. The next thing is their unalterableness. Except for seeming ruddier at times, they change not, the seasons that so transform the blue-green areas passing over them in vain. Thus both in look and deed they bespeak themselves vast Saharas, these great ochre stretches of the disk.

Their positioning tells the same story. This we perceive on considering what their situation is as compared with what it should be for such state.

Absence of moisture should not alter the general wind circulation sketched above, and we should expect to find, whatever the planet, the wet and dry zones much what they are on the earth, if trace of them still existed. To the map of Mars we therefore turn to mark whether this be so. In such envisagement, one antedating circumstance must be allowed for: the local positioning of the oceanic basins; for an ocean, by reason of its original supply, would outlast its latitudinal time-limit. Its marine constitution would defy the law.

Now, the oceans of Mars lay in the southern hemisphere of the planet. This qualifies the action in that hemisphere, and makes the southern subtropic zone one of verdure to-day. This, therefore, is no disproof of the general law; it is but an added argument that these present blue-green areas were seas at some former epoch.

Otherwise is it with the surfaceography of the northern hemisphere, since in the beginning that was probably fairly free from land-and-water distribution of a sufficiently pronounced type to hinder the play of the desert-making tendency. Here, then, we should look for confirmation of the principle that the subtropic zone should be more arid than the temperate one, and here we find something which is suggestive. The southern subtropic zone is destitute of blue-green areas — that is, areas of vegetation — all round the planet. Not so the temperate zone above it. In the latter are found all the larger blue-green regions in the planet's northern hemisphere — the Mare Acidalium, the Propontis, and the Wedge of Casius. And all these are approximately upon the same parallel of latitude. The Lucus Niliacus, and the Mare Acidalium stretch from latitude 29° N. to latitude 55°; the Propontis from 37° to 48°; and the Wedge of Casius from 35° to 56°. That such consensus in situation can be due to chance is certainly unlikely. Here, then, linger the last vestiges of vegetation of the northern hemisphere.

The opaline tints of Mars.

As important is the present great extent of the Martian deserts. Beautiful as the opaline tints of the planet look, down the far vista of the telescope-tube, they represent a really terrible reality. To the bodily eye, the aspect of the disk is lovely beyond compare; but to the mind's eye, its import is horrible. That rose-ochre enchantment is but a mind mirage. A vast expanse of arid ground, world-wide in its extent, girdling the planet completely in circumference, and stretching in places almost from pole to pole, is what those opaline glamours signify. All deserts, seen from a safe distance, have something of this charm of tint. Their bare rock gives them color, from yellow marl through ruddy sandstone to blue slate. And color shows across space for the massing due to great extent. But this very color, unchanging in its hue, means the extinction of life. Pitilessly persistent, the opal here bears out its attributed sinister intent.

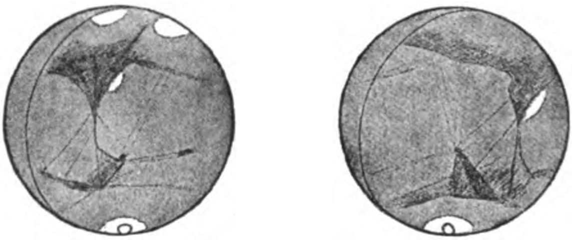
To let one's thoughts dwell on these Martian Saharas is gradually to enter into the spirit of the spot, and so to gain comprehension of what the essence of Mars consists. Without such background always omnipresent in the picture, the lesser and more pregnant features fail of effect in their true value for want of setting off. To conceive of this great buckler of brazen sand and rock, level as a polished shield, and stretching to the far distance, to stand sharp-cut there by the horizon of a sky, unrelieved by so much as mountain-notching of its blue, is to realize in part what life on it must mean. Where days and months of travel would bring one no nearer to its edge, despair might well settle on the mind. And the sun in its daily course rises from out the stony waste only to set in it again.

How the earth will follow Mars.

Pitiless indeed, yet to this condition the earth itself must come, if it last so long. With steady, if stealthy, stride, Saharas, as we have seen, are even now possessing themselves of its surface. The outcome is doubtless yet far off, but it is as fatalistically sure as that to-morrow's sun will rise, unless some other catastrophe anticipate the end. It is perhaps not pleasing to learn the manner of our death. But science is concerned only with the fact, and Mars we have to thank for its presentment.

Before the final stage in the long life drama of a planet is thus brought to its close, there will come a time when the water, having left the surface, still lingers for a little in the air. For the atmosphere is the pathway the water takes to the sky. Insufficient in amount to leave a surplus on the ground in the shape of oceans, or even lakes and ponds, a certain quantity will still hover up above. From the mode of its withdrawal, a planet must lose its surface water long before it loses the aqueous vapor from its air, so that the absence of the one argues nothing against the presence of the other. Now there are physical reasons connected with evaporation which would make for more water in the air of Mars than of the earth, and yet not permit of precipitation.

In Chapter III we marshalled the evidence we have that water exists on the surface of Mars: in the polar caps and practically nowhere else. We have now to see what proof there is that it still exists in the Martian air. The evidence on which this rests is twofold: the



EFFECT OF THE SPRING MIST AROUND THE NORTH POLAR CAP OF MARS
Drawn January 25, 1905 (Martian date, June 23).

first telescopic, in the aspect of the disk. Water-vapor, as such, of course, we could not expect to see, as it is invisible constitutionally. But when, suspended in the air, it condenses into drops or spicules, we might hope for detection. Such proves a possibility occasionally on Mars.

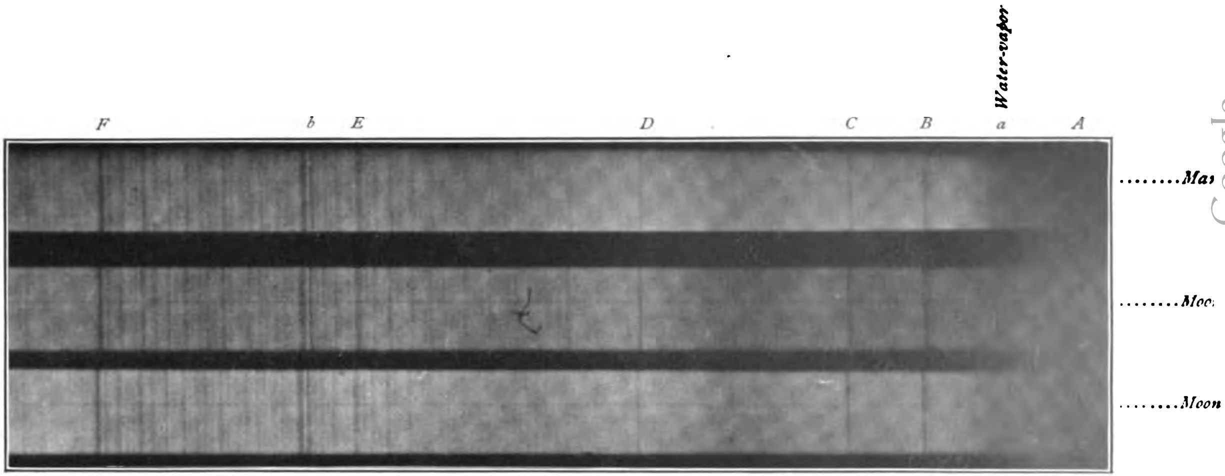
Water present in the Martian atmosphere.

As the North polar cap melts, there comes a season when an indefinite pearly appearance fringes its edge, obliterating its contours, which before were sharp. This persists for some weeks, off and on, and when at last it clears, the cap is seen to be reduced to its least extent. That it is mist caused by the melting of the cap there is little doubt.

But there is another instrument of astronomical research the special field of which is the study of the invisible. To see indirectly what cannot be seen direct is the province of the spectroscope. The spectroscope consists of a prism or train of prisms which disperse white light into a rainbow-tinted ribbon known as the spectrum, made up of rays of different wave-length from violet at one end to red at the other. Now it is a property of a gas, through which light passes, to absorb certain of the rays peculiar to itself, and so form dark lines across the spectrum at those points. Most of the lines thus observed in the solar spectrum come from gases in the photosphere of the sun, but there are certain others which arise in our own atmospheric envelope and are called telluric lines in consequence. Such are the oxygen and water-vapor bands. If now another planet, such as Mars, possessed either of these gases in its atmosphere, the light reflected from it should disclose the fact by deepening these bands. Much was hoped from the spectroscope on this point.

Up to and beyond the time when the lectures were written, of which this book is the outcome, the spectroscope had not proved itself a sufficiently delicate instrument to give other than an uncertain answer on the presence or absence of water-vapor on Mars. Huggins, Vogel, Janssen, all thought to see evidence of it there; Campbell, with more accurate instruments, could find none. Nor could any be obtained under still more favorable conditions of air and instrument at Flagstaff. The reason for inconclusion, though unsuspected at the time, lay in the position of the bands in the spectrum produced by water-vapor. These begin, indeed, in the yellow, are present in the orange and light red, but are broadest and darkest in the partially visible deep red and in the invisible spectrum beyond it. These strongest bands were beyond the appliances of the day for purposes of careful comparison, while the others were not sufficiently salient to make delicate contrasts unmistakable.

In the spring of 1908, Mr. V. M. Slipher succeeded at Flagstaff in bathing plates to sensitiveness through the red, and, exposing these plates in the camera of the spectroscope, photographed the spectrum first of Mars and then of the moon at the same altitude to well beyond the point where the great water-vapor band known as "a" lies. He took in all eight such plates, with the result that the "a" band showed stronger in the spectrum of the planet than in that of the moon. Now in the case of the moon it is through our own atmosphere only that we are looking; in the case of



SPECTROGRAM OF THE MOON AND MARS BY V. M. SLIPHER, LOWELL OBSERVATORY

Showing the "*a*" band stronger in the Martian than in the Lunar Spectrum; thus testifying to Water-vapor in the Martian atmosphere

Mars, through our own plus that of Mars. Any difference between the two must be due to the Martian air. A strengthening, then, in the expression of the "a" bands denoted water-vapor present in the atmosphere of Mars. Here we have the much-desired spectroscopic proof, and with it the explanation of why so much uncertainty existed among eminent spectroscopists before. To those versed in Mars it is chiefly of the nature of corroboration. For to the mind's eye reasoning had already revealed that water-vapor must be there, but now the bodily eye of any one may see. The thing is curiously paralleled by the way in which Clerk Maxwell's analysis showed the rings of Saturn to be made of discrete particles before the spectroscope in Keeler's ingenious hands stamped its evidence on a photographic plate.

That water-vapor exists in the air is cause for its deposition on the ground. But to be precipitated and to stay so are two very different things. The only way in which so scant an amount could remain deposited in any part of the planet would be as frozen moisture about the pole. For as snow it stays fixed, evaporation at a low temperature going so much less fast than from water under its appropriate higher one. A snow-field suitably situated might thus persist while a pond would speedily disappear. The polar snows would be the only place where moisture could descend to the surface to stay, being brought to the polar regions by the planetary winds.

With regard to the distribution of the humidity, what scant moisture the desert-born equatorial winds might possess would be deposited northward as they cooled, in part impermanently in the forties, in part more permanently at the poles. The return flow of air in winter, being steadily warmed, would not tend to deposit moisture down the disk; nor in summer either, to any extent, although from the melting of the cap such winds would then be more charged with vapor. Unlike our own earth, therefore, moisture would proceed poleward, to remain there. Not only, therefore, is the water much less in amount on Mars, but what is there tends to be kept about the poles. The only available supply lies in the arctic and antarctic regions, stationary on the ground or else is in process of journeying round to it again.

In this last stage of temporizing, the water that once as such bespread Mars's face now is. The well-nigh total disappearance of the one cap, and the entire extinction of the other, show how each summer melts what the winter had deposited, and that in both cases this is nearly the sum total of the cap. Covering as each does so much territory, one might suppose the water not scanty, but comparable in quantity to the earth's supply. If we calculate it, however, we shall find this anything but the case. At Point Barrow, in Alaska, in latitude 71° N., where the temperature is below freezing from September 1 to June 15, 75 inches of snow fall during the nine and a half months. Ten inches of snow are equal to one inch of water. This quantity, then, measures the amount of the Earth's impermanent cap, and forms a basis for comparison with the depth of the snow-cap melted on Mars. It seems, too, not an improbable value for what occurs there; for though on the one hand it is likely that day by day the snowfall is greater at Point Barrow than on Thyle, in Mars, at the same latitude, on the other, the winter season is there twice as long. To be lavish, we may estimate that the equivalent of 100 inches of snow fall on Thyle. That would mean 10 inches of water. Now, the southern cap of Mars, the larger of the two, covers 96° across at its greatest, which makes its area equal to one-fifth of the whole surface of the planet. To this we need not add the other cap, since it at the time stretches over only 6°, a vanishing quantity in comparison. On earth, oceans cover 72 per cent of the surface, and are, on the average, 2100 fathoms deep. Calculation from these data gives the amount of water on the earth as 189,000 times that on Mars. We said rightly, then, that Mars was badly off for water.

In consequence of this state of things, the water-supply of the planet is both scant in amount and tethered at that. For it is tied up during the greater part of the year at one pole or the other. For a few weeks only of each six months it stands unlocked, first in the arctic, then in the antarctic, zone. Then, and then only, may this deposit, meagre as it is, be drawn upon. Mars is indebted for the staff of life to a polar pittance sparsely doled out, and that only at appointed times.

The surface of Mars a waterless world.

Study of the natural features of the planet leaves us, then, this picture of its present state — a world-wide desert where fertile spots are the exception, not the rule, and where water everywhere is scarce. So scanty is this organic essential, that over the greater part of the surface there is none to quicken vegetation or to support life. Only here and there by nature are possible those processes which make our earth the habitable, homelike place we know. In our survey of Mars, then, we behold the saddening picture of a world athirst, where, as in our own Saharas, water is the one thing needful, and yet where by nature it cannot be got. But one line of salvation is open to it, and that lies in the periodic unlocking of the remnant of water that each year gathers as snow and ice about its poles.

A high type of life probable on Mars.

The evidence of observation thus bears out what we might suspect from the planet's smaller size: that it is much farther along in its planetary career than is our earth. This aging in its own condition must have its effect upon any life it may previously have brought forth. That life at the present moment would be likely to be of a high order. For whatever its actual age, any life now existent on Mars must be in the land stage of its development, on the whole a much higher one than the marine. But, more than this, it should probably have gone much farther if it exist at all, for in its evolving of terra firma, Mars has far outstripped the earth. Mars's surface is now all land. Its forms of life must be not only terrestrial as against aquatic, but even as opposed to terraqueous ones. They must have reached not simply the stage of land-dwelling, where the possibilities are greater for those able to embrace them, but that further point of pinching poverty where brain is needed to survive at all.

The struggle for existence in their planet's decrepitude and decay would tend to evolve intelligence to cope with circumstances growing momentarily more and more adverse. But, furthermore, the solidarity that the conditions prescribed would conduce to a breadth of understanding sufficient to utilize it. Intercommunication over the whole globe is made not only possible, but obligatory. This would lead to the easier spreading over it of some dominant creature, — especially were this being of an advanced order of intellect, — able to rise above its bodily limitations to amelioration of the conditions through exercise of mind. What absence of seas would thus entail, absence of mountains would further. These two obstacles to distribution removed, life there would tend the quicker to reach a highly organized stage. Thus Martian conditions themselves make for intelligence.

The probability of life on Mars at the present time.

Our knowledge of it would likewise have its likelihood increased. Not only could any beings there disclose their presence only through their works, but from the physical features the planet presents, we are led to believe that such disclosure would be distinctly more probable than in the case of the earth. Any markings made by mind should there be more definite, more uniform, and more widespread than those human ones with which we are familiar. More dominant of its domicile, it should so have impressed itself upon its habitat as to impress us across intervening space.

What the character of such markings might be, we shall best conceive by letting the pitiless forbiddingness of the Martian surface take hold upon our thought. Between the two polar husbandings of the only water left, stands the pathless desert — pathless even to the water semiannually set free. Only overhead does the moisture find natural passage to its winter sojourn at the other pole. Untraversable without water to organic life, and uninhabitable, the Sahara cuts off completely the planet's hemispheres from each other, barring surface commerce by sundering its supplies. Thirst — the thirst of the desert — comes to us as we realize the situation, parching our throat as we think of a thirst impossible of quenching except in the far-off and by nature unattainable polar snows.

Turning again to Mars with quickened sense, we witness an astounding thing, the study of which in its mien, its moods, and its meaning, the next two chapters will take up.

CHAPTER V

THE CANALS AND OASES OF MARS

THIRTY years ago what were taken for the continents of Mars seemed, as one would expect continents seen at such a distance to appear, virtually featureless.

Schiaparelli and the canals.

In 1877, however, a remarkable observer made a still more remarkable discovery; for in that year Schiaparelli, in scanning these continents, chanced upon long, narrow markings in them which have since become famous as the canals of Mars. Surprising as they seemed when first imperfectly made out, they have grown only more wonderful with study. It is certainly no exaggeration to say that they are the most astounding objects to be viewed in the heavens. There are celestial sights more dazzling, spectacles that inspire more awe, but to the thoughtful observer who is privileged to see them well there is nothing in the sky so profoundly impressive as these canals of Mars. Fine lines and little gossamer filaments only, cobwebbing the face of the Martian disk, but threads to draw one's mind after them across the millions of miles of intervening void.

Although to the observer practised in their detection they are at certain times not only perfectly distinct, but are not even difficult objects, — being by no means at the limit of vision, as is often stated from ignorance, — to one not used to the subject, and observing under the average conditions of our troublesome air, they are not at first so easy to descry. Had they been so very facile, they had not escaped detection so long, nor needed Schiaparelli, the best observer of his day, to discover them. But in good air they stand out at times with startling abruptness. I say this after having had twelve years' experience in the subject — almost entitling one to an opinion equal to that of critics who have had none at all.

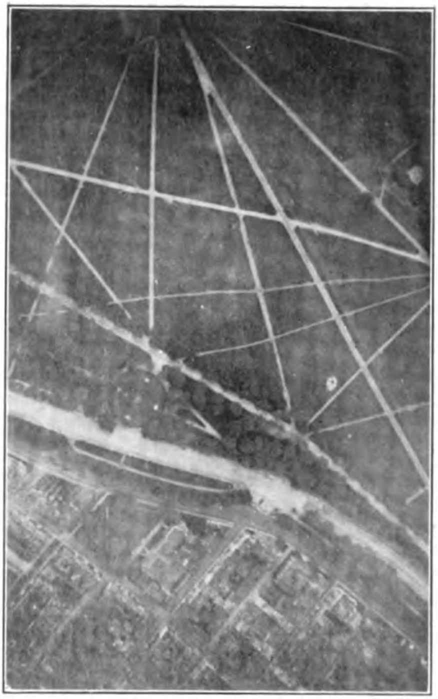
How beside the mark it is to credit them to illusion may at once be appreciated from the fact that experiment shows the main ones to appear through the telescope of the same size as a telegraph wire seen with the naked eye at a distance of a hundred and fifty feet. But if the air be not steady, they are blurred almost out of recognition.

With our air at its best, the first thing to strike one in these strange phenomena is their geometric look. It has impressed every observer who has seen them well. It would be hard to determine to which of their peculiar characteristics this effect was specially due. Indeed, it is probably attributable to their combination; for distinctive as each trait is alone, their summation is multiplicitly telling. That the lines run quite straight from point to point — that is, on arcs of great circles, or else curve in an equally determinate manner; that they are of uniform width throughout; that their tenuity is extreme and that they are of enormous length, are attributes each of which is geometrically startling and which, taken together, enhance this in geometric ratio.

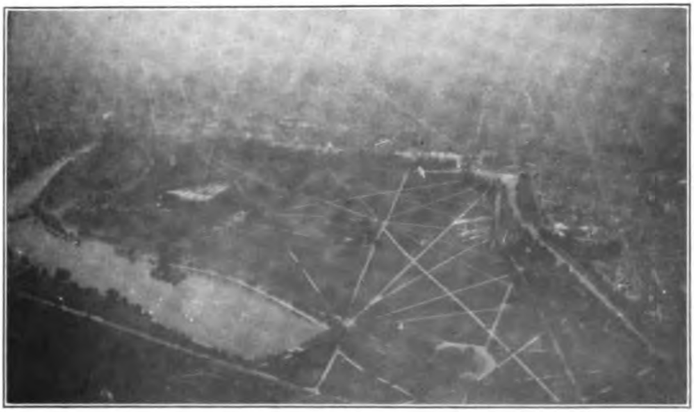
Lines are straight.

That the lines are absolutely straight — which means that on a sphere like Mars they follow arcs of great circles — is shown by two facts which fay into one another. One of these is that they look straight to the observer when central enough not to have foreshortening tell. This could not happen unless they were the shortest possible lines between their termini. The other proof consists in their fitting together to form a self-agreeing whole when the result of all the drawings — hundreds in number at each opposition — are plotted on a globe.

In regard to their width, it would be nearest the mark to say that they had none at all. For they have been found narrower and narrower as the conditions of scanning have improved. By careful experiments at Flagstaff it has been shown that the smallest appear as they should were they but a mile across. The reason so slender a filament is visible is due to its length, and this probably because of the number of retinal cones that are struck. Were only



Hyde Park and Park Lane, London, 1908
From a Free Balloon.



From Photographs at 2200 feet by Profs. Rotch and Lowell

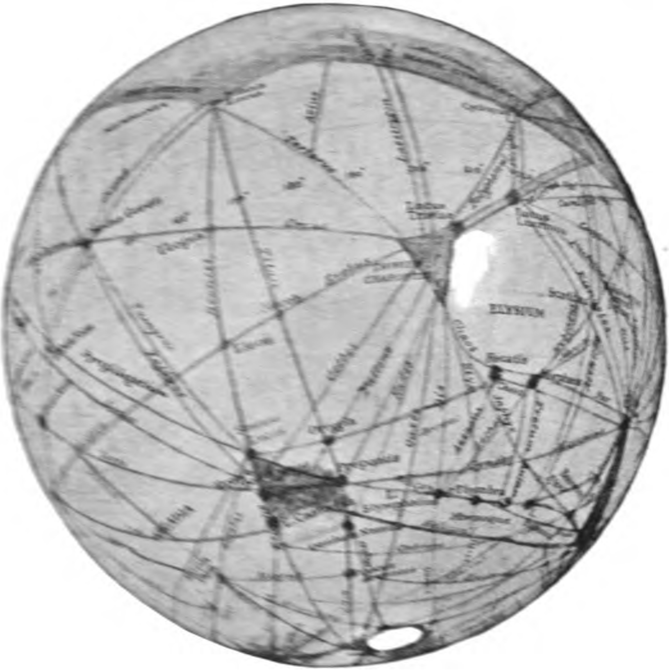
Hyde Park and The Serpentine
Showing Artificial Markings of Earth seen from Space.

one affected, as would be the case were the object a point, it certainly could not be detected.[16]

So much for the smallest canal now visible with our present means. The larger are much more conspicuous. These look not like gossamers, as the little ones do, but like strong pencil-lines. Comparison with the thread of the micrometer gives for the average canal a breadth of about ten miles. The canals, however, are by no means of a uniform width. Indeed, they are of all sizes, from lines it would seem impossible to miss to others it taxes attention to descry.

All the more surprising for their relative diversity is the remarkably uniform size of each throughout its course. So far as it is possible to make out, there is no perceptible difference in width of a canal, when fully developed, from one end of it to the other. Certainly it takes a well-ruled line on paper to look its peer for regularity and deportment.

True thus to itself, each canal differs from its neighbor not only in width, but in extension. For the canals are of very various length. Some are not above 250 miles long, while others stretch 2500 miles from end to end. Nor is this span by any means the limit. The Eumenides-Orcus runs 3450 miles from where it leaves the Phœnix Lake to where it enters the Trivium Charontis. Enormous as these distances are for lines which remain straight throughout, they become the more surprising when we consider the size of the planet on which they are found. For Mars is only 4220 miles through, while the earth is 7919. So that



A SECTION OF THE CANAL EUMENIDES-ORCUS TERMINATING IN THE JUNCTION TRIVIUM CHARONTIS

The length of this canal is 3540 miles. The remainder of the canal may be seen on the hemisphere shown on p. [illegible], where it starts from Phoenix Lake (Lucus Phoenicis).

a canal 3540 miles long, for all its unswervingness to right or left, actually curves in its own plane through an arc of some 90° round the planet. It is much as if a straight line joined London to Denver, or Boston to Bering Strait.

It should be remembered, however, that it is the actual, not the relative, length we have really to consider. But this is surprising enough — more than sufficient in the Eumenides-Orcus to span the United States.

Odd as is the look of the individual canal, it is nothing to the impression forced upon the observer by their number and still more by their articulation. When Schiaparelli finished his life-work, he had detected 113 canals; this figure has now been increased to 437 by those since added at Flagstaff. As with the discovery of the asteroids, the later found are as a rule smaller and in consequence less evident than the earlier. But not always; and, unlike asteroid hunting, it is not because of easy missing in the vast field of sky. The cause is intrinsic to the canal.

This great number of lines forms an articulate whole. Each stands jointed to the next (to the many next, in fact) in the most direct and simple manner — that of meeting at their ends. But as each has its own peculiar length and its special direction, the result is a sort of irregular regularity. It resembles lace-tracery of an elaborate and elegant pattern, woven as a whole over the disk, veiling the planet's face. By this means the surface of the planet is divided into a great number of polygons, the areolas of Mars.

Schiaparelli detected the existence of the canals when engaged in a triangulation of the planet's surface for topographic purpose. What he found was a triangulation already made. In his own words, the thing "looked to have been laid down by rule and compass." Indeed, no lines could be more precisely drawn, or more meticulously adjusted. Not only do none of them break off in mid-career,* to vanish, as rivers in the desert, in the great void of ochre ground, but they contrive always in a most gregarious way to rendezvous at special points, running into the junctions with the space punctuality of a train on time. Nor do one or two only manage this precision; all without exception converge from far points accurately upon their centres. The meetings are as definite and direct as is possible to conceive. None of the large ochre areas escapes some filament of the mesh. No single secluded spot upon them could be found, were one inclined to desert isolation, distant more than three hundred miles from some great thoroughfare.

Canals in dark regions.

For many years — in fact, throughout the period of observation of the great Italian — the canals were supposed to be confined to the bright or reddish ochre regions of the disk. None had been seen by

* Their seeming occasionally to do so is due to their mode of growth seasonally or to certain latitudes being better shown than others at the time.

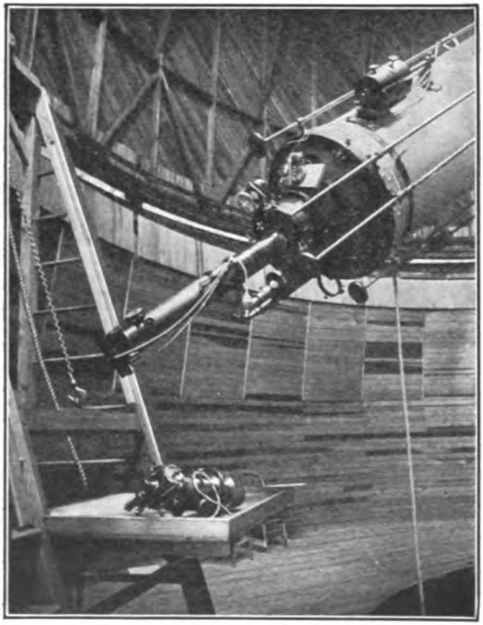
him elsewhere, and none was divined to exist. But in 1892, W. H. Pickering, at Arequipa, saw lines in the dark regions; and, in 1894, Douglass, at Flagstaff, definitely detected the presence of a system of canals criss-crossing the blue-green similar to that networking the ochre. Later work at Flagstaff has shown all the dark areas to be thus seamed with lines, and lastly has brought out with emphasis the pregnant fact that these are continued by others connecting with the polar snows.* Thus the system is planet-wide in its application, while it ends by running up to the confines of the polar cap. The first gives it a generality that opened up new conceptions of its office, the second vouchsafes a hint as to its origin.

CANALS IN DARK REGIONS CONNECTING WITH THE POLAR CAP

For many years the pioneers in this discovery of another world had their revelations strictly to themselves, decried as baseless views and visions by the telescopically blind. So easily are men the dupes of

* Previous to 1907 the fact was known only for the northern hemisphere. In 1907 the Flagstaff observations disclosed the important extension of the scheme through the antarctic zone; a striking confirmation of theory.

their own prejudice. But in 1901 attempts began to be made at Flagstaff to make them tell their own story to the world, writing it by self-registration on a photographic plate. It was long before they could be compelled tc do so. The first attempts showed nothing; the next, two years later, did better, evoking faint forms to the initiate, but to them alone; but two years later still, success crowned the long endeavor. At last these strange geometricisms have stood successfully for their pictures. The photographic feat of making them keep still sufficiently long — or, what with heavenly objects is as near as man may come to his practice with human subjects, the catching of the air-waves still long enough to



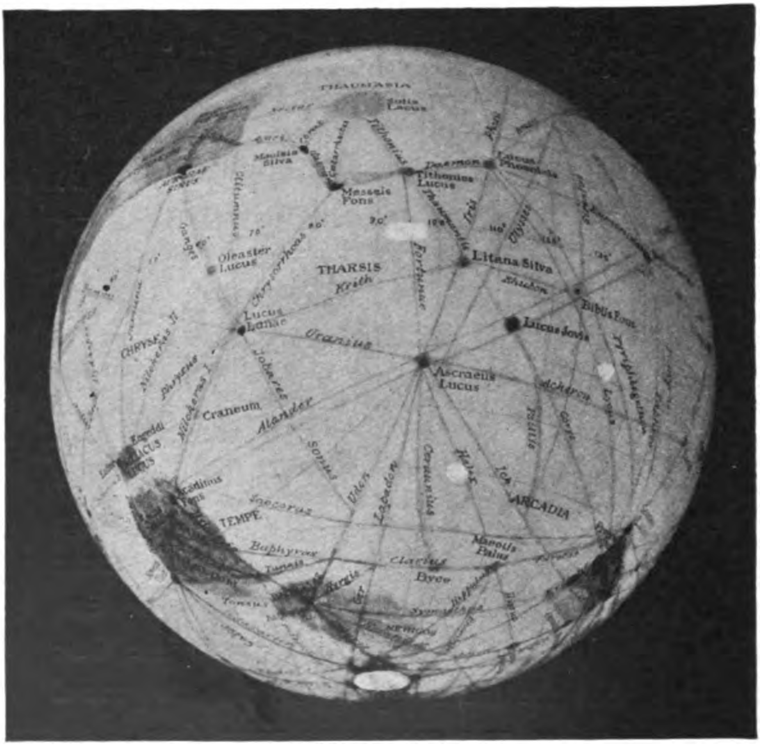
Photographic Apparatus of the Lowell Observatory
Devised by Mr. C. O. Lampland, and used in getting the photographs of the canals of Mars.

secure impression of them upon a photographic plate — has been accomplished by Mr. Lampland. After great study, patience, and skill he has succeeded in this remarkable performance, of which Schiaparelli wrote in wonder to the present writer: "I should never have believed it possible."

Regard for positioning is one of the most significant characteristics of the lines. They join all the salient points of the surface to one another. If we take a map of the planet and connect its prominent landmarks by straight lines, we shall find, to our surprise, that we have counterfeited the reality. That they are so regardant of topography on the one hand, and so regardless of terrain on the other, gives a most telltale insight into their character; it shows that they are of later origin than the main markings themselves. For they bear testimony to this without regard to what they are. Their characteristics and their attitudes, in short, betray that at some time subsequent to the fashioning of the planet's general features the lines were superposed upon them.

Canals superposed over main features.

But this is not all. Since the seas probably were seas in function as in name once upon a time, the superposition must have occurred after they ceased to be such; for clearly the lines could not have been writ on water, and yet be read to-day. We are thus not only furnished with a datum about the origin of the canals, but with a date determining when it took place. The date marks a late era in the planet's development, one subsequent to any the



HEMISPHERE SHOWING THE OASIS CALLED ASCRAEUS LUCUS

From this radiate many canals. Also in the upper right-hand space is shown the continuation of the Eumenides-Orcus.

earth has yet reached. This accounts for the difficulty found in understanding them, for as yet we have nothing like them here.

Oases. Next in interest to the canals come the oases.

Many years after the detection of the canals, scrutiny revealed another class of detail upon the planet of an equally surprising order. This was the presence there of small, round, dark spots dotted over the surface of the disk. Seen in any number, first by W. H. Pickering in 1892, they lay at the meeting-places of the canals. He called them lakes. Some few had been caught earlier, but were not well recognized. We now know 186 of them, and we are very certain they are not lakes. In the case of one of them, the Ascraeus Lucus, no less than seventeen canals converge to it.

It thus appears that the spots make, as it were, the knots of the canal network. They emphasize the junctions in look and at the same time indicate their importance in the system. For just as no spot but stands at a junction, so, reversely, few prominent junctions are without a spot, and the better the surface is seen, the more of these junctions prove to be provided with them.

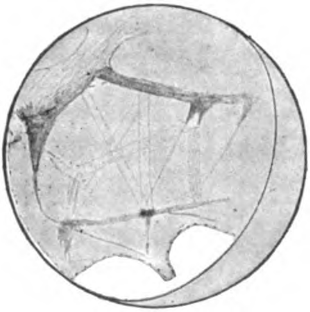
Their form is equally demonstrative of their function. They are apparently self-contained and self-centred, being small, dark, and, as near as can be made out, round. It is certain that they are not mere reënforcements of the canals due to crossing, for crossings do occur where none are seen, while the lines themselves are perfectly visible, and of the same strength at the crossing as before and after.

We now come to a yet more surprising detail. The existence of the single canals had scarcely been launched upon a world quite unprepared for their reception, and duly distant in their welcome in consequence, before that world was asked to admit something more astounding still; namely, that at certain times some of these canals appeared mysteriously paired, the second line being an exact replica of the first, running by its side the whole of its course, however long this might be, and keeping equidistant from it throughout. The two looked like the twin rails of a railway track. (See map opposite page 217.)

To begin by giving an idea of the phenomenon, I will select a typical example, which happened also to be one of the very first observed by me — that of the great Phison. The Phison is a canal that runs for 2250 miles between two important points upon the planet's surface, the Portus Sigaeus, halfway along the Mare Icarium, and the Pseboas Lucus, just off the Protonilus. In this long journey it traverses some six degrees of the southern hemisphere and about forty degrees of the northern. In 1894 the canal was first seen as a single, well-defined line — not a line that admitted of haziness or doubt, but which was as strictly self-contained and slenderly distinguished as any other single canal on the planet. A Martian month or more after it thus expressed itself, it suddenly stood forth an equally self-confessed double, two parallel lines replacing the solitary line of some months before. Not the slightest difference in the character, direction, or end served was to be detected between the two constituents. Just as certainly as a single line had shown before, a double line now showed in its stead.

Study of the doubles has been prosecuted for some years now at Flagstaff, and its prosecution has gradually revealed more and more of their peculiarities. The first thing this study of the subject has brought out is that duality, bilateralism, is not a universal feature of the Martian canals. Quite the contrary. It cannot be said in any sense to be even a general attribute of them. The great majority of the canals never show double at any time, being persistently and perpetually single. Out of the 437 canals so far discovered, only 51 have ever shown duplicity. From this we perceive that less than one-eighth of all the canals visible affect the characteristic, nor are these 51 distinguished in any manner, by size or position, from those of the other 386 that remain pertinaciously single. They are neither larger nor smaller, longer nor shorter, nor anything else which would suffice on a superficial showing to distinguish their strange inherent potentiality from that of those which do not possess the property.

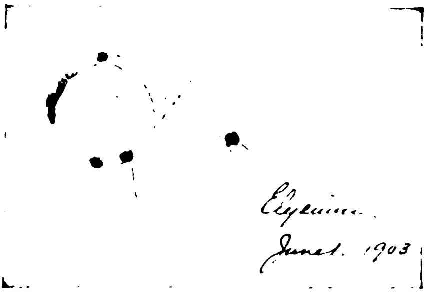
Now, this fact directly contradicts every optical theory of their formation. If the doubles were products of any optical law, that law should apply to all canals alike, except so far as position, real or relative upon the disk, might affect their visibility. Now, the double canals are not distinguished in any of these ways from their single sisters. They run equally at all sorts of angles to the meridian, and are presented equally at all sorts of tilts to the observer; and yet the one kind keeps to its singularity, and the other to its preference for the paired estate.



Single and Double Canals
In a drawing made July 15, 1905.

Width differs for different doubles.

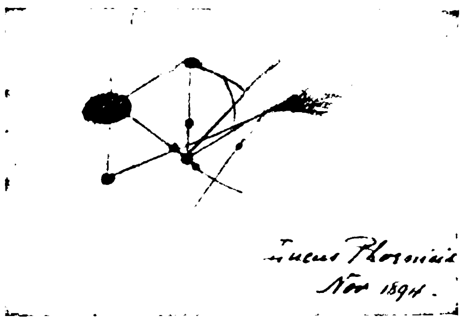
The next point is that the width of the gemination — the distance, that is, between the constituents of the pair — is not the same for



A Mass of Double Canals, Elysium (see the Hemisphere, Page 150)
From a drawing made on June 1, 1903.

all the doubles. Indeed, it varies enormously. Thus, we have at one end of the list the little, narrow Djihoun, the constituents of which are not separated by more than two degrees; while at the other end stands the Nilokeras, with its members eleven degrees apart. That is, we have a parallelism of seventy-five miles in one case, and one of four hundred in another. This fact disposes again of any optical or illusory production of the lines; for were their origin such, they would all be of the same width.

Position is the next thing to be considered. A general investigation of this shows some results which are highly instructive. To begin with, the distribution of the doubles may be broadly looked at from two points of view, that of their longitudinal or latitudinal placing upon the planet. Considering the longitudinal first, if we cut the planet in halves, the one hemisphere extending from longitude 20° to 200° and the other from 200° to 20°, more than two-thirds of



A Mass of Single Canals about Lucus Phoenicis (see the Hemisphere, Page 156)

From a drawing made in November, 1894.

all the double canals turn out to lie in the second section; the numbers being fifteen in the one to thirty-six in the other. It appears, then, that the doubles are not evenly distributed around the planet.

We now turn to their partition according to latitude, and here we are made aware of a significant distribution affecting them. If we divide the surface into zones of ten degrees each, starting from the equator and travelling in either direction to the pole, and count the double canals occurring in each, we note a marked falling off in their number after we leave the tropic and subtemperate zones, and a complete cessation of them at latitude 63° north. The actual numbers are as follows:—

Between 90° S. and 30° S.	0
Between 30° S. and 20° S.	3
Between 20° S. and 10° S.	9
Between 10° S. and 0°	20
Between 0° and 10° N.	29
Between 10° N. and 20° N.	26
Between 20° N. and 30° N.	23
Between 30° N. and 40° N.	20
Between 40° N. and 50° N.	4
Between 50° N. and 60° N.	3
Between 60° N. and 63° N.	2
Between 63° N. and 90° N.	0

As a double may pass through more than one zone, it may be counted more than once, which explains the total in the table, though the doubles number but fifty-one.

Thus the doubles are tropical features of the planet, not general ones. Decidedly this proclaims again their reality, for were they optical only, they could not show such respect for the equator — a respect worthy of commendation from Sydney Smith. **Area of zones.**

Another of their peculiarities consists in their being confined to the light regions. For, with one possible exception, no doubles have been detected in the dark areas of the disk, whereas plenty of single canals have been found there.

Yet to the dark areas they stand somehow beholden. For the great majority of them debouch from what were once thought seas, to traverse the great deserts. Of the 51 doubles, no fewer than 28 are thus immediately connected with the 'seas.' But this is not the end of the dependence. For the remaining canals, 23 in number, each connect with one or other of the doubles that personally connect with these dark regions. In all but two cases the secondary dependence is direct; in these two a smaller dark patch occurs in the line of the connection.

Thus, the double canals show a most curious systematic dependence upon the great dark areas of the southern hemisphere. In this they reproduce again the general dependability of single canals upon topographic features; but with more emphatic particularity, for they prove that not only are prominent points for much in their localization, but that different kinds of terrain are curiously concerned. The relation of one kind of terrain to another is essential to their existence, since they are virtually not found in the blue-green areas, and yet are found in the light only in connection with the blue-green. That the blue-green is vegetation and the ochre desert leads one's thought to conjecture beyond.

To turn, now, to another mode of position, we will look into the direction in which these doubles run. To do this, we shall segregate them according to the compass-points. Any one of them, of course, runs two ways; as, for example, N.N.E. and S.S.W., and we shall therefore have but half the whole number of compass-points to consider. Taking the direction two points apart, we shall have eight sets, dividing the canals into bunches, as follows: —

S. and N.	7
S.S.E. and N.N.W.	5
S.E. and N.W.	4
E.S.E. and W.N.W.	3
E. and W.	6
E.N.E. and W.S.W.	6
N.E. and S.W.	12
N.N.E. and S.S.W.	8
	51

At first, to one considering this table, no marked preponderance for one direction over another manifests itself in the orientation. Still, a certain trend to the east of north as opposed to the west of north is discernible. For 25 doubles run within 45° of northeast and southwest, to 12 only that do the same thing for northwest and southeast. Following up the hint thus given us, we proceed to apportion the canals first into quadrantal points. The result is a fairly equable division all around the circle. Now, as a matter of fact, by lumping the doubles of the two hemispheres together, we have almost obliterated a striking fact which lies hidden in the table. If, instead of thus combining them, we separate those exclusively of the northern hemisphere from those of the southern one only, and now note in each of these what proportion trend to the west of south as against those that run to the east of it, and *vice versa*, we come out with significant results. In the northern hemisphere, the proportion of double canals to show a westward trend as opposed to an eastern is 17 to 4. In the southern hemisphere, the easterly-trending outnumber the westerly-trending by 1 to 0; while for those whose course is common to both hemispheres we find for the ratio of southwestern to southeastern 8 to 7.

How can this be explained? Consider a particle descending from the pole to the equator under the push of a certain momentum. As the particle (of water, for example) reaches a lower and lower latitude, it comes upon a surface which is travelling faster and faster eastward, because, since all parts of the body, whether the earth or. Mars, rotate in the same time, those particles where the girth is greatest have the farthest distance to go.

In consequence of this the particle would constantly be going at a less speed to the east than the spot upon which it found itself adventured, and so relatively to that place would move to the west. From the south pole to the equator, therefore, its course would always show a deviation southwesterly from a due north and south direction.

In the southern hemisphere, on the other hand, since the rotation of the planet is the same, its direction with regard to the pole is different, for the surface upon which the particle successively comes still sweeps to the east. It would, therefore, relatively to the surface, move to the northwest, and we should have in this hemisphere a northwesterly trend from the pole equatorward.

This is actually what we see in the doubles of Mars. The proportion of canals trending to the west as against those trending to the east in the northern hemisphere is, as we have seen, 17 to 4; while in the southern hemisphere the proportion trending to the east is 1 to 0. As for canals occupying both grounds a compromise is effected, the canals running according to the hemisphere in which the greater part of their course is situated. This is certainly a very curious conclusion, and seems to justify the name canals as typifying a conduit of some sort in which something flowed.[17]

The canals are subject to change.

Passing strange as is the mere look of the canals, study has disclosed something about them stranger yet: changes in their aspect depend on the time. Permanent the canals are in place, impermanent they prove in character. At one epoch they will be conspicuous objects, almost impossible to miss; then, a few months later, acuteness is taxed to discover them at all. Nor is this the whole story; some will show when others remain hid, and others will appear when the first have become invisible. Whole regions are affected by such self-effacement or an equal ostentation; while neighboring ones are simultaneously given to the reverse.

Curiously enough, the canals are most conspicuous not at the time the planet is nearest to the earth and its general features are in consequence best seen; but as the planet goes away, the canals come out. The fact is that the orbital position and the seasonal epoch conspire to a masking of the canal phenomena. For the planet comes to its closest approach to the earth a little before it reaches in its orbit the summer solstice of its southern hemisphere. For two reasons this epoch of nearness is an unpropitious date for the canal exhibit: first, because the bright areas, where the canals are easiest made out, lie chiefly in the hemisphere then tipped away from the earth; and secondly, because it is not the Martian season for the canals to show.

Due to this inopportune occurrence of the two events, approach and seasonableness, the canals lay longer undetected by man than would otherwise have been the case. Something of the same infelicity of appointment defeats the making of their acquaintance by many observers to-day. They look at the wrong time.

New method of research.

From their changes in conspicuousness it was evident that the canals, like the large blue-green patches on the disk, were seasonal in their habit. To discover with more particularity what their law of change might be, an investigation to that end was conceived and undertaken at the opposition of 1903, and in consequence a singular thing was brought to light. The research in question was the determination from complete drawings of the disk of the varying visibility of the several canals statistically considered during a period of many months.

For the making of the drawings extended over this time, and by a comparison of them one might note how any particular canal had altered in the interval. Their great number enabled accidental errors to be largely eliminated, and so assured a more trustworthy result. Systematic conditions affecting visibility — such as our own air, the position of the marking, and the size of the disk — were allowed for, so as to make the drawings strictly comparable. On the average, there were for each canal 100 drawings in which that canal either appeared or might have done so. And as 109 canals were considered in all, there resulted 10,900 separate determinations as basis for the eventual conclusion.

The object now was to adopt some procedure by which this mass of material might be made to yield statistical information, not simply qualitative but quantitative results. Here the planet itself suggested a way. Owing to the rotation of Mars any region would be carried in and out of sight to an observer in space once in 24 hours and 40 minutes. But owing to an analogous rotation of the earth the observer himself is not always in a position to see. Furthermore, the two rotations are not quite synchronous and are besides complicated by the motions of the two planets in their orbits. The result is that there takes place a slow falling behind in the longitudes of Mars presented centrally to the earth at the same hour on successive nights. If we could only see the planet for a minute each night, we should think it to be slowly rotating backward at the rate of 9.6° of its own longitude a day. In consequence any given marking can only be well observed for about a fortnight consecutively, after which it passes off the disk at the hours suitable for observation, not to return again for a month. Its times of showing are called presentations.

Now in the subject we are considering these presentations mark epochs six weeks apart at which the state of any marking may be examined in all the drawings in which it might then appear, a percentage of visibility deduced for it and then the percentages for its several successive presentations compared.

By this method results may be got of quantitative value, capable of approaching something like exactitude from being each the mean of many observations, and observations made with an eye to no specific outcome — indeed, incapable of being so adapted in advance as the result showed.

It is pleasing to note that to no one has the method commended itself more than to Schiaparelli. To welcome new procedures is the test of greatness, for it betokens breadth of view. Most men's knowledge is cut on a bias of early acquisition, and cannot be adapted to new habits of thought.

The percentages of visibility of the 109 canals at each of their presentations having thus been obtained, a tabulation of them showed what had been each canal's history during the period it was under observation. From perusal of the table could be learned the canal's career, whether it had been a mere unchanging line upon the planet's disk, or whether for reason peculiar to itself it had varied during the interval. To show this the more easily, the percentages were plotted upon coördinate paper, in which the horizontal direction should represent the time and the vertical the amount of the percentage. Then the points so found could be joined by a smooth curve, and the curve would instantly acquaint the eye with the vicissitudes of the canal's career from start to finish. The curve, in fact, would be its history graphically represented, and furthermore, would furnish a sign-manual by which it might be specifically known. The curve could be considered the canal's cartouche, — after the manner of the ideographs of the Egyptian kings, — symbolizing its achievements and distinguishing it at once from others.

Since the height of the curve from the horizontal base to which it stood referred denoted the degree of visibility of the canal at the moment, any deviation in this height along the course of the curve showed that the canal was then changing in conspicuousness from intrinsic cause. If the height grew greater, the canal was on the increase; if less, it was on the decline. For precautions had already been taken to eliminate every circumstance, it will be remembered, which could affect the canal's appearance, except change in the canal itself.

Not only increase or decrease in the canal stood forth thus manifestly confessed, but any change in the rate of such wax and wane also lay revealed. In looking at them, one has only to remember that the action proceeds from left to right and that the ups and downs of the curve show exactly what that action was.

Only one possible form out of them all indicates that no action at all was going on — the straight horizontal line. That cartouche signifies that its canal was a dead, inert, unchanging phenomenon for the period during which it was observed.

Now, of all the 109 canals examined, only three cartouches came out as horizontal straight lines, and even these it is possible to doubt. This is a most telling bit of information. To begin with, it is an *obiter dictum* of the most subtly emphatic sort upon the reality of the canals. It states that the canals

At the Telescope

Experiments in Artificial Disks.

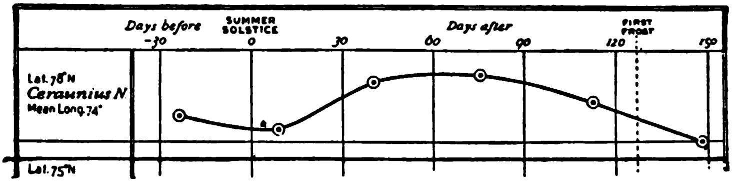
cannot be optical or illusory phenomena of any kind whatsoever without in the least going out of its way to do so, as a judge might lay down some quite indisputable point of law in the course of a more particular charging of the jury. For an illusion could no more exhibit intrinsic change than a ghost could eat dinner without endangering its constitution. The mere fact that it is an illusion or optical product renders it incapable of spontaneous variation. Consequently, its cartouche would be a horizontal straight line. As the cartouches are not such lines, we have in them instant disproof of optical or illusory effects of every kind.

Now, that the cartouches are curves shows that the action in them is not uniform, but increases or decreases more at one season than at another. Furthermore, as the curves both rise and fall in the course of their career, the action they typify must consist of alternate wax and wane. It is, therefore, periodic, which leads us again to the fact that it is seasonal.

Thus, to take the canal Ceraunius, we note that it dwindled from the time it was first observed, June 5 in the Martian calendar, till about the end of June. It then started to increase in conspicuousness intrinsically, in short to grow, until the early part of August, subsequently to which it again declined, vanishing after the first frost. Its cartouche further shows that its waning was a slow process of extinction, its wax a relatively sudden one.

Search for clew to decipherment.

From the knowledge about the individual canal which the cartouches thus afford, we advance to what they prove capable of imparting by collective coördination with one another. To compare them it was necessary to select some point of the cartouche



CARTOUCHE OF THE CERAUNIUS

From a chart made by Professor Lowell.

adapted to comparison purposes. The one that suggested itself was the point where the curve fell to a minimum. This point denoted the time at which each canal began to increase in conspicuousness, the dead point from which it rose. This dead point was found for each cartouche, and starred on the curve. When this had been done and the cartouches tabled, at a first glance it seemed as if comparison were hopeless for the detection of any underlying principle and each cartouche only a law unto itself.

But by recalling that the canals exist upon the surface of a globe and that the two directions for positioning a place upon a sphere are longitude and latitude, we are led to try latitude as the more promising of the two to furnish a clew.

To this end the canals were segregated according to the zone on the planet in which they lay, and their separate values for consecutive times combined into a mean canal cartouche for the zone. This was done for all the zones, and the mean cartouches were then placed in a column descending according to latitude.

Quickening of canals according to latitude.

The result was striking. Following down the column, there is evident a delay in the time of occurrence of the minimum as we descend the latitudes. This means that the canals started to increase from their dead point at successively later epochs in proportion to their distance from the planet's polar cap.

Now, before seeking to put this symbolism into comprehensive terms, — to do which, I may add parenthetically, is just as scientific and far more philosophic than to leave the diagram as a cryptic monument of a remarkable law, which it were scientifically impious to interpret, — another fact exhibited by the diagram deserves to be brought out. It appears, if attention be directed to it, that in all the mean canal cartouches, the gradient is less before the minimum than after it. What we saw to occur in the Ceraunius is the expression of a general law governing the canals. The curves fall slowly to their lowest points, and rise sharply from them. What this betokens will suggest itself on a moment's thought. It means that the effects of a previous motive force were slowly dying out in the first part of the curves, and then a fresh impulse started in to act. The new impulse was more instant and of greater strength in its action, and by piecing the two parts of the curve together, we conclude that it was in both cases an impulse which acted fairly quickly and of which the effects took a longer time to die out. The mean cartouches, then, assure us of two quickenings and lead us to infer that both were of the nature of forces speedily applied and then withdrawn.

Quickening starts at polar cap.

To interpret now the successive growth of the canals latitudinally down the disk is our next concern. We saw that it started at the edges of the polar cap. Now, such an origin in place at once suggests an origin of causation as well, and furthermore precludes all other. For the origin of time was after the melting of the cap. First the cap melted, and then the canals began to appear. Those nearest to the cap did so first, and then the others in their order of distance from it, progressing in a stately march down over the face of the disk.

Thus we reach the deduction that water liberated from the polar cap and thence carried down the disk in regular progression is the cause of the latitudinal quickening of the canals. A certain delay in the action, together with the amount of darkening that takes place, seems to negative the supposition that what we see is the water itself.

On the other hand, vegetation would respond only after a lapse of time necessary for it to sprout, — a period of, say, two weeks, — and such tarrying would account for the observed delay.

Vegetation, then, explains the behavior of the canals. Not transference of water merely, but transformation consequent upon transference, furnishes the key to the meaning of the cartouches. Not the body of water, but the quickened spirit to which it gives rise, produces the result we see. Set free from its winter storage by the unlocking of the bonds of its solid state, the water, accumulated as snow, begins to flow and starts vegetation, which becomes responsible for the increased visibility of the canals.

Waked in this manner, the vegetal quickening, following the water with equal step, but only after due delay, passes down the disk, giving rise to those resuscitations we mark through the telescope, and attribute not without reason to seasonal change.

Change it is, and seasonal as well, yet it is not what we know by the name in one important particular. For it is a vernal quickening peculiar to Mars which knows no counterpart on earth.

The earth as witnessed from space.

To realize this, we must try to see ourselves as others might see us. If we could do away with the cloud-envelope which must to a great extent shield our earth's domestic matters from prying astronomers upon other orbs, and selecting some coign of vantage, as, for example, Venus, scan the face of our familiar abode from a distance sufficient to merge the local in the general aspect, we should at intervals of six months notice a most interesting and beautiful transformation spread over it. It is the vernal flush of the earth's awakening from its winter's sleep that we should then perceive. Starting from near the line of the tropic, we should mark the surface turn slowly virescent. As the tint deepened, we should see it also spread, creeping gradually up the latitudes until it stood within the Arctic Circle and actually bordered the perpetual snow.

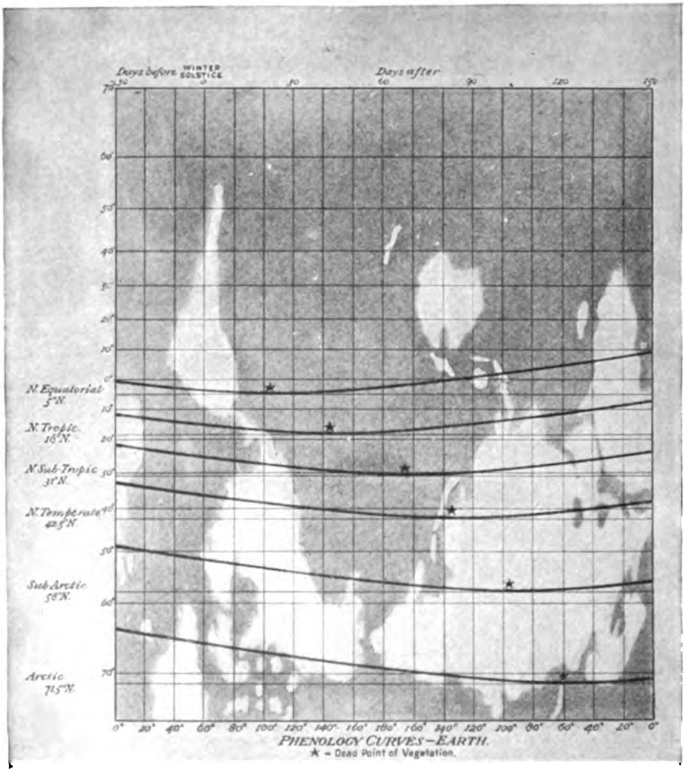
We should witness thus on the earth much what we mark on Mars at intervals twice as long, because there timed to the greater length of the Martian year. But one striking difference would be patent to the observer's eye: on earth the wave of wakening would travel from equator to pole; on

Mars it journeys from pole to equator. So much alike in their general detail, the two would thus be parted by the opposite sense of the action to a diversity which at first would seem to deny any likeness in cause. To us the very meaning of seasonal change hinges on the return of the sun due to our change of aspect toward it. That the reverse could by any reason be ascribed to the same means might appear at first impossible.

Not so when we consider it with care. Apart from the all-important matter of the seed, two factors are concerned in the vegetal process, the absence of either of which is equally fatal to the result. The raw material, represented by oxygen, nitrogen, a few salts, and water, is one of these; the sun's rays constitute the other. Unless it be called by the sun, vegetation never wakes. But, furthermore, unless it have water, it remains deaf to the call. Now, on the earth water is, except in deserts, omnipresent. The sun, on the other hand, is not always there. After its departure south in the autumn, vegetation must wait until its return in the spring.

Melting first necessary on Mars.

Mars is otherwise circumstanced. Dependent like us upon the periodic presence of the sun directly, it is further dependent upon the same source indirectly for its water-supply. Not having any surface water except such as comes from the annual unlocking of the snows of the polar cap, vegetation must wait upon this unlocking before it can begin to sprout.



SPROUTING TIMES OF VEGETATION ON THE EARTH

The earth is represented upside down, in direct comparison with Mars as we see it in the telescope.

From a chart made by Professor Lowell.

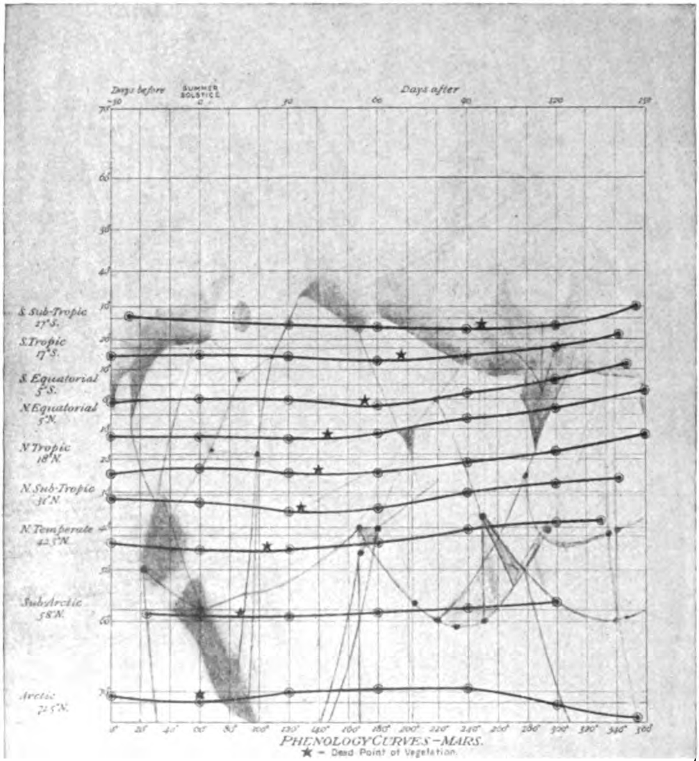
The sun must have already gone north and melted the polar snows before vegetation starts, and when it starts, it must do so at the north, where the water arises, and then follow the frugal flood down the disk. Thus, if it is to traverse the surface at all with vegetation in its train, the showing must begin at the pole and travel to the equator.

This, to us, inverse manner of vernal progression is precisely what the cartouches exhibit. Their curves of visibility show that the verdure wave is timed not primarily to the simple return of the sun, but to the subsequent advent of the water, and follows, not the former up the parallels, but the latter down the disk.

Speed of spread of vegetation.

It is possible to gauge the speed of the latitudinal sprouting of the vegetation, and therefore of the advent of the water down the canals, by the difference in time between the successive darkenings of the canals of the several zones. Thus it appears that it takes the water fifty-two days to descend from latitude 72° N. to the equator, a distance of 2650 miles. This means a speed of 51 miles a day, or 2.1 miles per hour.

So, from our study, it appears that a definite law governs the wax and wane of these strange things. Quickened by the water let loose on the melting of the polar cap, they rise rapidly to prominence, to stay so for some months, and then slowly proceed to die out again. Each in turn is thus affected, the march of vivification stalking the latitudes with steady stride down the surface of the disk. Nothing stops



Sprouting Times of Vegetation on Mars

From a chart made by Professor Lowell.

its measured progress, or proves deterrent to its course. One after the other each zone in order is reached and traversed, till even the equator is crossed, and the advance invades the territory of the other side. Following in its steps afar, comes its slower wane. But already, from the other cap, has started an impulse of like character that sweeps reversely back again, travelling northward as the first went south. Twice each Martian year is the main body of the planet traversed by these antistrophic waves of vegetal awakening, grandly oblivious to everything but their own advance. Two seasons of growth it therefore has, one coming from its arctic, one from its antarctic, zone, its equator standing curiously beholden semestrally to its poles.[18]

There is something stirring to thought in this solidarity of movement, timed in cadence to the passage of the year. Silent as it is, the eye seems half to catch the measured tread of its advance as the darkening of the canals sweeps on in progressive unison of march. That it means life, not death, detracts no jot from the moving quality of its effect. For all its peaceful purpose, the rhythmic majesty of the action imposes a sense of power on the mind, seeming in some better way to justify the planet's name in its wholly Martian character. Called after the god of war, the globe is true to its character in the orderly precision of its stately processional change.

CHAPTER VI

PROOFS OF LIFE ON MARS

ASTRONOMICAL discovery is of two kinds. If it consist simply in adding another asteroid or satellite to those already listed, obedience to the law of gravitation, with subsequent corroboration of place, alone is needed for belief. But if it relate to the detection of an underlying truth as yet unrecognized, then it is only to be unearthed by reasoning on facts after they are obtained, and effects credence according to one's capacity for weighing evidence. Breadth of mind must match breadth of subject. For to plodders along prescribed paths a far view fails of appeal; conservative settlers in a land differ in quality from pioneers.

Discovery of truths similar to detective work.

Discovery of a truth in the heavens varies in nothing, except the subject, from discovery of a crime on earth. The forcing of the secrets of the sky is, like the forcing of man's, simply a piece of detective work. It is the finding of a cause in place of a culprit; but the process is quite similar. *Causa criminis* and *causa discriminis* differ only by a syllable.

Like, too, are, or should be, the methods employed. In astronomy, as in criminal investigation, two kinds of testimony require to be secured. Circumstantial evidence must first be marshalled, and then a motive must be found. To omit the purpose as irrelevant, and rest content with gathering the facts, is really as inconclusive a procedure in science as in law, and rarely ends in convincing, any more than in properly convicting, anybody. For motive is just as all-pervading a preliminary to cosmic as to human events, only for lack of fully comprehending it we call the one a motive and the other a cause. Unless we can succeed in assigning a sufficient reason for a given set of observed phenomena, we have not greatly furthered the ends of knowledge and have done no more than the clerkage of science. A theory is just as necessary to give a working value to any body of facts as a backbone is to higher animal locomotion. It affords the data vertebrate support, fitting them for the pursuit of what had otherwise eluded search.

Coördination is the end of science, the aim of all attempt at learning what this universe may mean. And coördination is only another name for theory, as the law of gravitation witnesses. Now, to be valid, a theory must fulfil two conditions: it must not be contradicted by any fact within its purview, and it must assign an underlying thread of reason to explain all the phenomena observed. Circumstantial evidence must first lead to a suspect, and then this suspect must prove equal to accounting for the facts.

This method we shall pursue in the case before us; and it will conduce to understanding of the evidence to keep its order of presentation to the detective in presenting it at the bar of reason.

Review of the natural chain of evidence.

Starting with the known physical laws applicable to the concentration of matter, we found that though in general the course of evolution of the earth and Mars was similar, the smaller mass of Mars should have caused it to differ eventually from the earth in some important respects.

Three of these are noteworthy: (1) its surface should be smoother than the earth's, (2) its oceans relatively less, (3) its air scantier. On turning to Mars itself we then saw that these three attributes of the planet were precisely those the telescope disclosed. (1) The planet's surface was singularly flat, being quite devoid of mountains; (2) its oceans in the past covered at most three-eighths of its surface instead of three-quarters, as with us; (3) its air was relatively thin.

Aspect of Mars corroborates principles of planetary evolution.

We next showed that physical loss should, from its smaller mass, have caused it to age quicker, and that this aging should reveal itself by the more complete departure of what oceans it once possessed and by the wider spread of deserts.

Telescopic observation we then found asserted these two peculiarities: (1) no oceans now exist on the planet's surface; (2) desert occupies five-eighths of it.

From such confirmation of the principles of planetary evolution from the present aspect of the planet Mars, we went on to consider the two most essential prerequisites to habitability: water and warmth. Water we sought first; and we found it in the polar caps. The phenomena of the polar caps proved explicable as consisting of water, and not as of anything else. Still more important was the question of temperature. We took this up with particularity. We found several factors to the problem not hitherto reckoned with, and that when these were taken into account the result came out entirely different from what had previously been supposed. Instead of a temperature prohibitive to life, one emerged from our research entirely suitable for it. And this even more for animals than plants. For a climate of extremes was what that of Mars appeared to be, with the summers warm. Now, investigations on earth have shown that it is the temperature of the hottest season that determines the existence of animals, cold much more adversely affecting plants. Yet to the presence of the latter the look of the disk conformed. Scanning it, we marked effects which could only be explained as vegetation. Thus the conditions on Mars showed themselves hospitable to both great orders of life, the latter actually revealing its presence by its seasonal changes of tint.

Animal life disclosed only by mind.

Here we reached the end of what might directly be disclosed in the organic economy of the planet. For at this point we brought up before a most significant fact: that vegetable life could thus reveal itself directly, but that animal life could not. Not by its body, but by its mind, would it be known. Across the gulf of space it could be recognized only by the imprint it had made on the face of Mars.

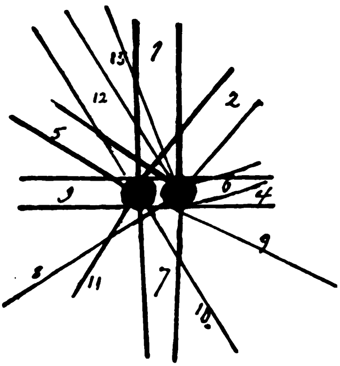
Canals confront the observer.

Turning to the planet, we witnessed a surprising thing. There on the Martian disk were just such markings as intelligence might have made. Seen even with the unthinking eye, they appear strange beyond belief, but viewed thus, in the light of deduction, they seem positively startling, like a prophecy come true.

Confronting the observer are lines and spots that but impress him the more, as his study goes on, with their non-natural look. So uncommonly regular are they, and on such a scale, as to raise suspicion whether they can be by nature regularly produced. Next to one's own eyesight the best proof of this is the unsolicited indorsement it has received in the scepticism their depiction invariably evokes. Those who have not been privileged to see them find it well-nigh impossible to believe that such things can be. Nor is this in the least surprising. But however consonant with nescience to doubt the existence of the lines on this score, to do so commits it to witness against itself of the most damaging character the moment their existence is proved. Now, assurance of actuality no longer needs defence. The lines have not only been amply proved to exist, but have actually been photographed, and doubt has shifted its ground from existence to character, a half retreat tantamount to a complete surrender. For without equal investigation, to admit a discovery and deny its description is like voting for a bill and against its appropriation. It reminds one of the advice of the old lawyer to a junior counsel: "When you have no case, abuse the plaintiff's attorney."

Unnatural regularity, the observations showed, betrays itself in everything to do with the lines: in their surprising straightness, their amazing uniformity throughout, their exceeding tenuity, and their immense length. These traits, instead of disappearing, the better the canals have been seen, as was confidently prophesied, have only come out with greater insistence. With increased study not only the assurance gains that they are as described, but a mass of detail has been added about them impossible to reconcile with any natural known process.

A single instance of the methodism that confronts us will serve to make this plain. The *Lucus Ismenius* is a case in point. The marking so called consists of two round spots each about seventy-five miles in diameter. They lie close together, not more than fifty miles of ochre ground parting their peripheries. Into them converge a number of canals—seven doubles and five singles. Now, the manner of these meetings is curiously detailed. Three of the doubles embrace the oases, just enclosing them between their two arms. The four other doubles send a line to each oasis to enter it centrally. Which connection the double shall adopt apparently depends upon the angle at which the approach is made. If the direction be nearly vertical to the line of the two oases, the entrance is central; if parallel, it is an embrace. As for the singles, they connect with one or the other oasis, as the case may be. Such precise and methodical



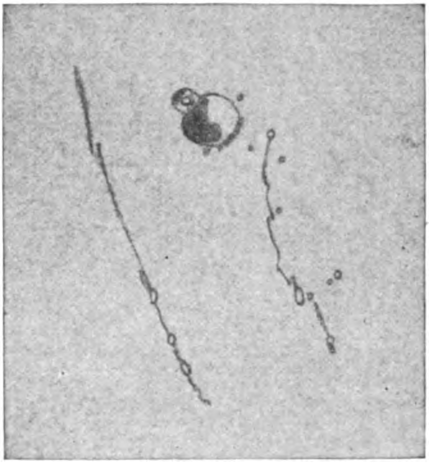
Luci Ismenii, revealing the Systematic Method in which the Double Canals enter the Twin Oases

1. Euphrates, double.
2. Hiddekel, double.
3. Protonilus, double.
4. Deuteronilus, double.
5. Astaboras, double.
6. Djihoun, double.
7. Arnon, convergent double.
8. Aroeris. 9. Sados.
10. Pallacopas. 11. Phthuth.
12. Naarmalcha, double.
13. Naarsares.

arrangement, thus marvellously articulated and detailed, discloses an orderliness so surprising, if on nature's part, as to throw us at once into the arms of the alternative as the least astonishing of the two.

Not rivers.

Before passing on to reason upon the fact, we note that the characters mentioned are themselves enough to negative all suppositions of natural cause. First, the lines cannot be rivers, since rivers are never straight and never uniform in width. Now, we see the canals so well as to be quite certain of their evenness. The best proof of this is that, though each is uniform, some are at least ten times the size of others. If one of them dwindled *en route*, we should have ample measure of the fact.



From a drawing by Professor Lowell.

THE MOON, SHOWING THE STRAIGHT WALL AND RILL TO THE RIGHT OF BIRT, MAY, 1905

These are palpable cracks like those in a ceiling, and quite unlike the uniform canal lines of Mars.

Not cracks.

Nor can the lines be cracks in the surface, because cracks also are not straight, and because cracks end before finishing. We have examples of undoubted cracks in more than one heavenly body, and their appearance is quite unlike the look of the lines of Mars. The moon offers such in many, if not all, of her so-called rills.

To the most superficial view these suggest their nature, but when carefully examined at Flagstaff, corroboration of the fact came out in certain definite characteristics. For the rills proved to be made of parts which overlapped at their ends, one fractional line taking up the course before the other had given out, thus exactly reproducing the composition of the cracks in any plaster ceiling.

Mercury bears testimony to the same effect. Its lines, more difficult than the canals of Mars, — for we see Mercury four times as far off when best placed as we do Mars, — though roughly linear, are not unnatural in appearance even at that great distance, and show irregularities suggestive of cracks.* In the markings on Venus, too, there is nothing unnatural.

Other natural explanations prove impossible.

Rivers and cracks are the two most plausible suppositions made to account for the lines on any theory of natural causation. Other guesses have been in-

* Lately, at least two critics have stated that the descriptions of the spoke-like markings seen on Venus at Flagstaff in 1897 and later, are inconsistent. The seeming inconsistency is due to our own air, which sometimes defines them, sometimes not. The important point about them is that the Venusian lines are *irregular*. — P. L.

From drawings by Professor Lowell.

MERCURY

These two plates show the irregular character of the lines on the planet Mercury, differing entirely in look from the canals on Mars. The plates also show the libration due to the eccentricity of the planet's orbit, from the fact that the markings appear farther and farther from the terminator, the latter being the elliptical contour separating the illuminated from the unilluminated portion of the disk; or nearer and nearer according as the libration swings one way or the other.

dulged in, such as that meteors by their passing attraction have raised the lines as welts upon the surface — welts easily allayed by application of the fact that the lines change with the seasons, actually disappearing at certain epochs, to revive again at others. Such suggestions there are, but none have been advanced to my knowledge that bear the most cursory inspection.

Still more inexplicable on any natural hypothesis is the systematized arrangement of the lines to form a network over the whole planet. That the lines should go directly from certain points to certain others in an absolutely unswerving direction; that they should there meet lines that have come with like directness from quite different points of departure; that sometimes more than ten of them should thus rendezvous, and rarely less than six; and that, lastly, this state of intercommunication should be true all over the disk, are phenomena that no natural physical process that I can conceive of — and no one else seems to have been able to, either — can in the least explain. Yet this arrangement cannot be due to chance, the probabilities against the lines meeting one another in this orderly manner being millions to one.

Oases equally inexplicable.

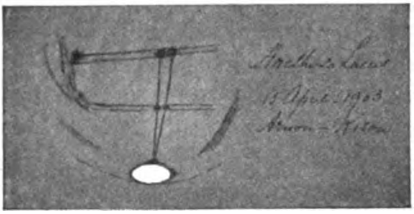
But the canals are not all that is wonderful; we have to reckon with the oases as well. These are remarkable, both in themselves and in their relation to the system of lines; for they occur at the junctions — only at the junctions, and virtually always at the junctions. They are thus of the nature of knots to the network. No explanation can be given of this by purely physical laws.

So we might go on, with the enigma of the double canals more and more mysterious the more one learns about them — with their strange positioning on the planet in the tropical belts; with the curious phenomenon of converging or wedge-shaped doubles descending to join them from the pole; and with other facts equally odd.

A CORNER OF MARS, JUNE 10, 1907

But long before the catalogue of geometric curiosities had drawn to its close, — for it were wearisome to count them all, and where even one is so cogent, numbers do not add, — it becomes apparent to any one capable of weighing evidence that these things which so palpably imply artificiality on their face cannot be natural products at all, but Artificiality suggests itself.

that the observer apparently stands confronted with the workings of an intelligence akin to and therefore appealing to his own. What he is gazing on typifies not the outcome of natural forces of an elemental kind, but the artificial product of a mind directing it to a purposed and definite end.



ARETHUSA LUCUS, APRIL 15, 1903, SHOWING CONVERGING CANALS FROM THE NORTH POLAR CAP

When once this standpoint is adopted, we begin to see light. The recognition of artificiality puts us on a track where we gather explanation as we proceed.

Great-circle character of the canals.

Thus two attributes, one of the canals, the other of the oases, find explanation at once. The great-circle directness of the lines stands instantly interpreted. On a sphere a great circle takes the shortest distance between two points. It offers, therefore, the most expeditious route from one place to another. It is, then, that which, when possible, intelligence would adopt. Even in the case of our very accidented earth, our lines of communication are being rectified every year as we progress in mastery of our globe.

Equally suggestive is the shape of the oases, or spots, that button the lines together. For they show round. Now, a solid circle has the peculiar property that the average distance from its centre to all points in it is less than for any figure enclosing a like area. It would be the part of intelligence, then, to construct this figure whenever the greatest amount of ground was to be reached for tillage or any other purpose at the least expenditure of force.

Circularity of oases.

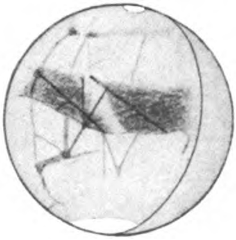
No less telltale is their behavior; and now not only of the bare fact of artificiality, but of the manner in which it came to be.

The extreme threads of the world-wide network of canals stand connected with the dark-blue patches

Note of water runs through the action.

CANALS FROM THE SOUTH POLAR CAP, THE WHITE BONNET AT THE TOP OF THE PICTURE, JUNE 6, 1907

Martian date, September 22.



CANALS FROM THE SOUTH POLAR CAP, SHOWN AT THE TOP OF THE PICTURE, OCTOBER 25, 1907

Martian date, December 18.

at the edge of one or the other of the polar caps. But they are not always visible. In the winter season they fail to show. Not till the cap has begun to melt, do they make their appearance, and then they come out dark and strong. Now, the cap in winter is formed of snow and ice that melts as summer comes on. Here, then, the attentive ear seems to catch the note of running water.

From their poleward origin the lines begin to darken down the disk. One after the other takes up the thread of visibility, to hand it on to the next in place. So the strange communication travels, carried from the arctic zone through the temperate and the tropic ones on to the equator, and then beyond it over into the planet's other hemisphere. A flow is here apparent, journeying with measured progress over the surface of this globe. Here, again, the mental ear detects the sound of water percolating down the latitudes.

Across what once were seas, but are seas no more, the darkening of the lines advances, with the same forthrightness as over the ochre continental tracts. Blue-green areas of vegetation and arid wastes alike are threaded by the silent deepening of tint. Latitude bars it not, nor character of country. It great-circles the old sea bottoms as cheerfully as it caravans the desert steppes. This persistency made possible by the loss of what the seas once held, the thought of water is once more thrust upon the sense, its absence now as telling as its presence was before. One hears it in the very stillness the lack of it promotes.

Then, as with quickened sense one listens, the mind is aware of antiphonal response in the unlocking of the other cap to send its scanty hoardings in similar rilling over the long-parched land. The note of water confronts us thus at every turn of this strange action. Water, then, must be the word of the enigma: the clew that will lead us to the unloosening of the riddle.

But though water it be, this is not the complete solution of the problem; for, as one ponders, the unnatural character of the action dawns on one. That a wave of progression passes through the canals down the disk; that something, then, proceeds from the pole to the equator; and that this something can be none other than water, giving rise to vegetation, sounds simple and forthright. The startling character of the action is not at once apparent. It becomes so only when we try to account for the locomotion. When we so envisage it, the transference turns out to be a most astounding and instructive thing.

Its locomotion explained.

To understand wherein lies its peculiarity, we must consider the shape of the planet. For the planet is flattened at the poles by $\frac{1}{190}$ of its diameter. This, to begin with, will make the action seem even stranger than it is. It might seem at first as if the water in going to the equator had to run twenty-one miles uphill.

Mars' surface in fluid equilibrium.

If Mars did not rotate, its figure would be a sphere, except for such tidal deformation as outside bodies might give it, because its own gravity would pull it into a shape similar in all directions. As Mars rotates, its rotatory momentum bulges it at the equator, changing the sphere into what is called an oblate spheroid of the general form of an orange. The ellipticity of a rotating mass is affected not only by the size of the body and by the speed of rotation, but by the distribution of the matter composing it. Thus it is different for a homogeneous body than for a heterogeneous one, and differs according to the law of density from surface to centre. Now it is an interesting fact that the oblateness of Mars — $\frac{1}{190}$, found by two independent methods quite independently applied; one from measurements of the planet made in 1894 at Flagstaff by Mr. Douglass, reduced and discussed by the director; the other from the motions of the satellites by Hermann Struve — should fall between the value it would have, were it homogeneous, and that which it would show did the density increase from surface to centre in the same manner as on earth. But we can see from theory that it should lie between these two extremes. For the compression there is not so great as with the earth because of Mars' smaller mass. In this we find another proof, were any needed, that the evolution of both planets was as sketched in our opening chapter. A rapidly rotated mass of putty will take on the same shape. In the case of Mars the stresses are so enormous that for a long acting force, such as is here concerned, the planet, although probably as rigid as steel, behaves as if its mass were plastic. The result is that the direction of gravity is always perpendicular to the surface at every point; or, in other words, the surface is in stable equilibrium.

Gravity incapable of water transference.

Now, the fact that every point of the surface is in equilibrium means that any particle of a liquid there — as, for example, a drop of water — would not move, but would stay where it was. For all the forces being exactly balanced to rest, their resultant cannot solicit it to stir. Just as on the surface of the earth, water upon a level stretch of ground shows no tendency to move.

Consequently, any water set free near the pole by the melting of the polar cap would stay where it was liberated without the least inclination to go elsewhere. The only force which would have the slightest effect upon it might be its own head, if it had any. Were the melting ice or snow that gave birth to it ten feet thick, and it is more likely to be less, it would give rise to an average head of water of five feet. Now, a head of five feet could not urge the water against surface friction more than a few miles at most. So that any such impulse is quite impotent to the effects we see.

Face to face, then, we find ourselves with a motion of great magnitude occurring without visible or physically imaginable cause. A body of water travels 3300 miles at the rate of 51 miles a day under no material compulsion whatever.

It leaves the neighborhood of the pole, where it was gravitationally at home, and wanders to the equator, where gravitationally it was not wanted, without the slightest prompting on the part of any natural force. The deduction is inevitable; it must have been artificially conducted over the face of the planet. We are left no alternative but to suppose it intelligently carried to its end.

Nor is this the limit of the extraordinary performances shown by the progressive darkening of the canals down the disk. Were they actuated by natural forces, what they next do would be simply incredible. For, not content with descending to the equator without visible means of propulsion, once arrived there, they promptly proceed to cross it into the planet's other hemisphere and run up the latitudes with equal celerity on the other side. Now, any physical inducement given them to come equatorward must have its action reversed so soon as that dividing-line was crossed. If, then, they were in any way helped to the earlier part of their peregrination by natural forces, they would be hindered by them in this latter portion of their career. Thus, the only rational result of our discussion of the canals is that these things are not dependent on natural forces for their action, but are artificial productions designed to the end they so beautifully serve. In the canals of the planet we are looking at the work of local intelligence now dominant on Mars. Such is what the circumstantial evidence points to unmistakably.

DJIHOUN

The "original" canal leaves from the tip of the *Sinus*, the "duplicate" from higher up its coast.

To detection of a motive we now turn. And here it is our study of planetary evolution in general becomes of service. As a planet ages, its surface water grows scarce. Its oceans in time dry up, its rivers cease to flow, its lakes evaporate. Its fauna, if it have any, dependent as they are upon water for life, must more and more be pushed to it for that prime necessity to existence.

As the water leaves a planet, departing into space, so much of it as does not sink out of sight into its interior stands for a while a-tiptoe in its air before taking final flight into the sky. In the planet's economy it has ceased to be water, and become that more ethereal thing, water-vapor. In one way and place only does it ever in any amount descend to earth again and take on even transiently its liquid state. This is in the polar caps. The general meteorologic circulation of the planet deposits it there throughout the winter months. From the cold of the arctic latitudes its deposition takes the form of snow or ice, and in consequence of this solid state is largely tethered to the spot where it falls, remaining *in situ* until the returning sun melts it in the spring. This is the state of things on Mars.

When this unlocking occurs, and while the water is in its intermediate liquid state, between not easily transportable ice and ungatherable vapor, it is in a condition to be moved, and may be drawn upon for consumption. Then, and then only, is it readily available for use, and then, if ever, it must be tapped.

Now, in the struggle for existence, water must be got, and in the advanced condition of the planet this is the only place where it is in storage and whence, therefore, it may be had. Round the semestral release of this naturally garnered store everything in the planet's organic economy must turn. There is no other source of supply. Its procuring depends upon the intelligence of the organisms that stand in need of it. If these be of a high enough order of mind to divert it to their ends, its using, from a necessity, will become a fact. Here, then, is a motive of the most compelling kind for the tapping of the polar caps and the leading of the water they contain over the surface of the planet: the primal motive of self-preservation. No incentive could be stronger than this.

DIFFERENTIATION OF THE GANGES

The *Ganges* is the double canal going upward, a little to the left from the centre of the disk. It will be noticed that the right-hand line is stronger than the left-hand one.

Our motive found being of the most drastic kind, it remains now to examine whether it can be put into execution.

Organisms evolve as a planet ages.

As a planet ages, any organisms upon it would share in its development. They must evolve with it, indeed, or perish. At first they change only as environment offers opportunity, in a lowly, unconscious way. But, as brain develops, they rise superior to such occasioning. Originally the organism is the creature of its surroundings; later it learns to make them subservient to itself. In this way the organism avoids unfavorableness in the environment, or turns unpropitious fortune to good use. Man has acquired something of the art here on the earth, and what with clothing himself in the first place, and yoking natural forces in the second, lives in comfort now where, in a state of nature, he would incontinently perish.

Such adaptation in mind, making it superior to adaptation in body, is bound to occur in the organic life on any planet, if it is to survive at all. For conditions are in the end sure to reach a pass where something more potent than body is required to cope with them.

One species supplants all others.

It is possible to apply a test to tell whether such life existed or not. For certain signs would be forthcoming were such intellect there. Increase of intelligence would cause one species in the end to prevail over all others, as it had prevailed over its environment. What it found inconvenient or unnecessary to enslave, it would exterminate, as we have obliterated the bison and domesticated the dog. This species will thus become lord of the planet and spread completely over its face. Any action it might take would, in consequence, be planet-wide in its showing.

Now, such is precisely what appears in the world-spread system of canals. That it joins the surface from pole to pole and girdles it at the equator betrays a single purpose there at work. Not only does one species possess the planet but even its subdivisions must labor harmoniously to a common aim. Nations must have sunk their local patriotisms in a wider breadth of view and the planet be a unit to the general good.

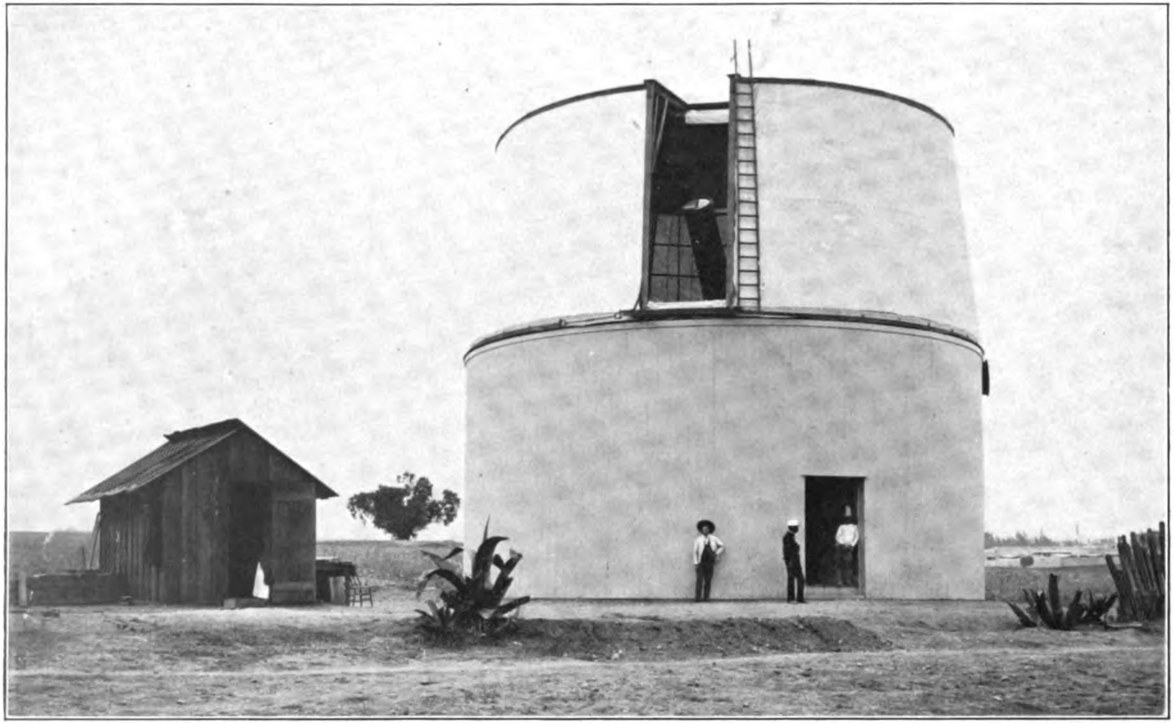
To die of thirst.

As the being has conquered all others, so will it at last be threatened itself. In the growing scarcity of water will arise the premonitions of its doom. To secure what may yet be got will thus become the forefront of its endeavor, to which all other questions are secondary. Thus, if these beings are capable of making their presence noticeable at all, their great occupation should be that of water-getting, and should be the first, because the most fundamental, trace of their existence an outsider would be privileged to catch.

The last stage in the expression of life upon a planet's surface must be that just antecedent to its dying of thirst. Whether it came to this pass by simple exhaustion, as is the case with Mars, or by rotary retardation, as is the case with Mercury and Venus, the result would be all one to the planet itself. Failure of its water-supply would be the cause. To procure this indispensable would be its last conscious effort.

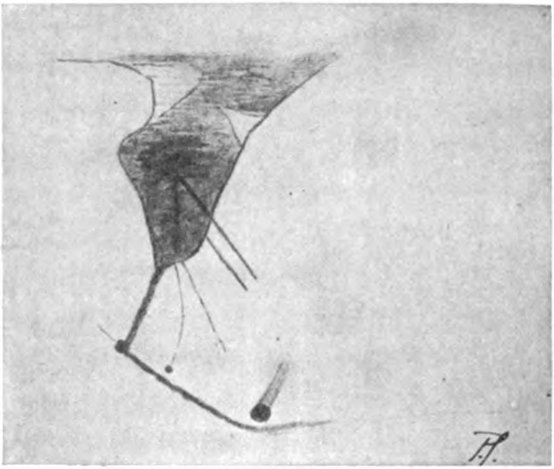
End foreseen. With an intelligent population this inevitable end would be long foreseen. Before it was upon the denizens of the globe, preparations would have been made to meet it. And this would be possible, for the intelligence attained would be of an order to correspond. A planet's water-supply does not depart in a moment. Long previous to any wholesale imminence of default, local necessity must have begun the reaching out to distant supply. Just as all our large cities to-day go far to tap a stream or a lake, so it must have been on Mars. Probably the beginnings were small and inconspicuous, as the water at first locally gave out. From this it was a step to greater distances, until necessity lured them even to the pole. The very process, one of addition, instead of one of total synchronous construction, seems to show stereotyped to us in the canals. These run in their fashioning rather with partial than with teleologic intent, giving as much concern to halfway points as to the goal itself, although in their action now they are totally involved. The thing was not done in a day, and by that very fact stamps the more conclusively its artificial origin.

The ability of beings there to construct such arteries of sustenance, two considerations will help to make comprehensible: one of these minifies the work, the other magnifies the workers. In the first



Dome of the Lowell Observatory — In Tacubaya, Mexico — where Mars was observed during the Winter of 1896–7

place, it is not what we see that would have to be constructed. The object of endeavor is not only the water itself, but the products that water makes possible. It is vegetation which is matter of immediate concern, water being of mediate employment. This, then, is what would probably show. Just as



NORTHEAST CORNER OF AERIA, JULY 2–5, 1907

on the earth it is the irrigated strip of reclaimed desert, and not the Nile itself, which would make its presence evident across interplanetary space. If these lines are irrigated bands of planting, the vertebral canal would be a mere invisible thread in the midst of that to which it gave growth. This alone would have to be made, and indeed it would probably be covered to prevent evaporation.

Now, we have evidence that the canals are thus composed of nerve and body. When they lie down, they do not entirely vanish. Under the visual conditions of Flagstaff they may still be made out in their dead season, the mere skeletons of themselves as they later fill out. And even so we do not actually see the nerve itself.

For the construction of these residuary filaments we have a plethora of capabilities to draw upon: in the first place, beings on a small planet could be both bigger and more effective than on a larger one, because of the lesser gravity on the smaller body. An elephant on Mars could jump like a gazelle. In the second place, age means intelligence, enabling them to yoke nature to their task, as we are yoking electricity. Finally, the task itself would be seven times as light. For gravity on the surface of Mars is only about 38 per cent of what it is on the surface of the earth; and the work which can be done against a force like gravity with the same expenditure of energy is inversely as the square of that force. A ditch, then, seven times the length of one on earth could be dug as easily on Mars.

With this motive of self-preservation for clew, and with a race equal to the emergency, we should expect to note certain general phenomena. Both polar caps would be pressed into service in order to utilize the whole available supply and also to accommodate most easily the inhabitants of each hemisphere. We should thus expect to find a system of conduits of some sort world-wide in its distribution and running at its northern and southern ends to termini in the caps. This is precisely what the telescope reveals. These means of communication should be, if possible, straight, both for economy of space and of time, it being especially necessary to avoid any wasteful evaporation on the road. Construction of such would needs be very difficult, if not impracticable, on earth, owing to the often mountainous character of its surface. But on Mars this is not the case. As we have seen, there are fortunately no mountains on Mars. Thus the great obstacle to canals, and, in consequence, the great obstacle to their acceptance, is providentially removed. Terrain offers the least of objections, terror the greatest of spurs, to their construction.

Thus we see that not only should the execution be possible, but that it should exhibit precisely the phenomena we see.

Further phenomena.

It would be interesting, doubtless, to learn how are bodied these inhabitants that analysis reaches out to touch. But body is the last thing we are likely to know of them. Of their mind as embodied in their works, we may learn much more; and, after all, is not that the more pregnant knowledge of the two? Something of this we have surveyed together. But beyond the lime-light of assured deduction stand many facts awaiting their turn to synthetic coördination which we have not touched upon. It is proper to mention some of them under due reserve, for they constitute the bricks which, with others yet to

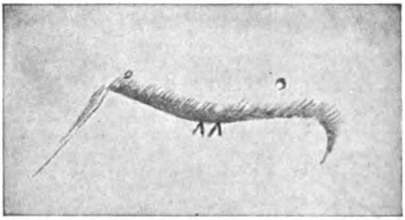
THE CARETS OF MARS

Carets at the borders of the "seas"; showing those of *Icarii Luci* and their resemblance, in miniature, to the two forks of the *Sabaeus Sinus*. These carets are distinctive phenomena, marking the entrance of the canals from the dark regions into the light. They are found at such points, and at such points only.

come, will some day be built up into a housing whole.

Not least of these are those strange caret-shaped dark spots at the points where the canals leave the dark regions to adventure themselves into the light. No canal thus circumstanced in position is apparently without them, and, unlike the oases, they do not show round. On the theory of canalization they are certainly well placed. We have seen that the blue-green regions and the ochre ones lie undoubtedly at different levels, the former standing much lower than the latter.

Here, then, should occur difficulties in canalization which would have to be overcome. Are these, then, the evidence of their surmounting? They certainly suggest the fact.



MOUTHS OF EUPHRATES AND PHISON

The drawing shows the way in which each branch of the two double canals enters the desert from a common point of departure.

Then the oases themselves lure our thoughts afield. Important centres to the canal system they are on their face. But, if centres to that, they should bear a like relation to what fashioned the canals. That they dilate and dwindle seasonally points to vegetation as their chief constituent, whence their name. But behind, and informing this, must be the bodied spirit of the whole. We are certainly justified in regarding them as the apple of the eye of Martian life — what corresponds with us to centres of population.

An interesting phenomenon about the oases makes this the more probable. Observation discloses that the oases are given to change both of size and tone.

They fade at certain seasons, retaining only a relatively diminutive dark kernel. They are thus formed of two parts, pulp and core. The pulp itself indicates vegetation, since it follows the same laws as the canals; the core may well be the evidence of the permanent population. That the largest are some 75 miles across, seems to give sufficient space for living and the means to live. If our cities had to be their own sources of supply, they might well be of this size. As it is, Tokio is ten miles by ten, and London yet larger. But we must in this be careful to part surmise from deduction.

Speculation excluded.

In our exposition of what we have gleaned about Mars, we have been careful to indulge in no speculation. The laws of physics and the present knowledge of geology and biology, affected by what astronomy has to say of the former subject, have conducted us, starting from the observations, to the recognition of other intelligent life. We have carefully considered the circumstantial evidence in the case, and we have found that it points to intelligence acting on that other globe, and is incompatible with anything else. We have, then, searched for motive and have lighted on one which thoroughly explains the evidence that observation offers. We are justified, therefore, in believing that we have unearthed the cause and our conclusion is this: that we have in these strange features, which the telescope reveals to us, witness that life, and life of no mean order, at present inhabits the planet.

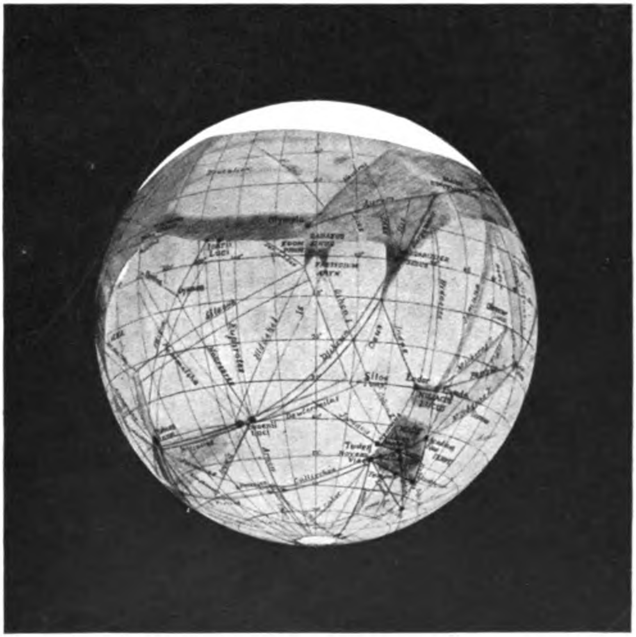
Part and parcel of this information is the order of intelligence involved in the beings thus disclosed. Peculiarly impressive is the thought that life on another world should thus have made its presence known by its exercise of mind. That intelligence should thus mutely communicate its existence to us across the far stretches of space, itself remaining hid, appeals to all that is highest and most far-reaching in man himself. More satisfactory than strange this; for in no other way could the habitation of the planet have been revealed. It simply shows again the supremacy of mind. Men live after they are dead by what they have written while they were alive, and the inhabitants of a planet tell of themselves across space as do individuals athwart time, by the same imprinting of their mind.

Our life not unique.

Thus, not only do the observations we have scanned lead us to the conclusion that Mars at this moment is inhabited, but they land us at the further one that these denizens are of an order whose acquaintance was worth the making. Whether we ever shall come to converse with them in any more instant way is a question upon which science at present has no data to decide. More important to us is the fact that they exist, made all the more interesting by their precedence of us in the path of evolution. Their presence certainly ousts us from any unique or self-centred position in the solar system, but so with the world did the Copernican system the Ptolemaic, and the world survived this deposing change. So may man. To all who have a cosmoplanetary breadth of view it cannot but be pregnant to contemplate extra-mundane life and to realize that we have warrant for believing that such life now inhabits the planet Mars.

Martian life nearing its end.

A sadder interest attaches to such existence: that it is, cosmically speaking, soon to pass away. To our eventual descendants life on Mars will no longer be something to scan and interpret. It will have lapsed beyond the hope of study or recall. Thus to us it takes on an added glamour from the fact that it has not long to last. For the process that brought it to its present pass must go on to the bitter end, until the last spark of Martian life goes out. The drying up of the planet is certain to proceed until its surface can support no life at all. Slowly but surely time will snuff it out. When the last ember is thus extinguished, the planet will roll a dead world through space, its evolutionary career forever ended.



APPEARANCE OF MARS IN 1905

PART II

NOTES

PART II. NOTES

I

On Moment of Momentum

The momentum of a body is the quantity of motion it contains, which is its mass multiplied by its velocity, *i.e.* the sum of the motions of all the particles composing it. Its moment of momentum about any point is this quantity into the perpendicular from the point upon its instantaneous course. It is thus

$$m \cdot v \cdot r,$$

where m is its mass;

v its velocity at right angles to the shortest distance to the point;

r its perpendicular distance from the point.

Suppose, now, two bodies, one x times the mass of the other, to be revolving round each other in circles and, for simplification, that both are homogeneous and non-rotating. If m be their united mass, the relative velocity of one about the other is

$$v^2 = k^2 m\left(\frac{2}{r} - \frac{1}{a}\right) = k^2 \frac{m}{r}$$

for a circular orbit, k^2 being the unit force at unit distance.

Then the moment of momentum of the system round its centre of gravity is

$$(1-x)m \cdot \frac{mx}{m} k \frac{m^{\frac{1}{2}}}{r^{\frac{1}{2}}} \cdot \frac{mx}{m} r + mx \cdot \frac{(1-x)m}{m} k \frac{m^{\frac{1}{2}}}{r^{\frac{1}{2}}} \cdot \frac{(1-x)m}{m} \cdot r$$

since the velocities of the bodies about their centre of gravity and their distances from it are inversely as their masses.

To find what partition renders this quantity a maximum, we must differentiate it with regard to x and put the derivative equal to zero. Thus

$$\frac{d\left[1-x\cdot x^2+x(1-x)^2\right]}{dx}=\frac{d\cdot x-x^2}{dx}=1-2x=0;$$

whence $x=\frac{1}{2}$, or the masses must be equal. That this gives a maximum is shown by the second derivative,

$$\frac{d(1-2x)}{dx}=-2.$$

Applying this to Jupiter and the Sun, we see that the moment of momentum of the two is only $\frac{1}{250}$ of what it might be were the mass otherwise distributed to get the greatest effect. In other words, the quantity of motion in the solar system is almost the least possible; and from the principle of the conservation of the moment of momentum of a system of bodies by their mutual action, this has always been so.

For the system α Centauri, though the mass of its two suns is only 2.14 that of the Sun's, the moment of momentum is about 2000 times as great.

2

The Connection of Meteorites with the Solar System

The speed with which meteorites are observed to enter the Earth's atmosphere is telltale of their relationship to the solar system. For the velocity of a body moving on a parabolic orbit with regard to the Sun, the greatest he can control, may be calculated, and this velocity compared with the observed ones. A solution of it by the writer by a method of interest in itself, that of a rotating field of force, has been published in the *Astronomical Journal* for April 17, 1908, and is here reproduced.

Consider a system of axes ξ, η, ζ, of which ξ and η rotate about ζ with a uniform angular spin n. Take the origin at the Sun, and let the ξ axis continually pass through the Earth supposed to travel in a circle. Then the space velocities u, v, and w expressed in the moving axes ξ, η, and ζ respectively, or the space rates of change of ξ, η, ζ, are

$$u = \xi' - n\eta,$$

$$v = \eta' + n\xi,$$

$$w = \zeta',$$

where the accents denote the derivatives with respect to the time. Similarly the accelerations or the forces which they measure, X, Y, and Z expressed in the same axes, are

$$X = u' - nv,$$

$$Y = v' - nu,$$

$$Z = w'.$$

Substituting for u, v, and n in the last equations their values from the first, we have

$$\frac{d^2\xi}{dt^2} - 2n\frac{d\eta}{dt} - n^2\xi = X,$$

$$\frac{d^2\eta}{dt^2} + 2n\frac{d\xi}{dt} - n^2\eta = Y,$$

$$\frac{d^2\zeta}{dt^2} = Z.$$

Let U be the potential of the forces,

$$\frac{dU}{d\xi} = X, \quad \frac{dU}{d\eta} = Y, \text{ and } \frac{dU}{d\zeta} = Z.$$

In the rotating field of force U is a function of ξ, η, and ζ only, since the time has been eliminated by the rotation. Therefore

$$\frac{dU}{dt} = \frac{dU}{d\xi} \cdot \frac{d\xi}{dt} + \frac{dU}{d\eta} \cdot \frac{d\eta}{dt} + \frac{dU}{d\zeta} \cdot \frac{d\zeta}{dt}.$$

If the equations of motion be multiplied by

$$2\frac{d\xi}{dt},\ 2\frac{d\eta}{dt},\ \text{and}\ 2\frac{d\zeta}{dt}$$

respectively, and added, they admit of an integral first found by Jacobi,

$$v_1^2 - n^2r^2 = 2\,U + C,$$

in which v_1 = velocity of the particle relatively to the moving axes, its relative not its space rate,
and r = its distance from the origin reckoned by the same.

We shall suppose the particle to be moving in the plane of the planet's motion, that of ξ, η. The velocity of encounter with the planet is thus made the greatest or the least possible, according as the particle overtakes the planet or meets it head on.

Calling V the space velocity of the particle, that is the velocity with regard to fixed axes, and A the moment of momentum with regard to the same at the moment, we have

$$V^2 = v_1^2 + 2\,nr\cos\alpha v_1 + n^2r^2,$$

in which α is the angle between v_1 and nr — hence $r\cos\alpha = p_1$, the perpendicular from the origin upon the particle's line of motion in space, but $A = v_1 p + nr^2$ by taking moments about the origin, of the particle's motion in the rotating plane plus that of the plane itself,

$$\therefore\ v_1^2 - n^2r^2 = V^2 - 2\,nA,$$

whence $$V^2 - 2\,nA = 2\,U + C.$$

We determine C by the consideration that for a parabola at infinity,

$$V=0 \text{ and } U=0,$$

whence — since $n=\frac{\sqrt{M}}{c^{\frac{3}{2}}}$ and $A=\sqrt{M+m}\cdot\sqrt{l}$,

$$C=-2nA=-\frac{2\sqrt{M}\cdot\sqrt{M+m}\sqrt{l}}{c^{\frac{3}{2}}},$$

where l is the parameter of the parabola and c the radius of the planet's orbit.

Suppose now the particle to be just overtaking the planet from behind, l will very approximately be $2r$, while

$$A=v_1p+nr^2$$

will

$$=V-v_0\cdot p+nr^2,$$

in which v_0 is the velocity of the planet in its orbit,

then $v_0p=nr^2$

and $A=r\cdot V.$

$$2nA=2nr\cdot V.$$

Let $M=$ mass of the Sun,

$m=$ mass of the planet,

$r=c=$ radius of the planet's orbit,

$\rho=$ distance from the Earth's centre to where the meteor enters the atmosphere, which for round numbers we may take at $3958.8+41$ miles, or 4000 miles.

Then the attraction of the Sun on the particle is

$$-\frac{M}{r^2} \text{ very approximately,}$$

that of the planet on the particle

$$-\frac{m}{\rho^2},$$

and that of the planet on the Sun which is to be applied reversed to bring the Sun to rest,

$$-\frac{m}{r^2}.$$

This latter force acts only in the line ξ.

Consequently, since X and Y are functions of ξ and η only, not involving t,

$$U=\frac{M}{r}+\frac{m}{\rho}-\frac{m\xi}{r^2};\quad \frac{dU}{d\xi}d\xi=Xd\xi,\quad \frac{dU}{d\eta}d\eta=Yd\eta,$$

our equation becomes

$$V^2-2nrV=2\left(\frac{M}{r}+\frac{m}{\rho}-\frac{m\xi}{r^2}\right)-2\frac{\sqrt{M}\sqrt{M+m}\sqrt{2r}.}{r^{\frac{3}{2}}}$$

Completing the square on the left-hand side and extracting the square root, we have

$$V=+nr\pm\sqrt{2\left(\frac{M}{r}+\frac{m}{\rho}-\frac{m\xi}{r^2}\right)-\frac{2^{\frac{3}{2}}M^{\frac{1}{2}}\cdot(M+m)^{\frac{1}{2}}}{r}+n^2r^2}.$$

Letting $M=1$ and $r=1$ and determining k, the coefficient of proportionality, so that V comes out in miles per second, — for k enters with the masses as k^2M unless the unit of time be canonically chosen, we find, since $v_0=nr$,

$$V-v_0= \text{the velocity relative to the Earth}$$
$$= 10.321 \text{ miles a second when the particle}$$

overtakes the Earth.

The Earth's effect in increasing the velocity which in this case is the greatest possible is

$$28.822 - 26.163 = 2.659 \text{ miles a second.}$$

In the other case, when the Earth encounters the particle head on, v_1 becomes negative and C negative.

$$A=-v_1p+nr^2$$
$$=-(V+v_0)p+nr^2.$$
$$-2nA=+2nrV$$

and

$$V^2 + 2\,nrV = 2\left(\frac{M}{r} + \frac{m}{\rho} - \frac{m\xi}{r^2}\right) + 2\,\frac{\sqrt{M}\sqrt{M+m}\sqrt{2\,r}}{r^{\frac{3}{2}}}$$

and

$$V = -\,nr \pm \sqrt{2\left(\frac{M}{r} + \frac{m}{\rho} - \frac{m\xi}{r^2}\right) + \frac{2^{\frac{3}{2}}M^{\frac{1}{2}}(M+m)^{\frac{1}{2}}}{r} + n^2r^2},$$

whence $V + v_0 = 45.197$ miles a second, and the effect of the Earth in increasing the meteor's velocity

$$= 26.696 - 26.163 = 0.533 \text{ mile a second.}$$

The geometric explanation why the velocities cannot be directly added is that when each body is supposed to act alone the times involved in their actions are different, while when they act together these are naturally the same. In the latter case the velocity due the Sun hurries the particle through the space faster than the Earth's pull alone could, and so gives the Earth less time to act.

Now if, instead of moving in a parabolic or controlled orbit, the meteor were travelling in a hyperbolic or uncontrolled one, its speed of encountering the earth would be greatly increased.

But there are no instances of meteors meeting the Earth at speeds exceeding or even equalling 45.1 miles a second. From this we perceive that they are not visitants from outer space, travellers from other suns, but are all part and parcel of the Sun's retinue, kin to Jupiter and the Earth, the remains, indeed, of those from which the planets were built up.

3

The Heat developed by Planetary Contraction

To find the heat evolved by the aggregation of particles into a planetary mass and the subsequent shrinking of that mass upon itself, we first find the work done by the contraction and then evaluate it in terms of heat.

Let $\qquad M' =$ mass within a radius r;

then the work done by a shell dM' contracting under the pull of M', the mass inside it, from infinity to the radius r is

$$-\int_{\infty}^{r} \frac{k^2 M' dM'}{r^2} = \frac{k^2 M' dM'}{r},$$

where k^2 is the force between unit masses at unit distance.

If the sphere be supposed homogeneous and M be the mass of the nebula of radius a at any time,

$$M' = M \cdot \frac{r^3}{a^3}, \qquad dM' = 3\, M \frac{r^2}{a^3} dr.$$

$$\therefore \int_0^a \frac{k^2 M' dM'}{r} = \int_0^a \frac{3\, k^2 M^2}{a^6} r^4 dr = \frac{3}{5} k^2 \frac{M^2}{a}, \qquad (1)$$

the work done.

But the sphere is really heterogeneous, and to determine the function of the density we proceed as follows:

The attraction, A, of the mass M' upon the shell dM' is:

$$A = -\frac{4\pi k^2}{r^2} \int_0^r \rho r^2 dr,$$

where $\rho =$ the density. Let $p =$ the pressure at the point.

Then $\qquad dp = -\rho A dr,$

whence $\qquad dp = -\frac{4\pi k^2 \rho \int_0^r \rho r^2 dr}{r^2} \cdot dr.$

Now, as Laplace says, both solids and liquids resist compression more the more they are compressed. The most simple expression of this fact is:

$$dp = h\rho d\rho,$$

which is Laplace's formula.

The Roche formula hardly gains in exactness enough to offset its greater complexity, as Tisserand has shown.

Whence, substituting Laplace's value for dp above,

$$\frac{r^2\dfrac{d\rho}{dr}}{\int_0^r \rho r^2 dr}+\frac{4\pi k^2}{h}=0.$$

Differentiating this, we have

$$\frac{d^2\rho r}{dr^2}+\frac{4\pi k^2}{h}\rho r=0.$$

The solution of this equation is, calling $\frac{4\pi k^2}{h}=m$,

$$\rho r = c\sin mr + c_1\cos mr;$$

but since the density ρ must remain finite at the centre where $r=0$, $c_1=0$; and $\rho=\frac{c\sin mr}{r}$. (2)

To find the two unknown parameters c and m, and thus h, we have for the Earth, if ρ_1 denote the density at the surface where $r=1$,

$\rho_1 = c\sin m = 2.74$, supposed all rock, (3)

or 2.5, allowing for the ocean;

and also since the mean density $= 5.53$,

$$5.53\cdot\frac{4}{3}\pi=\int_0^1 4\pi r^2.\frac{c\sin mr}{r}.dr. \qquad (4)$$

In the determination of the work done, we must write

$$\rho=\frac{c\sin m\dfrac{r}{a}}{\dfrac{r}{a}}$$

Then $$dM'=4\pi r^2 dr\cdot\frac{ac}{r}\sin m\frac{r}{a}.$$

$$M'=4\pi ac\int_0^r r\sin m\frac{r}{a}\cdot dr$$

$$=4\pi\frac{a^3c}{m^2}\left[\sin m\frac{r}{a}-m\frac{r}{a}\cos m\frac{r}{a}\right]$$

whence
$$M' = M \cdot \frac{\sin m\frac{r}{a} - m\frac{r}{a}\cos m\frac{r}{a}}{\sin m - m\cos m}$$

$$dM' = \frac{M}{\sin m - m\cos m} \cdot \frac{m^2 r}{a^2}\sin m\frac{r}{a}\cdot dr$$

$$\int_0^a \frac{k^2 M'\, dM'}{r} = \frac{k^2 M^2}{(\sin m - m\cos m)^2}\cdot$$

$$\int_0^a \left[\frac{m^2 r}{a^2}\sin^2\frac{mr}{a} - \frac{m^3 r^2}{a^3}\sin\frac{mr}{a}\cos\frac{mr}{a}\right]\frac{dr}{r}$$

$$= \frac{m\{m(\frac{3}{2} - \sin^2 m) - \frac{3}{4}\sin 2m\}}{2(\sin m - m\cos m)^2}\cdot\frac{k^2 M^2}{a}. \quad (5)$$

Since the work done by a mass M in cooling t degrees is

$M\sigma Jt$, where σ is the specific heat of the body,

and J the mechanical equivalent of heat,

in the case of a homogeneous body

$t = \frac{3}{5}\cdot\frac{k^2 M}{\sigma J a}$ for contraction from ∞ to the radius a,

and therefore $t = \frac{3}{5}\cdot\frac{k^2 M}{\sigma J a}(1 - \frac{a}{a'})$ for contraction from the radius a' to a. In the case of heterogeneity, the right-hand members of the equations should be multiplied by the ratio of (5) to (1).

During the evolution of the heat, radiation was steadily draining it away, according to the fourth power of the surface temperature (Stefan's law). Convection meanwhile was going on from the inside out, the quantity delivered from one layer to the next being proportionate to their differences of temperature dT, while this difference was itself dependent on the areas involved, which were as $\frac{r_{//}^2}{r_/^2}$, and therefore their increase in the ratio $\frac{r_{//}}{r_/}$. If we assume in consequence that the surface was never hotter than 10,000° F. or 5556° C., we shall have a heat sufficient to explain all the metamorphic and volcanic phenomena exhibited by geology.

ENERGY LET LOOSE DURING CONTRACTION. EVALUATED IN HEAT

CONTRACTION FROM INFINITY TO PRESENT STATE	BODY SUPPOSED HOMOGENEOUS. DEGREES FAHRENHEIT		BODY SUPPOSED HETEROGENEOUS ACCORDING TO LAPLACE'S ASSUMPTION. DEGREES FAHRENHEIT	
	Stone	Iron	Stone	Iron
Earth	80,520	146,400	89,377	162,504
Mars	16,303	29,642	17,118	31,124
Moon	3,665	6,664	3,812	6,931
CONTRACTION FROM METEORIC DENSITY TO PRESENT STATE				
Earth 3.5 to 5.5	11,262	20,476	12,501	22,728
Mars 3.5 to 0.71 × 5.5	584	1,062	613	1,115
Moon 3.5 to 0.66 × 5.5	44	80	46	83

4

THE HEIGHTS OF MOUNTAINS ON THE MOON

For simplification consider a mountain on the apparent lunar equator near the sunrise or sunset edge of the disk when the Moon shows half-full. Then, if $l =$ the apparent distance its star-like summit seems off the terminator,— the general dividing line between sunlight and shade:

$r =$ the radius of the Moon;

$h =$ the height of the peak;

we have

$$l^2 + r^2 = (r + h)^2.$$

The lunar diameter being 2160 miles, this gives for a mountain four miles high an apparent isolation from the terminator of 93 miles, or 23 times its height. For one a mile high, the distance is 46 miles or 46 times its height. Thus the principle affords an indirect kind of magnification, relatively greater and greater inversely as the square root of the height.

5

Heat acquired by the Moon

In the expression (5) for the work done by contraction in the case of heterogeneity, m will vary with each planet, since its determination depends upon both the surface and the mean density of the contracting body. For the surface density of the Moon we have a ground surface entirely; that is, one of rock. In consequence, we may perhaps estimate it as being that of the rocky exterior of the Earth, or 2.7, water being unity. The mean lunar density is 3.65. Putting these values in place of those of the Earth in (3) and (4), we get from the new (5) with the new m' the value for the Moon's contracted heat given in the table.

Since the rate of changes of the concentric shells is as $\frac{r}{r_1}$, while dr is taken constant, the gradient of temperature from the inside out will be greater, the smaller the body, and convection in it be more rapid. Also its surface being larger relatively to its volume, it would on that account radiate more. That surface, therefore, could never attain the degree of warmth of the other's in spite of the greater radiation at higher temperatures. We shall probably be within the mark if we take the surface temperature at its maximum as proportionate to the total heat evolved. This would give on the supposition of 10,000° F. for the Earth, 400° F. Abs. for the Moon, or $-59°$ below the freezing-point, a temperature quite incompatible with volcanic phenomena.

6

Surface Heat of Mars

For Mars, where again the surface is wholly ground, we have $\rho_{\prime} = 2.7$, while the mean density of the planet is 3.93. With these data we obtain a new m'' and the value for the heat evolved given in the table under heterogeneity.

Following the same course as with the Moon, we get a surface temperature for Mars at its maximum of 2000° F. This is just below the melting-point of (cast) iron, which is 2160° F. Such a temperature is insufficient for the display of metamorphic or of volcanic action such as occurred on Earth. For the like reason the crumpling of the crust in consequence of the planet's parting with its internal heat must have been much less pronounced.

7

The Boiling-point of Water on Mars

The boiling-points of liquids are functions both of the temperature and the pressure; a lower temperature being sufficient to cause ebullition if the pressure be less. On the kinetic theory of gases the cause of this is at once comprehensible. Boiling means that the particles of the liquid generally have attained speed enough to throw off the restraint of their neighbors and leave the surface. Release may come about through increase of velocity, or, in other words, increase of temperature, since temperature is only another expression for the mean velocity-square of the particles; or by decrease of restraint, which means decrease of the pressure upon them.

Gravity on the surface of Mars is only 38 per cent of that at the surface of the Earth, and if the amount of Martian air per unit of surface be $\frac{2}{9}$ that of the Earth, as later we shall see to be probable, the pressure there would be

$$p = M_{\prime}g_{\prime} = 0.09\ Mg,$$

where the unaccented letters refer to the Earth, the accented to Mars. Whence the boiling-point would be

$$44^\circ \text{ C. or } 111^\circ \text{ F.}$$

8

The Paleozoic Sun

M. Blondet's explanation of the greater warmth of paleozoic times was that the Sun then occupied a space large enough to be able to shine on the pole even in midwinter. To do this, the semidiameter of the Sun must have subtended at the centre of the Earth an angle equal to the tilt of the pole away from the Sun, or an angle of 23° 27′. This would give it a semidiameter of 37,000,000 miles, or a million miles larger than the mean distance of Mercury.

Its present mean density is 1.39 times that of water. The density of hydrogen, the lightest known gas, is 0.0000895 that of water at 0° C. and under a pressure of 760 mm. at Lat. 45°. The present diameter of the Sun is 866,000 miles. Its density then must therefore have been

$$d = 1.39 \cdot \frac{866000^3}{37000000^3} = 0.0000178,$$

or $\frac{1}{5}$ that of hydrogen.

Such tenuous matter could hardly have given out any heat at all. This is one insuperable objection. A second is that to suppose that the Earth can have condensed to a solid state while the Sun still remained of such gaseous tenuity, its material more sparse than that of any known gas, is to violate every conception of evolution. The thing is mechanically impossible.

When we reflect that so eminent a geologist as M. de Lapparent* espoused M. Blondet's hypothesis, we see how necessary to geologic conceptions is a foundation for them in astronomy.

9

Effect on the Earth of the Supposed Paleozoic Sun

As impossible the supposed paleozoic Sun proves from the point of view of the Earth. For on critical examination it turns out quite incapable of the climatic effect attributed to it, even supposing it emitted heat enough to have any effect at all.

To calculate its zonal influence we proceed as follows:

If a = coaltitude of the Sun, its insolation at the moment at the confines of the atmosphere is as cos a. The relative amount of the total insolation at a given latitude and for a given declination during twenty-four hours, supposing the Sun a point, and calling the insolation at the equator at the equinox unity, is expressible by spherical triangles as:

$$\mathrm{I} = 2\int_0^{\cos^{-1}(-\cot b\cdot\cot c)} \cos a\cdot dA = 2\int_0^{\cos^{-1}(-\cot b\cdot\cot c)} \cos b\cos c\cdot dA + \sin b\sin c\cos A\cdot dA$$

$$= 2(\cos b\cos c\cdot A + \sin b\sin c\cdot\sin A)\Big|_0^{\cos^{-1}(-\cot b\cdot\cot c)},$$

where b = the colatitude of the place,

c = the codeclination of the sun,

A = the hour angle from noon;

* "Traité Elementaire de Géologie," par De Lapparent.

the limits of the integration being the meridian, where $A = 0$ and the horizon where $a = 90°$ and its cosine 0, whence

$$0 = \cos b \cos c + \sin b \sin c \cos A,$$

or

$$A = \cos^{-1}(-\cot b \cot c).$$

But the area of the supposed paleozoic Sun cannot be considered a point because of its size. To deduce its effect each bit of it which rises above the horizon of the place must be taken into account and given weight inversely as the square of its distance off.

For our purpose, however, a sufficiently accurate approximation may be got by taking in each determination what would be the centre of mass of the solar zone above the latitude of the lowest central point visible supposing the Sun a flat surface. The point whose codeclination is considered then becomes

$$\bar{x} = \frac{2\, r^3 \int_0^{\cos^{-1} g} \sin^2\theta \cos \theta d\theta}{2\, r^2 \int^{\cos^{-1} g} \sin^2 \theta d\theta},$$

where θ = the angle from the pole of the ecliptic toward its equator;

and

$$g = \frac{\tan (23°.5 - b)}{\tan 23°.5}.$$

Something is omitted by this process because the visible zone really descends lower at the sides than in the centre, but on the other hand the effect on the tropical belt of the Earth is relatively greater than on the polar ones because of the less distance of the centre of the Sun. The result is to understate the case against the supposed paleozoic Sun and thus to increase the force of the reasoning.

From the table it appears that the climate in the polar regions would be unaffected in midwinter and midsummer, the only seasonal difference being that spring would come on somewhat earlier than now. Thus the seasons would still exist and the polar climate not be tropical at all.

The heat due the insolation at the equator at the equinox is taken as unity in both cases because no greater heat there is to be accounted for then than now.

INSOLATION

Equator at Equinox = 1.00 in both cases.

LATITUDE	EFFECTIVE DECLINATION OF SUN	INSOLATION PALEOZOIC SUN	INSOLATION PRESENT SUN
N.	S.	MIDWINTER	
°	°		
90	0	0.00	0.00
82	4.6	0.00	0.00
66.5	13.0	0.06	0.00
50	21.1	0.21	0.19
40	23.5	0.35	0.35
30	23.5	0.51	0.51
20	23.5	0.66	0.66
		EQUINOX	
	N.		
90	10.5	0.29	0.00
82	6.3	0.25	0.14
66.5	0.0	0.40	0.40
50	0.0	0.64	0.64
40	0.0	0.77	0.77
30	0.0	0.87	0.87
20	0.0	0.94	0.94
		MIDSUMMER	
90	23.5	1.25	1.25
82	23.5	1.24	1.24
66.5	23.5	1.15−	1.15−
50	23.5	1.15	1.15
40	23.5	1.15+	1.15+
30	23.5	1.13	1.13
20	23.5	1.09	1.09

10

On the Influence upon the Climate of Carbon Dioxide in the Air

From some careful and elaborate calculations of Professor Arrhenius it appears that an increase of carbonic acid in our air to thrice its present amount would raise the temperature as follows:

Carbonic Acid = 3

Increase in Temperature over Carbonic Acid = 1

Latitude	Dec.–Feb.	March–May	June–Aug.	Sept.–Nov.	Year
°	°	°	°	°	°
70–60	+ 9.1 C.	+ 9.3 C.	+ 9.4 C.	+ 9.4 C.	+ 9.3 C.
50–40	+ 9.5	+ 9.4	+ 8.6	+ 9.2	+ 9.2
30–20	+ 8.7	+ 8.3	+ 7.5	+ 7.9	+ 8.1
10–0	+ 7.4	+ 7.3	+ 7.2	+ 7.5	+ 7.3

We shall assume these figures to be correct and combine with them a table showing the present temperature at different latitudes in every month taken by him from Dr. Buchan and here abbreviated.

Carbonic Acid = 1

Latitude	Dec.–Feb.	March–May	June–Aug.	Sept.–Nov.	Year
°	°	°	°	°	°
70–60	− 21.1 C.	− 8.3 C.	+ 7.5 C.	− 6.0 C.	− 7.0 C.
50–40	− 1.4	+ 7.8	+ 18.7	+ 9.7	+ 8.7
30–20	+ 17.0	+ 21.5	+ 26.0	+ 23.0	+ 21.9
10–0	+ 25.5	+ 25.8	+ 25.4	+ 25.5	+ 25.5

From these two tables it appears that the increase of temperature from increase of carbon dioxide in the air from

1 to 3 would be only two degrees centigrade greater at 65° N. than at the equator; the mean for the year at the upper latitude being still only + 2°.3 C. while it would be 32°.8 C. at latitude 5° N. In the second place the seasons in the polar regions would remain substantially what they are now. For at latitude 70°–60° we should have:

TEMPERATURE WITH CARBONIC ACID = 3

LATITUDE	DEC.-FEB.	MARCH-MAY	JUNE-AUG.	SEPT.-NOV.
°	°	°	°	°
70–60 N.	− 12.0 C.	+ 1.0 C.	+ 16.9 C.	+ 3.4 C.

Such cold in winter would be prohibitive to tropic vegetation, and polyp corals could certainly not flourish on it seventeen degrees still farther north toward the pole.

EFFECT OF INCREASED CARBON DIOXIDE UPON PLANTS

Quite apart from the question of warmth it by no means follows that an increase of carbon dioxide in the air to three or four times its present amount would conduce to vegetation. With common plants and under otherwise present normal conditions it certainly does not. To determine what effect upon plants a greater percentage of it than the present one would have, careful experiments were performed in 1902 by Dr. Horace T. Brown, LL.D., F.R.S., and Mr. F. Escombe, B.Sc., F.L.S.* The plants selected were ordinary flowering plants or angiosperms. They found that an increase of carbonic acid in the atmosphere to 11.4 parts in 10,000 from the normal amount of 2.8 to 3 not only hurt the growth of the plants but pre-

* Proceedings of the Royal Society, 1902, Vol. LXX.

vented reproduction. The plants became sickly and were unable to flower and seed. The experiment, of course, does not show that a different effect might not be produced on cryptogams such as constituted the flora of Carboniferous times, nor does it demonstrate that with time enough adaptation to such changed surroundings might not result in a positive gain to the plants concerned; but it certainly affords no evidence in favor of either supposition.

II

Atmosphere of Mars

Amount. — Of the amount of the Martian atmosphere we have no certain knowledge. From its effects we know that such an atmosphere exists and these effects are compatible with an air thinner than our own. With regard to its density the best determination at present is to be got from the planet's albedo, the albedo of a body being its intrinsic brightness. Now from the albedo of various rocks, of forests, and of snow, and from the relative amounts of each that appear upon the Martian disk, we may calculate, taken in connection with the whole albedo of the planet, the proportionate albedoes of its surface and its air. Nearly five-eighths of the surface is desert which has an albedo of about .16, three-eighths a blue-green with an albedo of .07, while less than one-sixth is of a glistening white of roughly .75. These would combine to give an albedo of .13. This, however, is illuminated by so much only of sunlight as penetrates the air, about three-quarters of the whole. Whence the apparent albedo of the surface seen from without must be .10. Now as the total albedo of the planet is .27, and .10 is from the surface, the remaining .17 must be the albedo of the air.

Assuming the densities of the mundane and of the Martian atmospheres to be proportionate to their brilliancy, or as 75 to 17, which would seem something like the fact, since the denser the air the more dust it would buoy up, and it is chiefly by what it holds in suspension that we see it, we have for the Martian air a density about two-ninths of our own over each square unit of surface.

But, if the original mass of air on each planet was as that planet's mass, we should have for the initial amounts 9.3 for the Earth to 1.0 for Mars. This would be distributed as their respective surfaces, or in the ratio of 7919^2 to 4220^2, or as 3.5 to 1; which would give 2.7 times as much air for the Earth per unit of surface. The difference between $\frac{1}{2.7}$ and $\frac{1}{4.5}$, or the amount the albedo implies now present and the amount the planet would have had, assuming proportionate masses to start with, may perhaps be attributed to the greater relative loss of air Mars has sustained because of parting more quickly with its air envelope.

Surface density of its air. — To get the density of the Martian air at the surface of the planet, which is of course a very different thing from the amount of air above that surface, we must divide the amount by the relative gravity there. For the density of an atmosphere at any height being proportionate to its own decrease — if the density be taken as proportional to the pressure, which is practically true for gases at the atmospheric pressures considered, and if the temperature be considered constant — then if D denote the density at any point,

$$dD = -Dg \cdot dx,$$

where g denotes the force of gravity at the surface of the Earth and is constant for the distance concerned, and x is reckoned outward from the surface.

Whence $$D = Ae^{-gx},$$

A being the density at the surface.

Correspondingly, we have for Mars

$$D_1 = A_1 e^{-g_1 x},$$

A_1 being the density of its air at its surface and g_1 gravity there. For the whole mass of air over a given point we have for the Earth

$$\int_0^\infty D\,dx = \int_0^\infty A e^{-gx}\,dx = \frac{A}{g},$$

and similarly for Mars

$$\int_0^\infty D_1\,dx = \frac{A_1}{g_1}.$$

Taking $g = 1$ and therefore $g_1 = .38$, we have, since the whole mass of air above a point on Earth is 4.5 what it is on Mars,

$$A = 4.5\,\frac{A_1}{.38}.$$

Whence as $A = 30$ inches or 760 mm. barometric pressure,

$$A_1 = 2.5 \text{ inches, or } 64 \text{ mm.}$$

12

The Mean Temperature of Mars

Division of Radiant Energy

So soon as a radiant ray strikes matter it suffers division of its energy. Part of it is reflected, part absorbed, and part transmitted. What is reflected is sent off again into space, performing no work in the way of heating the body. Now the amount reflected is not the same in all cases, depending for its proportion upon the character of the matter the ray strikes.

If the surface of a planet be itself exposed unblanketed by air, the absorbed and transmitted portions go to heat the planet, directly or indirectly.

If the planet be surrounded by air, the portion transmitted by this air, plus what is radiated or reflected from it to the solid surface, must first be considered. Then, upon this quota as a basis, must secondly be determined how much the surface in its turn reflects. The balance alone goes to warm the ground or ocean.

Light and Heat

Radiant energy is light, heat, or actinism, merely according to the effect we take note of. If our eyes were sensitive equally to all wave-lengths, we could gauge the amount of heat received by a body by the amount of light it reflected, — that is, by its intrinsic brightness, or albedo. For this percentage deducted from unity would leave the percentage of heat received. This procedure may still be applied, provided account be also taken of the heat depletion suffered by the invisible rays. Two problems, then, confront us.

We must find the albedoes of the several planets in order to compare one with another in its reception of heat, and we must find the relation borne by the visible and invisible rays to the subject. The latter problem may best be attacked first.

Actinometers and pyrheliometers are instruments for measuring *in toto* the heat received from the Sun; and they have been used by Violle, Crova, Hansky, and others to the determination of this quantity at given places, and so to a conclusion as to the amount of heat outside our air, or the Solar Constant. Langley's great contribution to the subject was the pointing out that the several wave-lengths of the different rays were not of homogeneous action or modification, and that to an exact determination of the Solar Constant it is necessary to consider the action of each separately, and then to sum them together. To this end he invented his spectro-bolometer.

By means of this instrument Langley mapped the solar radiation to an extension of the heat spectrum unsuspected before. He then carried it up Mt. Whitney in California, and discovered two important facts: one, that the loss in the visible part of the spectrum was much greater, not only actually, but relatively to the rest, than had been supposed; and the other, that the greater the altitude at which the observations were made, the larger the value obtained for the Solar Constant. Both of these are pertinent to our present inquiry.

With a rock-salt prism, instead of a glass one, he next extended still farther the limits of the heat spectrum toward the red, the effect of the solar radiation proving not negligible as far as $\lambda = 15\ \mu$.

In 1901 Professor Very, who had been his assistant earlier, published an important memoir on the Solar Constant, based upon these bolometric observations, but with a value for it got from spectral curves derived from simultaneous actinometric and bolometric determinations at Camp Whitney and Lone Pine, and extended from them outside the atmosphere by taking both air and dust effects into account in selectively reflecting and diffracting the energy waves. The air effect is proportionate to the air mass, but the dust effect increases in greater ratio as one nears the surface of the ground. The formulæ he used were adaptations of those by Rayleigh for accounting for the selective reflection and diffraction of small particles.*

Energy of Visible and Invisible Spectrum

Planimetrical measurement of the area enclosed by the curve deduced for outside our atmosphere gives the following results:

* U. S. Department of Agriculture, Weather Bureau, No. 254.

DISTRIBUTION OF HEAT IN THE SPECTRUM

	WAVE-LENGTHS	PERCENTAGE
Invisible	$\lambda = 0.2\ \mu–0.393\ \mu$	2.5
Visible	$\lambda = 0.393\ \mu–0.76\ \mu$	32.
Invisible	$\lambda = 0.76\ \mu–15\ \mu$	65.5
		100.

giving for the

Visible portion, 32 per cent,
Invisible portion, 68 per cent,

of the whole.

LOSS OF HEAT IN TRAVERSE OF THE AIR

Turning, now, from the question of the initial heat for different parts of the spectrum at the time the solar radiation enters the air, we come next to consider the loss the several rays sustain in their traverse of it.

From Very's curves for the radiation at the confines of the atmosphere at Camp Whitney and at Lone Pine, 18 $\lambda = 1.2\ \mu$, we get the amount transmitted at these two stations, employing planimetric measurement as before, and introducing with him the absorption in the red and infra-red from the Alleghany measures, which he considers the same at Lone Pine.

From Very's measures we have, calling the whole heat at the confines of the atmosphere unity, —

TRANSMISSION

	$\lambda = 0.2\ \mu–1.2\ \mu$	$\lambda = 1.2\ \mu–15\ \mu$
Outside	50.	50.
Camp Whitney	31.3	
Lone Pine	24.3	25.1

To get that for sea-level we shall take Crova's actinometric measures at Montpellier (height 40 m.), made on August 13, 1888, at $12^h 30^m$, under a barometer of 761 mm. Simultaneously with these, other self-registering ones were taken by him on Mt. Ventoux (height 2000 m.). The respective calories he obtained were, —

	Montpellier	Mt. Ventoux
Aug. 13, $12^h 30^m$, 1888 . . .	0.975 calory, bar. 761.1 mm.	1.360 calories, bar. 613.5 mm.

We shall reduce these to the same scale as the Lone Pine results, made with the pyrheliometer and used by Very, to wit: —

	Lone Pine
Aug. 11, 12, 14, 12^h–$12^h 30^m$, 1881.	1.533 calories, bar. 663 mm.

giving for

Montpellier	Mt. Ventoux
1.180 calories	1.643 calories

This value of 1.180 is one which is probably about the average of clear days in our latitude, the day in question being registered by Crova as "very clear."

From these several data we find the following values for the solar radiation received at the respective posts, in calories in one column, in percentage of that entering the atmosphere in another.

Solar Radiation

	Bar.	Calories	Percentage
Outside the atmosphere . .	0	3.127	1.000
Camp Whitney	500 mm.	1.896	.606
Lone Pine	663 mm.	1.533	.490
Montpellier	761 mm.	1.180	.377

The loss in the visible spectrum is almost wholly from selective or general reflection and from diffraction, that in the invisible one from selective absorption. The absorptive loss by bands in the former is only about 1 per cent of the whole, and the loss by reflection in the latter probably not over 7 per cent of its depletion.

In view of the fact that the absorption is known to take place high up in the air, Very adopted the Alleghany amount for Lone Pine, the difference being insensible; but when it comes to Camp Whitney it is clear from the above that 9 per cent of it is got rid of between $\lambda = 1.2\ \mu$ and $= 10\ \mu$ by rising the 11,700 ft. from sea-level.

Depletion in Visible Rays

We may now find the depletion in the visible part of the spectrum which is not in general the same as that for the invisible part, decreasing relatively with the altitude and reversely increasing as the air envelope becomes thicker. It does this at a greater rate than the increase of the air mass, because the particles suspended in the air—dust, water globules, and ice—augment more rapidly than the air mass as one approaches the ground.

Drawing the curve for transmission at the sea-level on the same principles as those for outside the atmosphere at Camp Whitney and at Lone Pine, and then measuring the amounts of transmission of each within the limits of the visual rays, from $\lambda = .393\ \mu$ the K line to $\lambda = .76\ \mu$ the A band, we get the following table:—

TRANSMISSION OF SOLAR RADIATION IN THE VISIBLE SPECTRUM

	CALORIES RECEIVED FROM THE WHOLE SPECTRUM	VISIBLE PORTION TRANSMITTED
Outside the atmosphere . .	3.127	1.000
Camp Whitney	1.896	.664
Lone Pine	1.533	.482
Sea-level	1.180	.210

The relative loss in the regions I, $\lambda = .393\ \mu$ to $\lambda = .76\ \mu$, and II, $\lambda = .76\ \mu$ to $\lambda = 1.2\ \mu$, between the several stations is as follows:—

	I	II
Outside to Camp Whitney	0.105	0.029
Camp Whitney to Lone Pine	0.055	0.010
Lone Pine to sea-level	0.086	0.027

LIGHT RECEIVED FROM THE DAY SKY

To these transmissions must be added that part of the solar radiation which is lost by reflection and diffraction in the atmosphere before reaching the ground, but is reflected again upon it, causing the brightness of the day sky. This amount is sufficient to obliterate the stars. Compared with direct sunlight, its ratio as determined by Langley * is

	SUN	SKY
Illumination	80	19

or 24 per cent of the sun's light.

We must therefore increase the energy transmitted by 24 per cent of itself. This gives finally:—

* "Professional Papers of the Signal Service," Vol. 15.

	TRANSMISSION		PORTIONS REFLECTED INTO SPACE
Outside	1.00	100	0
Sea-level	0.21	26	74

ALBEDO OF THE EARTH

Now the fraction of the incident energy in the visible spectrum is that by which we see the body and is called its albedo. The albedo of our air, then, comes out .74. To get the whole albedo of the Earth we must add to it the albedo of the surface.

The albedo of various rocks and of the ocean is as follows:

White quartzite . .	0.25	Dark slate . . .	0.09
Clay shale	0.16	Ocean	0.075

For forest we may perhaps take . 0.07
and snow according to purity . . 0.50–0.78

The percentages of distribution of surfaces being about

Ocean	72 per cent	Steppes and desert .	10 per cent
Forest	10 per cent	Polar caps	6 per cent

we deduce 11 for the albedo of the surface. But this being illuminated by only 25 per cent of the light outside the air gives about 3 for its quota to the planet's illumination. When finally the Earth's whole albedo to one viewing it from space becomes $.74 + .03 = .77$ albedo of the Earth for a clear sky.

As the Earth's is about 50 per cent cloud-covered (see the researches of Teisserenc de Bort on Nebulosity) and the albedo of cloud is .72, we get .75 for the mean albedo of the Earth.

Value of Loss of Light a Minimal One

That the value above found for the percentage transmission of solar radiation to the Earth's surface is a maximal rather than a minimal amount, and the albedo a minimal rather than a maximal one, is hinted by the fact that the higher the observer ascends above the surface, the greater his estimate of the solar constant becomes. Thus Langley in his memoir on the Mt. Whitney expedition says: —

"In accordance with the results of previous observers, then, and of our own with other instruments, *we find a larger value for the Solar Constant as we deduce it from observations through a smaller air mass.*" The italics are his.*

Depletion by Water-vapor on Mars

We are now in position to estimate the heat actually received respectively at the surfaces of Mars and the Earth. The visual part of the spectrum containing 32 per cent of the incident solar radiation gives us its quota directly from the albedo, since the heat received = 1 albedo. The infra-red portion containing 65 per cent of the whole depends upon the character of the air and of what it holds in suspension. The greater bulk of the depletion in this part of the spectrum comes from the absorption by water-vapor, water itself, or ice and carbon dioxide. At the Earth's surface the transmission in consequence is about 50 per cent; at Camp Whitney it was about 59 per cent. We might, therefore, suppose it still greater through the air of Mars, which is very thin, and if we did so we should find a still larger fraction of solar heat to be received by the planet's surface; so that such a supposition would actually increase the cogency of the present argument.

* "Researches on Solar Heat," p. 68.

But the very thinness of the air joined to the lesser gravity at the surface of the planet would lower the boiling-point of water to something like 110° F. The sublimation at lower temperatures would be correspondingly increased. Consequently the amount of water-vapor in the Martian air must on that score be relatively greater than in our own.

Depletion by Carbon Dioxide

Carbon dioxide, because of its greater specific gravity, would also be in relatively greater amount, so far as that cause is considered. For the planet would part, *cæteris paribus*, with its lighter gases the quickest.

Whence, as regards both water-vapor and carbon dioxide we have reason to think them in relatively greater quantity than in our own air at corresponding barometric pressure. We may therefore assume provisionally that the absorption due this cause is what it is with us at Camp Whitney, or about 40 per cent of the whole, leaving 60 per cent of the heat transmitted.

It is distinctly to be noted that though this estimate lowers the determination of the heat received at the surface of Mars, what is thus lost in reception goes to make the retention of the heat received all the greater.

Albedoes of the Planets

The albedoes of the several planets, according to the latest determinations, those by Müller at Potsdam, together with that found above for the Earth and that obtained for the Moon by Zöllner, stand thus: —

Mercury	0.17	Jupiter	0.75	(using Struve's latest diametral measures, .78)
Venus	0.92	Saturn	0.88	
Earth	0.75	Uranus	0.73	
Moon	0.17 (Zöllner)	Neptune	0.63	
Mars	0.27			

Heat received by Earth and Mars

We will now apply the argument from the albedo.

Heat received at the Surfaces of Mars and the Earth

	Per cent of Whole Energy	Per cent of Heat received to Whole Energy	
		Mars	Earth
Visual spectrum	32	73	23
Infra-red	65	60	50
Total	. . . .	64	41.5

The ultra-violet rays slightly increase the depletion by selective dispersion for both planets, and probably the more for Mars.

Insolation

But this is not all. The above deduction applies only to such sky as is clear. Now the Earth is cloud-covered to the extent of 50 per cent of its surface on the average; Mars, except for about six Martian weeks, at the time of the melting of the polar cap and over an area extending some fifteen degrees from the pole, stands perpetually unveiled. The surface thus fog-enveloped is .034 of its hemisphere, and the time .23 per cent of the half year, whence the total ratio of cloud to clear the whole year through over the whole surface is less than 1 per cent.

The albedo of cloud being .72, its transmission, including absorption re-given out, cannot exceed .28 for the visible spectrum, and may be taken as .20 for the whole.* Consequently the effective heat received on this score by

* This agrees with Arrhenius' estimate of the heat transmissibility of cloud.

the Earth is about as $.20 \times .50 + 1.00 \times .50 = .60$, and for Mars .99, giving the ratio between the two planets that of .60 to .99.

Taking now Stefan's law that the radiation of a body is as the fourth power of its temperature, and remembering that, since the two planets maintain their respective mean annual temperatures, they must radiate as much heat as they receive, we have the following equation from which to find the mean annual temperature of Mars, x, in which $459.4° + 60°$ or $519.4°$ F. on the absolute scale denotes the mean annual temperature of the Earth:—

$$x : 519.4° :: \sqrt[4]{1^2 \times .64 \times .99} : \sqrt[4]{1.524^2 \times .415 \times .60}$$

or
$$x = 519.4° \tfrac{892}{872},$$

giving
$$x = 531.4° \text{ Abs.} = 72° \text{ F. or } 22° \text{ C.}$$

Heat received and Heat retained

Such, then, would be the mean annual temperature of the planet, were the heat retained as well there as here. I am far from saying that such is the temperature. For the retention is not the same on the two planets, being, on account of its denser air, much better on the Earth. But that such is the amount received is enough to suggest very different ideas as to the climatic warmth from those hitherto entertained.

Temperature deduced from Heat Retained

To obtain some idea of the heat retained and of the temperature in consequence we may proceed in this way:

Let y = the radiant energy received at the surface of the Earth.

y_1 = that similarly received on Mars.

e = the relative emissivity or the coefficient of radiation from the surface of the Earth, giving the ratio of the loss in twenty-four hours to the amount received in the same time, due to factors other than the transmissibility of the air, which is separately considered.

e_1 = the same coefficient for Mars.

Clouds transmit approximately 20 per cent of the heat reaching them; a clear sky at sea-level, 50 per cent. Consequently as the sky is half the time cloudy, the mean transmission through its air envelope for the Earth is

$$.35\,e.$$

For Mars it is $.60\,e_1$.

To get, then, the mean temperature of the planet in degrees, x, from the heat retained, which is the daily mean receipt less the mean loss, we have the following equation, the mean temperature of the Earth being [519.4° F. Abs.] 288° C. above absolute zero:—

$$\frac{x}{288.5} = \frac{\sqrt[4]{y_1(1 - .60\,e_1)}}{\sqrt{y(1 - .35\,e)}}.$$

Determination of e

To find e we have the data that the fall in temperature toward morning on the Earth under a clear night sky is about 18° F. or 10° C.; under a cloudy one, about 7° F. or 4° C. Taking the average day temperature from these data at 292° Abs. on the centigrade scale, or 19° C., and considering an average day sky and a clear night, we have the transmission or loss

$$\tfrac{1}{2}(.35 + .50)e \text{ or } .425\,e;$$

while for an average day and a cloudy night it is

$$\tfrac{1}{2}(.35 + .20)e \text{ or } .275\, e.$$

We form the following equation to determine e: —

$$\frac{292^\circ - 10^\circ}{292^\circ - 4^\circ} = \frac{\sqrt[4]{y(1-.425\, e)}}{\sqrt[4]{y(1-.275\, e)}},$$

whence $$e = .47.$$

Since the radiation by day is greater by about 1.15 than by night, being as

$$\frac{292^4}{282^4},$$

we have more approximately

$$\tfrac{1}{2}(.40 + .50)e \text{ or } .45\, e$$

for a clear night and average day and

$$\tfrac{1}{2}(.40 + .20)e \text{ or } .30\, e$$

for a cloudy night under the same conditions.

This gives $$e = .46,$$

or substantially what it was before. It changes the final result for the mean temperature of Mars by less than two-tenths of a degree.

Determination of e_1

Since in the mean the planet radiates as much heat as it receives and

$$\frac{y_1}{y} = 1.10,$$

the radiation must be in the same ratio. Whence, the loss by radiation in twenty-four hours on Mars, so far as it depends on the heat received, is

$$\begin{aligned} e_1 &= 1.1\, e \\ &= .51, \end{aligned}$$

or by the more approximate calculation in the paragraph above, it still

$$= .51.$$

Substituting these values in our equation (page 250), we find x, the mean temperature of Mars,

$$= 8^\circ.7\,\mathrm{C}.$$

$$\text{or} = 47^\circ.7\,\mathrm{F.},$$

taking into account the heat radiated away as well as the heat received and gauging the temperature by the heat retained; by the net, instead of the gross, amount of the radiant energy received.

If we assume clouds to transmit less heat than 20 per cent, we diminish y and increase $(1 - .35\,e)$, so that the ultimate result is not greatly altered.

If we take Arrhenius' formula for the temperature T of the Earth's surface as affected by the air-envelope, we have as determined in his paper on the effect of carbon dioxide in the air:—

$$T^4 = \frac{\alpha A + M + (1 - \alpha)A(1 + \nu) + N\left(1 + \frac{1}{\nu}\right)}{\gamma(1 + \nu - \beta\nu)},$$

where α = atmospheric absorption for solar heat,

β = atmospheric absorption for earth-surface heat,

A = Solar Constant, less loss by selective reflection by the air,

M = heat conveyed to the air from other points,

N = heat conveyed to the surface from other points,

$\nu = 1 -$ albedo of the surface,

γ = radiation constant.

The values for these quantities found bolometrically for a clear sky are $\alpha = .50$,

$A = 1 - .79 \times .32 = .747$ = whole spectrum − albedo of the air × visible portion,

$\beta = \alpha$ approximately,

$\nu = 1 - .11 = .89$

For the Earth in its entirety $M = 0$ and $N = 0$, since what is lost by convection in one place is gained in another.

Applying this same formula to the case of Mars, we have similarly

$a_1 = .40$ approximately,

$A_1 = \frac{1^2}{1.524^2}(1 - .17 \times .32)$ = whole spectrum − albedo of its air × visible portion

$= \frac{.946}{1.524^2}$

$\beta_1 = a_1$ approximately.

$\nu_1 = 1 - .13 = .87.$

Whence for the Earth under a clear sky

$$T^4 = \frac{A(1 + \nu - \nu a)}{\gamma(1 + \nu - \beta\nu)},$$

and similarly for Mars, substituting its values for A, a, and β.

Since in both $a = \beta$ and $\gamma_1 = \gamma$ approximately, we have for T_1 for Mars,

$$\frac{T_1^4}{T^4} = \frac{A_1}{A}.$$

But the Earth is .50 cloud-covered, and the transmission of cloud being not more than .20 (the value he takes), we have finally

$$\frac{T_1^4}{T^4} = \frac{A_1}{A}\frac{.99}{.60},$$

whence

$$T_1 = .974\ T,$$

and T being 519.4° Abs. on the Fahrenheit,

$$T_1 = 505.7°, \text{ that is, } 46.3° \text{ F. or } 8° \text{ C.},$$

a result substantially the same as we have deduced.

Had we assumed β to be .70 and to be in like proportion to a for Mars, we should have had

$$T^4 = 1.140\frac{A}{\gamma}$$

and

$$T_1^4 = 1.101\frac{A_1}{\gamma_1},$$

which gives not far from what we had before, since it lowers the resulting temperature for Mars by only about 4° F. or 2° C.

13

A Dust Storm on Mars *

On May 25th at 15^h 34^m G. M. T., Mr. V. M. Slipher noticed a large projection about halfway down the terminator of the planet. He at once notified me and we then proceeded to observe it by turns.

What first impressed me was its size. This, both in length and height, was excessive. The projection consisted of a long band of light, a little north of the centre of the arc of the phase ellipse, lying parallel to the terminator but parted from it by a dark line half the band's own width. To this effect I made a sketch of it at 15^h 37^m. The next thing to strike the eye was its color. This was not white nor whitish but ochre-orange, closely assimilated in tint to the subjacent parts of the disk, the region to the north and west of the western end of the Deuteronilus. Such distinctive complexion it kept throughout the time it was visible. Coincidentally Baltia, then close on the terminator and north of the projection, showed white. The seeing was 5 on a scale of 10 — sufficiently good to disclose the Phison and Euphrates double — the power 310 and the aperture that of the 24-inch.

As soon as possible micrometric measures were begun of its position and length, the position angle taken being that of the tangent to the terminator at the point directly under the projection. For such tangent, together with the projection's distance from the disk, furnishes all the data necessary to determine its location. Measures of this angle were repeated at intervals during the time of visibility.

At 15^h 41^m the separation of the projection from the terminator seemed to have sensibly lessened and I recorded it in another sketch. The whole projection appeared to

* Reprint of Lowell Observatory Bulletin, No. 1, June 9, 1903.

have moved bodily in. At 51^m, however, it seemed higher again but then advanced rapidly toward the disk, for by 55^m only the tip of it could be seen. Thus it showed for some minutes, being last seen for certain at 16^h 8^m and vanishing completely after 16^h 10^m.

My measures and notes were as follows, where P. A. denotes the position angle of the tangent to the terminator as above described: —

15^h 37^m Projection on terminator — found about five minutes before by Mr. Slipher. The projection is long and is separated from the terminator by a dark line. (Drawing.)

41 P. A. 200.°4 along terminator.

44 Projection less separated from terminator. (Drawing.)

48 P. A. Projection 199.°9.

51 Length projection 0.″92; now seems higher again.

55 Just about gone; only the tip showing apparently. No striking separation now.

16^h 10^m P. A. Projection 199.°8; only suspected by glimpses; surely seen last at 16^h 8^m.

Impression that projection had moved toward north as regards Deuteronilus.

During the course of the observation a 12-in. diaphragm was tried once but in this case without gain. At the same time Mr. Slipher's measures were these: —

15^h 42^m (?) P. A. Projection 203.°7.

45 P. A. Projection 204.°0.

Length 1.″58.

52 P. A. Projection 201.°0.

Of the apparent perpendicular distance of the top of the projection from the terminator our respective estimates were: —

By Mr. Slipher, .067 of the radius of the disk.

By me, .075 of the radius of the disk.

These estimates were got from measurements of our drawings and from remembrance of the size of the projection as compared with the size of the disk.

To find from these data the position of the projection upon the planet we may proceed as follows: We shall first determine the height of the highest point of the projection above the planet's surface.

Taking the centre of the disk for origin and the minor axis of the phase ellipse for the axis of x,

let d = perpendicular from the projection upon the terminator.

d_1 = distance to the terminator perpendicular to the phase axis.

r = distance from the centre of the disk to the foot of the perpendicular d.

t = distance of the projection from the centre.

ψ = angle between r and t.

χ = exterior angle between d and r.

A = phase latitude of the tip, or its latitude in the auxiliary circle to the phase ellipse.

ϕ = angle between the tangent to the terminator under the projection and the major axis of the ellipse.

a = radius of the disk, in seconds of arc.

a_0 = radius of the disk in miles.

h_1 = height of the projection in the plane of the circle of its phase latitude.

h = its true height.

ξ_1 = angle in the plane of the phase latitude circle between the tip of the projection and the point on the terminator.

ξ = same in the plane passing through the origin, the observer, and the tip.

θ = angle between r and the axis of x.

x and y the coördinates of the foot of d.

x_1 and y_1 those of the foot of d_1.

E = angle of the phase.

P = position angle of the polar axis.

Q = position angle of the phase equator.

B = latitude of the centre of the disk.

λ = longitude of the centre of the disk.

By a property of the ellipse we have

$$\tan\theta = -\frac{\tan\phi}{\cos^2 E},$$

also
$$r^2 = \frac{1}{\sin^2\theta + \sec^2 E\cos^2\theta}.$$

Then in the triangle made by r, d, and t we have

$$t^2 = d^2 + r^2 + 2\,dr\cos\chi,$$

and
$$\chi = \theta - \phi,$$

whence we can find y_1, d_1, and then A, since

$$\sin A = \frac{y_1}{a}.$$

Now
$$\tan\xi_1 = \frac{d_1}{\sin E\cdot a\cos A},$$

and
$$h_1 = (\sec\xi_1 - 1)a_0\cdot\cos A,$$

then since

$$a^2 = (a+h)^2 + h_1^2 - 2(a+h)h_1\cos A,$$

we find h.

Since the height of the projection is always small with regard to the radius of the disk, we may take

$$d_1 = \frac{d}{\cos\phi} \text{ approx.,}$$

and
$$\tan\xi_1 = \frac{d}{\cos\phi \sin E \cdot a \cdot \cos A} \text{ approx.,}$$

and
$$h = (\sec\xi_1 - 1)a_0 \cdot \cos^2 A \text{ approx.}$$

If, as in the present case, the projection is nearly on the phase equator, the process admits of still greater simplification. For then both ϕ and A become small and

$$\tan\xi = \frac{d}{a\sin E} \text{ approx.,}$$

and
$$h = (\sec\xi - 1)a_0 \text{ approx.}$$

In the present instance the height distance, from my estimate, is

$$h = 17 \text{ miles.}$$

From Mr. Slipher's,

$$h = 14 \text{ miles.}$$

We can now find the position. Were the body causing the projection upon the surface of the sphere, with radius unity, we should have t equal to the sine of the angle from the centre of the disk to the tip of the projection. Since in reality the projection is raised above the surface, it may be considered to be upon the surface of another sphere concentric with the first and of radius $a + h$. The point directly under it will not, therefore, be where the tip appears. But since codirectional lines from the same point, in this case the common centre of the two spheres, are altered in the ratio of their length, however projected, we have for the point upon the planet's surface directly under the projection a distance which we will call p.

$$p = \frac{a}{a+h}t.$$

The angle between its direction and that to the planet's pole, or γ, is

$$\gamma = Q - P - \theta + \psi,$$

while the distance in angular measure to that pole is the colatitude of the centre. We thus have two sides and the included angle of a spherical triangle given from which to find the colatitude of the point or the third side and the lower angle or the longitude of the point from the centre of the disk.

Thus calculated the positions of the projection at the several moments when the measures were taken prove to be as subjoined.

G. M. Time	Latitude	Longitude
May 26, 15^{h} 41^{m}	18° 31′ N.	39° 45′
48	19 44 N.	39 59
16 10	21 24 N.	40 33

From the successive positions of the centre of the projection it appears that that centre changed its place during the time of its visibility. It was three degrees farther north and three-quarters of a degree farther west at the end of the observations than it had been at their beginning. Such shift could be due to either of two causes. Bodily transference over the planet's surface would account for it; or obliquity of tilt of the projection's medial line to the terminator would produce a like effect. To which of the two possible causes the result was to be attributed was conclusively shown by the observations of the next day. It is worth noticing that the shift was recorded in the notes as impressing itself upon the eye apart from the measures and confirmatory of them.

At 15^{h} 51^{m} I measured the length of the projection along the terminator and found it to be $0.''92$. If we allow 0.″15 for irradiation, this makes it 0.″77. Now the diameter of the disk at the time was 10.″76 according to Mr. Crommelin's ephemeris which takes the value to be 9.″30 at distance unity. Mr. Slipher's measure makes it greater, but as his estimates from his drawing make it less we may, perhaps, consider the above as a fair measure. We have, then, for its value in degrees upon the planet's surface and in miles respectively:—

Length of projection = 8.°2 = 300 miles.

On the next evening, May 27th, the return of the projection's longitudes off the terminator was duly awaited. They were due about 38^m later than on the preceding night, but in order that if the projection had moved to the eastward in the interval it might also be caught, observations were begun some time beforehand. My notes and measures read as follows:—

15^h 40^m Cannot certainly see anything on terminator, though I can suspect at times something at its centre but cannot be sure. Seeing 3.

44½ Suspect something just below centre of terminator.

52 Distinctly suspicious.

58 Certainly have seen a small projection. P. A. 195.°8. Seeing 4.

16 3 Thought to see it again.

5 P. A. 196.°6, had previously thought it higher (up terminator). Were it anything like that of last night, it must certainly have been seen.

17 Can see nothing on terminator. Seeing a good 5.

27 Suspect projection again but cannot be sure. P. A. 196.°2. Have been observing about half the time.

16 39 No projection visible. Seeing 3.
40 No projection visible. Seeing 4.
41 No projection visible. Seeing 4.
44 No projection visible.

At $16^h\ 15^m$ I made a drawing of the whole planet under seeing as good as on the night before, using an 18-inch diaphragm upon the 24-inch objective, which diaphragm was also employed throughout the observations recorded above.

Mr. Slipher, who observed with me by turns, could not detect any projection.

From these observations it is at once evident that the something which caused the projection of May 26th, had ceased to exist in situ and in size on May 27th. It had changed its place as the position angles show, and had greatly diminished in extent during the twenty-four hours elapsed. For the position of the terminator with regard to the surface was substantially the same as on the day before. *Q-P* having changed in the interval only $+0°.13$, $B-0.°02$, and $E+0.°29$. The chief effect of these slight alterations of phase aspect would have been to delay the advent of the projection by about one minute of time.

If we take now the mean of the two measures of the position angle at $15^h\ 58^m$ and $16^h\ 5^m$, we find for the position of the tip of the projection at $16^h\ 3^m$

G. M. T.	Latitude	Longitude
May 27, $16^h\ 3^m$	25° 29′ N.	31° 43′
and 16 27	25 45 N.	36 51

Comparing these positions with those of May 26th, we see that the object causing the projection shifted its place over the surface of the planet from

latitude 18° 31′ N., longitude 39° 45′, on May 26th,

to latitude 25° 29′ N., longitude 31° 43′, on May 27th,

taking the time of greatest apparition on both occasions. It, therefore, moved 7° in latitude to 8° in longitude in the twenty-four hours, or 390 miles, at the rate of sixteen miles an hour. From this we infer: First, that it was not a mountain or mountains illuminated by the sun; and, second, that it was what alone fits the observations, an enormous cloud travelling northeast and dissipating as it went.

Turning now from the observations of May 27th to those of May 26th, with the recognition of the rate of shift deduced from this comparison of the two sets, we see that the change of place recorded by the first night's observations is to be ascribed to the second of the two possible suppositions mentioned in their discussion, or to the form and orientation of the cloud. Its longer axis lay E. by S. and W. by N. Its axis lay, then, roughly speaking, at right angles to the direction of its motion. This is further made evident by the measures of May 27th in which the same tilt of the cloud's axis to the meridians is disclosed.

We shall now see that Mr. Slipher's observations tell the same tale. If we deduce from his measures, as has been done by Mr. Lampland, the resulting positions of the apparent centre of the projection at different times on May 26th, we find as follows:—

G. M. T.	Latitude	Longitude
$15^h\ 42^m$	14° 52′ N.	38° 2′
45	14 58 N.	36 55
52	19 8 N.	38 21

Here again is evident a tilt of the axis of the projection to the meridians, such that the following end lay farther north and farther west than the preceding end.

It is of interest to inquire under what conditions, diurnal and seasonal, the cloud came into being. As to the time of day, the terminator in question was the sunrise one. The cloud, therefore, was first seen when it was half an hour before sunrise upon its part of the planet, and continued to be visible up to the rising of the sun. The place was within the tropics, in the desert region to the south of the Lacus Niliacus. With regard to the Martian season of the year it was, in this the northern hemisphere of the planet, at the time, according to the data of Crommelin's excellent ephemeris, what corresponds to the first of August with us and the sun was overhead in latitude 18° 7′ N. The cloud, then, when first seen was almost exactly under the sun. It then travelled north, dissipating as it went, and was practically dissolved again by the time it had reached 25° N. latitude.

Finally, its color leads me to believe it not a cloud of water-vapor, but a cloud of dust. Other phenomena of the planet bear out this supposition.

On May 28th no trace of it could be perceived by Mr. Slipher.

14

Mars on the Cause of an Ice-Age

In a paper read some years ago before the American Philosophical Society * the writer showed that Mars was at present in the condition to offer a crucial criterion on the correctness of Croll's ingenious theory as to the cause of our own Glacial Epochs, and that the evidence presented by the planet on the subject did not wholly support the theory.

* "Mars on Glacial Epochs." Proceedings Amer. Phil. Soc., Vol. XXXIX, No. 164.

Croll's idea was that increased eccentricity of orbit such as was true of the Earth in the past brought effects in its train, — change of ocean currents, increased precipitation, and so forth, — which caused a glaciation of the hemisphere possessing the long cold winters and the short hot summers. Study of Mars showed that this was putting the cart before the horse; that increased precipitation from whatever cause, and not increased eccentricity, was the true *primum mobile* in the matter.

The evidence offered by Mars consisted in the greatest and least size of its two polar caps. The minima were known; of the maxima that of the northern cap had been determined in 1897 at the Lowell Observatory. But for the southern cap only seasonal comparisons with the northern at corresponding dates enabled its maximum to be inferred.

Since then the actual maxima of the southern cap have been observed for the first time, and their direct data more than support the deductions of the previous paper. We may, therefore, conveniently review the subject again.

The eccentricity of the Earth's orbit at present is .0168. In the past it has been greater, fluctuating up and down between values whose extreme upper limit is .0747, according to Leverrier's calculations. Its highest amounts are those invoked to account for glacial epochs. At the present time the orbit of Mars is possessed of an eccentricity about five and a half times our own, or .0933. It is, therefore, now in a more favorable condition for eccentricity to tell than our Earth ever can have been.

The planet's axial tilt, too, upon which the differential action of the eccentricity in the two hemispheres depends, is about that of the Earth, being, according to the latest measures, those at Flagstaff in 1907, 23° 13′ against the Earth's 23° 27′.

Furthermore, these two quantities in the two orbits are circumstanced much the same, the line of apsides and that of the solstices falling in both not far apart. With Mars the aphelion of the orbit lies in longitude 153° 19′, the summer solstice of the northern hemisphere in longitude 176° 48′; with our Earth the aphelion is in longitude 280° 21′, the summer solstice of the northern hemisphere in longitude 270°. Thus both planets pass the points of which the near coincidence is vital to the effective working of the eccentricity, in fairly close succession. With Mars the summer solstices follow perihelion and aphelion; with the Earth they precede them. This has the effect in the northern hemisphere of Mars of curtailing the end of summer as compared with its beginning, and of prolonging it in the case of the Earth; similarly affecting winter in the other hemisphere. On the other hand, in the southern hemisphere of Mars summer is delayed into the autumn, while on the Earth it is clipped.

On Mars, then, at present eccentricity and tilt are such as to counterpart what the Earth has had in the past, only accentuated, while their positioning is not very different at the moment in the two.

It becomes now of interest to note what the result of such increased eccentricity is on Mars. It betrays itself of course in the maxima and minima of the two caps. For a glacial epoch means that the minimum of that hemisphere's cap is a maximum. What has been learned on this score, then, is given in the following table: —

Mars

NORTH POLAR CAP

Minima

Date	Observer	Time, ☉	Size	Mean
1886 . . .	Schiaparelli	78°–123°	3.°5	
1888 . . .	Schiaparelli	128°–172° ?	7.°0	
1901 . . .	Lowell	93°–114°	3.°0	
1903 . . .	Lowell	124°–150°	5.°0	
1905 . . .	Lowell	110°–149°	4.°6	
1907 . . .	Lowell	145°	7.°7	5.°1

Maxima

1897 . . .	Lowell	16 days after Aut. Equi. 8°	77°	
1907 . . .	Lowell	273°	90°	84°

SOUTH POLAR CAP

Minima

1862 . . .	Lassell	70 days after solstice 313°	5.°5	
1879 . . .	Schiaparelli	318°–335°	3.°8	
1894 . . .	Douglass and Lowell	299°	0.°0	3.°1

Maxima

1903 . . .	Lowell	135°	104°	
1905 . . .	Lowell	117°	104°	
1907 . . .	Lowell	142°	103°	104°

Perusal of the figures proves startling to the theory that eccentricity of orbit is responsible for glacial epochs. For they show that at its minimum the southern cap, which is the cap of the hemisphere of extremes where glaciation should appear, is not only not larger than the northern but is actually the smaller of the two. And this in face of a greater precipitation in that hemisphere betrayed by the cap itself. For at its maximum it surpasses, as the table shows, the northern cap at its corresponding season. Eccentricity, therefore, in the case of Mars, far from causing even a relative glacial epoch, produces exactly the reverse.

From the respective maxima and minima of the Martian caps it appears that the short hot summer of the hemisphere of extremes is able to dispose of the greater deposit of snow of that hemisphere's long cold winter. Secondly, that that hemisphere's precipitation is greater than that of the short mild winter of the hemisphere of means; and thirdly, that its short summer because hot is more effective in melting the accumulated ice and snow than the long but cooler summer of its antipodes. For it reduces a larger maximum to start with to a smaller minimum in the end.

With a certain amount of precipitation, then, to wit that existent at the moment on Mars, eccentricity is powerless to cause even an incipient glacial epoch. Suppose, now, the precipitation to be increased generally over the planet. The melting powers of the summers remain unchanged, approximately, except that with more deposit more fog or cloud would be raised which might tend to handicap the hotter. With precipitation equally increased the deposit would be more in the long cold winter in the climate of extremes. Its maximum would be raised and relatively to a greater extent than in the other hemisphere. But since the quantity melted in the short hot summer remained as before or even diminished, the minimum would be correspondingly raised until with increase of precipitation the minimum of the climate of extremes actually surpassed the minimum of means and glaciation set in.

Here, then, we see that by altering the amount of the precipitation, *from any cause whatsoever*, an anti-glacial condition is changed into a glacial one. No such upsetting of state follows a change in the eccentricity, but merely a greater or less accentuation of the phenomena. Eccentricity affects the degree, precipitation the very sign of the resulting action. Although, therefore, both are essential to any distinction between the condition of the two hemispheres, it is the amount of the precipitation that really settles the matter. And the cause of the amount need have nothing to do with the eccentricity. Whatever conduces to sufficient increase of precipitation will cause a glacial epoch irrespective of a large or a small eccentricity. Furthermore, as no planet at any time is without some eccentricity of orbit, it is precipitation that determines a glacial epoch or the reverse. Mars, then, throws this light upon the problem: it teaches us that glaciation need not result from eccentricity, and never will do so unaided by a factor which has no necessary dependence on eccentricity at all.

15

Tidal Effects

By 'unhampered age' may be denoted that placid course of evolution by which a planet goes to its death from intrinsic cause alone. For a planet, like a man, may end its life for other reason than senility. Like him it is subject to many vicissitudes in the course of its career. One cause of world-extinction, perhaps the commonest of all, is the tidal action due the Sun. For every planet that rotates angularly faster or slower than it revolves is perforce subjected to enormous partitive strains. Since its body is not absolutely rigid these strains become tides, superficial or bodily, which act as brakes to bring the rotation and the revolution to coincide. Eventually such synchronousness must result; it is only a question of time. When it befalls the planet that body ever after turns in perpetuity the same face to the Sun. This fate has already befallen Mercury and Venus, and must in time overtake the rest. One side of the planet is thenceforward forever baked; the other forever frozen. Whatever water originally existed there will have circulated, caught up by the heated currents of the sunward side, to the hemisphere that is turned away, there to be deposited as ice. This alone would terminate all possibility of life, and the planet roll a mummified mass through space.

16

On the Visibility of Fine Lines

The *minimum visibile* of the normal human eye is commonly taken at 1′ of arc. In other words, the separating power of the eye by which two objects may be distinguished as distinct has this for its minimum distance of effectibility. The limit is not, however, the same for all eyes, varying from individual to individual, and depends upon what is known to oculists as acuteness of vision. It is something quite apart from near-sight or far-sight and resides apparently in the fineness of the retinal rods, some eyes having these much coarser than others. Nor is it the same thing as sensitiveness to impression, though the one ability is often taken erroneously as guarantee for the other. Eyes, however, have two quite distinct capabilities, sensitiveness or the power of distinguishing faint contrasts such as detecting faint stars, and acuteness or the power of resolution of parts to which is due the detection of planetary detail. The existence of the one faculty does not in the least vouch for the presence of the other. Indeed, experience with many observers has shown me that the two are rarely, if ever, found in a high degree together.

Although points may not be distinguished as a rule if they lie closer together than 1′ of arc, it is an interesting and, at first, curious fact that a line, having a breadth much less than the *minimum visibile* and much less even than what would enable it to be seen were it a point, can be distinctly and easily perceived. Michelson has shown theoretically that this must be so, and has further experimented practically to the same conclusion. Before knowing of Michelson's work some experiments of my own had shown me that such was the case, as indeed every one unconsciously evidences when he sees a spider-web. My first experiments sufficed to show me a line whose breadth was less than 2.″6 of arc. It was a telegraph wire, seen against the sky, whose distance away was then measured. Recently I repeated the experiment with more care and with the results which follow.

On May 6 of this year a wire was stretched by Mr. Lampland and the writer from the top of the dome to the top of the anemometer stand near it in such a manner that it could be seen against the sky down a vista of half a mile to the west. The wire was an iron wire of the usual kind, .0726 inch in diameter, brownish and somewhat rusty. In color, therefore, it was not very dark. We began to observe it from a distance of 500 feet, at which it was instantly unmistakable, up to 2100 feet, where it wholly ceased to be visible. The distances at which it became less and less perceptible, the character of that perception, and the angular width of the wire at the several distances are given in the subjoined table. The remarks are mine, from my observations, but they were almost exactly concurred in by Mr. Lampland.

VISIBILITY OF A WIRE .0726 INCH IN DIAMETER

DISTANCE	ANGULAR WIDTH	REMARKS
500 feet	2."50	Evident at first glance.
600 feet	2."08	Evident at first glance.
700 feet	1."78	Evident at first glance.
800 feet	1."56	Evident at first glance.
900 feet	1."39	Evident at first glance.
1000 feet	1."25	Easily evident.
1100 feet	1."13	Perfectly visible.
1200 feet	1."03	Distinctly visible.
1300 feet	0."96	Visible but not easy.
1400 feet	0."89	Visible but not difficult.
1500 feet	0."83	Visible but difficult.
1600 feet	0."78	Glimpses only.
1700 feet	0."73	Well glimpsed. Imaginary wires glimpsed but not surely.
1800 feet	0."69	Well glimpsed. Imaginary wires glimpsed but not surely.
1900 feet	0."66	Glimpses not sure.
2000 feet	0."62	It and imaginary lines of equal impression.
2100 feet	0."59	Not visible.

It is interesting to note the fact that at a certain stage of difficulty in detection, imaginary wires or impressions of wires which did not exist were reported by the eyes or the optic lobes to the brain and that such could be distinguished from the true, not, be it understood, from their position, but from direct subconsciousness of the impressions they made. The sight of a wire carried with it at once a sense either of certainty or of doubt, and this as the table shows was a concomitant of the strength of the impression. Up to 1800 feet the eye or brain could distinguish of itself, apart from position, the reality or questionableness of the impression. At 1900 feet and still more at 2000 feet consciousness was unable to part the false from the true.

To apply this now to those tenuous lines upon the surface of Mars known as the "canals" of the planet. It may be well to say in premise that, when seen under good conditions of air and observer, they are not bands or washes or separating shades, but perfectly definite lines which range all the way from such as might be made by a pen and india-ink to gossamers like spider-webs seen to the naked eye. As a mean case of distance we may take the planet to subtend in diameter an arc of 14″. Suppose also that a power of 310 be used, which is also a mean power. If the telescope lost no light and the definition through it were as good as to the naked eye, it should be possible to observe a line on the planet whose width was

$$\frac{0.''69}{14.''0} \times \frac{1}{310} \text{ of the planet's diameter.}$$

Now the planet's diameter in miles is 4220 ±. In miles then the width would be

$$4220 \times \frac{0.''69}{14.''0} \times \frac{1}{310},$$

or $\frac{32}{48}$ of a mile. Say $\frac{3}{4}$ of a mile.

Were the planet at a near opposition when its apparent diameter is over 24″ and a power of 450 were used, we should have about one-quarter of this for the width which might be seen, or

$\frac{3}{16}$ of a mile.

As the telescope does lose both in light and in definition over the naked eye, it would not be possible to reach this limit. If, however, we suppose the naked eye to be three times as effective, it would seem not to favor the telescope.

At this estimate $\frac{1}{2}$ mile would be the limiting perceptible width.

Why a line can be seen when its width is but $\frac{1}{86}$ of the *minimum visibile* seems to be due to summation of sensations. What would be far too minute an effect upon any one retinal rod to produce an impression becomes quite recognizable in consciousness when many in a row are similarly excited. Psychologically it is of interest to note that there are stimuli perceptible so faint and so fleeting as to be even below this limit, and that, unable to rise into direct consciousness, leave only an indefinite subconsciousness of their presence which the brain is unable to part from its own internal reverberations. It is a narrow limbo, this twilight of doubt, since, as we see in the present instance, below $0.''59$ the object produced no effect, and above $0.''69$ the brain was cognizant of objectivity as such.

Notes on Visual Experiment

The following visual experiment was performed at the request of Director Lowell, and the notes may be considered as supplementary to those of the experiment on the visibility of a wire* — the experiments being identical, except that in the last instance a disk, having a fine line of same width as wire ruled across its face, was observed along with the wire.

As a check against any influence that a knowledge of the positions of the wire and line might introduce, the observer V. M. S. had nothing to do with the preparation and arrangement of the experiment, and made his observations going toward the disk and wire, the observations being begun at the extreme limit of visibility for the line and wire.

* Lowell Observatory, Bulletin No. 2.

For each series the results are practically the same for the two observers — the one having no knowledge as to the positions of the objects and making his observations going towards them, the other beginning observations near the objects and going away from them.

V. M. Slipher.
C. O. Lampland.

December, 1903.

Wooden disk eight feet in diameter, covered with white paper, with fine blue line, .07 inch wide, ruled across its face. Line on disk makes about same angle with horizontal as wire stretched above it. Disk suspended from cable, stretched from top of dome to a pine to the southwest. Plane of disk nearly in the meridian. Wire same width (.07 in.) and color as that used in the original experiment. (Lowell Observatory Bulletin No. 2.)

FIRST SERIES

Station

100 ft. Wire and lines on disk very distinct. — C. O. L.
Angular width: disk, 4° 35′; lines, 12.″48.

200 ft. Line stronger than wire. — V. M. S.
About the same as the 100 ft. station. — C. O. L.
Angular width: disk, 2° 17.′5; lines, 6.″24.

300 ft. Line stronger than wire. — V. M. S.
Both wire and line on disk strong and well seen. Perhaps line the stronger. — C. O. L.
Angular width: disk, 1° 31.′7; lines, 4.″16.

400 ft. Line the stronger. Probably due to background offering greater contrast. — V. M. S.
About as well seen and as evident as at 300 ft. station. — C. O. L.
Angular width: disk, 1° 8.′8; lines, 3.″12.

500 ft. Wire and line equally sharp and evident. — V. M. S.
Wire and line evident and distinct at first glance. — C. O. L.
Angular width: disk, 55′; lines, 2.″50.

600 ft. Disk in shadow, yet line well seen, as is also wire. Line more permanently visible, perhaps. — V. M. S.

Line on disk distinct and evident, but becoming more difficult. Illumination very bright and glaring. Wire distinct and evident first glance. — C. O. L.

Angular width: disk, 45.′8; lines, 2.″08.

700 ft. Inaccessible. — V. M. S.

Poor station for observation. — C. O. L.

Angular width: disk, 39.′3; lines, 1.″78.

800 ft. Inaccessible. — V. M. S.

Wire comes out very distinctly — stronger at times. Line on disk becoming more difficult — somewhat difficult at times from this station, but perfectly evident with good illumination. — C. O. L.

Angular width: disk, 34.′4; lines, 1.″56.

900 ft. Can see wire. Disk in shadow of tree. — V. M. S.

Angular width: disk, 30.′6; lines, 1.″39.

1000 ft. Wire more difficult but perfectly evident. Line on disk also becoming difficult, but glimpse it definitely with good illumination. — C. O. L.

Angular width: disk, 27.′5; lines, 1.″25.

1100 ft. Can see wire and line. Shadow is on disk. — V. M. S.

Both wire and line on disk perfectly and distinctly seen. — C. O. L.

Angular width: disk, 25′; lines, 1.″14.

1200 ft. Certainly glimpse line; poor glimpses of wire. — V. M. S.

Wire rather difficult and at times not seen, but glimpsed perfectly at intervals. Line on disk glimpsed distinctly at times when angle of illumination changes. — C. O. L.

Angular width: disk, 22.′9; lines, 1.″04.

1300 ft. Certainly glimpse line and wire. — V. M. S.

Wire difficult now, but glimpsed at times. Line on disk fairly well glimpsed as wind swings disk, but becoming difficult — somewhat faint. — C. O. L.

Angular width: disk, 21.′2; lines, 0.″96.

1400 ft. Do not glimpse either wire or line. Hasty observations. — V. M. S.

Line on disk glimpsed at times as disk swings, but faint, diffuse, and difficult. Wire glimpsed but difficult. — C. O. L.

Angular width: disk, 19.′6; lines, 0.″89.

1450 ft. Certainly glimpsed wire. Cannot certainly glimpse line. I get glimpses of a fictitious as well as what I take to be a real line. It is (if glimpsed) illy defined. — V. M. S.

Angular width: disk, 19′; lines, 0.″86.

1500 ft. Wire at this station extremely difficult. Not certain that I glimpse it. Line on disk seen at times, but now faint and diffuse. Shadow of tree on part of disk. — C. O. L.

Angular width: disk, 18.'3; lines, 0."83.

1600 ft. Wire not certainly glimpsed: imaginary wires seem about equally strong. Shadow of tree on disk, obscuring line. — C. O. L.

Angular width: disk, 17.'2; lines, 0."78.

SECOND SERIES

Same disk, and wire for comparison, as used in the first series of these observations.

Station.

100 ft. Wire and line on disk very distinct and clear cut. — C. O. L.

200 ft. 300 ft. station remarks hold. — V. M. S. (Observations made going towards wire and disk.)

About the same as at 100 ft. station. Line the stronger. — C. O. L.

300 ft. 400 ft. station remarks hold. — V. M. S.

Well defined at first glance — both wire and line on disk, line perhaps the stronger. — C. O. L.

400 ft. Line easier than wire and more definite. (Due to backgrounds ?) — V. M. S.

Distinct and well seen at first glance. (Line appears the stronger). — C. O. L.

500 ft. Line more definite than wire. (Some telephone wires pass before the disk; these are easier and more definite than wire.) — V. M. S.

Distinct and well seen at first glance. No appreciable difference from 400 ft. station. — C. O. L.

600 ft. Line easier than wire, except where the latter crosses cables. (Cables from which disk is suspended.) — V. M. S.

Wire and line on disk seen with perfect ease and distinctly, but fainter than at 500 ft. station — seen at first glance. — C. O. L.

700 ft. Line easier than wire. — V. M. S.

800 ft. Disk inaccessible. Wire seen. — V. M. S.

Poor station. Trees interfere with observations. — C. O. L.

900 ft. Wire and line only fairly seen. — V. M. S.

Wire quite well seen but somewhat faint and diffuse. Line on disk glimpsed at times but difficult. Disk very bright —

illumination not the best for seeing line. Later: Line seen quite well when the disk was swung by the wind. Faint. — C. O. L.

1000 ft. Inaccessible. — V. M. S.

Wire glimpsed at instants. Disk obscured by trees. — C. O. L.

1100 ft. Line well glimpsed: wire doubtfully. — V. M. S.

Wire glimpsed, but faint and diffuse and not visible all the time. Line on disk distinctly seen when disk swings around for favorable illumination. — C. O. L.

1200 ft. Glimpse wire rather doubtful. Line and wire glimpsed somewhat more certainly than at 1300 ft. station. — V. M. S.

Wire very difficult — glimpsed but faint and diffuse. Line on disk glimpsed but faint. — C. O. L.

1300 ft. See some markings on disk as before, *i.e.*, in second and fourth quadrant. Perhaps glimpse wire. Line more definitely glimpsed. — V. M. S.

Wire very difficult — glimpsed at intervals — diffuse and somewhat uncertain. Line on disk also very difficult most of the time; very faint and diffuse. As disk swings from wind it is distinctly glimpsed at times. — C. O. L.

1400 ft. Glimpse line and have occasional glimpses of fictitious markings (on disk). I once imagined I glimpsed wire. There is a dark spot in second quadrant, and glimpse line from 0° to 290°. — V. M. S.

Cannot certainly say that I glimpse wire — now of about same strength as imaginary wires. Line on disk fairly well glimpsed at times, as disk swings, but faint and diffuse. — C. O. L.

1500 ft. Cannot see wire. Suspect it and line on disk at times, but uncertain. — C. O. L.

17

Canals of Mars

At the opposition of 1907, 264 canals were seen and drawn by the writer; a large number also by Mr. C. O. Lampland; and many, including some new ones, by Mr. E. C. Slipher in South America, not yet catalogued and mapped.

Of the 264 canals mapped, 85 were new. Owing to the tilt of the axis and to the Martian season of the year, these were mostly not only in the southern hemisphere but in the more southern part of it. The position of the new canals was as follows: —

1) 32 in the light regions.
2) 34 in the dark regions or in those of intermediate tints.
3) 12 in or through the southern 'islands.'
4) 7 at the edges of dark regions.
   85 in all.

Added to those already recorded these make: —

336 + 32 = 368	in the light regions.	(1
101 + 53 = 154	in the dark ones.	(2, 3, 4
522	in all.	

Of the canals seen 28 were double or about $\frac{1}{9}$ of the whole number showing. Those not hitherto so seen were the

Cyclops II
Cambyses (?)
Ambrosia
Glaucus
Bias

making 56 doubles in all.

18

Position of the Axis of Mars

which determines the seasons on the planet

The position of the pole of Mars, determined by Lowell in 1905 from a synthesis of his own observations on the polar caps and of previous ones of the same, was: —

R. A. 317.°5 Dec. 54.°5

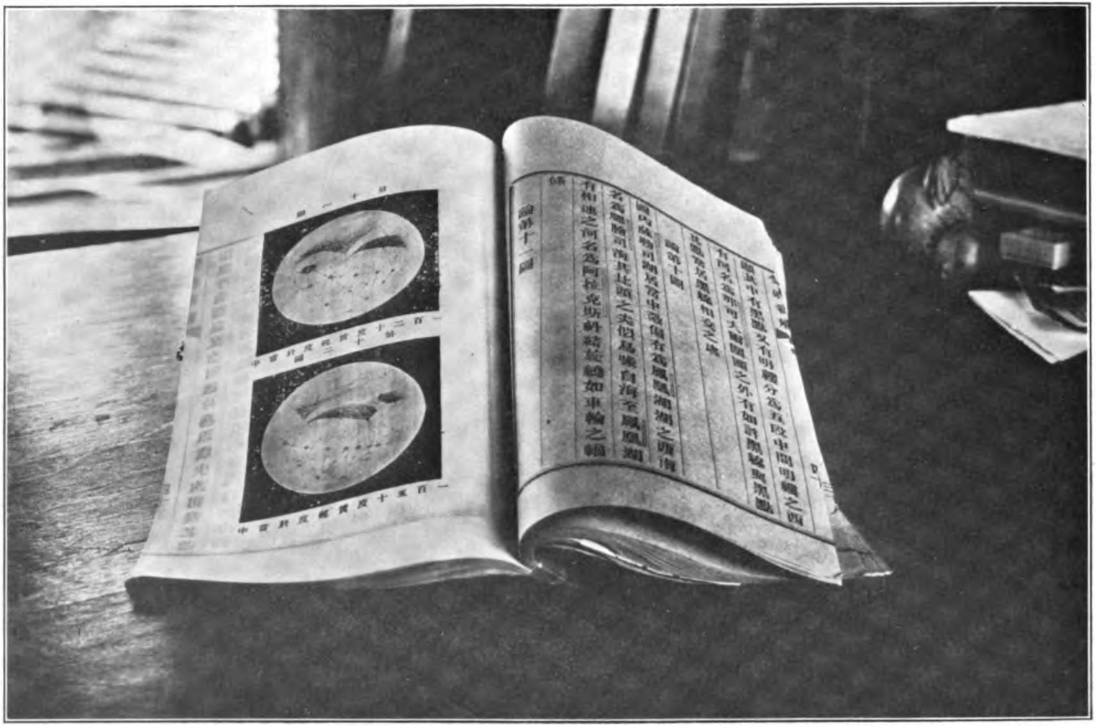
This gave for the tilt of the Martian equator to the Martian ecliptic

$$23^\circ\ 59'.$$

This position of the axis of Mars was adopted by the British Nautical Almanac. The same is to be incorporated in the American Ephemeris.

In 1907 two very full series of observations on the south cap were obtained at Flagstaff which confirmed the several previous series taken there, suggesting that still greater weight should be given them in the synthesis than had previously been assigned. The resulting inclination of the Martian equator upon the Martian ecliptic is

$$23^\circ\ 13'.$$



PHOTOGRAPH OF A CHINESE TRANSLATED EDITION OF LOWELL'S "MARS"

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