

also darker than usual and may finally become a dark zone instead of a bright one. The obliteration of the southern component of the south equatorial belt, of course, makes the south tropical one a more conspicuous feature, but if there is any shift in latitude it is slight.

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REPORT ON MARS, NO. 37.

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[Continued from page 447.]

WHAT I BELIEVE ABOUT MARS.

Since this is obviously a personal statement including a general discussion, and not a record of new facts, it is recommended that those who are interested only in the latter should skip it. Schiaparelli set a precedent by making such a statement, and apparently as an excuse for so doing, prefaced it by the quotation "It is permitted to talk foolishly twice a year" (Flammarion's *Mars II*, 262). It required considerable courage on his part, since he was at that time being bitterly criticized by his fellow astronomers for insisting on the existence of the canals. It is sometimes said concerning him that the term "canale" which he used meant a channel, and that he did not really mean a canal as we use the term in English. In point of fact that is exactly what he did mean. He thought when he first used the term that the seas were water, and he remarks (translation) "These lines (the canals) owe their color to the same cause as that of the seas, and can only be canals or straits of communication" (Flammarion I, 298). Moreover, neither was he the originator of the term canal as applied to Mars, but undoubtedly took it from Father Secchi, who preceded him by twenty years. The latter in referring to what we now call the Syrtis or Syrtis major spoke of it as the "Atlantic Canal." Incidentally Secchi was, I believe, the first observer to record its occasional blue tint. Oddly enough he refers to the Ganges, which seems to have been an unusually conspicuous canal in his day, as the Isthmus (Flammarion I, 135).

Lowell made a still more definite "confession of faith," in his book "Mars," even before he was recognized as a Martian observer, and was roundly criticized for it by several astronomers. His confession was based fundamentally on a suggestion of mine, my first explanation of the canals. As a result of the Arequipa observations in 1892 it became evident, since the canals crossed the seas, that both could not be water. I suggested to him that as distinguished from the lighter regions the seas were fertile plains, and the canals strips of vegetation, irrigated as in Arequipa by small canals, which in the case of Mars were invisible to us. Later I abandoned the explanation, but as he wished it pub-

lished I gave my consent and it appears in his book "Mars," p. 165, in a form entirely satisfactory to me. Several years later Schiaparelli suggested the same idea (*Flammarion II*, 260). My objection to the theory was, since I tried to explain the whole canal system this way, that I believed that the water would not flow through the canals unless forced by artificial pumping, and I did not believe that any Martian inhabitants would undertake to produce a whole planetary circulation artificially. Lowell believed in pumping, but it was evident in any case that much of the water did not go that way, but was deposited as snow at the poles. Nevertheless he obtained many converts to his pumping hypothesis, and one of these, a hydraulic engineer, computed that the whole planetary circulation could be maintained by a constant expenditure of energy not exceeding 4000 times the power of Niagara.

My second explanation of the canals was that they were volcanic cracks, and that the steam expelled from them nourished the vegetation along their borders. When I visited Hawaii in 1905 I inquired for a desert containing steam cracks, and there photographed and later published a picture of a narrow band of vegetation crossing the desert, and maintained by the escaping steam. Nevertheless this idea did not satisfy me, since the Martian canals were so wide and so numerous that they would have involved an improbable amount of volcanic activity on that planet. This idea therefore was also abandoned.

My third explanation was due to a visit to the Azores in 1907. On one of the islands I noticed a distant hill striped and crossed with narrow dark lines. On inquiry it seemed that formerly the hill was densely wooded, but that most of the trees had been cut down to furnish pasturage for cattle. However, certain lines of them had been left standing in order to provide protection from the winter winds, which were cold and very severe. A photograph of this hill was also published (*Harper's Monthly* 1908, 192; see also my book "Mars" 1921, 147). That the Martian canals were planted lines of vegetation, or vegetation left standing in cleared fields, certainly seemed more practical than either of the two previous explanations, but shared with the first the objection that it involved the assumption, not necessarily impossible, of intelligent life upon the planet.

My fourth explanation of the canals has been already dealt with in some detail in Report No. 19, and was also referred to in my last. It is based on my belief that on account of the lack of oceans, the Martian meteorology is much simpler than our own. There appear to be no cyclones on Mars, excepting perhaps during the semi-annual cloudy seasons, when broad dark bands having a large northerly or southerly inclination cross their deserts. These appear to be due to moistened soil. Occasionally perfectly round dark areas several hundred miles in extent suddenly appear and slowly fade out. No better explanation occurs to me than that these too are due to moistened ground. Possibly showers occur at night. Their meteorology appears to resemble somewhat that of our tropics, but is quite unlike that of our temperate

zones. My belief is that on account of this lack of oceans, Ferrel's theory of the winds applies much better to Mars than it does to the earth. The winds are believed to start in the polar swamps, where the moisture, evaporated during the late spring and early summer, first increases the pressure, and then maintains it in excess over that of the surrounding atmosphere. These winds travel along curved tracks, as computed according to Ferrel, and deposit a considerable portion of their moisture in the warmer regions of the planet. The remaining moisture continues on its course through general diffusion to the other pole, where a low pressure is found, due to its continual deposition in the form of snow. The earlier wind tracks are very definite like the earlier course of our West India hurricanes. It is demonstrated by means of the radii of their curvature that along them the winds must blow with hurricane velocity for weeks at a time, but, since the temperature fails to fall to the dew point, no clouds are seen except at the sunrise and sunset limbs of the planet. This leads us to believe that clouds, and perhaps rains, may occur nevertheless, with a lower temperature at night. Five such tracks in the northern and one in the southern hemisphere have been definitely located. Nearly all the planetary moisture in a state of transit, excepting during the two rainy seasons, is believed to be carried along these curved tracks, and vegetation presumably springs up in them as a result. On account of the small force of gravitation on the planet, the compression of its atmosphere decreases very slowly with the altitude, and this, affecting the temperature, in part accounts for its comparative freedom from cloud. Ferrel's theory demands curved canals only, but on the earth we find some narrow wind tracks that are absolutely straight. This is strikingly the case with certain of our western tornadoes, the width of whose tracks rarely exceeds a quarter of a mile, while the length in some cases has extended for three hundred miles and more, 1200 times their width (*Monthly Weather Review*, 1926, 54, 58). Our thunder storms also travel in narrow straight tracks, but are wider.

This fourth explanation is the one to which I definitely adhere for the transfer of the water from pole to pole, and back again. It involves no artificial aid whatever, but I am nevertheless far from denying the possibility of the existence of animal life, and even of intelligent animal life upon our neighboring planet. In making this latter statement I am fully aware that I shall be severely criticized like my predecessors by some of my contemporaries. Until comparatively recently I have felt very definitely that we did not know enough about the surface conditions upon Mars to predicate intelligence there, although it was quite possible and perhaps probable that lower forms of animal life might exist. For many years we have been practically certain, in spite of the mathematicians, that the temperature of the planet was similar to that of our own. We based our assurance on the melting snow caps, on the proof that these caps could not be frozen carbon dioxide, and on the developing and vanishing green of the vegetation.

We are glad that the physicists have at last confirmed this knowledge, but the conclusions of some of them, as distinguished from their observations, are inaccurate and not to be depended on, as has already been pointed out by Coblentz. All that they could do was to determine the temperature of the soil combined with that of the upper Martian atmosphere. The results obtained at Mount Wilson reduced to ordinary units are a continued temperature of -90° F. at the melting snow cap, a temperature of $+9^{\circ}$ F. at the equatorial limb, and $+80^{\circ}$ F. at the center of the disk (Annual Report of the Director for 1926, 104). According to the Pub. Astr. Soc. Pac. 1924, **36**, 271, however, the result $+9^{\circ}$ F. when first published was not the temperature at the limb, but "the mean value over a region extending inward to about one-fourth of the radius towards the center," that is to say, to about 50° from the limb. We shall perhaps be not far out of the way if we call it the temperature of a region at rather less than 25° from the limb. Further we find the statement "the actual temperature at the limb must be much lower than this." Near the limb, the effect of the cold upper atmosphere necessarily predominated, and they obtained a result far too low. Near the center of the disk the result must also have been too low, though to a less degree. With a nightly temperature such as these results imply, combined with a polar temperature as stated, the polar caps could never melt and disappear. But supposing for a moment that for some reason they could melt in the daytime, then with such a low temperature at night, they would always be in strikingly lower latitudes on the sunrise limb than they would on the sunset. This is not the case. Moreover with such extreme temperatures, and according to Mount Wilson *much lower* at night, even at the equator, than $+9^{\circ}$ F., vivid green vegetation such as we see could not possibly exist. It may be suggested here, however, that the temperature which they have deduced for the polar cap lies between the melting points of solidified ammonia gas and carbon dioxide. If they really believe that such temperatures obtain there, it might be well for them to look for the lines of these two gases on their spectrum plates, where they could hardly fail to be very marked.

But why go to such farfetched means of settling the temperature of the planet, when we have an absolutely reliable and accurate one by direct observation close at hand. On Mars as on the earth, regardless of atmospheric pressure, high or low, snow will melt at 32° F. As has been already shown in Report No. **31**, during the month of March on Mars, the snow is melting in latitude 60° , which corresponds on the earth to the latitude of Hudson Bay. During our March our snow is melting in latitudes 35° to 37° , corresponding to that of the states of Virginia and North Carolina. At this season of the year it is clear that these northern portions of Mars are far warmer than the same latitudes on the earth, and the same is true later in the season in the polar regions in Martian July and August, when the snow cap disappears. One of the main reasons for this difference between the two planets is believed to be the great density of the Martian atmosphere. That is to say, we

believe it contains many more molecules per square foot of surface than does that of the earth. This matter is taken up quite fully in our Report No. 30, and need not be further dealt with here than to add that additional confirmation of this result is given by the very low limb temperatures recorded at Flagstaff and Mount Wilson. If there were no atmosphere at all, the temperature of the surface near the limb would not differ greatly from that at the center of the disk, as is clearly shown in the case of the moon, and should be much higher than the observations indicate. In other words the extremely low temperature found is of itself a conclusive proof of a dense atmosphere, such as occurs still more markedly in the case of the planet Jupiter. The yellow clouds on Mars, as compared with our white ones, can also only be accounted for by a very absorptive atmosphere.

My observations and measures of Martian clouds in 1922 and the infra-red photographs of Dr. Wright in 1924 confirm one another in leading to the further conclusion that, in spite of the low gravitative force on Mars, the atmospheric pressure at its surface must be at least as high, and pretty certainly materially higher than that on the earth at sea level. If so, this will largely neutralize the smaller proportion of free oxygen found in the Martian atmosphere. It is mainly these considerations of pressure and oxygen that have led me to modify my former view that we knew too little of the surface conditions to form any reliable opinion on the question of intelligent life on the planet. Now that we feel assured that the atmospheric conditions that obtain there are much the same as those found upon the earth, we feel much more at liberty to interpret what we see occurring there in the light of intelligent activities.

For the benefit of those persons who have never lived away from those countries which are dependent only on frequent rains, a few facts may be stated here that are well known to those who live in countries dependent largely or wholly on irrigation. (a) In a desert country like Egypt the desert extends to within a few yards of the river, except where the land is irrigated. (b) Unless one of two things happens, any country will become an absolute desert. Either the land must be occasionally soaked naturally by rain, or else it must be frequently completely flooded artificially by irrigation from overflowing ditches. A ditch or canal which cannot be made to overflow the surrounding region is of no use at all. A cloudy sky, a moist atmosphere, or a heavy dew is no better. (c) When the rain falls on some of our more marked desert regions, such for instance as occur in portions of South America, where an occasional shower of rain falls perhaps only once in three or four years, it brings forth a profuse growth of vegetation of which not a trace was previously seen. The plant life matures and fertilizes in a few weeks, and then dies down and disappears. (d) Terrestrial crops require at least one foot of annual rainfall, or even a little more, or two feet of irrigation. Double to treble these figures give plentiful crops.

Let us imagine the average depth of the snow over the whole polar cap when at its maximum diameter to be twelve feet. If melted this would give us one foot of water, enough if applied to the best advantage to water we will say an equal area of vegetation. Now compare the area of the polar cap in any drawing with the area of the Martian maria. It is scarcely one quarter their size, and we think we have been rather liberal as to the depth of snow. It is clear then that the maria must contain a good deal of water that is not supplied by the polar cap. It is also clear that this must be spread over its surface either by rainfall or by irrigation. There is no other way. At the coming apparition we expect to see the maria overspread in part by heavy clouds. Neither in 1922 nor in 1924 were they fully covered. The atmosphere of the whole planet was hazy, but that does not mean rain. To maintain the vegetation on the maria throughout the year where no visible clouds occur, *there must either be rains at night, or artificial irrigation.* There is no alternative. In our tropics the rains come in the afternoon. In the rainy season they may last through the night, and even into the morning. Presumably the reason they do not have afternoon clouds and rain on Mars is that the temperature is too high for the dew point. It is only at night that it reaches it, and that rains may occur. I rather think they do occur, but of course we don't know. Their heavy clouds seldom extend far past the terminator, perhaps never more than two hours, save in their two cloudy seasons.

The maria reach up to the southern polar cap when it first begins to melt, with certain lighter spots scattered here and there. This is clearly shown in Report No. 29. As the cap melts the southern boundary of the maria retreats northerly. In 1924 some of these dark southern regions of the maria were visible for a large part of the twenty-four hours (see Report No. 34, Figures 1, 4, 5, and 8). No trace of cloud was seen during that time on either limb, only the usual haze. The temporary darkening of these regions I believe was due to vegetation, and if not watered by rain, it must have been irrigated. An uncontrolled overflow of a stream, tearing away and redepositing the soil along a narrow track would not produce the large uniform grey areas that we observe.

We must now return to the question of the canals. Referring to our earlier discussion of Aethiops and Amenthes-Thoth, and their northern extensions, we have here described two parallel so-called canals 1000 miles apart, 200 to 300 miles wide, and straight or nearly so, proceeding from the melting southern snow cap for 4000 miles nearly due north. It is certain that they cannot be tornado tracks nor anything like them. Neither is it possible for the moisture to traverse their full length through the atmosphere propelled by the wind. In such a case they would necessarily be curved. If Dr. Trumpler's drawing and mine (Report No. 34, Figures 17 and 29), confirmed further by Mr. Atkins' unpublished drawing, are correct, the main portion of the right hand canal, as distinguished from its faint cut-off, is somewhat curved, but it

is curved in the opposite direction to that required by Ferrel's theory. This makes it worse for the theory than if the canal were straight. It is certain therefore that the theory will not explain this particular marking. Both the right and left hand canals unite here in what is temporarily a very dark portion of the mare, which is known as the Tyrrenum Sea. We can hardly doubt that this temporary excess of darkness is due to an abundance of vegetation, growing as the result of the excess of water brought to it by these southern canals, across the surface of the planet. But we must constantly remember that the word canal as applied to Mars does not mean a water canal, but merely a dark marking. Within these two dark markings water channels, natural or artificial, almost certainly exist. We believe that the maria occupy the lowest levels on Mars, and that water is brought to them, not by pumping, but by the simple force of gravity. Water flows to them from the southern polar cap, perhaps in some cases directly by natural channels. In certain other cases like that of these two canals, we have broad areas of vegetation through which invisible, partly natural, temporary streams must carry the life giving flood.

From the polar cap to the northern edge of the mare is in general about 2000 miles. Comparing it with the Ohio river, the latter is 1000 miles long and falls 500 feet. A drop of 1000 feet from the snow to the extreme northern edge of the mare would not, we may believe, be excessive on Mars. In flood the Ohio discharges three-quarters of a cubic mile of water per day, which is between thirty and forty times as much as when the river is low. The amount it can carry thus evidently depends mainly upon the supply. In 1924 the two canals were clearly seen for 150 days. If in that time we assume that they between them carried 200 cubic miles of water, and that the Tyrrenum sea covered a quarter of a million square miles, they should have been able to cover it with water, not allowing for loss and for the vegetation upon their own banks, to a depth of four feet. An irrigation scheme of this sort, if developed with natural water channels as a subsidiary to the general planetary circulation, need require little artificial direction beyond what we give to such matters on the earth. Since the force of gravity on Mars is less than with us, the cross sections of the equivalent canals must obviously be greater. The development of many of the smaller canals such as those mapped in Thaumasia (Report No. 35) might be similarly produced, but in some of these cases the canal itself is both straight and narrow, hardly a twentieth of its length, so that they certainly cannot be natural river channels, unless in order to carry the water as quickly as possible, and avoid seepage, evaporation, and flooding, they were artificially straightened.

The canal Bathys was one of the four most readily seen in Thaumasia, as is described and mapped in Report No. 35. It was not detected either at Greenwich or Mount Wilson, but both the Meudon and Yerkes telescopes were able to show it very faintly (Figures 54 and 55). Indeed it was quite narrow—not over 25 miles in width. Its high visibility was

doubtless due to the fact that it was exceptionally dark. To Phillips and to Du Martheray (Figures 51 and 52) it was very clear. If we examine it on the map (Figure 50) we shall see that it starts from lake No. 4, towards which a dark canal proceeds from the snow cap according to Hamilton, Wilson, and Douglass (Figures 10, 11, and 33). Proceeding through Solis in Figure 50, it broadens like an elongated terrestrial lake where it is crossed by a similar canal coming down from Vitis. Possibly connecting also with lakes 5, 6, and 7 it crosses Thaumasia again, and joins the mare lying to the east of it. Here it seems to terminate. When traversing Solis it was clearly seen by Hamilton and myself (Figures 5 and 6) and somewhat more vaguely by Trumpler (Figure 8). At its crossing of eastern Thaumasia it was distinctly narrower and more difficult than Bathys, and the same remark applies to No. 15 as compared to Vitis. It is thought that this prolongation of Bathys, which we have called No. 12, could not have been more than 5 miles in width where it crossed eastern Thaumasia, which would have been the narrowest visible when the planet was at that distance, according to my measures made on artificial disks. Hamilton thought he saw a still narrower parallel canal extending along the southern edge of Nectar, and another along the northern, thus making a triple (Figure 4). Although I looked for them I could not see them, and since they were not otherwise confirmed, according to our rule they are not entered on our map. We have here it seems to me the most striking confirmation yet detected of my first "explanation," an irrigating ditch with vegetation growing along its sides. It is I think a little curious that I should have proposed the explanation, rejected it, later actually seen the ditch, and finally confirmed it by studies conducted at my own observatory!

Of course what we see is only the main water course. Invisible side ditches must serve for irrigation purposes, if that is what our drawings imply. Its straightness between the bends is remarkable. No sinuosities exist or, if they do, they must be extremely small, little if at all exceeding the width of the canal, as demonstrated in Report No. 6. It is indeed possible that even where it is traversing Nectar it is merely a darker band of vegetation growing along the real water course, but supposing that that is the case, the canal itself must still be pretty wide, and comparable to one of our largest rivers, to carry all the water necessary. Its length is 1600 miles. Under these circumstances with a total drop of 800 feet, the water would readily flow through it by the force of gravity alone, but unless it were a straightened natural river course, executed originally by the water itself, an engineering work of such magnitude seems as impossible to us as the New York bridges would be to a bushman from central Africa.

Although we have thus now actually seen what our theory of 1893 described, yet it does not follow that all the straighter canals of Mars are constructed upon this principle. Something of the sort is evidently also shown in Figures 21, 22, 23, and 24, previously discussed, but the disagreement between the observers makes that case less satisfactory

than the other. The water apparently comes down on either side of Hellas, flows to the center of the disk, and then continues on to Euxinus. In the southern extension of the parallel canals Aethiops and Amenthes-Thoth no one suspected any central ditches. There may, however, have been narrower, natural, temporary streams, which, with side ditches, served to irrigate the land as long as there remained any water in them. Other similar northern as well as southern temporary circumpolar canals exist, which may be similarly explained as areas artificially irrigated by streams flowing under the influence of gravity.

The question now naturally arises, are there any canals in lower latitudes, which if dependent on irrigation would involve streams flowing sometimes in one direction and sometimes in the other. Such cases would naturally rule out the possibility of gravitation as a driving force. In the year 1916 the northern, and in 1924 the southern polar caps were each reduced to half their maximum dimensions. The water from them should then have been travelling in about the maximum volume southerly and northerly respectively. Comparing the drawings of these two years (Reports Nos. 17 and 34) we find comparatively few of the prominent canals in common. Nepenthes was certainly different in shape and location. Thoth also seemed to have swung into a different position. Indeed the only prominent unchanged equatorial canals that I could identify in these two apparitions were Oxus and Gehon.

In addition to these, however, there are certainly a large number of long, fairly wide, faint temporary canals, lying in a more or less north-east and southwest direction between the equator and 60° north, whose existence cannot be explained by gravity. They do not seem to irrigate anything in particular, excepting themselves, but they do not appear to me to be sufficiently permanent in the general Martian circulation to make it necessary for us to explain them by an artificial pumping hypothesis. That hypothesis appears to me more improbable than the assumption that they are simply desert crops, planted so as to catch all the moisture possible as it travels during the semi-annual rainy seasons from pole to pole. On this hypothesis they simply are planted in those favorable locations where they will be most accessible, or otherwise useful to their owners, and it is assumed that larger areas are not needed. The only alternative seems to be to explain them as shower tracks existing quite independently of, and in opposition to, the general planetary circulation. Those that are curved would imply a circulation from south to north, while the northern polar cap is melting. The straight ones are too long to be explained in that way. That is certainly unsatisfactory, and I really see no reason why explanations involving intelligent life should be handicapped as against those that do not. Even supposing that the proposer had a bias in favor of the former, which is certainly believed not to be the case in this instance, it appears to me, supposing of course that we really desire an explanation, that that explanation should be tentatively accepted which involves the least and fewest improbabilities in the opinion of the reader, regardless of all

other considerations. Knowing as we do how on the earth life exists under the most diverse conditions, it would appear that on a planet where the surface conditions are so similar to our own the presence of intelligent life involves no improbability whatever. The narrow desert canals of Mars near longitude 180° depend for their moisture almost entirely on the melting of the northern polar cap, and are most visible between $\odot 60^\circ$ and $\odot 150^\circ$, M. D. May 17 to August 38 (Report No. **31**, Figure 1). The desert canals near longitude 120° are fewer, but more permanent. They appear to depend more on the southern cap.

Turning now to our map of the planet (Report No. **36**, Figure 1) and starting with Hammonis, point No. 86, as a center, we notice four arcs of parallel canals stretching to the northwest of it. Indeed there may be a fifth one lying between stations 25 and 36. The inner arcs are the darkest and narrowest. This is perhaps the first time that we have detected anything approaching a systematic arrangement of the desert canals on Mars. Point No. 15, Acidalium, in the northern hemisphere, is located at the end of a promontory somewhat as Hammonis is in the southern. From it we see also five parallel lines of canals extending to the southwest of it. They are hardly arcs, and are not as conspicuous nor as easily seen on Mars as those we have associated with Hammonis. The arcs of Nectar-Bathys and Agathodaemon-Araxes are similarly placed with regard to lake No. 1 in Figure 50. The radiating canals about the circular Elysium, with the central dot, form a different arrangement altogether. These various systems account for the majority of the desert canals shown upon the map, and none of them suggest the idea of mere accident.

My present position is that I believe that most of the water on the planet stays permanently in the southern maria, and that most of the water from the melting polar caps is distributed through, and by means of the planet's dense atmosphere. The remainder of the water from the caps does not leave the planet's surface, but travels across it in invisible natural or artificial water courses to the nearest mare north or south, under the influence of gravitation. The vegetation of the planet is watered in part by rains at night, and during its two rainy seasons partly by rains in the daytime. If it receives any more water at all, it must necessarily come from artificial irrigation. On the whole adopting for the general circulation explanation number 4, for some of the smaller and shorter canals where necessary explanation number 1, and for the very faint desert canals explanation number 3, the canal system of Mars does not seem to me now so impossible of explanation as it did when I first began to study the planet in 1890. These three types of canals differ from one another also in their general appearance. Those produced under explanation number 4, of which Thoth-Nepenthes is an example, are curved and conspicuous. Those produced under explanation number 1, of which the southern prolongation of Amenthes is an example, are generally more or less straight, circumpolar, and conspicuous, while those produced under explanation number 3, the desert