REPORT ON MARS, NO. 40.

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THE POSITION OF THE PLANET'S POLAR AXIS.

This matter has been dealt with previously in Reports Nos. **26**, **28**, **32**, and **33**. The first two and the last dealt exclusively with the apparitions of 1914, 1916, 1918, 1920, and 1922 by the latitude method. The third depended on position angles of the polar cap in 1924. This we believe to be a distinctly inferior method, for reasons stated elsewhere, but it was the one employed by all previous observers and was adopted by me for that reason. Nevertheless it was found that the result obtained agreed with that secured from the five previous apparitions, namely that the location of the polar axis as given in the *Ephemeris* was in error by about 3°. The suggestion was made to me by a prominent astronomer that the earlier results might be caused by a steadily increasing systematic error of my eye, causing me to place the planetary detail year by year successively farther and farther north. While this idea did not appeal to me as plausible, it had been my intention as soon as possible to continue my computations of latitude for the three remaining apparitions of 1924, 1926, and 1928, by which time the planet would again have arrived in that portion of its orbit where it was observed during the apparition of 1914, thus completing the planet's year. Should his explanation of my results be correct, we should expect to find the planetary detail perhaps become stationary, or else continue on its course towards the north. On the other hand if the position of the pole was in error, the detail would now apparently begin to shift back again towards the south. The test of the two explanations would therefore be crucial. Since it seemed to be a matter of some importance to all those interested in mapping the planet, or recording the yearly changes in position of its markings, I decided to make a determination of the apparent change in latitude throughout the planet's year of certain points at once, without waiting for the apparition of 1928, and thus securing a new and perhaps better determination of the location of the pole. As it turned out, besides recognizing a new fact, it was fortunate that I did so.

In Report No. **33**, Table I, of the 100 measured points recorded there, 30 were selected whose latitudes were supposed to be particularly well known, and these were grouped in classes A and B. In an investigation of the present character where it is important that every point should be well seen, and should not be far from the center of the disk during some drawings at least at each of the seven apparitions, it is clear that we must put a limit on their latitudes. All points were therefore rejected which lay outside of the torrid zone, that is to say whose latitudes exceeded 24°. Furthermore we rejected the more poorly observed of any two points which lay within 10° of longitude of one another. This was because of the fact that such points would be likely to be found on the same drawings, and would therefore give these particular drawings undue weight in our investigations. Otherwise there was no advantage to be gained by a more uniform distribution of points than that of those that remained on our list. A single stationary point accurately observed is all that is needed theoretically for this investigation.

By a third limitation we rejected all those points which were at times so inconspicuous that they could not be measured at every one of the seven apparitions. Fourthly we rejected all those points of which the average deviation of a single measure in latitude in our published list equalled or exceeded ±3°.0. This we did because we considered these points either to be slightly changeable in latitude with the seasons, or else less accurately measured. Out of the complete list of thirty latitudes determined during these five apparitions with the corrected pole, the average deviation of only one exceeded ±2°.9, while in the column determined by the *Ephemeris* there were eight. Nevertheless in the present investigation we have based our determinations exclusively upon the *Ephemeris* values. This we have done firstly in order to give the *Ephemeris* every advantage, not using any points which according to it were poorly determined, and secondly because we wished to locate the pole afresh, to start in as before from the very beginning, and as if no previous correction had been made. There now remained just ten points available for our latitude campaign.

Table I refers exclusively to the three apparitions of 1922, 1924, and 1926. Of the last two no Martian measures of latitude have previously been published. Following the plan adopted in our previous Reports the number of measures accepted for any station, at any apparition, no matter how completely observed, has been limited to four. The total number possible for any apparition for these ten stations will therefore be 40. The total number hitherto published in the *Harvard Annals* **82**, 75, for the apparition of 1922 was 20. For reasons which will appear presently this number was considered insufficient. Other measures were therefore made and combined with them, bringing the total up to 35, and these appear in Table I. The first two columns of the table give the numbers assigned to the stations in our survey, published in the *Annals* and in Reports Nos. **33** and **36**, and their longitudes as computed by the *Ephemeris*. The third column gives the corresponding mean latitudes of the five apparitions, taken from Report No. **33**, together with the average deviation of a single drawing from the mean of the five. The next three columns refer to the survey of 1922, and the remainder to those of 1924 and 1926. These columns give successively the number of measures, the mean latitude of the point with the average deviation of a single measure from that of that apparition, and the

TABLE I.

LATITUDES IN 1922, 1924, AND 1926.

Sta.	Long.	Mean Lat.	No.	Lat. 1922	L—M	No.	Lat. 1924	L—M	No.	Lat. 1926	L—M
7	19°3	— 1°3±2°3	4	+ 1°6±2°0	+2°9	4	— 1°4±1°1	—0°1	4	— 1°4±1°0	—0°1
8	30.4	— 1.7±2.4	4	+ 2.6±1.0	+4.3	4	— 3.4±1.5	—1.7	4	— 5.8±2.4	—4.1
23	72.0	—11.6±1.3	2	— 9.7±1.0	+1.9	3	—10.5±1.6	+1.1	2	— 8.2±1.6	+3.4
24	84.1	—22.0±1.6	4	—20.9±2.9	+1.1	4	—22.5±0.8	—0.5	(4	—17.4±0.8	+4.6)
43	165.1	—18.4±2.9	4	—14.1±1.2	+4.3	4	—14.1±1.5	+4.3	4	—21.6±1.4	—3.2
46	175.5	+ 0.5±2.0	1	+ 3.8	+3.3	3	— 2.5±0.8	—3.0	2	— 0.6±1.4	—1.1
50	196.5	—14.5±2.8	4	— 9.4±2.8	+5.1	4	—12.3±1.7	+2.3	4	—16.7±2.6	—2.2
58	231.9	— 2.2±1.8	4	+ 0.3±0.8	+2.5	4	+ 0.8±1.0	+3.0	(4	—11.7±0.6	—9.5)
94	346.3	— 2.6±2.7	4	— 0.5±1.4	+2.1	4	— 2.8±0.8	—0.2	4	— 1.4±0.7	+2.0
98	359.0	+ 8.6±1.9	4	+11.0±2.8	+2.4	4	+ 5.5±1.6	—3.1	4	+ 0.1±2.0	—5.0
Mean		±2.2		±1.8	+3.0		±1.2	+0.2		±2.0	—1.3

TABLE II.

LATITUDES ACCORDING TO THE EPHEMERIS.

Sta.	1914 ⊙ L—M	1916 ⊙ L—M	1918 ⊙ L—M	1920 ⊙ L—M	1922 ⊙ L—M	1924 ⊙ L—M	1926 ⊙ L—M
7	8°6—0°7	53°0—0°9	89°4—0°8	130°1—0°5	181°4+2°9	246°7—0°1	300°4—0°1
8	6.4—2.0	55.8—1.5	83.1 0.0	122.2—0.7	192.8+4.3	244.2—1.7	305.1—4.1
23	14.7—3.2	58.8+1.5	86.0+0.1	130.2+0.5	182.6+0.9	257.9+1.1	326.0+3.4
24	14.2—0.9	58.8—2.2	86.0+0.4	111.7—0.9	181.5+3.4	237.0—0.5	(309.8+4.6)
43	17.5—1.4	50.6—3.1	87.2—0.2	143.6—0.1	170.1+4.5	241.7+4.3	310.9—3.2
46	10.9+1.8	53.6—1.2	97.1—3.6	143.6—0.2	197.8+3.3	234.3—3.0	316.4—1.1
50	24.1—5.0	70.2—2.0	95.7+0.7	122.9+5.1	173.5+1.4	244.7+2.3	300.2—2.2
58	14.6+0.5	44.2—0.8	88.2—0.6	132.5—1.2	183.9+1.9	243.6+3.0	(308.1—9.5)
94	17.7—2.6	47.7+0.5	90.2—0.1	129.8+0.5	168.6+1.9	247.3—0.2	311.9+2.0
98	4.7—3.1	63.2+0.9	89.5—1.7	174.0+1.5	167.0+2.5	246.7—3.1	320.8—5.0
Mean	13.3—1.7	55.6—0.9	89.2—0.6	134.1+0.4	179.9+2.7	244.4+0.2	311.5—1.3

difference between this mean latitude and the mean latitude of the first five surveys as given in the third column of the table, which we have taken as a standard.

It is believed that these ten points are the most reliable ones so far found, for latitude determinations to be carried out through the planet's entire year, taking into consideration their latitude, their visibility, and their stationary character. Faint prolongations, sometimes double, of both Titanum and Laestrigonum were detected in 1924, but they were not sufficiently dense to interfere with the measures. The names of the ten stations are as follows: 7 Thymiamata f., 8 Aromatum S. p., 23 Maeisia, 24 Solis N., 43 Titanum N., 46 Aesculapius, 50 Laestrigonum N., 58 Cimmerium N., 94 Edom S., and 98 Furca N. f. The total number of measures included at each of the apparitions is as follows: 1914 20, 1916 20, 1918 20, 1920 18, 1922 35, 1924 38, 1926 36. Total 187.

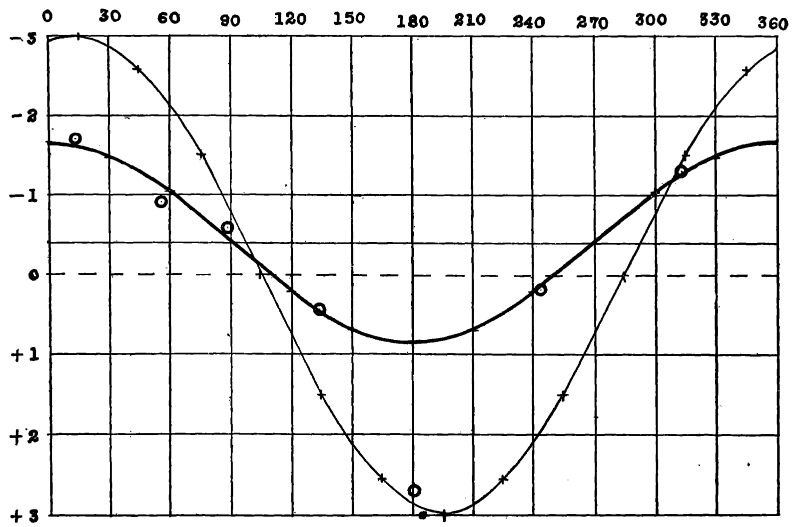

FIGURE 1.

In Table II, following the numbers of the stations, we have fourteen columns which give ⊙ the mean solar longitude of the planet at the time that the observations of each station were made at each apparition, and the difference between the latitude at that apparition and that of the mean of the first five apparitions. The numbers in the first eleven columns are deduced from the detailed account given in the *Harvard Annals*. The numbers in the last four, excepting the solar longitudes are copied from the equivalent columns of Table I. The means of the last fourteen columns are plotted as circles in Figure 1, with the solar longitudes indicating the position of the planet in its orbit as abscissas, and the values of L—M as ordinates. For reasons which will presently be explained the measures of Stations 24 and 58 made in 1926 were rejected. If the pole were correctly located according to the *Ephemeris,* if the stations were stationary, and the observations without error, it is clear that the result would be a straight horizontal line with ordinate 0°. If the revised position of the pole, published in Report No. **33**, were correct, the observations should lie along the finer curve of sines. In point of fact they agree better with the heavier line. The two curves are obviously similar but the latter has less than one half the amplitude of the former.

Disregarding for the moment the last two circles in the figure, and considering only the first five, based on the five apparitions from which the finer curve was deduced, we see at once that it only agrees fairly well with two of them. This curve was computed from observations of twenty-six accurately observed stations, all of which were believed to be fairly stationary upon the planet. The little circles in the figure were based only on the ten stations within the planet's torrid zone, which gave the least evidence, according to the survey based on the *Ephemeris,* of individual motion. It is true that none of the circles differ from the curve by as much as 1°.5 or 60 miles, and at the distance at which the planet was usually observed during these apparitions, with a diameter let us say of 14″, this deviation amounts to only about 0″.2, but we expect much better agreement than that. Disregarding now the observations made in 1922, and turning to the heavier curve, we find that the six remaining observations agree with it in a more than satisfactory manner, their average deviation amounting to only ±0°.09, or to ±3.3 miles. For the last two apparitions, with an average diameter of 20″, this would amount to only ±0″.016. But this is too close, and must be accidental. Nevertheless with an average deviation of a single observation of ±1°.5, as we see by Table I was obtained in 1922 and 1924, when we were using the Harvard telescope, we should expect for the mean of let us say 25 observations a deviation of ±0°.3. This would correspond to ±11.0 miles on Mars, and when the diameter of the planet was 20″, to an average deviation of ±0″.052, or to a probable error for the mean of each apparition of ±0″.043. This is the justification for rejecting the drawings of the apparition of 1922.

Now then the question immediately arises what is the matter with these drawings?

The first step taken was to make all available measurements of them up to the adopted limit of four to each station. This gave us, as we have seen by Table I, 35 measures instead of 20. The result when plotted is a black dot in solar longitude 185°. Instead of helping the agreement with the heavy curve it makes it worse, although bettering it slightly with the other. Turning to the latitude columns of Table I, we find that the average deviation for 1922 stands between those of 1924 and 1926, which agree well with the heavy curve. The latitudes of the ten points in 1922 therefore all hang together as closely as in the two later years.

There seem to be three available explanations of the difficulty. (a) That the lighter curve is the correct one, and that the errors are accidental. (b) That the heavier curve is the correct one, and that my eye without changing its accidental errors appreciably, changed its systematic one, so that during that apparition, and during that one only, I drew all the stations on the average 2° too far to the north. Since during this apparition the equator passed near the center of the disk, and all the stations therefore passed near its center, there seems to be no obvious reason why such a systematic error should have arisen. (c) It is suggested that about half-way between the summer solstice of the northern hemisphere and its autumnal equinox, when the moisture from the melted northern cap had passed well to the south, vegetation began to develop on the deserts on the borders of the maria, carrying them in the course of three terrestrial months to an average distance of 80 miles farther north than they had been before. It is further suggested that those portions of the deserts, lying on the borders of the maria, are more suitable for vegetation than those desert regions farther to the north, where the elevation is perhaps greater, and the temperature lower. Three terrestrial months later, when the water supply had reached its minimum, being largely locked up in the southern polar cap and the surrounding maria, vegetation had again retreated to its former more permanent location. At the opposite season of the Martian year, when the southern cap had melted, the moisture never reached the deserts, but was all absorbed by the maria themselves. Thus during about one-quarter of the Martian year our method of locating the planet's axis by means of a survey of its surface is not available.

In Report No. **26** we suggested that the large difference between the latitudes for 1914 and 1922, amounting to 2°.9, might be accounted for either by an error in the location of the pole, or by a universal advance of vegetation in the interval towards the north. We rejected this last explanation as improbable. It now appears that both explanations are correct, and combine to produce the actual result, the vegetational advance being slightly the more important of the two. An examination of Table I, under the column L—M for 1922, shows that while three of the stations, numbers 8, 43, and 50, are especially effective in carrying the average of that year to the north, yet there is not a single station which does not lie below the heavy curve. The effect therefore appears to be universal.

As bearing on this question of a shifting of the markings with the seasons, if we turn again to Report No. **33**, Table I, we shall find, as previously mentioned, that 8 stations out of the 30 were ruled out because their average deviations in latitude equalled or exceeded ±3°.0. At first we might assume that these large deviations were due to these stations being badly observed. Let us turn now however to Table II in the same Report. In its eighth column are given the differences in latitude of 27 of these stations as observed at the apparitions of 1914 and 1922. Their mean difference —5°.64 was used later in that Report to compute the lighter of the two sinusoid curves shown in Figure 1. Turing now to the eight stations themselves, we find that six of them, namely numbers 68, 63, 55, 17, 69, and 92, show higher differences in Table II than any other of the 27 stations, the lowest being —7°.4. The difference of the seventh of these stations, number 74, is exceeded by only that of one station. The difference of the eighth station, number 54, stands about midway in the list.

Now all this evidently means not that these eight stations were badly drawn, as we at first assumed, for in that case the measures would have been widely scattered, but would not necessarily give sinusoids of large amplitude. It was because they had such large amplitudes, much larger than the other stations, as indicated by their large differences in Table II, that their average deviations from their mean positions in Table I were so large. They were well observed, but moved more than the others between the apparitions of 1914 and 1922. Indeed the average motion of these seven stations extended from an ordinate of —3°.8 in 1914 to one of +4°.9 in 1922, a difference of 8°.7. The average difference of the 10 selected stations was only 4°.8. It is obvious that such a range of difference must be caused by something other than an error in the location of the planet's axis, namely an actual seasonal shifting of some of the stations over the surface of the planet. We thus find that many, probably all, of the stations do actually move at certain seasons of the year. I therefore conclude, in spite of the fact that the curve with the larger amplitude agrees better with the varying positions of all the 26 stations, that this fact is due largely to their irregular proper motions over the surface of the planet, and that the curve of lesser amplitude, based on stations which are generally stationary is the curve representing the real error in the position of the axis of the planet, and is therefore the curve that we should adopt. For six apparitions out of the seven the ordinates agree well with this curve, and I believe that the mean position of the stations in the seventh, in 1922, should be rejected for the purpose now in hand.

We must now explain in some detail why the drawings of Station 24 during the apparition of 1926 were rejected. Those who read our last previous Report will recall that during that apparition the whole face of Thaumasia was transformed. This fact was noted and commented upon by several of our observers. Figure 17 shows well the temporary meridional extension of Solis, while Figure 20, which may be compared with Figure 19, shows that the change was due to an extension north and south, rather than a contraction east and west. Central Solis lies outside the torrid zone, and its location during the southern winter is sometimes uncertain. The latitude of the southern side of the formation was measured on the four drawings from which the measures of the northern side were made. Its mean latitude proved to be 30°.5 S, which is identical with its position on our map, published in Report No. **36**. It therefore appears that the extension of this formation was toward the north in 1926, and the results for 1926 in Table I verify this statement, and indicate why it was proper to omit it.

The case of Station 58 is similar. It lies on the edge of a region noted for its changes, and which exhibited very marked alterations at the apparition of 1926. We shall hope to discuss these in a later Report. We were not at all surprised therefore on constructing Table II to find the exceptionally large deviation of 9°.5 in the last column, and we attribute it to actual motion of this Station, and feel justified therefore in omitting it. Since by the smooth character of our curve shown in Figure 1 we think we have now eliminated all effects due to advancing vegetation, we believe we may safely take the semi-amplitude of the curve 1° 15′ as the real error in position of the pole as given in the *Ephemeris*. Since the node of our curve lies in solar longitude 90°, our result for the inclination of the axis of the planet to the axis of its orbit coincides closely with the value found in the *Ephemeris*, and is **24° 1′**. A distinct advantage of this graphical treatment of the measurements over the analytical method previously adopted is that the position of the pole now depends on all the measurements made at six different apparitions extending throughout the planet's year, instead of depending only on the three apparitions of 1914, 1918, and 1922. Indeed it was largely the results obtained in 1920 and 1924 which led me to the conclusion that those secured in 1922 should not be considered as decisive.

The fact that the horizontal axis of the curve lies 0°.40 above the origin produces no effect on the position of the axis of the planet, but merely indicates that our previous assumption as to the location of the zero ordinate, namely as to the planet's equator, was in error by about 15 miles. The location of the pole now becomes **316° 7′** in right ascension, or $\mathbf{21^h\,4^m\,27^s}$, and **+53° 38′.5** in declination, the epoch being 1905. The change from the *Ephemeris* values is 1°.4 in right ascension and 0°.9 in declination, the total change amounting to 1°.25 measured on a great circle. The Adopted constants C and D of our former computations now become +1°.25 and 0°. In order to correct the *Ephemeris* computations of any observations for this Adopted position of the pole, we may use the heavy curve of Figure 1 directly to correct the latitudes, substituting A for ⊙ as described in Report No. **28**, but for the longitudes we must compute the curves by means of the new constants C and D. However, for all practical purposes the error will be very small if we take two-fifths the correction as given by the curves published in that Report, or in the *Harvard Annals* **82**, 75, and add the result to the *Ephemeris* position.

While it is believed that the above constants give all the accuracy that is at present required by our observations of the planet, and will readily