
REPORT ON MARS, NO. 32.**Location of the Southern Polar Cap.**

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LOCATION OF THE SOUTHERN POLAR CAP.

In Reports Nos. 26 and 28 we showed by means of latitude determinations of various well marked points on the planet's surface, that the position of the axis of Mars as given in the Ephemeris was in error by about 3° . All previous observers who had located it had done so by means of observations of the polar caps. In the summer of 1924 we decided that we too would locate it, as far as practicable at this very favorable apparition, by this older method of observation. When the caps are large, and extend into comparatively low latitudes, they melt in the noonday hours, so that at sunset their rims are in a higher latitude than at sunrise. Moreover both caps are often irregular in shape and marked angularities of outline sometimes occur. This is especially noticeable in the case of the southern cap. It therefore seemed best to confine our observations to periods when the diameter of the cap did not exceed 1000 miles. Another cause further limiting the range of our measurements is due to the gibbous shape of the planet, when a portion of the cap may remain unilluminated on the dark limb. Even the approach of the terminator we found involved considerable subjective errors. The size of the disk is of less importance, and satisfactory measures were actually made in 1919 when its diameter was only $6''.2$. As a result of the two above limitations it appears from a study of the last six apparitions, that the position angle of the northern cap can in general only be accurately measured between solar longitudes $\odot 60^\circ$ and 130° , and the position angle of the southern one between $\odot 230^\circ$ and 295° . Only 135° out of the whole orbit of the planet can therefore properly be used, and often not that.

Since even when small the cap is frequently not circular, it is clear that measures of the position angle of its apparent major axis cannot be depended on for this purpose. What we must measure is the position angle of that portion of the limb lying half-way between the extremities of the cap. For this purpose we usually laid off by the eye an arc three times the length of the cap, and symmetrically placed with regard to it. We then measured the position angle of its middle point. The thread may be placed either just inside, or just outside the limb. Lowell recommended the former, but we found that measures of the latter gave quite as small average deviations. Also their position angles averaged slightly higher. Both methods were used every night when practicable. A complete determination consisted of six measures, three made in one direction and three alternating with them in the

other. Measures were secured both by Mr. Hamilton and myself.

Comparing our readings with the computed position of the polar axis of the planet, as given in the Ephemeris, it is clear that if the cap was centered on the planet's southern pole, our readings, starting with an origin on the equator, would always be 90° . If the cap was centered to one side of the pole, and we plotted our results with Martian central longitudes ω as abscissas, and the position angles as ordinates, we should obtain a curve of sines (Figure 1) rising equally above and below position angle 90° . If owing to an error in the Ephemeris we did not compare our measures with the true polar axis,

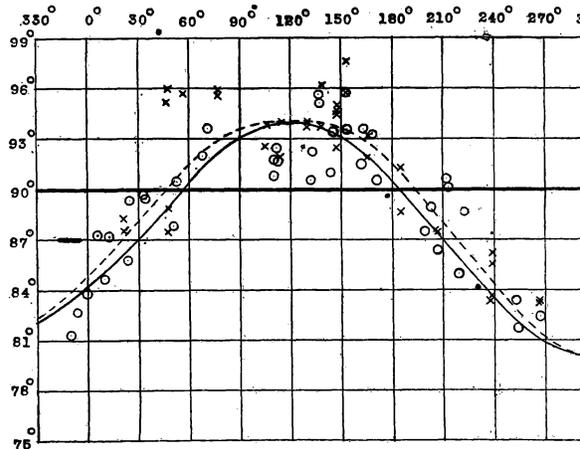


FIG. 1. Position Angles of the Southern Polar Cap.

our curve would rise equally above and below some other position angle. The difference between that angle and 90° would give us the error in the Ephemeris at that time, that is to say for the geocentric longitude of Mars when the observations were made.

Our first satisfactory observations were secured by Mr. Hamilton on September 9, $\odot 253^\circ.3$, M. D. November 41, and are indicated in Figure 1 at the right by crosses. Our last accepted observations were made by myself on November 15, $\odot 294^\circ.9$, M. D. December 51, and are indicated by circles. The observations were continued until December 11, $\odot 310^\circ.2$, M. D. January 21, after which extensive clouds formed covering the cap. Diameter of the cap 280 miles, or $7^\circ.6$. During this interval the phase axis approached nearer and nearer, and finally coincided with the polar axis. Corrections were computed in order to convert tangents to the terminator to tangents to the limb, but at this point measures by Mr. Hamilton and myself became markedly divergent, and we concluded that our eyes were affected differently by the proximity of the darker terminator. It was therefore finally decided to reject all observations made during this last period.

An examination of the remaining observations clearly indicates a

sinusoidal curve, here represented by the continuous line, and although four of the results deviate from it by over $5^{\circ}.5$, yet few of the others show exceptional deviations,—in no case exceeding $4^{\circ}.5$. Unfavorable weather was the cause of the paucity of early observations. What is at once obvious, however, is that the results are by no means symmetrical about the ordinate of 90° , indicated by the heavy horizontal line. The axis of the sinusoid as drawn coincides with 87° . Mr. Hamilton's measurements average a little higher than mine, but a curve based on them exclusively would not raise the axis above 88° . It is therefore clear that our united as well as our individual observations

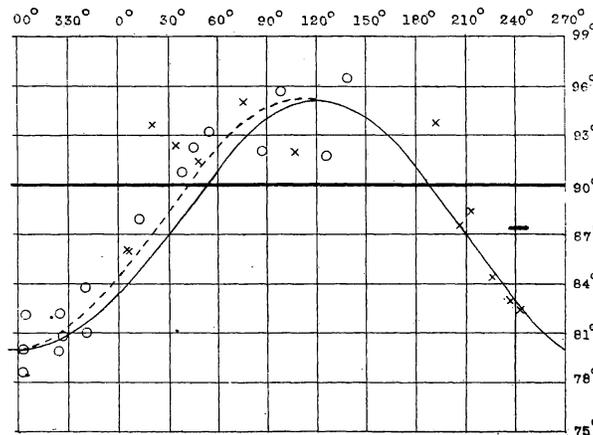


FIG. 1 (Continued).—Position Angles of the Southern Polar Cap.

of the polar cap fully confirm my previous ones of Martian latitudes in showing that the error in the present Ephemeris is of a very considerable size.

The lowest ordinates represent the extreme position of the center of the cap when it was on the phase side of the planet, that is the night side. The whole of the cap was visible however, since the observations were made at the time of the summer solstice of the southern hemisphere. The highest ordinates represent the extreme position of the center of the cap when it was on the day side of the planet, but not at the time when the sun was on its meridian. The diameter of the cap varied during the observations from 19° or 700 miles to 7° or 250 miles. The continuous curve in Figure 1 was drawn to agree as closely as possible with the observations while meeting the requirements that its period should be 360° and its axis horizontal. It differs from a true curve of sines, however, in that it was found necessary to make the amplitude 8° for the early observations, but only 7° for the later ones. This shows that as the cap grew smaller the side most remote from the pole melted faster than the side nearest it, causing the center of the cap to approach the pole 1° , or 37 miles, in 36 days. The rejected ob-

servations following the last ones plotted, and made in November and early December, showed the amplitude of the curve, and the corresponding distance of the cap from the pole, still further reduced to about 5° . The reduction was again therefore mainly on the sunward side of the curve. These observations carried the axis still further down, but since the observers could not agree satisfactorily between themselves, it was decided as above stated that all of these measures should be rejected.

Turning now to our former determination of the size of the errors in the Ephemeris, based on our observations of the latitude of 13 clearly marked points on the planet's surface, let us see where this determination would lead us to locate the axis of the sinusoid. A simple solution of spherical triangles shows that, assuming the error C to be $-2^\circ.9$, and error D $-0^\circ.4$, then the position angle of the axis of the sinusoid on September 9 would be $87^\circ.5$, and on November 15, $87^\circ.0$. These angles are indicated in Figure 1 by the short heavy horizontal lines at the two ends of the curve. The result already obtained from the polar snows, that is to say the location of the axis of the sinusoid in latitude 87° , is thus seen to agree in a very satisfactory manner with our computed results.

Even after allowing for this change in position of the axis of the planet, it is still evident that the sinusoid does not fit the observations as well as it should. If we increase further the amplitude of the early part of the curve, this will not help the observations below the axis, and if we incline the axis, that would imply that the error in the Ephemeris was unbelievably large. If we widen the curve at the top and narrow it at the bottom, as shown by the dotted line, it will undoubtedly fit the observations better, though it will no longer be a curve of sines. The nodes will then be alternately 200° and 160° apart. It is not easy to interpret this phenomenon, even if the cap was then due exclusively to cloud, and I merely mention it in passing.

TABLE I.
MEASURES OF POSITION ANGLE BETWEEN ω 60° AND 180° .

		Pickering				Hamilton					
		Inside Disk		Outside Disk		Inside Disk		Outside Disk			
1924		P.A.	Dec.	P.A.	Dec.	1924	P.A.	Dec.	P.A.	Dec.	
Oct.	24	93.7	+1.4	91.5	-1.6	Oct.	27	92.4	-1.2	94.7	-0.2
	27	92.2	-0.1	90.6	-2.5		28	91.9	-1.7	93.1	-1.8
	27	90.6	-1.7	93.2	+0.1		29	93.9	+0.3	96.2	+1.3
	28	95.1	+2.8	95.8	+2.7		29	95.9	+2.3	97.6	+2.7
	28	93.6	+1.3	95.8	+2.7		30	92.0	-1.6	94.1	-0.8
	29	91.8	-0.5	91.7	-1.4		30	93.8	+0.2	94.0	-0.9
	30	90.8	-1.5	92.5	-0.6		30	94.6	+1.0	95.0	+0.1
	30	91.0	-1.3	93.5	+0.4	Nov.	1	92.6	-1.0	93.9	-1.0
Nov.	9	92.0	-0.3	93.7	+0.6		8	95.7	+2.1	95.9	+1.0
		92.3	± 1.2	93.1	± 1.4			93.6	± 1.3	94.9	± 1.1

Let us now examine these results a little more closely, because they have a distinct bearing on the value that we should attach to the position of the axis of Mars as given in the Ephemeris. At the maxima

and minima of the curve the ordinates, that is the position angles, change but slightly. At the second maximum, between central longitudes ω 60° and 180° the writer and Mr. Hamilton each secured 18 measures involving 108 readings for each observer. These measures are entered in Table I, the left hand portion being devoted to my measures, the right hand to those of Mr. Hamilton. Following the date, the first two columns give the position angles and deviations when the thread in the eyepiece was superposed on the disk of the planet, the other two columns give the same results with the thread outside. Mr. Hamilton's measures are similarly arranged. First it will be noticed that my average position angle for the eighteen measures is $92^\circ.7$, while Mr. Hamilton's is $94^\circ.2$, a difference of $1^\circ.5$, a pretty large quantity when it comes to finding the location of the planet's axis. Next we notice that we both find that measures made with the thread outside the disk give larger values than those with the thread inside, in my case by $0^\circ.8$, in Mr. Hamilton's by $1^\circ.3$. Lowell used no outside measures, which partly explains the small inclination that he obtained.

The location of the axis of Mars as adopted in the Ephemeris depends on the position in the heavens of the northern pole of the Martian axis as given in Bulletin No. 24 of the Lowell Observatory. Lowell does not state precisely how he located it, but the observations of Schiaparelli, Lohse, Cerulli, Struve, and himself, for different apparitions ranging from 1877 to 1905, were plotted on a chart, fourteen points in all; and he then says "From all these determinations the probable value seemed to the writer to put the pole of the axis in R. A. $317^\circ.5$ and Dec. $54^\circ.5$." Apparently it was located by inspection, and possibly by mental weighting of the results. The position he selected lies near the center of an area some 4° in diameter, which contains all the observations mentioned. As far as the inclination of the axis is concerned 6 of the 14 determinations agree with ours within $0^\circ.2$, and 2 more, —one on either side,—within about $0^\circ.5$. The remainder, consisting of two of Lohse's positions and all four of Lowell's, indicate a much smaller inclination, and it is because of these that the Ephemeris value differs in this respect from ours by nearly a degree.

Where all the previous measures differ from ours, however, is in the azimuth, the angle at right angles to the inclination. Struve's value, based exclusively on the changes in the orbits of the two satellites, falls much nearer ours in this respect than any of the others,—about $1^\circ.5$,—and it is a great pity that the ephemeris based on it by Marth was ever changed. Our observations of the polar cap were made between such dates, that is between such values of \odot , as to include the planet's winter solstice, 270° . They were therefore particularly adapted to determining the azimuth of the axis, but gave no indication of the inclination. Our value of this latter quantity therefore rests solely on our measures of the latitudes of selected points scattered over the surface of the planet, during five different apparitions. Our measures of the azimuth of the pole based on the southern

polar cap, as shown by the sinusoid, Figure 1, agree most satisfactorily, as we have seen, with our measures based on the latitudes of the selected points. Why they should differ so greatly from the measures of other observers it is difficult to understand.

To both of us the displacement of the cap from the Ephemeris pole on the night side of the planet was conspicuously greater than on the day side. Indeed if we compare all the observations made near the second maximum of the curve, between ω 60° and 180°, with all those made near the minimum, between 240° and 0°, we find but a single observation made at the maximum which is farther from the ordinate of 90° than the very nearest of all the observations made at the minimum. The same is also true of the first maximum. We cannot believe that any other astronomer, watching the planet, and measuring the cap between the dates when we observed it, could have possibly thought that the cap was equally displaced on both sides of the Ephemeris pole.

The only explanations that we can offer for the discrepancy between the results are (*a*) to believe that when the others observed the planet, it was not well located in its orbit to determine the azimuth, (*b*) that the proximity of the terminator affected their readings, (*c*) that they only placed the thread of their micrometers inside the disk, instead of both inside and out, and finally (*d*) that their subjective errors due to astigmatism and other causes were different from ours.

It is well known that all measures of position angle are influenced by subjective errors, often small, but increasing in magnitude with the difficulty of the observation. We have also found them in the case of Mars to increase with the approach of the terminator. Such measures therefore should always be avoided if any other kind of observation can be substituted for them. The method of locating the axis based on latitudes is not subject to this defect. Let us suppose for example that we actually drew all central Martian markings three per cent of the radius too far to the north, then while their computed latitudes would be in error by this amount, the difference in their latitudes, let us say in 1914 and 1922, would still remain 6°, just as we have already found it to be in our previous Reports. The error of the position of the axis, half that amount, would therefore remain unchanged by this assumed subjective error.

By the method of latitude determinations the azimuth of the axis is corrected when the planet is at its equinoxes, and when in consequence its equator crosses the central meridian at the center of the disk. The positions of the markings at the two equinoxes should therefore appear exactly alike at these times. The azimuth by means of the polar caps on the other hand is determined, as we have seen, when the planet is at its solstices, and the caps are then subject to small shifts of position, as Lowell and others have shown.

The reason why he obtained such a different value for the inclination from other observers is not easy to explain, but we find in general that position angles of the southern cap give higher inclinations than

those of the northern. Thus of the four observers quoted by Lowell, Schiaparelli's highest inclination $24^{\circ} 57'$ was obtained from the southern cap, his lowest $24^{\circ} 09'$ from the northern. Lohse's highest inclination $24^{\circ} 51'$ was obtained from the southern cap, his two lowest $24^{\circ} 03'$ and $22^{\circ} 04'$ from the northern. Cerulli's single high inclination $24^{\circ} 45'$ was obtained from the southern cap. All four of Lowell's inclinations, ranging from $22^{\circ} 37'$ to $23^{\circ} 55'$ were obtained from the northern. As he himself pointed out, he obtained a lower average inclination than anybody else, but he did not attempt to explain it.

LOCATION OF THE POLAR CAPS.

The question of the exact location of the caps is perhaps of little consequence, since our results agree in general with those previously secured by other observers, and since we know the caps to be movable, depending for their location on the season, and also doubtless whether they happen at the time to be composed of snow or cloud. For the southern cap we find its longitude to coincide with that of the node of the sinusoid following, that is to the right of, the minimum position angle. When the cap is less than 1000 miles in diameter, but still composed of snow, its longitude as found this year by the continuous line was 30° , referred to the corrected pole, and its latitude 82° , that is to say $90^{\circ} - 8^{\circ}$. When later it was composed of cloud, its latitude rose to 83° . Its mean longitude remained at 30° . The longitude of the northern cap was similarly found, from a well distributed but limited series of measures made in 1920. In that case it coincided with the node following the maximum position angle, which proved to be in 310° . The latitude of the cap was $87^{\circ}.5$. This deviation from the northern pole is slightly larger than that found by most of the other observers, possibly because the measures were few, but possibly because it really was this year slightly more remote than usual from the pole.

TABLE II.

LOCATION OF THE POLAR CAPS.							
<i>Southern Cap</i>				<i>Northern Cap</i>			
Year	Observer	Long.	Lat.	Year	Observer	Long.	Lat.
1783	Herschel	..	81.2	1882	Schiaparelli	346	89.7
1830, 7	Bessel	..	83.4	1884	Schiaparelli	324	87.3
1837	Beer and Maedler	..	82	1886	Schiaparelli	295	88.7
1877	Schiaparelli	29	83.8	1886	Lohse	285	88.7
1879	Schiaparelli	48	85.0	1898	Cerulli	341	88.1
1894	Lowell	30, 54	83, 85	1901	Lowell	(103)	89.6
1896	Cerulli	32	83.0	1903	Lowell	340	89.2
1907	Lowell	38	83.3			351	88.1
1907	Lampland	33	82.8	1905	Lowell	(8)	89.0
1909	Lowell	17	84.1			(28)	88.3
1909	Slipher, E. C.	29	84.4	1920	Pickering	310	87.5
1909	Jarry-Desloges	30	81				
1911	Lowell	33	86.4		Mean	321	88.5
1911	Slipher, E. C.	28	86.8				
1909	Jarry-Desloges	30	81				
1924	Pickering	30	82, 83				
	Mean	32	83.9				