Popular Astronomy.

Vol. XXIX, No. 1 JANUARY, 1921. Whole No. 281

REPORT ON MARS, No. 23.

By WILLIAM H. PICKERING.

SEASONAL CHANGES.

The observed changes on Mars are of four kinds, secular changes, seasonal changes, daily changes, and hourly changes. Anyone who has observed Mars for over fifteen years under favorable conditions, and has thus been able to compare his own drawings made at the same season of the Martian year, after an interval of that duration, must have noticed differences in its appearance that were obviously real, and not due to mere errors of drawing. It is hoped to give some examples of this sort that have occurred in the writer's own experience in a later publication. Examples of certain other secular changes have been already published in Reports Nos. 7 and 14. Examples of certain daily changes, that is, changes which require only a few days for their completion have been given in Report No. 8, Figures 5 to 8, and in Report No. 20, Figures 1 to 6. The subject of hourly changes has already been briefly discussed in Report No. 18.

In the present Report we shall deal with seasonal changes, as indicated by drawings made always by the same observer in different years. The three apparitions of 1914, 1916, and 1918 are peculiarly favorable for this comparison, because after the equinoxes rapid changes occur in the visibility of the canals, while the distance of the planet at these three apparitions was nearly the same. Some of these changes are exhibited in Plates I and II, and a detailed description of the drawings is given in Table I. In the second column of the table

PLATE I

Fig. 1
Pickering
5° A

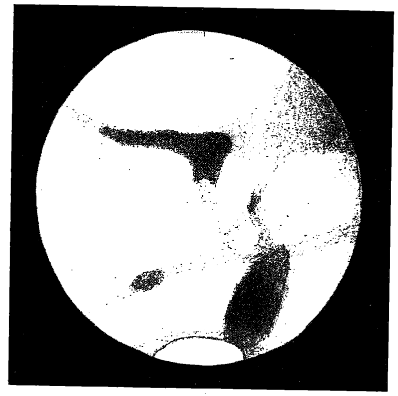

Fig. 2
Pickering
0° A

Fig. 5
Pickering
64° B

Fig. 6
Schiaparelli
298° F

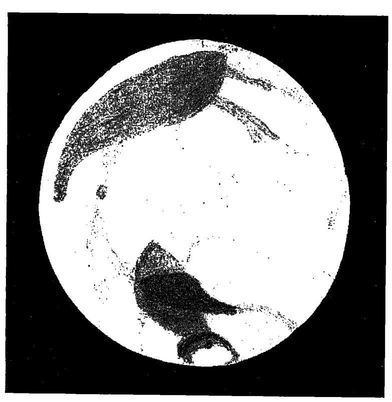

Fig. 9
Pickering
57° B

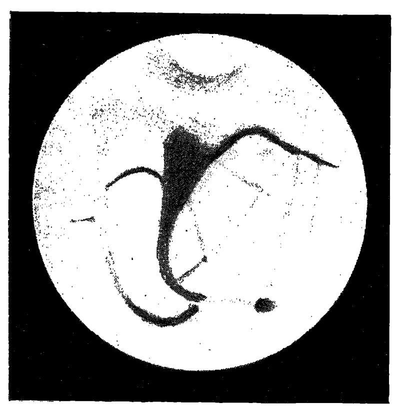

Fig. 10
Schiaparelli
295° F

PLATE II

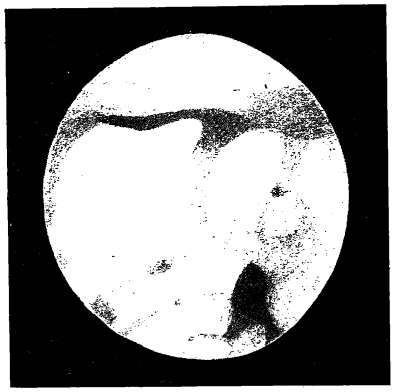

Fig. 3
Pickering
1° A

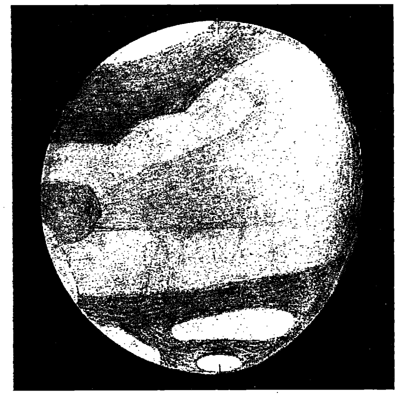

Fig. 4
Pickering
118° C

Fig. 7
Pickering
299° F

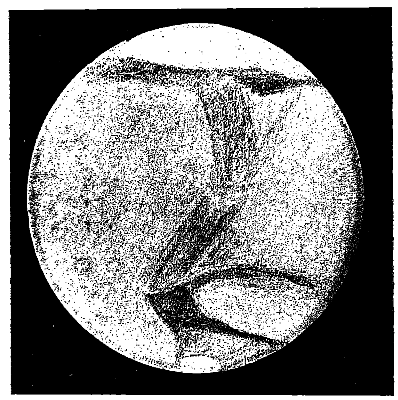

Fig. 8
Buckstaff
47° B

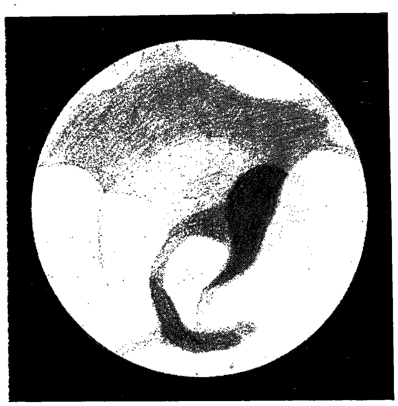

Fig. 11
Pickering
273° F

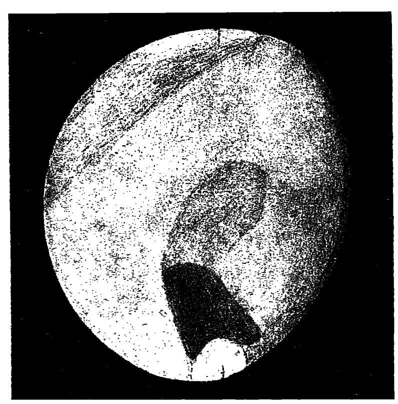

Fig. 12
Pickering
55° B

TABLE I.

FUNDAMENTAL DATA OF THE FIGURES.

No.	Obs.	Aper.	Magn.	Seeing	Date	Reg.	Long.	Lat.	Diam.	⊙	M.D.
1	Pk	11	660,330	10	1914 Jan. 4	**A**	5°	+ 5°	15″.0	16°.6	Mar. 34
2	Pk	11	" 430	9, 7	1916 Mar. 5	**A**	0	+14	12.5	63.2	May 23
3	Pk	11	" 430	11	1918 Apr. 28	**A**	1	+23	11.6	106.1	July 6
4	Pk	11	" 430	9, 8	1920 Jun. 11	**C**	118	+23	12.8	148.7	Aug. 36
5	Pk	11	" 330	10	1913 Dec. 31	**B**	64	+ 5	15.0	14.7	Mar. 30
6	S	8	—	—	1877 Oct. 14	**F**	298	—25	18.8	280.1	Dec. 28
7	Pk	12.5	475	—	1892 July 17	**F**	299	—15	23.1	213.8	Oct. 35
8	B	8.5	320	—	1920 Jun. 18	**B**	47	+23	12.1	152.3	Aug. 42
9	Pk	11	660,430	9	1918 Apr. 21	**B**	57	+22	12.1	103.0	June 55
10	S	18	—	—	1884 Feb. 19	**F**	295	+13	13.1	52.5	Apr. 56
11	Pk	11	660	8	1913 Dec. 10	**F**	273	+ 9	14.0	4.7	Mar. 10
12	Pk	11	660	8	1920 July 22	**B**	55	+21	9.6	170.7	Sept. 20
13	Ph	8	—	7	1916 Feb. 5	**E**	240	+17	13.8	50.4	Apr. 51
14	Ph	12.2	400	7	1918 Mar. 23	**E**	246	+22	14.1	90.0	June 27
15	Pk	11	430	10,12	1916 Mar. 9	**F**	303	+14	12.2	65.0	May 27
16	Pk	11	660,430	7, 6	1918 Apr. 3	**F**	301	+22	13.6	94.8	June 38
17	D	8	350	9	1916 Mar. 13	**F**	287	+14	11.7	66.7	May 31
18	D	8	450	7, 9	1918 Mar. 29	**F**	304	+22	13.9	92.5	June 33

Pk. indicates the writer, S., Schiaparelli, Ph., the Rev. Mr. Phillips, D., Professor Douglass and B., a new observer, Mr. Buckstaff, to whom we shall refer again in a later report.

If we compare Figures 1, 2, and 3 of region **A**, reprinted from Reports 8, 17, and 21, and drawn on the Martian Dates March 34, May 23 and July 6, we shall notice besides the diminishing size of the north polar cap, that the number of canals has steadily increased, the newer ones being always narrower than their predecessors. On the other hand the southern detail has diminished.

If we next compare Figures 5 and 9 of Region **B** taken from Reports 8 and 21 we shall find the same three changes to have taken place. The decrease in the number of southern canals is very marked, as is also the increase of the northern ones. Region **C**, the extensive desert region of the planet, after the disappearance of the southern canals, shows little or no clearly defined change, except for the diminution of the snow cap. In Region **D** on the other hand the steady increase in the number of northern canals is about as marked as it is in Region **A**. In Region **E** the increase is marked in the first period, but not in the second, and the same is true of Region **F**. Mars has now been well observed from the vernal to the autumnal equinox, and there is no evidence in any one of the six sections of an increase in the southern detail, but on the other hand in some sections there is clear evidence of its diminution. For the northern hemisphere as a whole, the maximum number of canals occurs shortly after the summer solstice.

In Table II is recorded the work of the three observers who reported in 1914, 1916, and 1918. In the first four columns is given the year and the total number of canals seen by each, which were confirmed by at least one other observer. In the last column is given the total number of canals, each of which was seen by all three of them. Mr.

Phillips was perhaps rather more conservative than usual in 1916, or else he had unfavorable weather. Otherwise a steady increase in the number of canals recorded by each observer will be noted.

TABLE II.

CANALS SEEN AT RECENT APPARITIONS.

Year	Ph	Pk	D	Total
1914	33	36	45	24
1916	27	42	47	23
1918	51	57	59	36

If now, however, instead of comparing drawings taken a few months apart in the spring of the Martian year, we compare those taken in the late autumn when the winds are blowing northerly, with those taken in the spring, during the southern migration of the Martian moisture, we shall obtain still more marked differences in the surface detail. In Figure 6, reprinted from Report No. 7, is shown Schiaparelli's drawing of the region of the Syrtis Major, made in 1877. We may compare it with a drawing by the writer, Figure 7, made fifteen years later, taken from the same report. The Martian dates of these drawings as shown in Table I are December 28 and October 35. They were therefore drawn during the northerly flow of moisture from the melting southern polar cap, and may be compared with Figures 10 and 11 taken from the same Report. The Martian Dates of these last were April 56 and March 10, and they were drawn in our calendar years 1884 and 1913. The northern polar cap was then melting, and the moisture of the planet consequently travelling southerly.

In each of these four drawings Hammonis Cornu, the desert promontory at the following end of Sabaeus, is clearly shown, and in the first two, made after the September equinox, we can measure the distance from it to the northern point of the Syrtis. Any change in this distance, due to the alteration in the latitude of the center of the disk, when laid off on the last two drawings would be slight. We can therefore see at once how the increased visibility of Nilosyrtis, which is now deluged with the water from the northern polar cap, prolongs the Syrtis in a northerly direction. In Figure 10 it reaches Protonilus, in Figure 11 it reaches in extreme density only half way to that canal. This difference appears to be secular rather than seasonal, but the density and width of these northern canals after the March equinox is clearly much greater than in the two other drawings. The detailed structure of the southern maria, on the other hand, after the September equinox, when they receive the water from the melting southern cap, is obviously greater than in the drawings made during the northern spring. The detail in each hemisphere develops chiefly after the melting of its own cap.

The vegetation on Mars, as opposed to Dr. Lowell's statement, Lowell Bulletin No. 12, §52, appears according to our observations to develop only once a year, in each hemisphere, as it does with us. It reaches its maximum in the northern hemisphere after the melting of the northern cap, and in the southern hemisphere after the melting of the southern one. Though the water crosses the planet's surface twice a year, after each equinox, yet only once does the vegetation develop. There seems to be no defined minimum of vegetation, at least as far as the southern hemisphere is concerned, except where the surface is covered with snow. In other words drought and cold appear to be equally efficient in suppressing vegetable life. Without solar heat moisture is insufficient. In the northern hemisphere as a whole, the maximum of vegetation occurs about 190 days after the maximum rate of melting of the northern cap, or 210 days after the equinox. Its development is therefore far slower than with us.

We have found evidence of progress of development from the pole towards the equator, such as was described by Dr. Lowell for the minimum of northern vegetation. That is to say the maximum development is in the reverse direction to what we find on the Earth, where the progress is from the equator towards the pole. The rate we have found is about 30 miles per day or 100 feet per minute in the middle latitudes. The rate Lowell found was 50 miles per day for the minimum (Bulletin **12**, 85).

But besides the development of the canals, a certain bodily displacement of them is found to take place. Thus in Report No. 4 it was shown that both Castorius and Propontis advanced towards the west and south, in what would correspond to the latter part of the Martian March. In 37 days, taking average values, the advance of Castorius was 400 miles, or at the rate of 11 miles per day, or 40 feet per minute. Propontis moved just half as fast.

In Report No. 19 it was suggested that the curvature of the great canals leading away from the north pole was due to the direction of the planetary winds, depositing moisture along their course. From the curvature, the velocity of the winds was calculated, and found in general to be something over 100 miles an hour. There was one case however, Casius-Thoth, where the canal not only crossed the tropic, as did the others, but nearly reached as far as the equator, and where owing to its straightness the velocity came out very high—some 230 miles an hour. It thus equalled the maximum observed velocity of the winds in our own upper air currents. Owing to the small density of the Martian atmosphere, about one-quarter of our own, it is believed that this is the maximum speed possible on that planet. The measures were based on drawings made early in the Martian May, when the northern snow cap was melting rapidly. It was then predicted, POPULAR ASTRONOMY 1918, **26**, 41, Report No. 19, p. 9, that when the snow cap had diminished in size, we would find this velocity had decreased, and that this would be indicated by a shorter radius of curvature of the canal. Figures 13 and 14 taken from drawings by Mr. Phillips, Figures 15 and 16 from the drawings by the writer, and Figures 17 and 18 by Professor Douglass, all published in Reports Nos. 17 and 21,

PLATE III

Fig. 13
Phillips
240° E

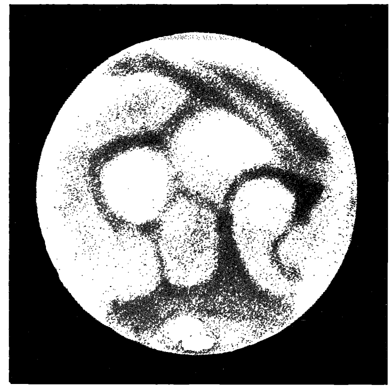

Fig. 14
Phillips
246° E

Fig. 15
Pickering
303° F

Fig. 16
Pickering
301° F

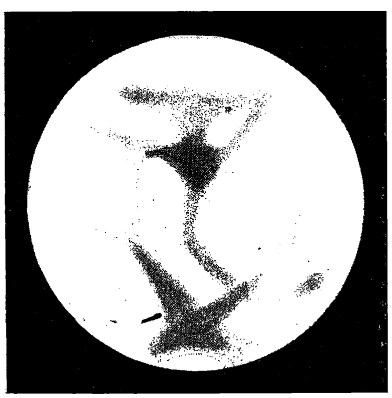

Fig. 17
Douglass
287° F

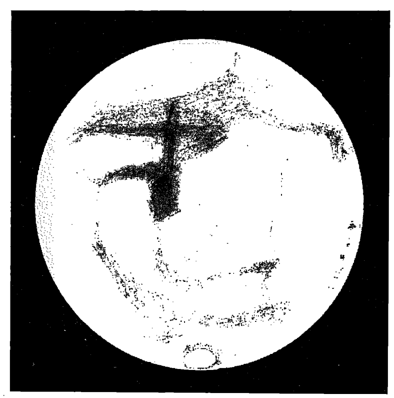

Fig. 18
Douglass
304° F

illustrate this effect. In each pair the canals are more sharply curved in the second drawing. Indeed Nilosyrtis in the drawings of Messrs. Phillips and Douglass shows the effect perhaps even more clearly than Casius-Thoth.

Computing the velocity of the wind in Casius as was done in Report No. 19, we find that while in 1916 M. D. May 27, in the vicinity of Nuba, the velocity reached 230 miles an hour, in 1918 M. D. June 38, in the same vicinity, the velocity of the wind was reduced to 94 miles. In 1920 on M. D. August 13 at the same place, when the snow cap had slightly increased in size, and was melting rather rapidly, as indicated by the dark ring of marsh surrounding it, the velocity had risen again to 130 miles per hour. It must be remembered that since the Martian atmosphere is, as above stated, only one-quarter as dense as our own, the effect produced by these high winds there would be only one-quarter as great.

Towards the close of Report No. 19, after describing the theory of Aerial Deposition of the canals, and showing how the velocities were computed, the writer expressed the hope that his readers would suggest any difficulties that might occur to them with regard to the theory. In the Journal of the B. A. A. 1918, **28**, 138, two such objections are offered, and since no more have appeared, these will now be considered. The first was that, considering the high velocity of the polar winds, capable of reaching the equator from the polar cap in about two solar days, the canals seemed to grow comparatively slowly. In reply to this criticism it should be stated that usually the canals do not grow in length, they merely fade out, and later reappear by darkening along their whole extent at once. That is the growth seems to be not in length, but in density, presumably owing to the development of vegetation. That they develop throughout their whole length at once, of itself implies a high speed of transportation of the necessary moisture.

The second objection raised to the theory was the difficulty of understanding why the canals should appear season after season in approximately the same relative positions. In Report No. 19, p. 15, it is stated that in consequence of the almost necessarily tetrahedral contraction of a cooling planet, the water from the melting polar cap should be deposited in three main depressions along its border. These three regions have been identified as Acidalium, Propontis, and Boreosyrtis. While the winds from the polar cap may perhaps blow southerly over a large portion of its rim, it is only where they cross these three depressed regions that they are able to secure the necessary moisture with which to mark their course over the desert regions of the planet. The longitudinal arrangement of some of the Martian snowstorms, which we shall study presently, throws further light on this matter.

So much evidence has already been given in Reports Nos. 4, 12, 15, 16, and 18 regarding the shifting detail on the surface of Mars, that it may seem wearisome as well as unnecessary to give more, but something bearing on the seasonal changes has come up at this past apparition that appears to be appropriate in this connection. It relates to the shifting northern boundary of the southern maria, and indicates that when the southern polar cap increases in size, a portion at least of this boundary also moves northward. The results are given in Table III where the successive columns give the date of the observation, the solar longitude, the corresponding Martian date, the diameter of the disk, the longitude of the center, the latitude of the center, the observed latitude of the edge of the mare, the latitude according to the map in Report No. 15, and the advance of the mare towards the north. The average deviation of the observations, when made near opposition, is found in general to be about one degree. The map has been found correct at earlier apparitions. The last observation was made with the micrometer, and gave an average deviation of 0″.1, or about two degrees of latitude. But little weight is attached to it however, because, as shown in Report No. 22, the systematic errors occurring with this instrument, when small planetary detail is to be measured, are so large, that the method of observation later mentioned in that Report gives results that are far preferable to any micrometric measures. Indeed the measurement was only made in order to see how large a difference between the results obtained by the two methods we were likely to find.

One more change may now be mentioned on account of its special interest, which while it may be seasonal, is perhaps more likely to prove to be secular. In Schiaparelli's maps from 1877 to 1888 we find the two canals Thoth and Nepenthes drawn much as we have seen them at the last few apparitions. From 1890 to 1903 they were replaced by the canal named by Lowell Amenthes. In 1903 for one or two presentations Thoth reappeared (Lowell Bulletin No. 8). It was soon replaced again however by Amenthes, which remained visible through 1907, with Thoth perhaps occasionally showing. In 1909 neither were well seen, but in 1911 Thoth was exceedingly pronounced, while Amenthes had entirely disappeared, and has remained so up to the present year. Thoth-Nepenthes has been such a conspicuous object upon the planet for the past eight years, that perhaps some of us had forgotten that Amenthes ever existed, but this past August it reappeared beside Nepenthes, ⊙ 176°.8, M. D. Sept. 30, and on Sept. 11, ⊙ 200°.2, M. D. Oct. 13, had replaced it, Nepenthes becoming invisible. The planet was then so remote, so far south, and so near the Sun, that it is feared no other observers were watching it, but if so, the writer would be glad to hear from them.

TABLE III.

THE NORTHERN BOUNDARY OF THE SOUTHERN MARIA.

1920		⊙	M. D.	Diam.	Long.	Lat.	Obs.	Map	O—M
May	28	141°.6	Aug. 22	14″.1	214°	+22°.8	—15°.6	—23°	+ 7°4
June	1	143.6	Aug. 26	13.7	185	+22.9	—21.6	—32	+10.4
Aug.	13	183.1	Sept. 41	8.4	193	+17.0	—18.7	—32	+13.3
"	"	"	" "	"	213	"	(— 4.6)	—23	(+18.4)

THE DISAPPEARANCE AND FORMATION OF THE NORTHERN POLAR CAP

These two phenomena occur at about the same season of the Martian year, in the month of August, and sometimes one and sometimes the other occurs first. In looking over their past history, we find that little of importance was discovered prior to the present century. In 1903 however Lowell made some interesting observations, which are recorded in Bulletin No. 2 of the Lowell Observatory. He states that for weeks prior to the disappearance of the northern cap "it had stood flanked round by subsidiary white patches". With the exception of the large white spot, called Olympia by Antoniadi, located in longitude 206°, latitude +83°, and which always appears in this same place when the cap is sufficiently small, nothing of the sort was seen here this past year. Several remote tropical clouds, such as Nix Olympia, were however seen. Olympia is probably an elevated region,—a table land, although not high enough to project beyond the terminator. A snowy region of similar shape is found near the south pole.

On July 5 Lowell made his last measure of the northern cap, which was then reduced to the very small diameter of 4°.1. Since the measure was made between the threads of a micrometer, however, a correction of several degrees must be added to this figure. On this same night he states that there became visible along the terminator north of Arethusa lake a large white patch which had not been visible two nights previously. He says "It became clear that in the last forty-eight hours a white deposit had taken place over a region of many hundred miles square." It stretched from the neighborhood of the polar cap to latitude +55°. It crossed Pierius, which at the same time could be seen running through it. This proved that the deposit was not cloud. On July 7 it was impossible to recognize the old polar cap amid the large white areas about it. On July 16 he recorded "North polar snows diffuse and indefinite; no polar sea nor definite cap, only more brilliant where the cap was." On July 11 Gale reported that "The cap is at the center of a bright hazy area" (Mem. B. A. A. 1903, **16**, 98). Molesworth later reported "Cap very indefinite and nebulous."

In 1905 on May 19, Bulletin No. 22, Lowell records "a large and salient white patch to the south and west of the old polar cap." It was "instantly recognized as not having been there the day before." It reached to latitude +63°, mid-longitude 230°. Phillips writing in June says the whole of the district north of +65° was whitish, though not uniformly so. At first there scarcely seemed to be any definite polar cap visible (Mem. B. A. A. 1905, **17**, 59).

In Bulletin No. 30 Lowell records that in 1907 April 8 a large white patch appeared to the left of the cap, which had not been seen two nights before. Other patches appeared during the next fortnight, and it was "not until April 21 that the cap settled down to a permanent increase of snow covered area." It then reached to latitude +53°.5, but fluctuated considerably, and almost disappeared in the middle of May. It extended however to $+49°$ on May 28, ⊙ 177°.0. This was its most southerly extension, and would correspond to M. D. Sept. 31.

Dealing now with the experiences of recent years, we may say that prior to the vernal equinox, the northern polar cap is covered with clouds. These can be distinguished from the snow by their yellow color, their lesser brilliancy, and their constantly varying size. Observers should therefore always record the color as well as the brightness of any bright area seen. In case there is snow at either pole, it will serve as a standard of whiteness. The northern cap appears to be of its maximum size some two or three weeks before the equinox. Shortly after that date the clouds vanish, the snow exposed having approximately the same area as the clouds that previously covered it. For six terrestrial weeks after the equinox it melts rapidly, the maximum rate being reached after some three weeks. For the next thirteen weeks the diminution is slow, and after that, for twenty-six weeks, or sixteen weeks after the solstice, the area remains practically constant, with but small fluctuations. This carries it well into the Martian August.

During this interval the cap has been sometimes seen sharply defined, but surrounded by a fainter white collar of uniform width, presumably due to frost (see Report No. 20, p. 2). On this occasion the solar longitude was 75°.5, M. D. May 51. Lowell describes what appears to have been the same phenomenon in Bulletin No. 20. He says it was visible many times in January, February, and March, 1905. It was observed here only once, as an unsymmetrical marking this past year, ⊙ 87°.4, M. D. June 21, although the planet was very well situated to show it. It is possible that several of the appearances described by Lowell may have been due to cloud, as he himself suggests. His earliest and last observations correspond to ⊙ 87°.8 and 120°.7, or to M. D. June 22 and July 36.

On July 5, 1918, ⊙ 138°.5, M. D. Aug. 16, a small accession to the snow cap was noticed about trebling its area. This seems to have been the first real snowstorm of that apparition, although it was not recognized as such at the time. On M. D. Aug. 27 a very considerable storm occurred. Others followed, our last satisfactory observation being made on the Martian Date of Sept. 13.

On June 1 of the present year, M. D. Aug. 26, the northern polar cap of Mars was bright, sharply defined, and reached only as far south as latitude $+84°$, corresponding to a diameter of about 500 miles. For several months it had presented but slight variations in its dimensions, and no indications of any change whatever were apparent, such for instance as extensive cloud formations. The central latitude of the disk was $+22°.9$, so that the pole was turned well towards us, and the whole of the snow cap was clearly visible. What was my surprise then on the following evening, ⊙ 144°.1, when the central meridian was 198°, to see a long line of white lying along the terminator, and extending as far south as latitude + 40°. As the planet rotated the white area slowly came on to the disk. It extended farthest south in Neith, in longitude 280°, but crossed Casius, covering Utopia and Uchronia, and extended to within about 100 miles of the polar cap. That this brilliant and conspicuous formation was not due to cloud was quite evident, since the new fallen snow was of a dazzling whiteness, and quite unlike the yellow clouds, some of which lay along the limb on the opposite side of the planet. It was indeed whiter than either of the polar caps, which doubtless had small scattered clouds floating over them. It covered not only the brighter regions, but also portions of Utopia, as above noted, which on May 29 had been strikingly dark, 4.

It evidently had been snowing during the Martian night, as the snow reached to the sunrise terminator, but there was no indication that the snow extended as far as the sunlit polar regions. The area covered by the storm was at least 800,000 square miles, or one-quarter of the area of the United States. It was necessary to stop observing before the whole of the western boundary of the snow came into view, on account of clouds in our own atmosphere, and after 13^h, central meridian 239°, Mars was too low to observe longer under the local weather conditions. Had anyone been observing the planet to the west of us, they could have seen the phenomenon much better than we did. The month of June is in the height of our cloudy season, and unfavorable to work of this sort. June 3 and 4 were cloudy, but the next night we had a clear view, and followed the planet until after midnight. The snow had mostly melted south of latitude + 60°, and the eastern border was no longer sharply bounded by a dark marshy area, as it was on the night of June 2. It was on the contrary hazy and indistinct, although the snow was still white, thus implying that it had broken up into small isolated patches not individually distinguishable. This snowstorm deposited an area of snow which while lying in general in an east and west direction had a marked southerly extension between Casius and Nilosyrtis.

In the next storm, observed June 11, M. D. Aug. 36, this extension was lacking, and we could see the whole area of snow deposited (see Figure 4). The elliptical northern polar cap will be at once recognized at the bottom of the picture, and the southern snow nearly opposite to it. Just above the northern snow cap we see the area of fresh fallen snow, and at the limb in the same latitude we see another one. Just above that, also on the limb and indicated by dots, we find a yellowish white area not so bright nor so white as the others, which we interpret to be clouds. This storm was rather smaller than its predecessor, and measured 1,450 miles by 480, thus covering an area of 700,000 square miles. It lay between longitudes 90° and 205°, it therefore crossed the Propontis' depression, and lay between latitudes + 64° and + 77°. It covered portions of Nerigos, Scandia, Panchaia, and Ierne. It too failed to reach the polar cap. For several nights preceding and following this observation it was cloudy here, but Mr. R. N. Buckstaff of Oshkosh, Wisconsin, who was observing on June 12, makes no mention of any unusual northern snow. He states that "the markings around the north polar cap were gray green." This would indicate that the snow had all melted by this time, and that the fall was therefore light.

The next storm was observed by Mr. Buckstaff himself on June 18, M. D. Aug. 42 (see Figure 8). It also had an east and west extension, but was located rather farther south than its predecessor, between latitudes $+40°$ and $+55°$. It stretched westerly from the Acidalium marsh, but as it lacked observers farther to the west, its length is unknown. On June 19 the westerly portion of it had melted. No further observations could be obtained until June 22 when it had disappeared. Mr. Buckstaff states that it was not visible on June 17. The writer observed the planet on June 17 and 20, but no snow was visible on either of those nights, so this snowfall too was short lived, and apparently lasted no more than two days.

None of these storms reached the polar cap, but on July 2, M. D. Aug. 56, the next storm observed here had a north and south extension instead of an east and westerly one. It included the cap, and extended south to latitude about $+65°$, in longitude 260°. It is possible, that this snow was in part what was left from the first storm, as it was in the same portion of the planet, but this does not seem at all likely. Moreover it had certainly since then extended towards the north, as it now included the polar cap. This same white area had been noticed as early as June 29, but its outline was then so hazy and indistinct that it could not be observed satisfactorily. No further observations could be made until July 2.

There was evidently another storm July 16 and 17 which included the cap. Its boundaries were indistinct, and it stretched directly across the disk from terminator to limb. By July 20 and 22, M. D. Sept. 18 and 20, the indistinctness had vanished, and it was now seen to extend in a north and south direction, its southern point reaching latitude $+68°$ in longitude 30°, or directly into the Acidalium marsh (see Figure 12). It measured about 1000 miles in a meridional direction by a little over 600 in width, but appears very much foreshortened in the view. All this snow had disappeared by July 25.

All of these five snowy areas when first visible were in contact with the sunrise terminator, and it was clear that in every case the snow had been deposited at night. They were apparently never very deep. Judged by the color of the deposit, always a pure white, the clouds must have cleared away before sunrise. Only in the case of the storm of June 11 does a second drawing, shown in Figure 4, show the snow entirely clear of the terminator. It is apparent that we are never destined to observe the storm clouds sweep across the surface of the planet, leaving a white trail of snow behind them,—nor should we expect to do so, for theoretical reasons, as has been previously explained

(Report No. 19). The most we can hope for is to see far northern clouds bounding the snowy hegion.

It will be noted that each of these storms was associated with one of the three great polar marshes. The storms were of two kinds, those extending east and west, and those extending north and south. Both types are illustrated in Plate II. Two of this last type extended from Boreosyrtis between Casius and Nilosyrtis, and the other one down the middle of Acidalium, implying winds blowing towards the south. Of the two which stretched east and west, the first crossed the nearly dry Propontis area, while the other extended due west from Acidalium. Earlier in the season clouds were frequently observed in this latter region, and it will be noticed that on the second day, according to Mr. Buckstaff, the western end of the snow had melted, showing that the deposit was thicker near the marsh. Apparently this storm was carried on a wind blowing from the marsh towards the west.

In 1920 the first storm detected was on the Martian date of Aug. 27, and the last on Sept. 20. It will be remembered that each Martian month has 56 days, and that the equinox occurs on Sept. 36. The duration of these storms was therefore just seven weeks. Since then, for the past ten weeks, none have been observed. They appear therefore to have ceased. On Sept. 7 the northern polar cap disappeared, leaving the whole northern hemisphere entirely free of snow.

On Sept. 36, twenty-nine days later, and sixteen days after the last snowstorm, the cap reappeared, but under a new guise. It was no longer small, bright, and sharply defined. It was now very large, reaching latitude $+50°$, was whitish, and very faint, being brightest at the pole, where it reached brightness 8 on a scale of 10. It faded out very gradually without any defined southern boundary. It appeared simply like a deposit of thin hoarfrost, thickest near the pole. The southern cap on the other hand was distinctly yellowish and sharply defined. The next night the northern cap was greatly reduced in size. Its southern edge was still very hazy, but it did not reach beyond latitude $+60°$. In the early part of the Martian October its size was still further reduced, only reaching $+70°$. It was now white, sharply bounded, and of brightness 8 and 9. On account of the gibbous shape of the planet it was impossible to determine the size of the cap accurately, and by the middle of October it had nearly disappeared, being reduced to a short, extremely narrow, bright line. It is not likely that its real size was much reduced, however, since the Sun had now sunk 11° below the polar horizon, so that the northernmost latitude visible to us was 79°. Possibly one reason why the cap was still so small was that the planet was approaching its perihelion. This is reached at ⊙ 246°.7, M. D. November 31.

Comparing the results obtained at different apparitions, we find a marked similarity in the phenomena described, and if we compare the dates as given in Table IV, a surprisingly small variation in them.

The earliest snowstorm hitherto recorded fell on August 8. The record of this was secured by the writer, by means of photography in 1890 (Sidereal Messenger 1890, 254). See also Flammarion's Mars, I, 464.

TABLE IV.

FIRST FALL OF SNOW.

Year	☉	M. D.	Observer
1903	149°9	Aug. 38	Lowell
1905	149.0	Aug. 36	Lowell
1907	150.2	Aug. 38	Lowell
1918	138.5	Aug. 16	Pickering
1920	144.1	Aug. 27	Pickering

There would in general seem to be a succession of snowstorms lasting from early in August to the middle of September, followed by light frosts of very wide extent, and comparative absence of cloud. These summer snowstorms sometimes extend as far south as latitude + 40°. The extreme limit of the polar cap at the end of the winter at the apparitions of 1914 and 1916 did not pass latitude + 51°. According to Lowell, Bulletin 72, in 1911 it reached + 42° to + 45°.

These results give us information as to the small range of temperature between summer and winter on Mars in localities situated between these latitudes and the equator, and indicate that our own climate might be far less variable were it not for our extensive polar caps. Our winter isotherm of 32° passes south of the parallel of + 40° on both the eastern and western continents, while in summer it lies everywhere well to the north of + 70°. On the other hand in the southern hemisphere where the insolation is practically identical, but the polar cap is much smaller, the northern limit of isotherm 32° ranges only between latitude — 55° and — 68° throughout the year.

Tropical and even equatorial frosts near the sunrise terminator, have been several times recorded on Mars. All of these results lead us to conclude that the mean annual temperature of the planet as a whole is below the freezing point, as compared with a temperature of 59° for the Earth. Perhaps if we say that the mean equatorial temperature of the Earth is 80°, and that of Mars 40°, we shall not be far out of the way. This latter figure differs but little from that of Nova Scotia and Sweden, although their annual range of temperature is of course far greater. On the other hand the results, based on mathematical computations of the solar radiation, which make the mean temperature of Mars in the vicinity of — 40°, serve only as a warning, that we must fit our theories to our facts, rather than as in days of old, make statements or guesses to fit our theories.

The new polar cap appears to be formed by a succession of uniformly distributed frosts, rather than by local snowstorms, and as the planet approaches the Sun, these frosts become less extended than at first. The most wide-spread frost recorded by Lowell in 1907 occurred on

Sept. 31. The first and most extended one of the present year fell on Sept. 36. Both reached to the same latitude + 50°.

It seems a little surprising at first that the earliest snowstorms should not always, as in 1918, include the polar cap. This may perhaps be explained as follows. As is well known, at the time of the summer solstice, the point on the Earth which receives the greatest amount of heat from the Sun theoretically, is the north pole. As we proceed southerly to latitude + 60°, less and less heat is received. From thence to + 40° the heat increases, and then from there to the Antarctic circle the heat, or insolation as it is called, falls off to zero. This explains why cities in the latitude of New York in summer are so much hotter than those near the equator. The reason our polar regions are so cold, in spite of the high insolation, is on account of our huge ice cap. This does not apply so markedly on Mars, where the cap sometimes entirely disappears, as it did this year. Taking the insolation at the equator at the equinoxes as unity, Lowell finds for Mars, for the northern solstice, the value at the north pole to be 1.278, at latitude + 60° 1.154, at latitude + 44°.5 1.163, and at the equator 0.913 (Lowell Bulletin, No. 30).

Lowell did not apparently allow for the changing distance of the planet from the Sun, which would make a very considerable difference in these figures, but would affect them all alike. After the solstice the insolation at the pole decreases, while the northern minimum moves southward. At some date therefore, the whole northern portion of the northern hemisphere receives a nearly equal amount of heat from the Sun. We now find that it also has a nearly equal temperature, since we learn that snow may fall and melt in any latitude north of + 40°. Lowell finds for this date $\odot = 130°.2$. This corresponds to M. D. July 56. The Martian atmosphere seemingly somewhat delays the attainment of these equable conditions.

Throughout this extended region, the night temperature in August would appear to be below 32° Fahr., while the day temperature, as shown by the rapid melting, is above it. The snowstorms appear to mark the turn of the atmospheric circulation of the planet from southerly back to northerly, the cold winds of the north meeting the moisture bearing winds from the south, which finally replace them. The light frosts succeeding, imply an absence of cloud by night as well as by day. If we knew as much about the varying size of our own polar caps as we do about those of Mars, we could tell whether any similar phenomena obtained in our own polar regions. It seems unlikely, but possibly something might be learned, now that we know what to look for, by studying the meteorological records of polar explorers. Farther south, in our northern states, we know that our autumnal storms accompanied by high winds and heavy rainfall often begin about the last of September, but that October is usually sunny. It would appear that on Mars, for the northern hemisphere, immediately after the vernal equinox is the wettest portion of the year, and that the southern moisture begins to reach the northern pole just before the autumnal, without waiting for the canals. It is a matter of interest that snowstorms like these have only been recorded at the north pole,—never at the south.

Mandeville, Jamaica, B. W. I.
October 1, 1920.

THE LIMIT OF THE ASTRONOMICAL TELESCOPE.

By G. A. SHOOK.

(Continued from page 595, Vol. XXVIII.)

PART II.

THE EFFECT OF MAGNIFICATION.

The limit of resolution, or the angle that separates two objects that can just be distinguished as two, depends upon the aperture of the objective lens and cannot be increased by any combination of eyelenses but it may be diminished, however, if the magnification is not sufficient.

While the magnifying power does not depend upon the diameter of the objective or the diameter of the eye-lens, as is well known, but only upon the ratio of their focal lengths, *the ratio of the diameters of these two lenses does depend upon the magnifying power.*

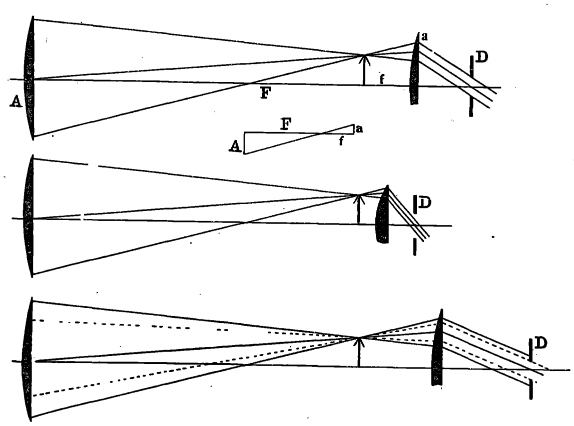

FIG. 1. Rays of light through the eye-piece; when the magnification is correct, when it is too high and when it is too low.