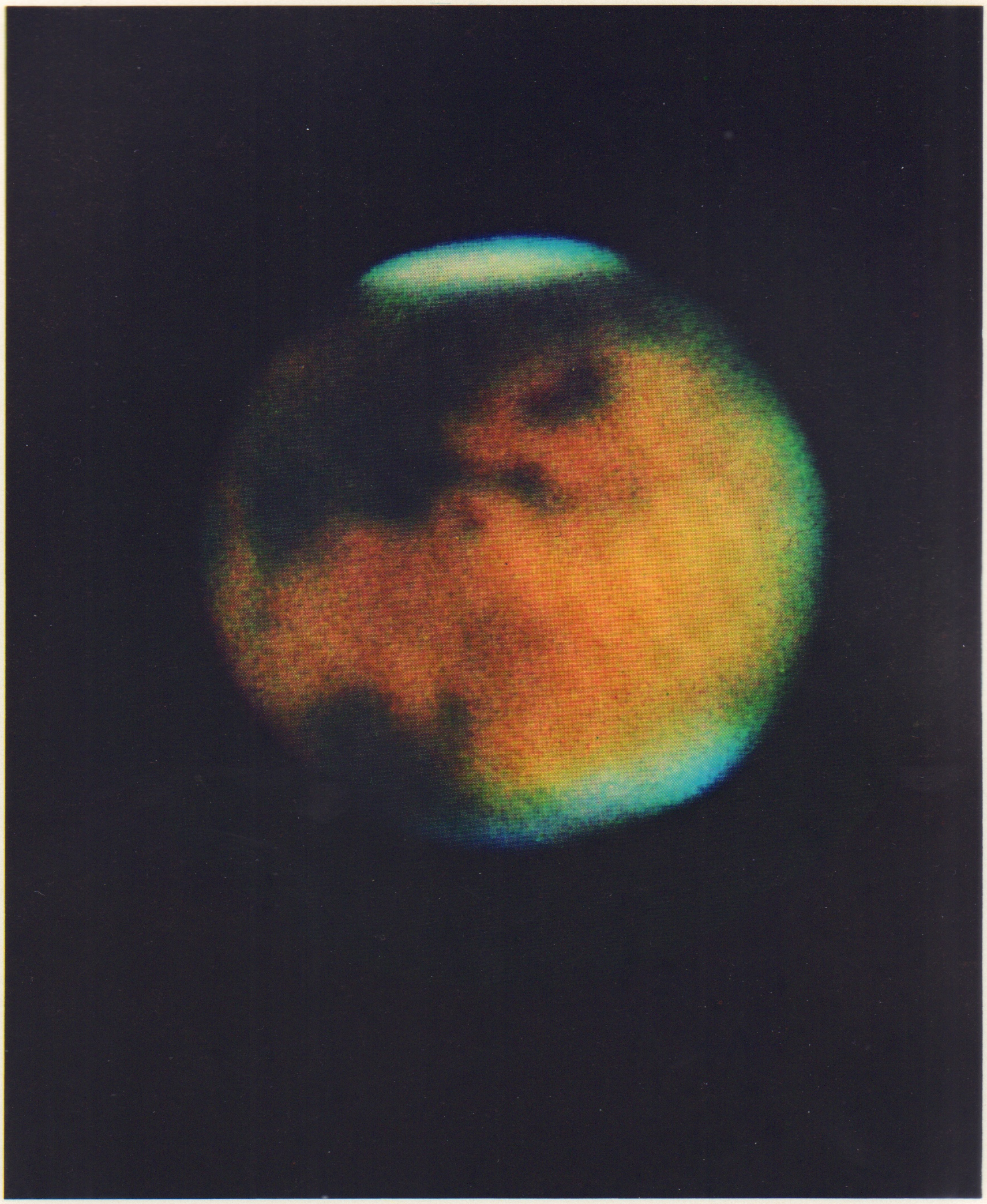
MARS

EARL C. SLIPHER

♂

THE PHOTOGRAPHIC STORY

MARS



A COLOR PHOTOGRAPH OF MARS *produced by the well-known Kodak Dye Transfer Process from a tri-color set of black and white separation negatives taken with the 27½-inch telescope alternately through blue, yellow-green and red transmission filters. Original photographs were made on July 4, 1954, by the National Geographic Society-Lowell Observatory expedition to the Lamont-Hussey observatory, Bloemfontein, South Africa. (The repeated copying of this photograph in the reproduction processes has greatly increased the color contrast.)*

The Photographic Story of

MARS

by

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♂

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FOREWORD

Less than two years after the short hop of the first airplane flight at Kitty Hawk, E. C. Slipher began making photographs of the planets at Lowell Observatory. Within the year of his most recent observations (1961), a space probe passed within 62,000 miles of Venus. As this book goes to press other probes are planned which are intended to pass even closer to Venus and Mars. Between these epoch-making events the author has carried on a continuous visual and photographic study of the brighter planets.

In accordance with a tradition established by the work of Percival Lowell, the founder of the Lowell Observatory, Slipher has devoted most of this effort to the study of the "Red Planet".

The value of his unique photographic record of Mars stems from his ceaseless effort and meticulous care. One must not think, however, that the results are based on these qualities alone. When his highly trained eye perceived the unusual, he made every effort to obtain a permanent photographic record and to follow the event throughout its life history. Although much is unavoidably lost in reproduction, the quality of the plates contained in this book attest to his photographic skill. Slipher was the first to make photographs systematically in different spectral regions and the first to discover the advantages of superimposing a number of images obtained under nearly identical conditions. Above all, he was the pioneer who recognized many important changes on Mars.

Many of his photographs have been published in textbooks and scientific journals and many more have been given to anyone who requested them. Although the great majority of the photographs presented here were obtained by the author, he has included some of the best obtained by other investigators.

This volume is a monument to the lifetime effort of a dedicated astronomer. He has doubtless lived on terms of intimacy with the planet Mars as has no one else. The accumulated evidence serves as a very solid foundation for his carefully considered conclusions.

In the years to come the surface of Mars will doubtless be photographed at close range. Such photographs can then be compared with others made from the Earth's surface at the same time. The interpretation of the latter can then be more precisely made and the historical record provided by the present reservoir of photographs should take on added importance.

In organizing the material for this book we have attempted to satisfy the requirements of two types of readers: the general reader and the specialist.

The background information contained in the opening chapters should provide the general reader with sufficient information to appreciate the photographs, to understand their descriptions, and to evaluate the author's conclusions. On the other hand both astronomers and scientists in crossed disciplines who are interested in space research, should find food for thought not only in the photographs and the general conclusions, but in the many technical details which must be considered before accurate conclusions can be drawn. The description of the changes in the Martian seasons, by one who has witnessed so many, should interest everyone with some measure of curiosity about Mars.

There are many facets to each phase of the problems encountered in studying a whole planet; the same facts therefore can be important background for several problems. Consequently, the perceptive reader will often encounter a repetition of facts in more than a single connotation.

John S. Hall, Director
Lowell Observatory

PREFACE

Percival Lowell founded his observatory at Flagstaff, Arizona in 1894 primarily to study the bodies of our solar system. He was especially interested in the properties of the planets and sharply focused his attention on Mars.

He hadn't observed very long before he began to recognize the earth-like character of the planet. Impersonal photographs became necessary to supplement and corroborate his visual observations. Slow plates, unsuitable emulsions, poor color filters, and inadequate camera equipment resulted in sub-quality pictures in the early oppositions. But by 1905 promising photographs were being obtained. Photographic techniques had so improved by the more favorable 1907 opposition that more than 18,000 useful photographs were secured. Since then, 27 oppositions of Mars have been observed and photographed. A vast collection of facsimiles and information has been amassed. This volume attempts to bring to the printed page, many reproductions of these photographs, as well as a comprehensive analysis and interpretation of the results.

The observations presented here have been made with various telescopes such as: the Lowell 24-inch refractor and 42-inch reflector; the 18-inch Amherst refractor used by the Lowell expedition to the Andes in 1907; the 27½-inch Lamont-Hussey refractor of the University of Michigan at Bloemfontein, South Africa. Photographs kindly supplied by other observers were made by Jeffers with the Lick 36-inch refractor; by Finsen with the 26½-inch refractor at Johannesburg, South Africa; by Humason with the 200-inch Palomar reflector; and by Leighton with the 60-inch Mt. Wilson reflector.

In order to obtain the most advantageous lookout point on Earth from which to study Mars various expeditions have gone to our south-

ern hemisphere. In this connection we are deeply grateful to Amherst College for the loan of its excellent refractor which was transported to Chile in 1907; and a special debt of gratitude goes to the University of Michigan for the use of the 27½-inch in 1939 and for its exclusive use from 1954 to 1957.

Our grateful thanks are here tendered to the many officials of national and local governments who so generously assisted our various expeditions by providing special trains and special provisions for transporting our telescope and equipment in Chile and Peru in 1907; and to the various officials of the Republic of South Africa and the city of Bloemfontein for valuable assistance to our expeditions there in 1939, 1954, and 1956. And we are especially indebted to the various members of the staff of the Boyden Station Observatory, Bloemfontein, for many valuable aids.

The persons who have sometimes assisted in the observations, the photography, the compositions and countless other ways are too numerous to mention individually but to all of them I am deeply grateful. Special thanks are due, however, Professor H. D. Curtis of the University of Michigan who opened the way to the first use of the Lamont-Hussey telescope in South Africa; to Dr. R. A. Rossiter who gave so much time and help in South Africa in 1939; and to A. P. FitzGerald, O. B. E., Belfast, Northern Ireland, who gratuitously and willingly worked for many months during the 1954 expedition.

Grateful appreciation goes to the National Geographic Society for jointly sponsoring our last two expeditions to Lamont-Hussey Observatory at the favorable oppositions in 1954 and 1956 and for their loan of the services of Donald McBain in printing and assistance in arranging many of the photographs.

We are also very grateful for contractural assistance from the Cambridge Research Laboratory and the Aeronautical Chart and Information Center of the United States Air Force, which has made possible the publication of this study of Mars.

Of course the author also owes a lasting gratitude to the present Director, John S. Hall and to the various members of the staff of the

Lowell Observatory during the times of these observations for their encouragement and suggestions.

The text is illustrated with 511 photographs, maps and charts dealing with physical properties of Mars and its atmosphere, which includes material furnished through the kindness of other related observations from Mount Wilson-Palomar, Lick and the Republic of South Africa observatories.

August 6, 1962
E. C. Slipher

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CHAPTER I

General Information about Mars

The planet Mars has been known to man since prehistoric times. It is sometimes fainter than Deneb and at other times brighter than Sirius. Its distinctive ruddy color makes it easy to distinguish from other objects. It is the fourth planet in distance from the Sun, and except for Venus, comes nearer Earth than any of the others. When nearest to us it shines with a brilliancy exceeding any of the others except Venus.

Mars is next to the smallest in size, being larger than Mercury only. Its diameter is 4,200 miles, a little more than half that of Earth. The polar flattening is very small, yet slightly greater than Earth's, being 1/190 of the diameter. The planet's surface amounts to a little more than one-fourth that of Earth.

The mass of Mars, as determined from the motion of its satellites, is approximately one-ninth that of Earth; the average density is about three-fourths. Someone weighing 100 pounds on Earth would weigh only 38 pounds on Mars, its surface gravity being only $\frac{3}{8}$ that on Earth.

Like the Earth, Mars is surrounded by a considerable atmosphere. Proof of its existence has been secured repeatedly during the last half century. The direct visual, photographic, and radiometric studies have disclosed it in different ways.

An important characteristic of Mars, and one which is involved in almost all planetary problems, is the reflecting power of its surface, or albedo. Albedo is defined as the ratio of the total amount of reflected light to the total incident light. In everyday life we habitually identify objects, although we may be unaware of it, as much by their brightness and color as by their other attributes. In a similar way, our recognition of the various features and phenomena of a distant planet may be influenced quite as much by their brightness and color as by their form and position.

The average albedo of the Martian surface for visual light is 0.15; that is, Mars reflects only about 15 percent of the sunlight that strikes it. The remainder is absorbed and goes to heat its surface. This albedo is a little more than twice that of the Moon or Mercury and about one-fourth that of Venus, but is still comparable with that of terrestrial soil or fairly dark rocks. Earth, on the other hand, because of its dense and more clouded atmosphere, reflects nearly three times as much incident sunlight as does Mars, its albedo being about 40 per cent. We see, therefore, that a much larger percentage of sunlight that strikes Mars is absorbed and goes to heat its surface. This apparently explains why Mars, although much farther from the Sun than Earth, is often warmed to a surface temperature well above freezing.

Gifford's (1952) reductions of over twelve hundred radiometric measures by Lampland at the oppositions from 1926 to 1943 show a number of areas whose maximum surface temperatures ran from 30°C (86°F) to 43° C. Radiometric measures by Sinton and Strong (1960) generally confirm these results. They found: "The maximum temperature at a favorable opposition for a desert area near the equator of the planet appears to be close to 25°C, and for a dark area it is about 8° hotter."

Since great bodies of water are lacking, on Mars, the solid surface does not store much heat and the diurnal fluctuation of surface temperature is greater than on Earth. The derived temperatures for Mars are for the solid surface and not the atmosphere. The temperature of the air above is probably very much lower. Terrestrial temperatures as ordinarily quoted on Earth, are for the atmosphere. Ground, or ocean, values are higher. On Mars the soles of one's feet might be warm while his ears and face were freezing.

The mean distance of Mars from the Sun is about 141,500,000 miles, and it moves in its orbit at a mean speed of 15 miles per second. Its orbit is the most eccentric (0.093) of all the planets except Pluto

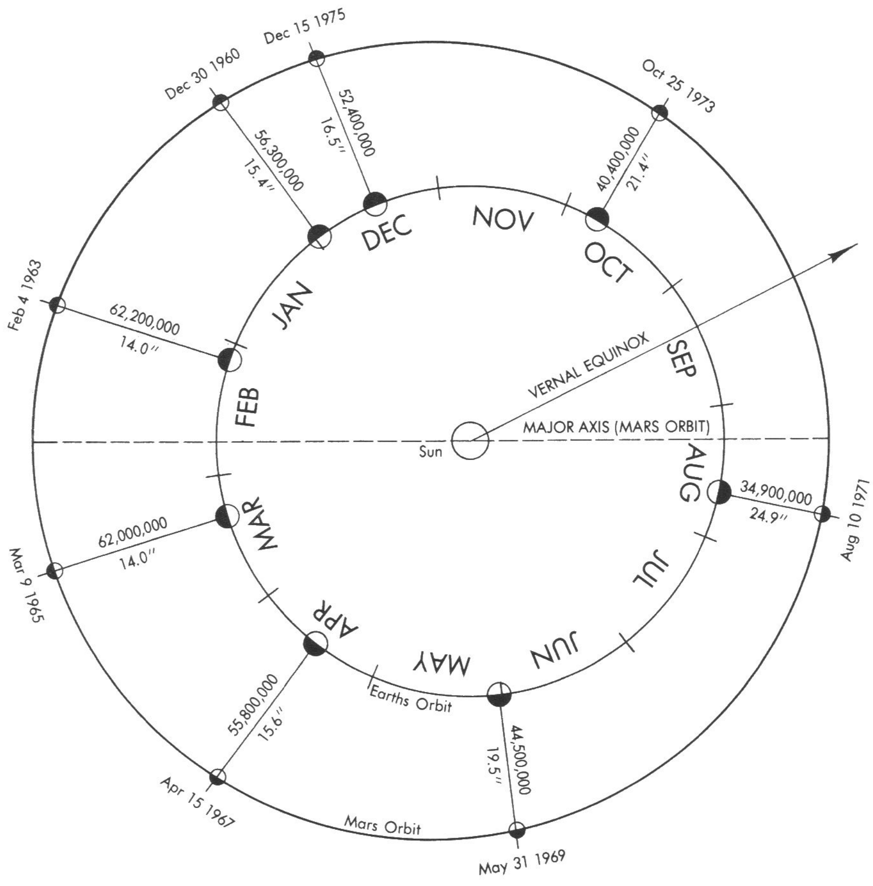


Figure 1. *Diagram of the orbits of Mars and Earth. The next most favorable opposition will occur on August 10, 1971 when the two planets will be separated by 34,900,000 miles.*

and Mercury; as a consequence, its distance from the Sun varies between 154,500,000 miles and 128,200,000 miles. This variation in solar distance is an important factor in explaining differences observed in the seasonal variation of the planet's snow caps and other phenomena. Its distance from Earth also varies greatly from 34,600,000 miles to 248,000,000 miles; this variation causes the apparent size of the planet's disk to range from 25″.1 to 3″.5 or a range of 50-fold in angular area. A disk with an angular size of 25 seconds of arc would appear as large as a dime (18 mm across) at 500 feet. The relative orbits of Mars and Earth are shown in Figure 1.

When Earth is approximately in line with Mars and the Sun, Mars is said to be in opposition (the difference in longitude of Sun and Mars is 180°). At times other than opposition Mars has gibbous phases like the Moon before and after full. The maximum amount of phase (47°) occurs when Earth is at its greatest angular distance from the Sun as seen from Mars. When viewed in the telescope at such times, Mars presents a disk which is strikingly gibbous, like the Moon three or four days from full.

Mars is farther from the Sun than Earth and therefore requires a longer time to complete its orbit about the Sun, its period of revolution being nearly twice Earth's, or 687 days.

The relation between the periods of revolution about the Sun of Earth and Mars are such that the two planets pass each other on the same side of their orbits only once every two years and one and two-thirds months. If the close approach occurs when Mars is at its nearest point to the Sun (at perihelion), then the distance separating them is the minimum, about 34,600,000 miles. These exceptionally favorable approaches occur once about every 15 years. Similarly, at those oppositions when Mars is farthest from the Sun, the least distance between the planets becomes 61,000,000 miles. At these unfavorable oppositions the apparent diameter of the planet's disk is only 13″.8, as compared with 25″.1 at the most favorable ones. In addition to appearing twice as big, at some oppositions Mars appears 4½ times as bright as at others. At the favorable oppositions it is always the southern hemisphere which is turned to our view; at the unfavorable ones, it is the northern. Photographs of Mars at such times are shown in Figure 2.

We next want to know how the two hemispheres are presented to Earth for our study. The tilt of the planet's axis is only slightly greater than that of Earth, so that the Martian seasons are nearly the counterpart of our own. The plane of Mars' orbit lies nearly in the plane of that of Earth, the angle between them being only 1°51′. As a result of this small inclination, the axis of Mars, when it is at opposition, shows nearly the same tilt to Earth as it does to the Sun.

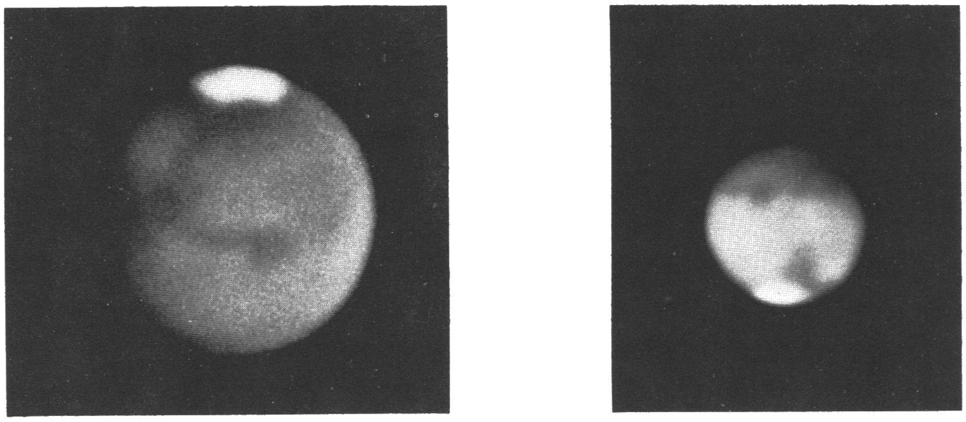


Figure 2. *Photographs of Mars showing relative sizes at most favorable and least favorable oppositions. That on the left was taken on August 2, 1924, that on the right on January 12, 1931.*

Consequently, as the Martian poles are alternately tipped toward the Sun in summer, they are at the same time tipped toward Earth. In the course of time, then, we see first one pole and then the other tilted to us at an angle varying up to 25°, which affords us an opportunity to study the Martian polar regions. At the time of the winter solstice, an average of about 50° of the Martian surface which is centered on the winter pole receives no sunlight and is completely hidden from view. At the same time, a like area about the summer pole is constantly exposed to the Sun and to our view. The apparent tilt of the axis of Mars is virtually the same to all observers on Earth. Even if two observers were at the opposite poles of Earth, their angle of view of Mars would differ by less than one minute of arc.

When Mars is nearest the Sun, it receives 43 per cent more solar energy than when it is at its maximum distance. Summer in the southern hemisphere always occurs when Mars is nearest the Sun, or at perihelion, and summer in the northern hemisphere occurs when it is farthest from the Sun, or at aphelion. Hence, the amount of light and heat that the two hemispheres receive during like seasons is very different. According to Kepler's law, Mars moves fastest along its orbit when nearest the Sun. Consequently, its southern hemisphere has shorter but hotter summers than does its northern hemisphere.

The amount of solar energy each hemisphere receives, is conspicuously portrayed by the difference in the extent of the snow caps in winter and their melting in summer. Because of the length of the Mars year and the orbital eccentricity of the planet, its seasons are longer and more unequal than those on Earth. Reckoned in Earth days these become: Spring, 199 days; Summer, 183 days; Autumn, 147 days; and Winter, 158 days.

We have learned the length of the Martian day from the punctual precision with which its markings have been observed to pass across the disk during the last 300 years. These rotations have been watched so long and well that we know its day to a few hundredths of a second. It is interesting to note that the length of the Martian day closely matches our own; it is about 40 minutes longer than ours. Thus Mars undergoes the vicissitudes of day and night just as does Earth.

Since the rotation of Mars is only about 40 minutes longer than that of Earth, an observer who sees a given marking near the center of the planet's disk at a certain hour on one night will find that it comes to the same position about 40 minutes later on the next night. Thus, the regions slowly fall backward night after night and new ones come into view until, after a period of about 40 days, the whole of the planet's circumference has been visible. Observers, on the opposite side of Earth, of course, may see the opposite side of Mars on any given date. In orderly rotation the features first appear at the right limb (in the inverting telescope), travel across the central meridian of the disk and vanish at the left border. The motion is so swift that it can be noticed in a few minutes.

The seasons and the alternation between day and night, therefore, should certainly make us feel at home on Mars. We would find climatic zones corresponding closely in general relationship to the tropical, temperate, and arctic zones on Earth, and across these zones the seasonal changes would occur.

Mars has two tiny moons, discovered by Asaph Hall in 1877 with the 26-inch telescope of the U. S. Naval Observatory at Washington. To see them requires a telescope of moderate power. Their diameters

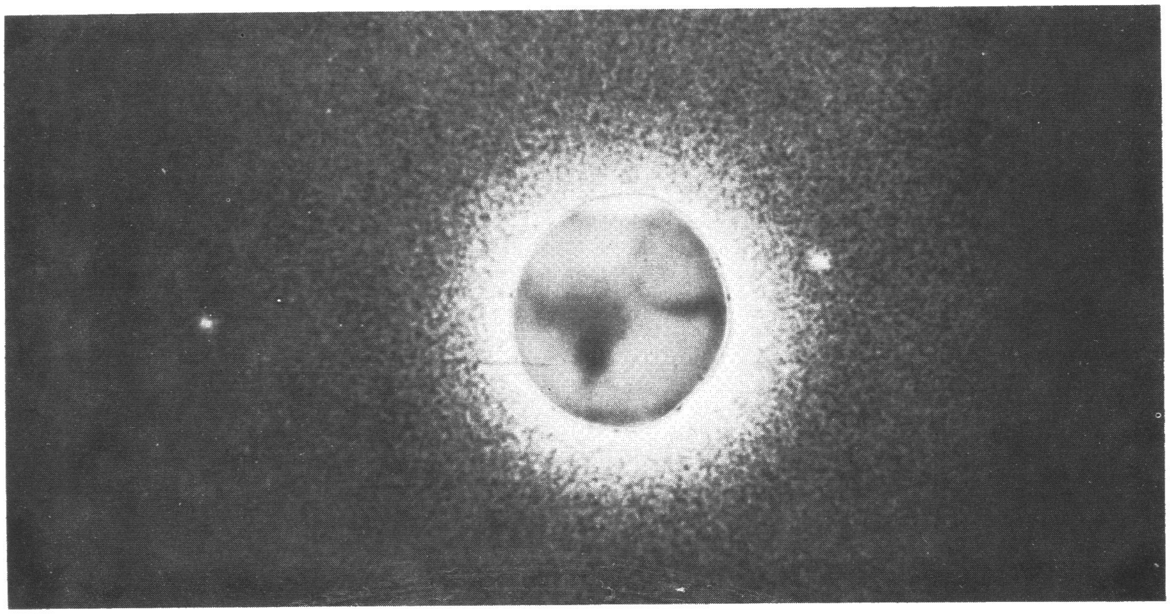


Figure 3. *Satellites of Mars photographed August 17, 1924. Phobos is close to the planet at the right. Deimos is considerably fainter and farther from the planet at the left. (Image of Mars printed separately.)*

are believed to be about 7 or 8 miles for Deimos, the outer one, and about 14 to 18 miles for Phobos, the inner one.

Their orbits, too, are the smallest of any bodies of the solar system and appear to be exactly circular with their planes in the Martian equator. The outer one (Deimos) revolves in a path 14,600 miles from the center of Mars in 30 hours and 18 minutes, and the inner one (Phobos), in a path only 5,800 miles from the center of the planet in 7 hours and 39 minutes. Thus, Phobos is the only known satellite that revolves in a period shorter than that of its planet. Its excessively short period causes Phobos to rise in the west, hasten across the Martian sky and set in the east after about 5½ hours. Three times in the course of a Martian day Phobos rises and sets. Indeed Asaph Hall, when he first observed an inner satellite, at first thought that there were two or three inner moons. Deimos does not do this; it rises in the east like the stars, but its orbital motion eastward among the stars is so nearly equal to its westward motion, imparted by the rotation of Mars, that it is nearly 132 hours (5½ days) between two successive risings.

The satellites' nearness to the planet also produces a great difference in their apparent size as seen when at the horizon and at the zenith. The inner one appears nearly half again as large at the zenith as at the horizon, where it is seen half the planet's diameter or 2100 miles farther away.

Deimos, being more distant, shows a less marked variation in apparent size.

To a man on Mars, Phobos would appear about half as large as does the Moon to us and Deimos would be only 0.07 (approximately one-fourteenth) as large. If there were total eclipses of the Sun by Phobos, the black spot on the disk of Mars should be visible in the best telescopes. None has yet been observed despite some 1150 eclipses per year because the satellite is too small to occult the Sun.

Because of the great contrast between the bright disk of Mars and the light of its satellites, it is difficult to photograph all three simultaneously. (Figure 3).

TABLE 1

Physical Data for Mars

Mean Distance from the Sun	141,500,000 miles
Intensity of Solar Radiation, Earth = 1.00	0.43
Eccentricity of Orbit	0.09
Sidereal Period	687 days
Rotation	$24^h37^m22^s.62$
Distance from Earth in miles	34,600,000 to 248,000,000
Apparent Angular Diameter	$25^\circ.1$ to $3^\circ.5$
Mean Albedo	0.15
Mass, Earth = 1.00	0.108
Mean Diameter	4200 miles
Density, water = 1	3.95
Mean Density, Earth = 1.00	0.72
Surface gravity, Earth = 1.00	0.38g
Inclination of Plane of Equator to Plane of Orbit	$23^\circ.57'$
Oblateness	1/190
Magnitude at Mean Opposition	−1.85
Velocity of Escape, miles/sec.	3.2

CHAPTER II

Observed Surface Features

Mars differs from other planets in showing strong, fixed markings. We do not need to imagine; we can actually observe what takes place.

To the eye the planet appears distinctly reddish-yellow, owing to the predominant color of the "desert" areas, which embrace about two-thirds of the surface. The remaining one-third to two-fifths of the planet consists of darker areas of greenish tinge, as the color photographs show; the nature of these has aroused much study and discussion. The dark regions show seasonal and secular changes in intensity, color and form which could lead to valuable information about the properties of the planet and its atmosphere.

Among the different classes of markings detaching themselves from this background, we recognize first the extended dark areas, generally designated by the term "mare". With irregular and partly connected outlines, the maria cover a large portion of the southern hemisphere. To a much lesser extent we find more or less isolated dark areas in the northern hemisphere, such as Mare Acidalium and Aquae Calidae. In a large refractor they appear to have a distinctly blue-green tinge. Visual color estimates are perhaps enhanced by the contrast with the normal surface, but it is independently supported by a comparison of photographs taken with the red and yellow filters. If both are taken on the same plate and if the exposures are such as to give equal intensity for the normal surface, then the dark areas are darker on the red images than on the yellow ones. Our "yellow" photographs (5000-5850A) are really composed of green and yellow light.

On close examination, the photographs of the larger dark areas (especially those with a red filter) reveal a great amount of structure, consisting principally of dark spots and bands and lighter areas. These are readily confirmed by visual observations. Changes in intensity exclude the old interpretation of the dark areas as regions covered by deep water. Spectroscopic observations indicate that the amount of water on Mars must be far less than that on Earth.

Boundaries of the dark areas usually appear quite sharp, especially the northern limits of M. Erythraeum, M. Sirenum, M. Cimmerium and Sabaeus Sinus. In other places, however, the dark areas fade out at times in gradual transition to lighter areas without any very marked limits. Depth of shading also differs widely from time to time; the northern part of Syrtis Major, Tyrrhenum Mare, Mare Sirenum and Sabaeus Sinus, and in the north the Mare Acidalium, are generally the darkest. Between these and the normal surface practically every intermediate shading is represented.

There is still another class of markings which course everywhere through the Maria and the deserts, enmeshing nearly the whole surface of the planet — the unique canal-oasis network system of Mars. This wonderful Martian network has no counterpart on any other planet and is unmatched by any features in nature. Because of the artificial character of the markings they have become the most mysterious and yet the most discussed and most widely debated of all planetary features.

Observations of the planet through the years have recorded many changes in the intensity and form of some of the surface features. The accompanying photographs from time to time clearly show innumerable changes in the surface features and in the polar caps. Most of these changes occur in strict obedience to the Martian seasons, but many others, as will be pointed out, occur in an anomalous manner and must be considered as purely secular. The changes can be expected only in the presence of a Martian atmosphere.

Observational discrepancies and differences in interpretation often occur in studies of Mars. Our view of the Martian surface is a bird's-eye view. The markings are in a state of perpetual and bewildering fluctuation, the slower and more gradual ones partly through change in the illumination of the Martian air and partly through inherent change in the markings themselves. No single observation can be *exactly* repeated even by the same observer, since identical conditions recur only after a lapse of at least fifteen years. Therefore, peculiarities on Mars recorded by different observers or phenomena seen at different times are liable to produce preplexing problems when we come to compare them and unravel their meaning. Thus, one cannot rigorously check one observation against another, especially as regards the minute or faint details, except those that are made at the same identical hour.

Almost as soon as telescopic power gave the planet a recognizable disk, observers saw the poles capped with white. Very soon these were discovered to grow and diminish in unison with Martian winter and summer. In due time the observations proved that the caps diminished at the same rate and in the same identical manner every Martian summer. Their maxima and minima were the same each Martian year; they differed for each cap, the south one becoming larger than the northern one in winter, but smaller in summer.

One of the most striking seasonal changes in the dark markings of Pandorae Fretum is outstanding, chiefly because it is isolated (Plate X). When the Pandorae Fretum reaches its maximum darkening in Martian summer, it embraces an area of more than one million square miles. It then becomes not quite as large and dark as the Sabaeus Sinus paralleling it to the north. When it fades out, again in autumn-winter, the color of the surface where it was situated returns to virtually the same color and brightness as the surrounding bright regions and remains so until the next spring returns to the southern hemisphere again. By Martian summer, as the photographs reveal, it darkens again in the same manner. Careful scrutiny shows that haze or veiling by the Martian atmosphere plays no part in its appearance or disappearance.

The same is true of the summer darkening and winter fading that takes place in the southern parts of Mare Tyrrhenum, Mare

Hadriaticum and all the other markings which undergo this type of seasonal change. This peculiar behavior seems to indicate that whatever darkens the surface in summer completely disappears in Martian winter, or the area in question changes its color in winter to that of the surrounding bright regions.

A more or less isolated marking which undergoes remarkable secular changes in size and shape is the Solis Lacus, displayed in Plate XXXIV. Observations show with certainty that since 1892 this feature has undergone numerous changes, which at times doubled its dimensions and obviously altered its form. Interestingly enough, after undergoing a major change for a time, it returns again to its former size and shape. In the 1958 and 1960 oppositions, after suffering many alterations, it closely resembled its appearance in 1907.

On the other hand, the darkening of certain other areas, like the Sinus Gomer in 1924 and the new dark area near Nuba Lacus in 1954 and like the darkening of the Casius in 1903, is still present and appears to have established a certain degree of permanency (Plate XXXV).

Not all the changes on the planet involve darkening of the surface. The Laestrygonum Sinus had always been a v-shaped bay on the Mare Cimmerium until about twenty years ago. At that time the somber mare to its south turned bright like the desert, leaving the Laestrygonum Sinus isolated except for two or three short canals which connected it with the Cimmerium. It has remained so at all the succeeding oppositions. This is the only example, during the period covered by these observations, where a dark area has permanently disappeared.

The great development of the Nepenthes-Thoth system of canals since 1909, of course with certain variations, is another example of remarkable and unexpected change (Plate XXXV). This change, too, cannot be ascribed to strict seasonal change and must be explained as a secular variation.

Probably the most changeless feature on the planet is the Sabaeus Sinus, running nearly parallel to the planet's equator. This feature has shown no appreciable change in size and form, and only slightly in intensity, for more than fifty years.

The extremely ephemeral dark spots which have appeared on Mars from time to time, such as that in August 1909; the example at the mouth of Astusapes and Astaboras in May 1920; the dark spots which accompanied the great storm in July 1922; the dark area in Aethiopis in October 1926; and the numerous examples in August and September 1956 — these are all seemingly of a special type of markings of a common origin.

At the 1956 opposition the southern Noachis and northern Australe regions were frequented from August 29 to September 5 by a series of large shadowy dark areas which changed markedly from day to day (Plate XXVII). Extensive bright cloud areas had been present in this part of the planet from August 20 and had invaded most of the southern hemisphere when these mysterious markings began to appear near the denser cloud formations. On September 8 to 13 even parts of the bright desert in Thaumasia around Solis Lacus turned as dark as any markings on the disk (Plate XLVI). These spots changed form and position from day to day. All spots of this type except a weak one in Eden region vanished by mid-September, leaving the disk normal in appearance again.

The resemblance in color and intensity of these markings to the dark collar which hugs the melting cap, and their intimate association with dense cloud formations, naturally suggests moistened soil.

Although further study is needed, it seems reasonable to suppose that these temporary darkenings are due to the familiar process of moistened soil and their sudden disappearance to its evaporation — a quick process under the conditions on Mars.

At one time certain observers, including Pickering (1920), believed their visual observations revealed a shifting of the coastlines and other markings on the planet. But many latitude and longitude measures of nearly 50 salient points on the photographs from 1907 to 1960 have failed to disclose any appreciable change in their position during this period. So the configuration of the surface of the planet, except for temporary seasonal variations and a few minor new spots, remains unchanged.

Polarization measurements on Mars by Lyot (1929) suggest that the light areas (desert) may be volcanic ash, but near infrared spectographic measurements by Kuiper (1952) suggest some kind of igneous rock such as felsite. Both these observations suggest that the light areas may possibly be similar to a terrestrial desert with a dusty surface, and this interpretation is to some extent confirmed by the large diurnal variation in temperature which indicates a surface of low thermal conductivity.

CHAPTER III

Martian Polar Caps

The polar caps of Mars are generally the first features to catch the eye when the planet is seen in a telescope. Cassini saw them in 1666 and Huygens in 1672. Both recorded the cap at the south pole in drawings, and Cassini saw caps at both poles simultaneously. With the increased optical power of modern instruments the caps have been observed in detail repeatedly, until we now have a fairly satisfactory knowledge of them.

The limits between which the polar caps of Mars fluctuate are far greater than on Earth. Our own polar caps are much greater than we think; indeed we live in them a good part of the time. Our winter snows are part of the seasonal polar cap. In our northern hemisphere they cover the ground at sea level more or less continuously down to latitude 50°. Snow stretches far down on the western flanks of the continents; in the middle and eastern parts it extends ten degrees even farther south. Our polar cap becomes 90° across in both hemispheres during the winter seasons.

On Mars, at their winter maxima, the polar caps extend over a similar stretch of latitude, but the southern one is considerably the larger. In 1909, 1922, and 1954 the southern cap came down to latitudes 42°, 40°, and 44°, indicating that the breadth of the cap was 96°, 100°, and 92° respectively (Plate XV). The time was late February or early March on the Martian calendar. The cap was still without a sharp contour in each case, showing that it had not yet shed its winter haze. Again on December 18, 1960, with the southern hemisphere at its autumnal equinox and the northern hemisphere just entering its vernal equinox, both caps came down below latitude

40°, in each case implying a breadth of 100° of Martian latitude for the caps.

To Sir William Herschel we owe the first study of the change in aspect of the polar caps. This eminent observer noted not only that the caps varied in size, but that the variation took place with a regular rhythm following the march of the seasons. For more than 200 years this seasonal waxing and waning of the polar caps has been observed. Studies of the south cap reveal that it has receded to the pole in unison with southern summers at nearly the same rate every year. Measures of the 1798 observations show that it then reached the same size at the Martian summer solstice as it has in recent years.

The polar caps differ greatly in size. At the vernal equinox the south snow cap is 70° in breadth; the northern one measures only about 53° at its maximum. This difference seems readily explained because the southern cap is formed during 382 days of autumn-winter when the planet is at aphelion, while the northern cap is laid down during only 305 days of autumn-winter while the planet is at perihelion.

The caps also differ widely in their rate of melting of the snow and ice of which they are composed. The southern one melts much faster during the shorter, hotter summer when the planet is near perihelion; the northern cap melts much more slowly during the long cool summer when the planet is at aphelion, never shrinking to a smaller compass than 6° in breadth.

Melting of the polar caps is intimately related to other phenomena observed, especially the summer darkening of the Martian surface. The rifts which divide up the caps, the brighter and more persistent areas, and the isolated fragments are always observed in the same places on the planet. A constant recurrence is the fact that the last remnant of the south cap is not centered over the pole, but is located some 6½° away in latitude 83½° and longitude 30°. The northern cap is more nearly centered on the pole, being only about one degree away in longitude 290°.

The most prominent and best observed example of an irregular structure recurring repeatedly in the melting south polar cap is the Mountains of Mitchel. Since their discovery in 1845 by Mitchel at Cincinnati Observatory, they have always appeared in the same place and always on the same seasonal date, June 3. In 1877 Green (1892) saw them as isolated bright points in latitude -73° and longitudes 267°, 282°, and 293°. Brett also saw them in 1877. In 1892 and 1894 they were noted by C. A. Young, W. W. Campbell, Schaeberle, Barnard, Lowell and others. These repeated, regular observations definitely prove that the cap reaches the same size on the same Martian date each year.

Every observer of Mars is well acquainted with the fact that the polar caps in waning do not preserve an exactly circular outline and are not of equal intensity in all parts. The edge is sometimes exceedingly irregular, owing both to dark indentations and bright projections. Portions of the caps may even become detached and remain as isolated bright points for several weeks. Dark markings and excessively bright areas within the cap are also common facts of observation. Melting of the caps is certainly affected by local conditions, and it is very important to know whether the local conditions at any point are such as to retard or accelerate the melting. For example, local conditions undoubtedly underlie the fact that the excessively bright areas within the cap, the bright projections on the edge, and the isolated bright spots just outside are in the same places at successive oppositions.

The polar caps seem to hold a key to the matter of the presence of water. Water is indicated too in the dark bluish band which tightly hugs the border of the melting polar caps. First recorded by Flagstaff observers in 1894, this band has been seen at the proper season ever since. It has been photographed countless times since 1907, when photography of the planet came into common practice at Lowell Observatory.

Lowell (1896) discussed this peculiar band which, although easily visible at the right time, has less often been distinctly noted in observations elsewhere. That it is seldom remarked upon by other observers is also very strange because a similar band was seen by Beer and Madler as long ago as 1830.

The band around the southern cap is most pronounced in tint where it is widest — notably in two spots where it expands into two bays, one in longitude 270° and another in 330°. It contrasts with adjoining darker areas in both tone and tint and is both darker and bluer. Pickering in 1896, using a polariscope, found that the light coming from these bays was polarized. To polarize the light it reflects is a property, as we know, of a smooth surface such as that of water.

The most significant fact about the band is that it keeps pace with the polar cap's retreat toward the pole, thus showing itself to be not a permanent marking of the planet's surface, but a temporary one dependent directly upon the waning of the cap. Its behavior suggests that it consists of water at the edge of the cap, which is due to the melting of the polar snow.

Not only do these bands conform to the cap in position, but they do so also in size. As the snows dwindle, the blue band shrinks in width to correspond. By Martian August the band becomes a barely discernible thread drawn around the tiny white patch which is all that remains of the great snow cap of earlier months. If the snow cap entirely disappears, as it did in 1894, the encircling band also disappears.

This dark collar was once thought by some to be an illusion due to a contrast effect arising from the brightness of the polar cap. But it can be readily observed with a red filter which reduces the snow cap to the same brightness as that of the rest of the surface of the planet.

Since the surface temperature of Mars is certainly much higher than that of its air, the dark collars can best be explained as moistened ground. This explanation supports the view that actual melting takes place rather than mere sublimation. Temperature measurements too strongly indicate that the melting of the snow is due to the heating of the ground at its edge.

The extensive and rapid melting of the caps shows that their

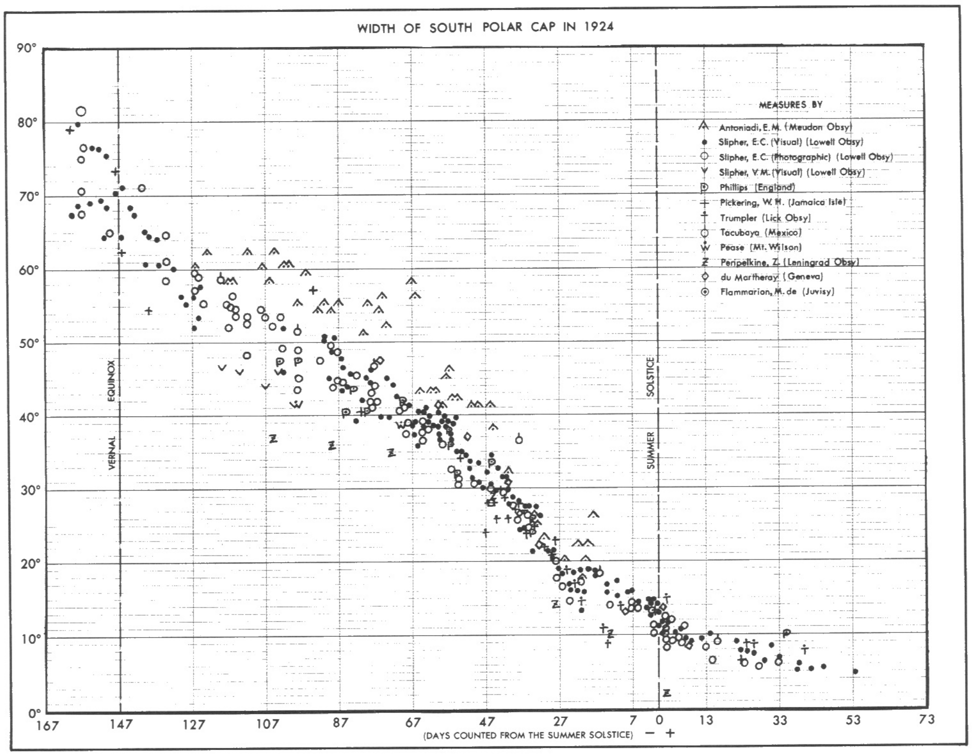


FIGURE 4. *This figure shows all the available observations (first mapped in 1925) of the size of the southern polar cap of Mars during its spring-summer recession at the favorable opposition (the nearest ever possible) in 1924. These observations embrace the Martian season from the vernal equinox to 54 days after the summer solstice of the planet's southern hemisphere. Without exception all the observations by more than a dozen observers working at nine different observatories, including a six-month series of photographs, reveal that the reported retardation in the melting of the cap in 1924 by Antoniadi was not observed elsewhere. Thus the observations indicate with the utmost clarity that the recession of the cap in 1924 was essentially normal.*

water content is small, a fact which points to a dearth of water on Mars. (The dearth of water is also shown by the aspect and behavior of the reddish regions of Mars which are shown to be deserts and by the character of the blue-green areas which are definitely not seas.)

Careful studies have been made of the recession of the south cap by determining its size throughout the Martian spring and summer of the southern hemisphere at the various oppositions. (See Figures 4 and 5.)

Some observers have thought their observations showed vari-

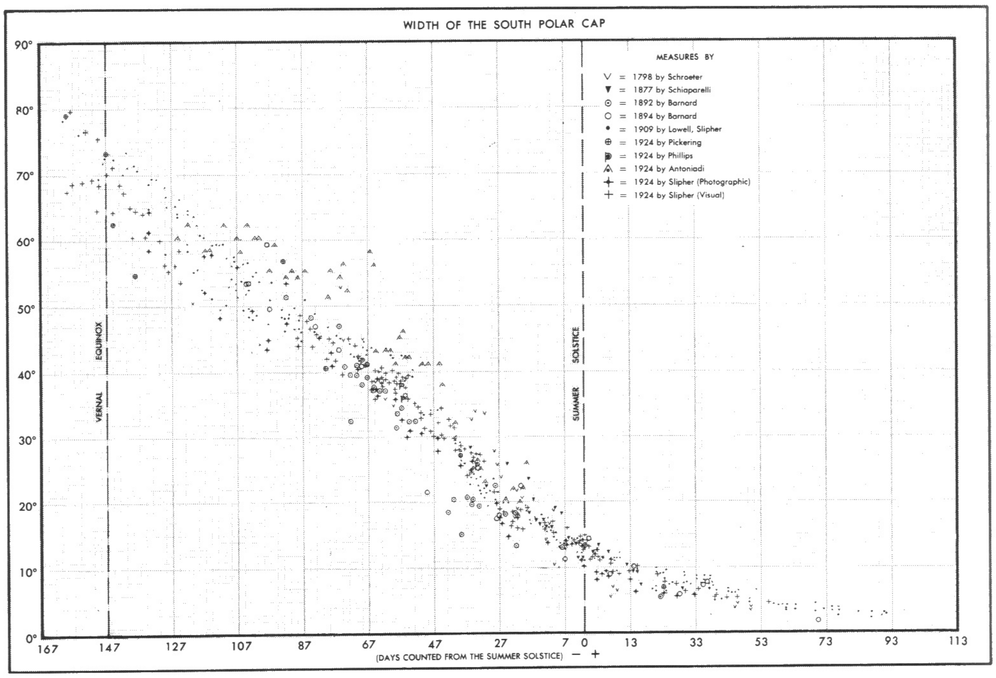


FIGURE 5. *This figure shows the measured width of the south polar cap for various oppositions from 1798 to 1924, and embracing the Martian season from before the vernal equinox to the end of the old snow 94 days after the summer solstice. Other measures derived from drawings in 1781, 1783, 1815, 1830, 1845, and 1862 were checked with those shown here but no notable deviations were found other than accidental errors attributable to optical limits of the observer's telescope. The plotted measures shown in the chart agree very well indeed and the deviations in the measures by the same observer are of about the same order as those that occur between different observers. This study revealed no evidence of any irregularity in the melting of the south cap at any of these oppositions during this long period of observation.*

ations in the seasonal melting of the south cap. Antoniadi (1924) announced a marked retardation in the decrease of the south cap; all other observers at that opposition and the undeniable photographs showed a normal rate of diminishing (Figure 4). The cap reached the Mountains of Mitchel at the appointed date. De Vaucouleurs (1950) remarked: . . . "this regularity is not perfect and rigorous . . . alternatively, we can say that in certain years the polar cap is a little smaller than normal, as in 1939, or a little larger, as in 1941."

On the contrary, the photographs show that the snow cap arrived at the Mountains of Mitchel if anything a little earlier in 1941 than the mean date (Table opposite Plate XVI), and that the breadth of the snow at the date of the summer solstice in 1941 was slightly smaller than in 1939 as shown in Table 2 of this chapter. Consequently the photographs do not support this statement by de Vaucouleurs.

The agreement among the various observers as to size of the snow cap at the summer solstice is remarkable. Only the 1894 value by Lowell, Douglass and Pickering deviates much from the mean,

TABLE 2

Width of the South Polar Cap at Summer Solstice

Date	Diameter (Degrees)	Observations by	Deviation from Mean
1798	12°0	Schroeter	+0°2
1877	12.5	Schiaparelli	+0.7
1892	10.5	Barnard	−1.3
1894	11.9	Barnard	+0.1
1894	8.8	Lowell, Douglass, Pickering (mic. meas. cor. for irrid.)	−3.8
1909	11.0	Lowell, Slipher (mic. meas.)	−0.8
1924	11.0	Slipher (photo)	−0.8
1926	12.8	Slipher (visual)	+1.0
1939	13.0	Slipher (visual)	+1.2
1941	12.3	Slipher (visual & photo)	+0.5
1954	12.0	Slipher (visual)	+0.2
1956	11°5	Slipher (photo)	−0°3
Mean	11°8		

but their micrometer measures were corrected for irradiation of the snow and therefore gave a smaller value. The diameter of the south polar cap measured from the time of the vernal equinox to that of the summer solstice by many different observers is shown graphically in Figures 4 and 5.

Kuiper (1957) reported in connection with his observations on September 9, 1956, that the south snow cap "was known to have disappeared about a week earlier" and a new cap appeared on the 9th. This startling announcement, if left unchallenged, may later lead to great confusion about the behavior of the Martian caps, because it required the fall of a new snow cap within a few days of the summer solstice. It is significant that our visual and photographic observations every night at Lamont-Hussey, the photographs at Lowell, Finsen's extensive photographs at the Republic Observatory and the long series taken by Jeffers at Lick Observatory definitely recorded the cap all through this critical period when it was often heavily veiled by dust clouds from August 28 to September 17. They reveal that its size, form, and markings matched precisely those always displayed by the snow cap at the same seasonal date every Martian year. Although presented here for another purpose, the following plate numbers refer to photographs obtained on September 3, 4, 5, and 8 which reveal the cap; XLI, No. 5; XXXI, No. 6; XLI, No. 6 and XLVI, No. 5, respectively.

It has been known for a long time (since 1907) that we observe two distinct types of polar caps. The spring-summer cap is seen as a deposit on the planet's surface; the autumn-winter cap is a cloud mantle. Observation shows that there appears about the poles of Mars near the time of the autumnal equinox a great hood of dull white which usually varies much from day to day. These white patches are generally more prevalent on the morning limb of the planet. The white areas spread with the advancing winter and finally cover the whole area. On December 18, 1960 (Plate XV) at the time of the equinoxes they had already invaded parts of the temperate zones beyond the 40th parallel.

These bright bluish-white obscuring veils, although quite variable, persist throughout the autumn and winter and begin to disappear at the vernal equinox ending the cold season. The cloud canopy then begins to lift, revealing the true snow cap as white, bright, and large, although much smaller than the cloud cover, being only 70° across. Clouds leave abruptly. After the vernal equinox no polar clouds hide the snow cap. About the middle of spring, rifts appear in the snow cap gradually dividing the snow into a number of sections of unequal brightness. These same divisions and bright sections appear in the caps in the same places every Martian year. As Martian summer comes to an end, the process is reversed. White patches appear in the polar regions and a great hood again begins to obscure the pole.

This polar hood is largely impervious to violet light. It appears large and bright in blue light, while yellow and red light largely penetrate it. Consequently, the blue photographs may display a large cloud cap whereas the yellow and red ones may show very little, if any, of the polar mantle. In Martian spring the polar snow caps appear much the same in both violet and yellow photographs, presenting evidence that at that time the cap is largely a solid deposit on the planet's surface.

White patches have sometimes been sighted on the sunrise edge in the colder latitudes of the planet — brilliant spots which vanished in the early morning hours. The glint of these objects, their resemblance to the snow cap, the time and place of their occurrence, and their behavior have led to the conclusion that they are patches of morning frost. Early it was claimed that these white patches showed a strong preponderance for the light regions and rarely appeared over dark regions. Their location obviously suggested to the observer that the light regions were colder than the dark ones, a fact confirmed many years later by the radiometric observations of Coblentz and Lampland and by Strong and Sinton.

Favorite locations for these frost patches are the "islands" in the southern hemisphere of Mars where they make their first appearance around the end of Martian August or early September in latitudes -60° to -70° in places where the solar insulation is then at its lowest point for this latitude of the southern hemisphere. These morning frost patches were seen and photographed at Flagstaff between November 3 and December 6, 1911, and were fully discussed by Lowell (1915). On November 14, 1911, such a white spot stood out on the limb during seven and a half hours of observations as drawings, measures and photographs of the planet showed, but did not advance upon the disk by as much as two hours after sunrise. The frost therefore extended more than 107° in longitude.

Lowell (1915) showed by calculation that the latitude of these frost patches marked the place of minimum solar insolation at the time of their occurrence.

On the contrary, the general absence of frost or snow patches in the summer hemisphere during the period from Martian April to September implies that the surface temperature there remains generally much higher. Every aspect of the face of Mars supports this conclusion, and the radiometric measures made at Lowell by Coblentz and Lampland at the oppositions of 1922, 1924, and 1926 support in a general way this reasoning as to the temperature conditions on Mars and their relation to cloud formation.

Direct radiometric measurements of planetary temperatures were begun in 1922 with the 42-inch reflector at the Lowell Observatory by W. W. Coblentz (Bureau of Standards) and C. O. Lampland of the Observatory's staff. The two men repeated them in 1924 and 1926, and Lampland alone in subsequent years made many hundreds of temperature measures of Mars (1922, 1925, 1927).

These measures, made with thermopiles with the sensitive area only 0.12 mm in diameter, intercepted at close approaches of the planet only 0.01 part of its disk. It was therefore possible to measure the temperature of selected areas on the disk.

By introducing water cells or certain filters in the light path, they were able to separate the planetary from the solar radiation. These filters would absorb the energy at the longer wave lengths in the region where most of the planetary radiation lies. Temperature differences of the surface of the planet could in this way be determined with an accuracy of about 10° C.

Measurements at the 1924 opposition showed that the bright areas around the apparent center of the disk have a temperature of −10° to +5° C, while the contiguous dark areas have a temperature of +10° to +20° C. During the period covered by the observations, from July to September 1924, the temperature in the north polar region where winter prevailed remained fairly constant at −70° C; while in the south polar region where summer was advancing, the temperature increased to +10° C, and even higher at the Martian summer solstice. The temperature of the west limb, the sunrise edge of the planet, was lower than that of the east limb, being −45° and 0° C. respectively at opposition, August 21, 1924.

These and subsequent measures in 1926 and others extending until 1943 all agree in indicating that the summer hemisphere of Mars is warmer than the winter hemisphere and that the surface temperature rises as summer advances. It is hottest in the summer hemisphere not at the time of the Martian solstice, but a month or so later as is often the case on Earth.

Kuiper (1952) reported that he identified the polar caps as ice by comparison of the reflection spectrum of frost at low temperatures with spectra of the polar caps. Photometric measures of our yellow photographs in 1924 showed an albedo of about 0.55 (fresh snow: 0.8 - 0.85) but this seems fully explained by its age and probable dusty condition (Plate XLVIII). The monochromatic photographs show both that the snow caps are much more brilliant than any other part of the planet and that they shine by a bluer light. Spectrograms both at Lowell and Lick Observatories show the albedo of the cap in blue and ultraviolet light to be higher than the comparison spectrum of the Moon.

Wright (1925) considered the possibility that the high intensity of the polar caps in violet and ultraviolet might be due to some type of luminescence in this region of the spectrum, but contemporary spectrograms by Shane revealed no pecularities in the spectrum except that the cap was especially brilliant in these spectral regions.

Urey (1959) pointed out that the quantity of water can be estimated from the observation that the temperature of the night side of the planet is −70°C or higher, together with the occurrence of morning frost which clears away during the Martian forenoon. This determination requires that the surface frost point is higher than −70°C, and thus the surface partial pressure of water is 0.00194 mm of mercury or 2.6 dynes cm^{-2}. Surface temperature measures by Coblentz (1922), Coblentz and Lampland (1925, 1926), Pettit and Nicholsan (1924, 1925, 1930), Lampland (1926-1943) and Strong and Sinton (1956) appear to establish the necessary temperature criterion. Examples of morning frost complete the required observational material. Urey derived the total water content as 4.2×10^{-3} g. cm^{-2}, and concludes that it is probable that the actual amount may be higher by a factor of 10, namely 4.3×10^{-2} g. cm^{-2}. He states that this amount is not markedly different from other estimates that have been made by Dunham (1949), who estimated water as less than 5 cm atm. S. T. P. which is equivalent to 4×10^{-3} g. cm^{-2}. George (1950) found from comparisons with terrestrial fogs that a fog containing this amount of water (i.e. 2×10^{-3} g. cm^{-2}) in the line of sight would produce an easily detectable haze.

The polar caps have been studied by every means available: with the spectrograph, micrometer, polarimeter and photographically in spectral regions from the ultraviolet to the infrared. Their brightness has been measured by photoelectric photometry and their temperatures have been investigated by radiometric observations. This concentration of effort on the polar caps is indicative of their vital role in every Martian change.

CHAPTER IV

Atmosphere, Clouds, and Cloud Movements

The existence of a Martian atmosphere has been established by observations of the polar caps and their seasonal variations, by the formation and disappearance of clouds, by the motion of clouds, by the dense haze in which the planet is enveloped when viewed in blue or violet light, by the existence of a twilight arc, and by the sudden variations in color and intensity of the dark markings on the disk.

For a very long time the question whether free oxygen and water-vapor exist on Mars has been investigated by various observers. The strong telluric lines of these gases make it difficult to establish definitely the presence or absence of any weak components caused by the same molecules in the Martian atmosphere. There are, however, three methods by which weak components may be detected in the presence of strong lines. These methods depend on changes in the total intensity of the lines, displacements in their positions, and changes in their shapes.

The first method used by V. M. Slipher and Very (1909), compared the integrated intensity of a molecular band of oxygen in the spectrum of Mars with the intensity of the same band in the spectrum of the Moon at the same altitude. Very's measures of the Flagstaff spectra indicated that the integrated intensity of the B band of oxygen was somewhat greater in the spectrum of Mars than in the spectrum of the Moon and that the water-vapor band at 7200A is considerably stronger in the spectrum of Mars than in that of the Moon. These observations were made at a time when by spectrographic tests the air over Flagstaff was the driest it had ever been found to be. (As little as 0.2 mm of precipitable water has occasionally been observed.)

The method is, however, not extremely sensitive when used on low-dispersion spectra, and some think that Very's conclusions may be premature. In (1952) Kuiper reported that he had identified the polar caps as frozen water.

The second method, first proposed by Lowell, depends on the Doppler displacement of any Martian oxygen lines which may exist, relative to the telluric oxygen lines. The velocity of Mars at quadrature is sufficient to produce a displacement of Martian lines of 0.3A.

Early observations to detect oxygen in the Martian spectrum were inconclusive: Very, 1909; Campbell and Albrecht, 1910; Adams and St. Johns, 1926; Adams and Dunham (1934) employed the Doppler effect in an effort to record asymmetry in the lines. From a study of the displacement of the lines they concluded that the upper limit for the ratio of Martian to terrestrial oxygen in the atmosphere was not greater than 0.0015.

Kuiper (1952) identified carbon dioxide bands in the Martian spectrum and compared their intensity with the absorption in the terrestrial atmosphere, finding more than twice as much on Mars as on Earth. Grandjean and Goody (1955) have made a theoretical correction for pressure effect and estimate the $C0_2$ content to be 13 times that of the terrestrial atmosphere.

Urey (1959) pointed out that photochemical decomposition of carbon dioxide must produce unknown amounts of carbon monoxide. He also pointed out that the low estimate of the amount of free oxygen on Mars by Adams and Dunham (1934) is in accord with the photochemistry of its atmosphere. Urey also entertains the idea that Mars may have had oceans and glaciers at one time, and that their presence would account partly for the absence of mountains on the planet, because they would have been eroded to low levels.

Urey (1959) determined that "the presence of carbon dioxide in the high atmosphere prevents the dissociation of water below the tropopause by light in the Schumann region and hence water is preserved on Mars. With a tropopause temperature of 186° K or lower, water will not escape to the high atmosphere any more rapidly than it does on Earth, and with a very low temperature at some higher level the escape will be orders of magnitude less." He also points out (1959) that "carbon dioxide will be dissociated by light below 2000A into carbon monoxide and atomic oxygen and no other gas is present to protect it against dissociation by this radiation."

Based upon the possibility that most terrestrial argon has been produced by the decay of radioactive potassium, an interesting speculation concerning the atmosphere of Mars has been advanced by Brown (1952). If we assume the surface potassium content to be similar to that of Earth and if we neglect escape processes, then Mars should have an argon atmosphere similar to that of Earth. In fact, it might well be that argon is the major atmospheric constituent. Hans Suess (1959), Hamburg, independently arrived at the same conclusion. Suess's arguments are similar to those which are presented by Brown.

Little can be said about the nitrogen content of the Martian atmosphere. Although it could be a very important component, its presence would nevertheless be very difficult to detect.

Rosen (1953) suspected the existence of carbon in the upper atmosphere of certain stars and suggested its probable presence on Mars.

A far-reaching discovery very intimately related to the composition of the atmosphere is one made by Sinton (1957, 1959). He has identified C - H bands in the infrared spectrum of Mars at 3.67, 3.53 and 3.43 microns as being due to organic compounds; that is, the same kind of bands as are produced by vegetation. Significantly, repeated observations proved that these bands showed strongly in the spectrum of the dark regions, but were, at the same time, found to be weak or absent in the spectrum of the bright desert regions.

That the atmosphere of Mars is less than our own is clearly indicated by considering the comparatively low albedo. The albedo of Mars, 0.15, is considerably higher than that of Mercury and the Moon, but is not so high as that of the partially cloud-covered Earth, 0.39, and is much lower than that of Venus and the major planets.

The low albedo of Mars explains why surface features are clearly seen except during occasional "dust storms" or veils of haze, such as in 1941 and 1956.

Many attempts have been made to determine the total mass of the Martian atmosphere. Apart from an ingenious but imperfect method based on the heights and temperatures of convective clouds, all of these involve difficult optical techniques. The quantity which needs to be determined is the brightness of the atmosphere isolated from the solid surface. To find the mass some assumption must be made, which is usually that the air mass for Mars and the mass for Earth scatter similar amounts of radiation. Mars, however, has a persistent haze layer which could invalidate this assumption and might mean that existing estimates of the pressure are overestimated.

Numerical values reported for the surface pressure of Mars are remarkably concordant in spite of the many doubtful assumptions introduced. Many investigators have worked on this problem and have published determinations ranging from 65 to 110 mb. The most probable value appears to be 83 - 89 millibars, a value about one-eighth that of the Earth's atmosphere.

If this estimate of mass is correct, the bulk of the Martian atmosphere may well be molecular nitrogen, according to arguments based on the chemical abundance of this element and the nature of its nonactivity.

An outstanding characteristic of Mars is that, despite the presence of an atmosphere, the surface of the planet is almost always visible. Clouds do appear, however, and they are often divided for convenience into two general types: blue and yellow. It is not entirely appropriate, however, to describe all the clouds on Mars as blue or yellow. A better classification would be white and yellow. White clouds photographing brighter against the reddish disk in blue light have been termed blue clouds, while the yellow ones appearing bright visually and showing prominently in red and yellow photographs are termed yellow clouds. Actually the Martian clouds generally show a continuous shading of colors that are generally discernible visually.

Only the blue haze or violet layer which exhibits a planet-wide obstruction of the surface in blue light is strictly invisible to the eye.

Yellow clouds are rather infrequent and sometimes cover only a small fraction of the disk. They usually disappear within one or two nights. Such clouds were first frequently photographed (Slipher 1920, 1922) during the oppositions of 1920 and 1922. Temporarily concealing portions of the dark regions, they were most prevalent on the morning side of the disk, but on occasions also appeared at noonday and when certain regions approached the evening edge.

Photographs of April 12, 1920, showed unusual, vast bright areas on the morning and evening sides of the disk, especially over the Syrtis Major. Photographs of May 15, 1920, same longitude, showed the bright area of the Martian morning all but gone and that of the evening edge altered in size and brightness, but still obvious.

Likewise, photographs taken on April 23, 1920 longitude 240°, showed the Syrtis Major hidden during the Martian morning by a bright covering; it was normally dark again long before noon. On the other hand, photographs of May 24 - 26, 1920, showed the Syrtis Major at noon partly concealed by a bright covering in latitude - 2° that almost completely separated it from the dark mare above.

The most remarkable phenomenon of this class up to this time was the great white spot first seen and photographed on July 9, 1922, where on the 8th nothing unusual existed (Plate XIX). The white spot was situated over the dark region of the Margaritifer Sinus. Being sharply defined except at the south and almost as brilliant as the south polar cap and distinctly brighter than the north cap, it stood out with striking conspicuousness. It extended from longitude 5° to 30° and from latitude - 12° to - 25°, thus covering an area of 300,000 square miles. Photographs of the spot on July 10, 1922, compared with those taken on July 9, showed that it had changed position and form and that it was fainter as a whole, but embraced a larger area than on the first night.

Such yellow clouds which often cover large surface areas are probably chiefly due to dust. Observations of dust clouds in Earth's atmosphere have shown that powdered matter tends to display the color of the substance from which it is derived. In 1956 during the greatest Martian dust storm seen in more than 60 years, visual observations showed that the haze-covered regions were suffused with a bright rose-orange tint closely matching that of the planet's desert areas.

The 1956 storm began on August 20 (Martian date May 29), reached its maximum on September 7, and lasted until September 22 or later. It expanded around the planet and was most evident in the southern hemisphere. Its commencement and duration coincided with the period in the southern hemisphere when the heating of the planet's surface would be approaching maximum and when the winds might be expected to become most violent. The wide area covered and the long duration of the storm afforded ample opportunity for observations at Lamont-Hussey Observatory. Blue, green, yellow, orange, and red monochromatic photographs corroborated the visual observations of color. Terrestrial experiments seemed to be repeated on Mars.

While a few observers have thought the yellow clouds are low-level phenomena a few miles in height, most of the examples best observed and most susceptible of accurate measurements have been found at heights of 18 to 20 miles. In 1956 blue and yellow photographs showed that the dust clouds were higher than the blue-white polar winter cloud cover. Urey (1959) thinks that since the maximum level of clouds is 20 miles, this seems likely to be the altitude of the equatorial tropopause.

There are good reasons for believing that yellow clouds are sometimes composed of both dust and water. This conclusion is supported by the appearance of temporary dark areas often observed adjacent to many of the dense yellow clouds. These ephemeral dark spots, lasting usually only a single day, are intensely dark and occur in both darker regions and bright deserts. Surprisingly, when they occur in the light regions, they photograph as dark as if observed in the dark regions. Their form and outlines bear no relation to the permanent markings of the planet. Unlike the more permanent dark regions these temporary dark patches are without structure; they do not display details such as lines and dots like the canals and oases. They look like intensely shadowed areas.

Almost always blue photographs show bright cloud areas here and there around the autumn-winter pole. Most of them can be seen visually; they can also be photographed in yellow light, but in weak contrast to the bright areas as compared with the way in which they appear in blue photographs. These same clouds invariably vanish in companion red photographs, thus suggesting that they consist of fine cirrus (ice crystals) which can be penetrated by red light. This difference between blue and red photographs has been established by literally thousands of photographs during the last half century. The great yellow dust clouds, sometimes extending over vast areas of the middle latitudes, are not conspicuous in blue photographs, but are quite bright and impenetrable in red ones. Photographic evidence thus proves indisputably the presence of a second distinct type of cloud on Mars.

Bluish-white clouds are observed at various times anywhere on the planet, but most commonly over the winter poles, where they always leave a glistening white deposit when they clear away. In other parts of Mars they are sometimes observed on successive days and even for weeks in the same location (for example, the "W" clouds in the Tharsis). Certain examples, such as the "W" group, are apparently due to local circumstances and are strictly afternoon phenomena. The white polar winter clouds also belong to this type.

Dollfus (1948) finds that the polarization of the white clouds is identical with that of clouds formed of ice crystals. The polar winter cloud canopy, which becomes heavier as the season advances, shows a slightly different polarization curve, indicating the presence of larger ice crystals. This is consistent with their prominence in blue photographs and with the fact that they vanish in red light.

Bluish haze and clouds are rather common in the polar regions around the time of the Martian equinoxes, but such extensive canopies as those recorded on December 18, 1960, are indeed rare. Measurements of these 1960 photographs show that the southern polar cloud cap descended down to latitude -34° and the northern one to latitude +30°. Not since the equinoxes of July 17, 1922, when the cloud cover around the south pole descended below the northern edge of the Hellas to latitude -26° had our photographs recorded such a huge polar canopy. At the same time a huge northern cloud cap was also present.

Afternoon clouds over the southern Tharsis near Phoenicis Lacus and Arsia Silva and to the north of these points were first photographed by the author in 1907 while on the Lowell Expedition to South America (see Plate XXIV). Similar bright areas in the same locality were confirmed by photographs taken in Flagstaff and at the Lick Observatory in 1926. But those taken of the northern hemisphere showed the clouds conspicuously brighter in the shorter wave lengths than in yellow and red light, thus evidencing their pure white character as distinguished from the yellowish tint of dust clouds.

In 1954 a remarkable series of photographs of a similar group of clouds in the same place were obtained by the author at the Lamont-Hussey Observatory each night from June 20 to June 30. These photographs, combined with others taken at the same time, proved that the clouds were never present during the Martian forenoon. They began to appear weakly around two o'clock in the afternoon and grew brighter and more conspicuous, until near sunset, they rivaled the brilliance of the south polar cap, then emerging from its long winter night.

Another distinguishing characteristic of this group of clouds was their immobility as distinguished from the mobility displayed by yellow dust clouds.

Blue photographs taken in 1954 revealed a previously unrecognized feature about the atmosphere of Mars. This was the existence of a series of faint atmospheric belts across the face of the planet. These belts, less distinct than those of Jupiter and Saturn, showed a remarkable tendency to parallel each other, being sometimes parallel to the equator and at other times criss-crossing it. In general they showed a strong resemblance to the lines-of-flow maps constructed, from temperature measures and drift of clouds, to represent the circulation of the atmosphere of Mars (Plate XLIV).

In any case, the temporary existence of such weather bands or streamers and their appearance and behavior strongly suggest haze from condensation of water vapor.

Not all Martian clouds can be strictly classified as blue or yellow. Many examples, notably the "W" group are especially brilliant in blue light and are also clearly visible and can be photographed in yellow light — a fact known as long ago as 1907 (Plate XXIV).

Almost the only means available to determine the atmospheric currents on Mars is to measure the shift and direction of cloud movements. If a cloud of dust particles is raised, it would be shifted and expanded in the Martian air. The storm clouds continue to expand and spread over such wide areas as to finally become too evanescent and tenuous to be perceptible.

Studies have been made of the rate of expansion. Results agree with similar studies of terrestrial phenomena; for example, the spread of clouds from nuclear reactions.

An illustration of expansion is strikingly portrayed in photographs of the yellow storm of July 9 - 13, 1922. During the first two nights the cloud area was fairly condensed. Its displacement was readily measurable on succeeding nights; the cloud area was traveling north at 6 to 12 mi./hr. on July 9 and 10, respectively (Plate XIX).

On August 9 and 10, 1924, a well-defined cloud area developed over Isidis Regio between the Thoth and Syrtis Major. For a period of 24 hours or more this cloud maintained a fairly definite form and outline. Its motion was southerly; it appeared over Libya Region and the next night, the translation speed was 23 mi./hr (Plate XXV).

On October 12, 1958, an incipient cloud formation appeared in the Isidis Regio. On the following night its front had moved southward into Libya, and its northerly edge showed south of the Thoth. On October 14 it appeared decidedly farther to the left toward the afternoon side of the disk and higher toward the south. On these three nights the identification of the cloud area was reasonably certain. On the following night, October 15, identification was less certain because of new cloud formations over Libya and Isidis Regio. The motion and direction of the original cloud, however, led to the assumption that a faint cloud over the Hesperia at Poras on the 15th and a still fainter misty area over southern Tyrrhenum Mare might be the last remnant of the original cloud.

On the first two nights, when identification was certain, the motion of the cloud front was 20 mi./hr.; if the assumed identification was correct for the last two nights, the speed had increased to more than 27 mi./hr. The average velocity of yellow clouds is about 20 miles per hour.

Regarding a group of clouds that showed slight, if any, motion in 1954 (a quiescence repeated several times since 1907), McLaughlin (1956) wonders, "Is it absurd to suggest that this may have been a cloud formed by condensation of steam above or near active volcanoes?"

Perhaps the chief objection to this interpretation is that this group of clouds is seasonal in occurrence. They make their advent in the late afternoon at the time of the vernal equinox of the southern hemisphere and persist during Martian April into May, when they vanish for the summer. If these clouds were associated with volcanoes, they should continue throughout the day and for long periods of time.

Clouds on Mars, whether formed of dust or of water vapor appear to shift and expand in a manner comparable with such movements as we know them on Earth.

From a study of the cloud motions on Mars, Hess (1950) defined the wind pattern. He finds a system of trade winds very analogous to those on Earth.

CHAPTER V

The Violet Layer and Blue Clearing

For a very long time it has been known that some of the planets show different aspects when seen and photographed with various light filters. Mars gives amazingly different pictures with light of different colors.

If Mars is observed in red or yellow light, or any light of a wave length greater than 4550A, surface details in general can be clearly perceived. Toward the limb, however, where the path of observation through the atmosphere is very oblique, details are sometimes lost and the surface seems to brighten. In blue or ultraviolet light with wave lengths shorter than 4550A, surface details are usually absent. An even surface is broken only by bright, impermanent patches. The blue images are usually as bright at the limb as at the center, but often the rim is brighter than the center. This obscuring effect is attributed to what is known as a blue or violet layer. This property of the Martian atmosphere has been well demonstrated by color filter photography for half a century.

A critical study has been made of all our blue photographs from 1922 through 1960 with special reference to determining the degree of opacity or transparency of the violet layer on Mars. More than 60,000 photographs were studied by two observers working independently. The estimates of opacity of the violet layer were in surprising close agreement. The study revealed an astonishing number of previously unsuspected quick changes in the state of the violet layer. It also disclosed that blue photographs taken on the same date at different stations around the world showed wide differences in the opacity of the violet layer, sometimes varying from virtual opacity to nearly complete transparency (Plates XXX to XXXII). This variation showed that opacity did not extend all the way around the planet and that it varied in different longitudes. Actually at times one face of the planet was heavily obscured while the other face was nearly transparent. The variation was similar to Earth's variation of weather in different longitudes.

The results of this statistical study are displayed in graphical form in Figures 6 to 9 at the end of this chapter.

Attempts to determine the wave length at which opacity sets in are not wholly conclusive. The author has tried to establish the wave length at which the blue layer begins to show by photographing the planet on spectroscopic J plates, using Wratten No. 8 and No. 11 filters, and has found that the markings are not appreciably obscured by light of wave lengths from 4600 to 5200A. On the other hand, when Wratten D. 35 filters, which cut off all wave lengths longer than 4600A are used on 0-type spectroscopic plates thus centering the light around 4300A, it is found that the opacity of the Martian atmosphere is sensibly increased over the ordinary unscreened plate embracing 4000 to 5000A. The opacity is even greater in the ultraviolet below 4000A. This suggests that the obscuration by the violet layer does not occur gradually throughout the spectrum according to the Rayleigh law, but begins rather abruptly around 4550A.

There was some doubt at one time as to whether the absence of surface markings on violet images (4250A) was due to opacity of the violet layer or to a genuine lack of contrast on the surface. But the occasional clearings in the violet (1926, 1937 and 1941, particularly) prove that the surface has appreciable contrast also at 4250A and that the Martian atmosphere is normally opaque at that wave length. The reflectivity of Mars in blue light (4250A) is about seven percent.

A significant fact about the violet layer is that it has been observed to clear, particularly near oppositions, for a few days at a time. This happened at the oppositions of 1926, 1928, 1937, and 1941. In the first two oppositions the blue plates disclosed less conspicuous examples of the lifting of the violet layer, but extreme caution suggested waiting for more tell-tale examples of blue clearings to thoroughly clinch the evidence. Clear evidence came during the oppositions of 1937 (1937) and 1941. The dark markings (Syrtis Major, Sabaeus, and others) became so conspicuous on these dates that, had not one been aware of what spectral region was used in making the photographs, he might easily have mistaken them for ordinary yellow images of the planet. The clearings were so striking in character and were so closely associated with opposition that such occurrences were accepted to be the rule.

The failure of the event to occur at the favorable oppositions of 1954, 1956, and 1958 shows that it is a phenomenon not entirely dependent for its occurrence upon the circumstances found at opposition. It is a fact, however, that there were examples of outstanding clearing within ten to fourteen days of these oppositions. All together, observational evidence tends to support the conclusion that there is definite tendency for pronounced blue clearings to occur more often near opposition. On the other hand, recent study has disclosed examples of strong blue clearings as far as 60 to 70 days from opposition date (Plate XXIX). Near opposition the observers line of sight is nearly parallel to the Sun's rays.

It appears, therefore, that the times when blue clearing might occur cannot be predicted. Nor is it possible to detect its presence by ordinary visual observations. Even the yellow and red photographs do not seem to show any sign whether the violet layer is opaque or transparent.

In 1954 the violet layer had intervals of semitransparency over a period of nearly two months (see also previous chapter) during which time it showed signs of a zonal structure more or less parallel to the Martian equator (Plate XLIV). When these zonal belts were present, they were more pronounced in the Martian forenoon and early afternoon than in the late afternoon. This suggests that they may have been disrupted by convection during the Martian afternoon. In May 1952, streaks or belts were photographed in blue light which were parallel but tilted at a high angle with Mars' equator. In still other cases the blue photographs displayed a soft mottled pattern. Most frequently the violet layer produces a sensibly uniform appearance over the entire disk outside the polar caps, but when blue clearings occur exceptional opportunity seems to be given for closer observation of surface features.

The 1956 observations showed plainly that the state of blue clearing differed widely at Lowell Observatory, Lamont-Hussey, and Mount Stromlo, where observations were made on the same night. Such observations are separated by about 9 hours and 8 hours in longitude (Plate XXXII). The longitudes for midnight of the central meridian of Mars at these three stations differ about 135° between Lowell and Lamont-Hussey and about 120° between Lamont-Hussey and Mount Stromlo (Australia). This brings into view an entirely different face of Mars at the three stations, if observations are made in the same part of the night. The 1956 observations plainly reveal that the blue clearing differed markedly over the three faces of Mars in an interval of 8 or 9 hours on the same night (Plate XXXIII). The violet layer was opaque, or nearly so in Africa on nights when it was moderately clear at Flagstaff and extremely transparent at Mount Stromlo.

Wilson (1958) remarks on plates from the Lowell Observatory photographs of 1956 as showing "especially pronounced" blue clearing on certain dates and "moderate" clearing on other dates. His conclusions corroborated the determinations made at Lowell. Photographs made at Lowell and in South Africa were quite comparable, having been made at both observatories with blue-corrected visual refractors, on the same kind of Kodak spectroscopic plates and processed in the same kind of developer (Plates XXX, XXXI, XXXII).

The nature of the veil which obscures the face of Mars in blue light has been an unexplained mystery since its discovery. Various suggestions have been proposed from time to time.

For a long time this peculiar behavior of the atmosphere was believed to be due to color reaction between the bluish dark markings and the bright red deserts. This assumption held sway for many decades until 1937, when photographs in blue light showed conspicuous surface detail (1937).

This detail indicated that something about the atmosphere itself would have to account for the sharp changes that apparently can take place within a few hours. Russell (1935) speculated, "It is highly unlikely that there is actually a much greater quantity of atmosphere above a square mile on Mars than there is here." He further expressed the opinion that the Martian atmosphere is more probably full of some sort of finely divided matter which is "capable of an amazing amount of scattering and absorption of the short wave lengths."

What this stuff is we do not know. We do know that at times most of it is cleared out of the Martian air.

Certain investigators of the phenomenon have suggested a dust layer in the Martian atmosphere as the most probable explanation. For dust to behave in this manner in the blue of the spectrum, the particle would need to be very small in size and at least as small as the wave length of blue and violet light. But dust fine enough to be invisible as clouds and to scatter the blue rays could not be expected to come and go as quickly as these examples of blue clearings indicate. According to Stoke's law, which concerns the rate of fall of small particles, the fallout could not take place nearly as quickly as the blue clearings. This is corroborated by the common experience with fine dust raised by volcanic activity on Earth (Krakatoa and other active volcanoes). Volcanic ash ejected in such eruptions permeates much of the Earth's atmosphere and lasts for weeks.

Experiments at Flagstaff in photographing distance landscapes during a dust pall which crept in from a drought in the plains states some years ago clearly demonstrated that when the same filters and plates are used, there is no resemblance between the violet layer and dust palls (Plate XLVIII).

Photographs of Mars taken in 1956 also militate against the dust theory. The great yellow clouds which began to appear on August 20 spread over most of the planet into the densest dust pall ever recorded. The condition continued for about three weeks (Plates XXVI and

XXVII). During this time blue photographs at Flagstaff, Australia, and elsewhere recorded the maximum blue clearing. During June and July, before the storm began, the violet layer was practically opaque the whole time.

Efforts have been made to correlate the variations in the violet layer with possible diurnal, seasonal, solar, and other physical effects that might be involved in actuating these changes. As a rule the afternoon half of the disk has been more transparent to blue light than the morning side. This heightened transparency is probably due to the fact that limb clouds are more prevalent on the morning side than on the sunset margin of the disk. At times the distribution of Martian clouds seems not in accord with this usual condition, but the preponderance of observational evidence bears out the conclusion that cloud and haze variations are associated with temperature changes dependent upon rotation and revolution.

Another theory is that the violet layer may be formed of ice spicules. This idea is more consistent with the rapid clearing that has been observed, which does suggest a rapid evaporation of an obscuring cloud. It should be the exceptional, rather than the ordinary, state of affairs for aqueous clouds to form. Polarization of the light from the brighter parts of the violet layer seems to be nearly the same as that of ice clouds over the autumn-winter poles except the crystals are larger in case of the latter.

The possibility of a blue auroral emission was advanced as an explanation. The source of the blue light coming from the planet, it was hazarded, is not selective scattering by small particles but may be an emission. Such an emission, however, would necessarily be in certain spectral lines rather than being generally distributed over the blue end of the spectrum. Such lines have never been observed.

Hess (1950) suggested that the vertical temperature distribution was such as could cause condensation of carbon dioxide, a known constituent of the Martian atmosphere, which might explain the violet layer.

Later Hess (1957) revised his calculations on the condensation for both carbon dioxide and water vapor into the solid phase and rejected the carbon dioxide hypothesis in favor of water. In this connection he pointed out: 1) that clouds of frozen carbon dioxide would be far too opaque to be the cause of the blue haze; 2) that water ice clouds can cause the blue haze if the surface frost point lies near -90° C. But the theory and calculations are too extensive and complicated to present here and reference should be made to the original discussion. It should be pointed out here, however, that his calculations indicate that the precipitable water is much lower than that detectable at present, amounting to about 0.03 percent of the water above Mount Wilson in winter. He also points out that temporary local concentrations of H_2O may occur which could raise the frost point considerably. He concludes that indeed such concentrations must exist if any of the dense, long-lasting visible clouds are due to condensation rather than dust only. Certain of the dense clouds on Mars in 1956 appear to have been aqueous clouds such as contemplated by Hess, by the striking manner in which temporary darkenings occurred at the boundaries of dense cloud formations suggesting moistened soil (Plates XLI and XLVI).

Urey (1959) has pointed out that Hess' condensation of water makes it difficult to understand the uniform character of the blue haze over the planet. He adds, "One would surely expect it to exhibit latitudinal weather bands, and a nearly uniform temperature in the high atmosphere over the entire planet is most improbable." His first objection appears to be answered by the photographs of Martian weather bands in June and July, 1954 (Plate XLIV). The second objection is more serious and more difficult to explain by observational results, however, Gifford's diameter measures of our blue photographs at the opposition of 1956 indicate that the cloud level height at the planet's equator and poles may differ by a measurable amount. This result suggests the possibility that the second objection of the lack of a uniform temperature over the entire planet may be partially explained by a fluctuating altitude of the cloud level in different latitudes.

Gifford has made microphotometer measures of the equatorial and polar diameter of Mars from plates obtained by Bloemfontein in different wave lengths very close to the 1956 opposition. His unpublished measures are given in Table III.

TABLE III

Photometric Polar Flattening of Mars

Date (1956)	Color	Flattening Value	Standard Deviation
Sept. 9	Blue	−0.002	±0.005
Sept. 7	Blue	−0.008	0.005
Sept. 7	Yellow	+0.011	0.005
Sept. 7	Orange	+0.014	0.005
Sept. 7	Red	+0.012	±0.005

After correction for phase effect these data show that the yellow, orange and red images show an oblateness of about 1/96. This agrees well with the mean of the optical values derived by Trumpler (1927). However, the blue images show small "negative" flattening or little or no departure from sphericity. The measures made in the blue pertain to the blue layer, while those made in the yellow, orange and red represent measures of the surface. These data therefore provide further evidence that the blue layer is a high level phenomenon.

As to the suggestion that a haze of solid carbon dioxide, or ice, is responsible for the violet layer, Goody (1957) thinks this is very unlikely for carbon dioxide and not very likely for water vapor. Even the nearly saturated terrestrial atmosphere produces only patchy and intermittent clouds, not a permanent and complete veil of mist. Moreover, the optical evidence demands that the particles of the violet layer absorb in the blue and near ultraviolet whereas neither ice nor carbon dioxide has any absorption in this region.

Goody further points out that the only acceptable explanation of the observations is that the obscuration is largely due to absorption in blue and violet rather than to scattering. He quotes van de Hulst (1952) in support of his conclusion that only an absorbing medium is the acceptable process to account for a violet layer. Our 1956 blue photographs of bright bands on Mars clearly refute this reasoning and indicate that scattering is a dominant factor.

Urey and Brewer (1957) pointed out that the CO^+ ion absorbs in the blue and ultraviolet and fluoresces in longer wave lengths, and also that some fluorescence of N_2^+ and CO_2^+ may be expected and that the violet layer may be partly due to these effects. They suggest that the ions are produced by particle radiation from the Sun and that the disappearance of the haze at opposition is due to the deflection of these particles by Earth's magnetic field. They have not considered the problem of the polarization of the blue light. Their explanation would account for blue clearing at the time of opposition, but it would appear inapplicable for the cases of blue clearing observed far from opposition such as occurred in 1954, 1956, and in 1958.

Urey (1959) pointed out that photochemical decomposition of CO_2 must produce unknown amounts of carbon monoxide. Opik (1960) advanced the theory that carbon monoxide was the obscuring substance of the violet layer. He based his theory on the supposed limb darkening on blue photographs derived by Baravashev and Chekirda (1952). But their result appears to be erroneous. More than 30 years of fine monochromatic photographs by Wright (1925) at Lick, Ross (1928) at Mt. Wilson and the Lowell Observatory photographs from 1922 to 1960 and those made in South Africa show that the blue images are as bright at the limb as at the center. Often the rim of the blue image is brighter than the center. In fact, Wright measured the diameters of his blue and red images made with the 36-inch reflector and derived a measure of the photographable atmosphere of Mars from the greater diameter of the blue images extending to a height of 60 miles. It is the red image of the planet which shows limb darkening, not the blue. Thus the theory that carbon monoxide is the substance that produces the violet layer is untenable.

In addition to the above objections, other observed facts militate against the carbon monoxide theory: 1) the extreme brilliance of the polar cap in blue photographs at the very edge of the disk when central areas are opaque; 2) the sudden spells of blue clearing which are unexplainable on the basis of an ever-present gas; 3) the transparent atmosphere observed in Australia when observations in South Africa showed the atmosphere practically opaque at the same time. These facts virtually rule out a continuous gaseous medium and indicate a substance capable of relatively quick condensation and evaporation.

Kiess, Karrer and Kiess (1960) advanced the hypothesis that nitrous oxides of various compounds explain the violet layer and the blue clearings. From considerations of chemistry and spectroscopy the theory appears unsound; moreover, it fails to explain the behavior of the surface markings. Exponents of the theory point to the fading out of the blue spectrum of the planet, but numerous spectrograms taken at Flagstaff show precisely the same type of blue fading as that obtained from reddish soil, sand, and rocks, but nothing attributable to atmospheric absorption in the blue. Furthermore, spectrograms of the polar cap at Lowell and Lick (Shane 1925) observatories show its spectrum to extend with great strength through the blue violet and ultraviolet, thus exhibiting no absorption.

To explain the dark regions the authors suggest liquid tetroxide, but this substance will freeze during cold Martian nights with the result that markings would appear bright each morning as they rotate onto the disk. This, of course, is contrary to the observed facts.

Sinton (1961) has shown from his studies of the infrared spectrum of Mars that there is no positive evidence of NO_2 absorption; in fact, they reveal that less than 1.2 parts in a million of NO_2 and N_2O_4 can be present. These quantities are too small to produce the observed Martian phenomena, and therefore this theory must be rejected.

Bowen (1953, 1956) advanced a meteor-rainfall hypothesis that meteor streams carry dust particles into the terrestrial atmosphere, where, after falling for thirty days to reach the cloud level, they act as freezing nuclei and thus cause precipitation.

Kviz (1961) points out the effects of meteor streams on rainfall, cirrus clouds, concentration of freezing nuclei, and the like. He

TABLE IV

State of Blue Clearing at Various Oppositions
(Scale 0 - 5)

Date of Opposition	Degree of Clearing	Martian Seasonal Date So. Hemisphere	Declination (seen from Mars) Earth	Sun
Jun. 10 1922	Insufficient photographs Jun. 7, 15 1 - 1.5	Mar. 11	+5°5	+3°5
Aug. 23 1924	Insufficient photographs	May 28	−16°25	−21°20
Nov. 5 1926	Very Clear 4	Aug. 8	−16°8	−17°1
Dec. 21 1928	Clear 3	Sep. 25	−1°0	+0°5
May 19 1937	Clear 4±	Feb. 19	+12°2	+11°5
Jul. 23 1939	Nearly opaque 0 - 1	Apr. 22	−8°1	−12°2
Oct. 9-10 1941	Very Clear 4 - 5	Jul. 11	−20°3	−22°6
Dec. 6 1943	1 - 2 Nov. 23, 24, Dec. 4 1 - 2	Jun. 14	−5°0	−8°55
Jun. 25 1954	0 Jun. 13, 14 4 - 5	Mar. 25	+0°95	−1°85
Sep. 10-11 1956	0 Best Aug. 31 and Sep. 3, 5	Jun. 11	−19°3	−23°6
Nov. 16 1958	Best Nov. 6 to 10 3±	May 1 - May 5	−13°5	−13°5
Dec. 30 1960	Insufficient photographs	Sep. 26	+2°2	+4°2

suggests that blue clearing on Mars is likely to be of the same origin. If this is the cause, then all cases of blue clearing must occur when Mars is in certain heliocentric longitudes (at certain places in its orbit). But Table IV representing transparency of Mars atmosphere shows no correlations between blue clearing and the planet's heliocentric longitude.

Analysis of the various ingenious theories advanced to explain the violet layer has shown that not one by itself will explain the photographic record. The essential requirements of the composition of the violet layer are: 1) that it contain ice crystals or frost particles; 2) that it possess the property of comparatively quick evaporation or dissipation; 3) that its average albedo shall be as low as 0.09 or less in the blue region.

The structure of the violet layer is one of the most complex problems of areophysics and the identification of its substance is most difficult. The blue photographs of the brighter clouds and belts in it leave little doubt that they consist of the same particles as form the clouds over the autumn-winter pole, whence the snow cap comes, namely ice crystals. Polarization measures corroborate this.

Blue negatives supplied with light scales disclose that some of these atmospheric objects differ in albedo by a factor of 4 or 5 times. Many of the blue clouds and the winter polar cloud caps often rival the brightness of the snow cap, indicating an albedo in blue light of 0.25 to 0.30 or more; that of the dark clouds is sometimes as low as 0.02 to 0.04. This suggests that the particles in the layer actually differ in substance. And since the observations, including polarization measures, identify blue clouds as due to ice crystals we are reasonably certain of one component of the violet layer.

Although ice particles have been shown to be an important constituent of the violet layer and play a dominant role in obscuring the surface markings, they alone cannot account for the violet layer because, when present in sufficient quantity to completely conceal the surface, they would cause the brightness of the whole disk to rise to an unacceptably high albedo of 0.25 or 0.30 for the blue region.

Thus the ice crystals must be combined with some dark substance to reduce the albedo to something like 0.09 or less.

Hundreds of times in our visual observations at various oppositions, under conditions of super-seeing, we have noted peculiar bluish cloud veils which were described at the time as resembling smoke. These lead us to suggest a new approach to the problem of the violet layer. Since it has become increasingly evident that none of the explanations which are based on a single substance successfully accounts for the observed behavior of the violet haze, it appears that a combination of two or more substances is necessary to a solution of the problem. The existence of carbon is indicated by our observations of certain blue clouds and its presence is indicated by the theories of McLaughlin (1954) and independently by Rosen (1953). Furthermore, since there appears to be no theoretical bar to its presence in the Martian atmosphere, it appears reasonable to consider it in connection with the problem of the blue haze.

Carbon is non-volatile in character and will not alone account for the observations, but in certain circumstances it would appear to be a mistake to discard completely the concept that all non-volatile particles play any role in the violet haze. The discovery of strong nucleating properties of solid carbon dioxide, silver iodide and carbon has been relatively recent (1946, 1947) and experiments on terrestrial clouds have shown significant results. Considering the various essentials of the problem of the violet layer it appears that carbon might supply the missing key. Its presence in considerable quantity in the form of particles of appropriate sizes could, it seems, provide the required low albedo of the layer and carbon particles might act as nuclei for tiny droplets and ice crystals. These on rare occasions and under unknown conditions might be precipitated from the atmosphere and cause blue clearing.

An appropriate mixture of carbon particles, acting as a nucleating agent at times, and at other times accounting for the dark clouds, may combine with the ice crystals in such a manner as to explain all the observed properties and vicissitudes of the violet layer.

A puzzling feature of the violet and ultraviolet photographs is the great brilliancy of the polar caps, even through the deep obscuring atmosphere at the margin of the disk, and when the violet layer is so opaque as to hide completely the other surface markings over the center of the disk. Under these seeming opaque conditions of the violet layer, the startling strength of the polar cap in the violet and ultraviolet photographs has led some to think that it might be shining by luminescence of some kind. Consequently Wright (1925) sought the aid of Shane in making a series of spectrograms of Mars both with the ultraviolet spectrograph and, in the blue to red, with the ordinary spectrograph at Lick. The spectrum of the polar cap was seen to extend with great strength into the ultraviolet and in the matter of absorption lines is a replica of the spectrum of the rest of the planet, which means, of course, that it is reflected sunlight. It was concluded that the observations, taken together, left little room for doubt that the changes are progressive and not the result of local irregularities in the spectrum of the planet.

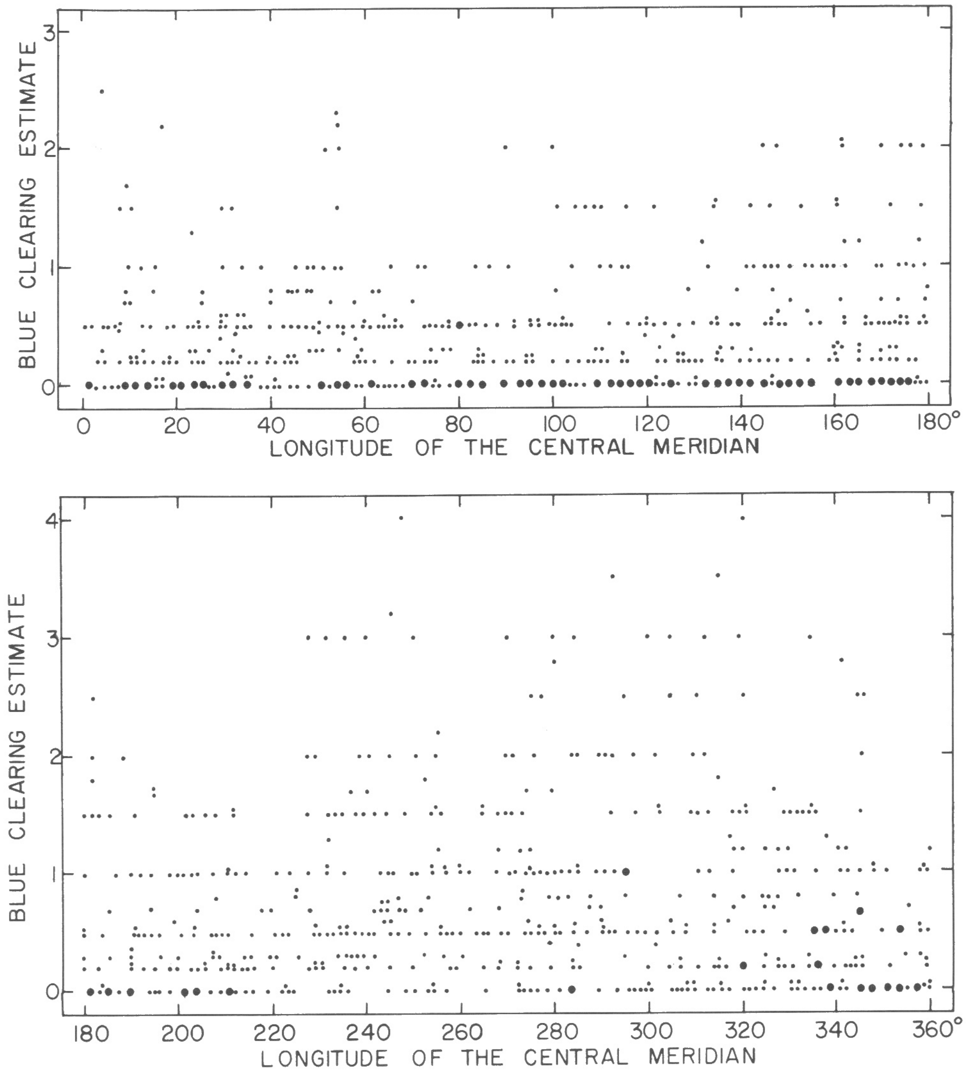
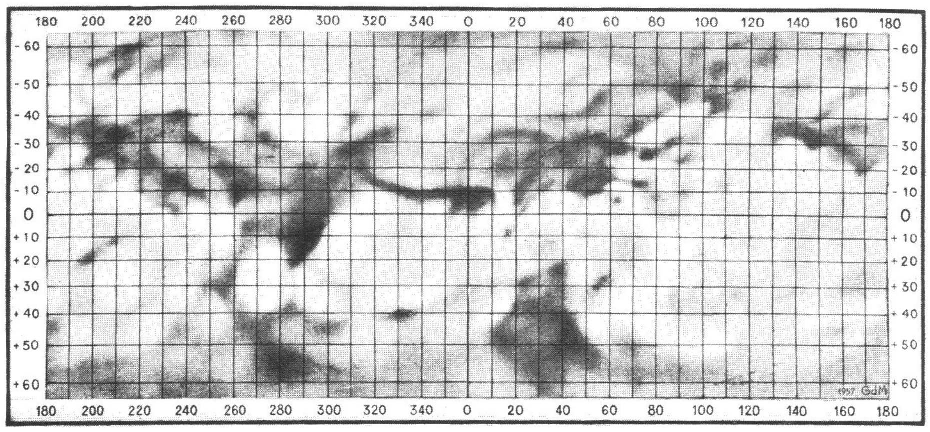


FIGURE 6. *The degree of blue clearing is plotted against the longitude of the central meridian of Mars. The data indicate somewhat more blue clearing around longitude 280° than elsewhere. Each small dot represents estimates from one plate—large dots represent 5 plates.*



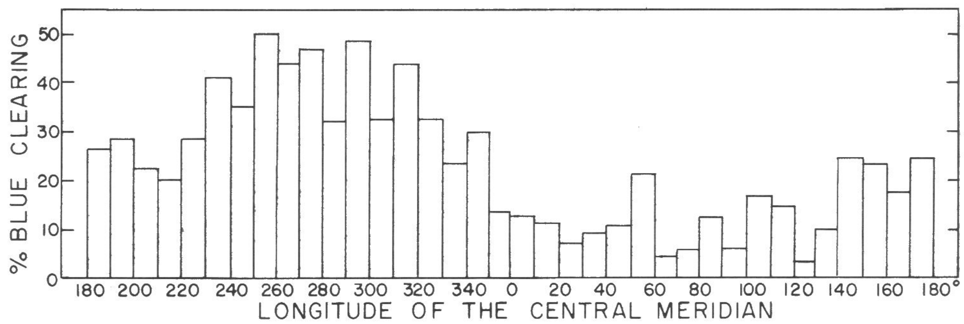


FIGURE 7. *Information given in Figure 6 presented here as a histogram. The percentage of blue clearing equal to or greater than one is shown as the ordinate.*

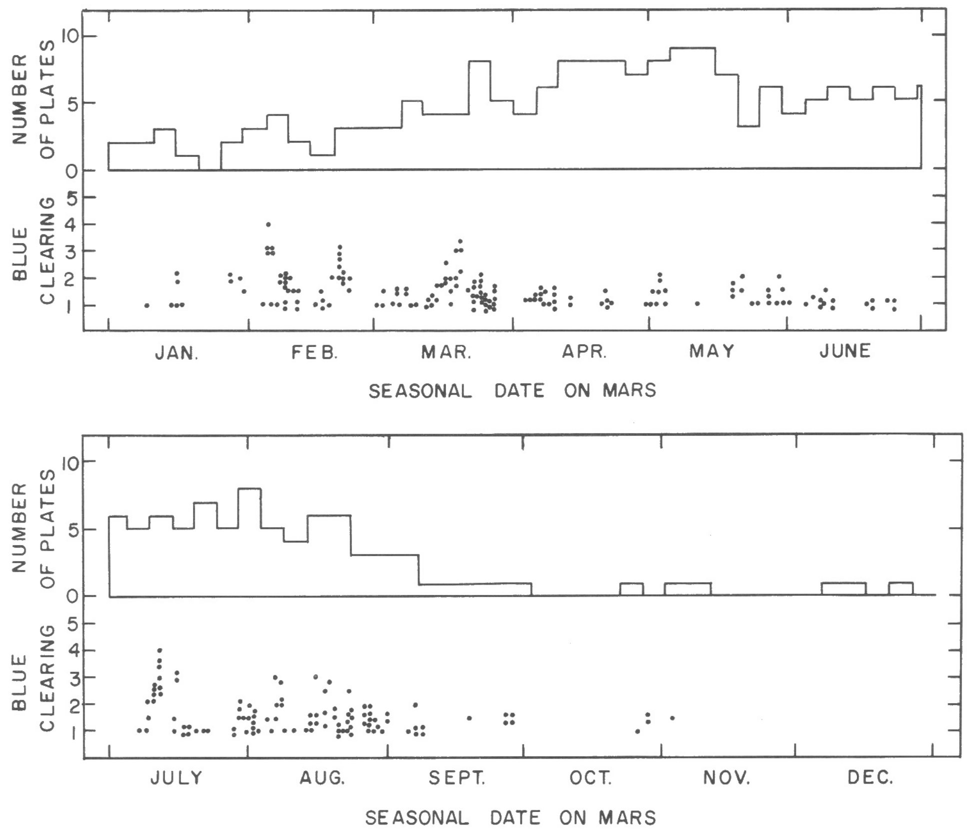


FIGURE 8. *Blue clearing is plotted against seasonal dates of the southern hemisphere on Mars. Each dot represents an estimate from a single plate. The histogram shows the average number of blue plates taken in five day intervals. More blue clearing seems to occur during the Martian months of February and March, and also during July and August. This result is in large part due to the fact that during November and December the northern hemisphere, which contains few outstanding surface markings, is under observation from Earth.*

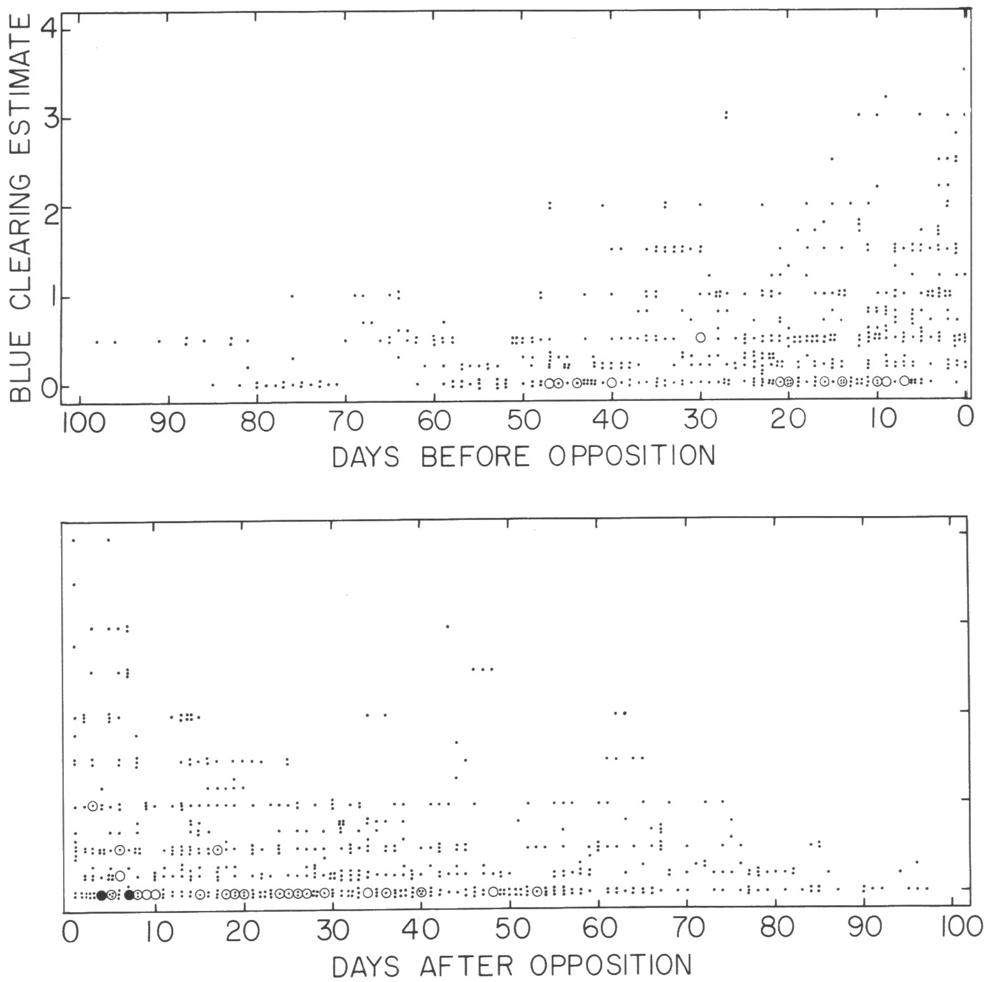


FIGURE 9. *Blue clearing is plotted against days from opposition. Dots, open circles and closed circles represent one, five and ten plates respectively. The data show a preponderance of blue clearing near oppositional date. Here again, the result may be somewhat misleading because near opposition the observer looks in a more nearly vertical direction through less atmosphere and is provided with the best opportunity to see the surface.*

CHAPTER VI

Photography of Mars

Application of large-scale photography to planetary research has transformed our methods of studying the surfaces of the planets. The more closely the exquisite prints recently taken at a number of the large observatories are studied, the more valuable they appear as an impersonal, accurate, and permanent record of the planets. In the eyes of the astronomer, their eminent value lies in their capabilities of exact measurement. These measurements can be made of the position, form and albedo of surface, or atmospheric phenomena.

To provide for position measures, the negatives obtained at the Lowell Observatory were trailed to mark the orientation; and to standardize them for photometric measures, the plates have (during the last 44 years) been exposed to a light scale before development.

Photographs of the planets are generally supposed to show little or nothing that cannot be better seen, and more accurately measured, visually. While this is perfectly true in regard to fine detail where the expert eye easily excels, in most other phases of planet study the photograph surpasses the eye in giving a far more informative and accurate record. In the important matter of detecting and recording slow, gradual changes in color, intensity, or change in position of features on a planet, the plate stands supreme. With special sensitive emulsions and appropriate filters, the observer can explore with light invisible to the eye so as to gain valuable information about a planet's atmosphere, its scattering properties, transparency, clouds and haze, and can accurately record variation in these.

Among the invisible phenomena revealed by the photograph is the opaque blue haze on Mars and its temporary clearing up from time to time. These periods of opaqueness and transparency of the Martian atmosphere to blue and ultraviolet light are entirely invisible to the eye.

Since 1903 the Lowell Observatory has secured large-scale color-filter photographs of the brighter planets and of Mars in particular, as a supplement to the visual and other studies. At each opposition of the planet a special effort has been made to maintain at least a systematic series of yellow photographs. Naturally greater numbers of photographs were made at one time than another, according to the favorable position of the planet, or because some outstanding activity occurred that required an extensive series of photographs to record the history and behavior of the change in progress.

A successful photograph of a planet depends upon securing the utmost possible definition. Definition far superior to anything usually attained in photographing comets, stars, and nebulae is necessary to catch the finer details on planets; and such definition is to be obtained by the most careful combination of atmospheric and instrumental circumstances.

It is common experience to find that in one second of time the telescopic image may perform many excursions with amplitudes exceeding one second of arc, or about 1/20 the diameter of Mars. The ordinary photographic plate will, under these circumstances, integrate all these images and show a blurring of detail. Tests have indicated that the image is in motion, even under rather good seeing conditions, in as short an interval as 1/60 of a second.

For this reason the exposures should be as short as possible. This time limitation sets a limit to possible magnification; for the faster the plates are, the coarser is their grain. If we try to avoid granularity by increasing the size of the image, exposure time is lengthened and the hazards of atmospheric disturbances are increased. Consequently, observers arrive at their own compromise involving the aperture of their telescope, the required exposure time, the grain of the plate, and the general quality of the seeing.

On the subject of superb seeing in planetary observations, Pettit

(1953) reported: "These are the moments when the whole canal pattern can be seen on Mars". He also stated that the longest he had seen the whole pattern was four or five seconds and that the whole period of visibility covered a period of fifteen or twenty minutes. Naturally this behavior of canal patterns under superlative seeing conditions emphasizes the need to be equipped and ready to photograph if advantage is to be taken of these brief intervals of extraordinary seeing. Holding equipment in readiness, however, is difficult to manage at most observatories with large telescopes which are occupied with mixed types of observations.

When a large refractor is used and seeing is excellent, the resolving power of the emulsion may limit the minimum size of marking that the photograph can register. The rapid 103-type Eastman emulsion has a resolving power of 60 lines per millimeter under maximum conditions of contrast, but this figure would be expected to fall to about 30 under the low-contrast values encountered in the actual planetary image. Moreover, since the apparent disk of Mars at the average opposition is under 20″ of arc, a focal length of about 190 feet is necessary to register linear markings 1/10 - 1/15 second of arc in width on such plates. The Lowell Observatory in 1909 adopted a focal length of about 178 feet for photographing planets on fast plates, and about 150 feet for lantern-slides and other slow-type, fine-grained emulsions.

Later, as faster plates became available, the focal length of the camera system was materially increased. At the 1954 and 1956 oppositions a focal length of approximately 220 feet was generally employed at Lamont-Hussey Observatory which showed the planet's disk about 8 mm in diameter in 1956. At this setting, the exposures on the Eastman 103-J, G, D, and E type emulsions for the different spectral ranges from 4650 to 5250A, 5000- 5750A, 5600- 6200A and 6200- 6700A respectively, were generally 1/25 to 1/15 second. The finer-grained type III Kodak spectroscopic emulsions sometimes employed, required exposures from 1/3 to 1 1/2 seconds.

Different observers, however, have chosen widely different magnifications at the telescope. Holden and Campbell (1890-1892) used an equivalent focal length up to 400 feet; in 1893 they used 237 feet; Lampland (1905) used 148 feet; Slipher (1907) used several from 150 to 215 feet; Hale (1909) used 100 feet with the 60-inch; Barnard (1909) about 165 feet (estimated); Wright (1924-1939) used the Crossley with a microscope objective for moderate enlargement, and a similar arrangement was used by Hubble (1924) with the 100-inch Mount Wilson (magnification unknown); Trumpler (1924) and Jeffers (1939-1956) photographed at the prime focus of the 36-inch refractor; while Humason (1953) used the 500-foot Coudé focus of the 200-inch reflector. Finsen's color photographs were made at an equivalent focal length of 85 feet.

Nothing is more vital to success in photographing a planet than the characteristics of the sensitive plate. The chief barrier to progress in planetary photography in the early years was the lack of plates properly sensitized for different colors of the spectrum, and the coarse-grain and slowness of the emulsions. For a very long time Cramer and Ilford produced the most useful orthochromatic emulsions, but they required long exposures. Fortunately, about 1937, the Eastman Kodak Company succeeded in developing a new series of emulsions, the spectroscopic plates, possessing vastly increased speeds and remarkable qualities. The faster types of these plates turned out to be 25 times faster than Cramer and other brands hitherto available for color-filter work on the planets. New emulsions marked a tremendous advance, and exposures for Mars, for example, were reduced from 2 - 4 seconds to 1/10 - 1/25 seconds.

Ross (1920) and Huse (1917) investigated the variation of resolving power with wave lengths for various plates and showed that the resolution of photographic emulsions is considerably higher in the violet and blue (4500A) than in yellow (around 5500A), but rises again (around 6500A) with almost all emulsions.

Ross (1920) investigated *photographic sharpness* and concluded that to secure sharp images, emulsions with both high contrast and low turbidity should be selected; also those whose characteristic curves have a small "toe". Ross also showed that the *resolving power of a photographic plate* varies with the sharpness and with the grain size. He suggested that astronomers are inclined to overestimate the advantage of small grain-size, for the true resolving power of some coarse-grained emulsions is far ahead of that obtainable with large telescopes. As a rule, what is needed is high speed rather than better resolving power.

In an investigation at the Eastman Kodak Laboratories of the limitations of planetary photography Ross (1923) found: Assuming a telescope of 270 foot focus and an object at a most favorable opposition of Mars, a fine-grained photographic plate is capable of showing linear objects 1.5 miles wide (about 0".009 arc). This result holds only in conditions of high contrast between detail and background, the size of minimum detail increasing with a lowering of contrast. Thus, for a relative contrast of 23 per cent the minimum width of a Martian marking which could be photographed was increased to 7 miles (0".04).

Of course, in taking a photograph at the telescope, the conditions will generally be less favorable than in the controlled conditions of the laboratory. This difference arises chiefly from image motion set up by imperfections in the Earth's atmosphere under even the best conditions, but sometimes too because the Martian atmosphere itself interferes, as many of the recent photographs clearly show. The finest linear markings found on our best images measure around 0".1 to 0".15 of arc, but their true width must be greater because irradiation will tend to narrow them down considerably. The smallest circular objects are about three times this diameter for dark spots, and even greater in case of white spots.

Pettit (1947) considered the problem of plate grain and image size most useful in photographing the canals. He concluded, from the standpoint of grain, that on any plate from lantern-slides up to and including the 103-type, an image of Mars 7.8 mm in diameter at a close opposition should reproduce the canals satisfactorily under ideal optical conditions.

Any device which promises to give better photographs of the planets is naturally of great interest to astronomy and merits a serious trial. In 1954 and 1956 several months were devoted, at the Lowell Observatory, to experiments by Wilson and Sturm with an image orthicon in photographing Mars. At the 1956 opposition more than two months were spent by Somes-Charlton and Barth in photographing the planet at Lamont-Hussey Observatory with image orthicon tubes from Pye Ltd., Radio Works, Cambridge, England. This work was a joint effort with the Mars expedition.

The efficiency of the orthicon photo cathode is known to be much greater than that of the photographic plate. Our comparisons in South Africa, however, showed that the over-all gain in speed achieved was less than 2 to 1. In addition, these indirect pictures had poorer definition on Mars than did the direct photographs. The indirect images obtained previously by Wilson and Sturm in 1954 showed more comparable definition, but did not equal that of the direct photographs.

Only at the closer approaches can Mars be observed to the best advantage either photographically or visually (Figure 2). Because of this limitation astronomers who have devoted their lives to the study of Mars have been able to keep the planet under constant scrutiny under the most favorable observing conditions for a total time of less than a year. One can only marvel, therefore, at the extensive amount of information that has been gathered over relatively short periods of time.

The number of photographs in the Lowell collection obtained at different oppositions and different stations is given in Table V. The dates of opposition from 1901 to 1973 are given in the first two columns. The third column shows the apparent diameter of Mars when it is nearest Earth. Its diameter at opposition may equal or be very slightly less than the given values. Eighty-six percent of the images tabulated in Table V were obtained by the author and, aside from those shown on Plates XVII and XVIII, he obtained most of the photographs appearing in this volume.

TABLE V

Photographs of Mars in the Lowell Collection
Oppositions of Mars 1901 to 1973

Year	Opposition	Diameter Perigee	No. of Images Flagstaff	No. of Images Southern Hemisphere
1901	Feb. 22	13.″8	....	
1903	Mar. 29	14.7	500	
1905	May 8	17.4	2500	
1907	Jul. 6	22.9	3000	13000
1909	Sep. 24	24.0	4500	
1911	Nov. 25	18.3	3000	
1914	Jan. 5	15.0	1000	
1916	Feb. 9	13.9	4000	
1918	Mar. 15	14.1	2000	
1920	Apr. 21	16.0	4000	
1922	Jun. 10	20.5	8000	
1924	Aug. 23	25.1	12000	
1926	Nov. 4	20.4	15000	
1928	Dec. 21	16.0	1500	
1931	Jan. 27	14.1	1000	
1933	Mar. 1	13.9	500	
1935	Apr. 6	15.0	5000	
1937	May 19	18.4	5000	
1939	Jul. 23	24.1	8500	8500
1941	Oct. 10	22.8	8500	
1943	Dec. 5	17.3	2000	
1946	Jan. 13	14.6	1000	
1948	Feb. 17	13.8	1000	
1950	Mar. 23	14.4	1500	
1952	Apr. 30	16.8	2500	
1954	Jun. 24	21.9	6000	20000
1956	Sep. 10	24.7	11000	37000
1958	Nov. 16	19.2	8000	
1960	Dec. 30	15.4	3500	
1963	Feb. 4	14.0	....	
1965	Mar. 9	14.0	....	
1967	Apr. 15	15.6	....	
1969	May 31	19.5	....	
1971	Aug. 10	24.9	....	
1973	Oct. 25	21.″4	....	
		Totals	126000	78500

Through the kindness of other observatories, however, additional photographs are included from Lick, Republic of South Africa, and from Mount Wilson and Palomar. The source of each photograph (except those from the Lowell collection) is indicated by a credit line. Other observers are identified as follows: Lowell, PL; Lampland, CL; Hess, H; V. M. Slipher, VS; Wilson, W; Giclas, G; and Neville, N. Except for isolated groups by Pickering (1905), Hale (1910), Barnard (1910), de la Baume-Pluvinel and Baldet (1910), and Tikhov (1911), the Flagstaff series was the only one regularly maintained up to 1924, when important contributions were made by Wright (1924-1929) and Trumpler (1924-1927) at the Lick Observatory, and Ross (1926-1929) at Mount Wilson.

Valuable results in this field have also been contributed by Jeffers (since 1939); by Lyot, Camichel, Gentili, and Dollfus (since 1941); by Pettit, Humason, and Richardson (since 1950); and by Finsen at the Republic Observatory, Johannesburg (1954-1956).

Many different telescopes were used in obtaining the photographs presented in this volume. These include the Lowell 24-inch refractor (with corrector lenses for the blue and red) and the Lowell 42-inch reflector; the Amherst 18-inch refractor and the 27½-inch Lamont-Hussey refractor (plus blue corrector), South Africa; the Lick 36-inch refractor; the 26½-inch telescope of the Republic Observatory; the 60-inch at Mt. Wilson; and the 200-inch at Mount Palomar.

The value of the photographs is enhanced by the use of color-filters and specially sensitized plates. These enable one to distinguish more readily what is due to the Martian atmosphere and what exists on the body of the planet. Most of the photographs have been made in rapid succession on each plate, averaging 30 to 40 images per plate. At both the Lowell and Lamont-Hussey telescopes the observer selected the moment of snapping the shutter by watching in a pilot telescope of high power for the moments of sharpest definition.

The Lowell photographs and those made by Finsen that appear here are composite pictures secured by meticulously superimposing, by special optical means, several of the best images on a plate into a single composite image on a fine-grained emulsion. Usually 5 or 6 separate images were used in this way for the purpose of enhancing the markings and reducing the effect of grain. These separate exposures must be obtained within a few minutes of each other in order to prevent blurring caused by the rotation of Mars.

To make full use of the golden chances presented by the close perihelion oppositions, we need a grandstand seat in the southern hemisphere. At these oppositions Mars lies so far south during the crucial months that the telescopes of the northern hemisphere can be used to observe it for only a short period each night and at a low altitude above the horizon, where turbulence of Earth's air interferes seriously with the seeing. For this reason Lowell Observatory has sent observers on four separate expeditions to the southern hemisphere. The first went to Chile in 1907 and three went to Lamont-Hussey Observatory, Bloemfontein, South Africa, in 1939, 1954 and 1956. At these southern stations Mars appeared almost directly overhead each night and the observer had the longest and best possible type of seeing, through the shortest possible path of clear, dry, semi-desert air.

For the 1907 Lowell expedition the 18-inch refractor of the Amherst College Observatory was set up in the desert (with no housing) near Alianza, Chile. The National Geographic Society generously agreed to sponsor jointly with us two six-month expeditions (1954 and 1956) to Bloemfontein.

During the expeditions of 1939, 1954, and 1956 the University of Michigan's 27½-inch Lamont-Hussey telescope, the largest refractor in the southern hemisphere was used. A blue-corrector lens was specially designed for the telescope so that sharp photographs could be secured, not only in the yellow and red, but in the blue end of the spectrum. It may be of interest to note, in passing, that the author observed with the Lamont-Hussey telescope on 93 and 123 consecutive nights out of 180 days of observations during the 1954 and 1956 oppositions, respectively.

At a conference at the Lowell Observatory in 1953, attended by about twenty-five astronomers, meteorologists, physicists, and other scientists interested in Martian research, the need was emphasized for a more complete world-wide photographic record of short-lived Martian phenomena, such as temporary clouds, blue clearing, and other day-to-day changes. The International Mars Committee was organized to enlist the aid of a series of observatories in different longitudes to undertake such a coordinated program of observations. The committee succeeded in securing the participation of the following observatories:

	Longitude		
Observatory Pic du Midi, France	0^h	$\frac{1}{2}^m$	E
Lamont-Hussey Observatory, South Africa	1	45	E
Helwan Observatory, Egypt	2	5	E
Kodaikanal Observatory, India	5	10	E
Boscha Observatory, Java	7	11	E
Lowell Observatory, U. S. A.	7	27	W
National University Observatory, Argentina	3	52	W

(In addition the Republic Observatory, the Lick and Mount Wilson Observatories contributed many nights to Mars' photographic programs).

Unfortunately no provision was made to assemble all these photographs and observations in one place for a collective integrated study; therefore no real synoptic study of the material has been made. Each of the observers, however, has briefly reported to the Committee the number, date, time and certain other essentials concerning his plates. Several fragmentary discussions of these Mars observations have appeared in different journals. The available particulars concerning the 1954 observations appear in "Mars, 1954, Report of the International Mars Committee"; like information concerning the 1956 opposition has been compiled and will be published soon.

CHAPTER VII

Author's Conclusions

So much emphasis has been placed on changes on Mars that the reader may wonder about its appearance now as compared with the past. Most of the changes are temporary seasonal variations of features that tend to return to what they were before. Schiaparelli (1878) was convinced that the general configuration he observed in 1877 was the same as that seen nearly a hundred years earlier by Schroeter, Herschel, and others. Present-day observations show features virtually the same as Schiaparelli represented them. So far as we can judge, therefore, the configuration of the surface of Mars is the same as it was 200 years ago and very probably the same as it has been for tens of centuries.

Doubtless in the more distant past the planet Mars possessed a far more extensive atmosphere with far more water and oxygen than now. Through inexorable time and the natural processes of physics its small mass has been robbed of most of these. Our smaller neighbor is generally accepted, cosmically speaking, as a dying world.

The facts about Mars as we have observed them may be summarized as follows:

1. The Martian day is about 40 minutes longer than ours. Every 38 days we can see the whole circumference of the planet.

2. Because the tilt of the axis is comparable to ours, the seasons are comparable to those on Earth.

3. In length the seasons are nearly double ours since the Martian year consists of 687 of our days, 669 of its own.

4. Polar caps which melt in the Martian summer and form again in the winter imply a substance deposited by cold.

5. The melting polar caps are bordered by a dark blue belt that retreats with them. This excludes the possibility of their being formed of carbon dioxide and suggests that the material composing them must be water.

6. The blue belt of the southern cap has widenings in it; they occur where the bordering blue-green areas are largest.

7. Extensive shrinkage shows the thinness of the polar caps.

8. Melting patterns are the same year after year.

9. Rifts and bright patches occur annually in the same places.

10. The south polar cap becomes much larger than the northern and sometimes melts entirely, implying again that the deposition in both caps is light.

11. The manner of the melting of the caps and their reforming affirms the presence of water vapor in the Martian atmosphere.

12. Since water vapor is present, of which the molecular weight is 18, it follows from the kinetic theory of gases that nitrogen, oxygen, and carbon dioxide, of molecular weight 28, 32, and 38 respectively, may be there too because they are heavier than water.

13. Limblight and clouds testify to the atmosphere of Mars. The evidence of a twilight arc tends to confirm this. The planet's low albedo indicates an atmosphere very much less dense than our own.

14. Permanent markings which show upon the disk prove that the surface itself is generally visible.

15. Outside the polar caps the disk is divided into red-ochre and bluish-green regions. The red-ochre areas appear like our deserts seen from afar and behave like them, being little affected by change.

16. The blue-green areas, once thought to be seas, cannot be such because they do not reflect an image of the Sun and they change in tint and expanse according to Martian seasons. Furthermore they are seamed by permanent lines and spots darker than themselves; there can be no large bodies of water on the planet.

17. The bluish-green areas fade out seasonally, as vegetation would, to ochre for the most part. Each hemisphere undergoes a similar metamorphosis as the season changes.

18. Recent infrared spectroscopy by Sinton (1959) revealed on Mars the same C - H bands that are common to terrestrial vegetation. The bands were found to occur only in the blue-green regions and were absent or very weak at the same time in the desert regions.

19. Changes in the dark areas follow the melting of the polar caps — not immediately, but only after a lapse of time.

20. Though not seas now, the dark areas suggest old sea bottoms. On the terminator they appear as depressions (whether because really at a lower level or because of less illumination is not certain). That they are now the parts of the planet to support vegetation seems reasonable, as water would be expected in the low, warm areas.

21. Terminator observations prove conclusively that there are no high mountains on Mars, and that the surface is surprisingly flat.

22. Terminator observations do reveal clouds, usually rather rare and often chiefly dust storms. At certain seasons and over the pole of the new-forming cap, however, the clouds are probably cirrus composed of ice particles.

23. In winter the polar region and sometimes the temperate zones are more or less covered by a whitish veil, which may be hoarfrost and sometimes cloud because the phenomena quickly come and go in blue and yellow photographs, but vanish in red photographs.

24. A cloud canopy which attends the forming cap and is always larger than the snow cap itself quickly evaporates with the advent of spring.

25. A spring haze often surrounds the north polar cap following its most extensive melting, appearing as a dull white collar. Otherwise, the Martian sky is generally clear in yellow photographs for weeks at a time, as it would be in a dry and desert land.

26. Rarely, widespread storms envelop the globe and obscure vast regions of the planet.

27. Every type of observation denotes that the Martian atmosphere is far more tenuous than ours; violet photographs, however, prove that it is from two to three times more opaque to blue and ultra violet rays than is our own atmosphere. The opaque violet veil some-

times clears away for one to five days revealing surface features nearly as prominently as do ordinary monochromatic yellow photographs.

28. When dense clouds appear on Mars, they are sometimes accompanied by the appearance of adjoining temporary dark patches which may occur in the desert or in dark regions. They generally last only one day, suggesting that they are caused by moistened soil.

Considering these points, which are the result of many kinds of observations, we see that the cumulative evidence suggests that:

1. Martian days and nights are substantially like our own.
2. The atmosphere contains some water vapor and carbon dioxide.
3. Water is scarce.
4. The temperature is colder than ours, but daytime temperatures are far above freezing except in winter and at times in extreme polar regions.
5. Some form of vegetation exists.

Most important of these conclusions concern air. To make possible vital processes of any sort, a planet must have an atmosphere. Such a covering serves two purposes: It keeps out the cold of space, permitting maintenance of a temperature sufficient to support life, and it affords a medium through which metabolism can go on.

Change in the Martian markings attests to the presence of air. The limb-light, the evidence of a twilight arc, the planet's low albedo, and spectrographic observations indicate that the atmosphere is thin. The occurrence of clouds floating visibly and traveling over the surface, occasional haze, and the violet layer so evident in blue photographs — each proves in its own way the existence of an atmosphere.

Water is the next substance vital to planetary processes. As to its actual presence, the polar caps have most to say; as to its relative absence, the great clarity of the Martian sky speaks. Most of the water on Mars appears to be locked in the polar caps during the winters. No bodies of water are observable.

The question of how much water there is on Mars has been the subject of much speculation. The early seasonal appearance of dark rifts in the snow cap and the fragmentary manner in which it disintegrates during the Martian spring and summer hint that the depth of the snow is not very great as compared with terrestrial snows. The solar energy received per unit area on Mars permits an estimate of the amount of snow and ice that can be converted into water; this roughly indicates a snow cap two or three feet in depth. Other lines of evidence indicate a depth of several inches but perhaps no more than one foot. Indirectly we surmise that the amount of snow in the south cap is quite considerable because its release of moisture at melting darkens many millions of square miles of the southern hemisphere and maintains the darkening throughout the Martian summer.

Some writers have erroneously assumed that the low brightness of the cap as compared with the brightness of fresh snow means that the snow is of insufficient depth to conceal the ground. But photograph No. 6, Plate XLVIII, of terrestrial snow clearly demonstrates the real reason why the Martian snow cap shows a low albedo.

Whether an estimate of the amount of water on Mars is true or not matters little because everything about Mars bespeaks that it is a planet more desert-like than anything we know here. That oxygen once was there is evidenced by the strong red color of the surface, an aspect to be expected from oxidation. Doubtless this accounts for the depletion of the oxygen. Since a general clearing of its sky is a regular step in a planet's development, we should expect to find a cloudless, transparent air in the case of a planet as relatively old as Mars. This is precisely what we do find.

A third presence on Mars indicates a living world: vegetation. The evidence is in the blue-green areas and the changes in their appearance. Vegetation would present exactly the appearance shown, and nothing we know of but vegetation could. The seasonal change that sweeps over them is metabolic; that is, it shows both growth and decay and proclaims an organic constitution such as only vegetation could produce. The blue-green lapses into ochre and revives again to blue-green just as vegetation does on Earth at the proper season under the stimulus of the Sun and the advent of water. Certain large dark areas, like the Pandorae Fretum, turn to chocolate-brown and ochre at times, the color of dead plants and fallow ground.

These seasonal changes of the dark areas have long been interpreted as vegetative even though the atmosphere is now almost devoid of free oxygen. If there was enough oxygen in the past to sustain life, and if the exhaustion by weathering were exceedingly slow, it is conceivable, but not considered probable, that the evolution of life may well have kept pace with it. Plants may have developed means of utilizing for their own internal respiration the oxygen produced by photosynthesis, just as desert plants on Earth have learned to store up water and protect themselves from evaporation.

There is no decisive evidence whatsoever that intelligent animal life exists on Mars. It is possible that Earth's human race, at its present level of intelligence, would be able to secure its survival, though in diminishing numbers, in enclosures supplied artifically with oxygen, provided it had the millions of years of warning that the changes would undoubtedly give and provided that it took the necessary precautions. At the present rate of rock weathering on Earth, however, there is enough oxygen in our atmosphere to last a billion years.

Finally, we preceive that, according to all these various observations, the conclusions are completely unified only if we admit the existence of some water vapor on Mars. All these conclusions are in beautiful harmony with terrestrial analogies, and the physical properties of Mars and its atmosphere are well understood if we admit that the polar caps and the cirrus clouds on Mars consist of snow and ice particles. Conversely, if they are not of water, then the ever-changing surface features of the planet and its atmosphere have no satisfactory explanation.

Our knowledge of Mars steadily progresses. Each opposition adds something to what we knew before. Since the theory of life on the planet was first enunciated some fifty years ago, every new fact discovered has been found to be accordant with it. Not a single thing has been detected which it does not explain. Every year adds to the number of those who have seen the evidence for themselves. Thus theory and observations coincide.

Photograph of Mars *obtained on August 24, 1956 by R. B. Leighton of the California Institute of Technology. The Mt. Wilson 60-inch reflector was used and its aperture was cut to 21 inches with an off-axis diaphragm. The exposure time was 20 seconds on Kodachrome Type A film. The positive, used in making the print, was composed by the Jet Propulsion Laboratory.*

Plate I

This face of Mars is famous for the fact that Huygens first observed the Syrtis Major near the central meridian of Mars on November 28, 1659, at 7 hours in the evening; it is therefore the first marking ever recorded on the planet. This region is also especially notable for having displayed some of the most remarkable changes in the dark markings of any part of the planet.

In this and in all of the photographs of Mars appearing in this volume the direction north is toward the bottom and west is to the right.

Noteworthy examples of change have been the vanishing, reappearance, and subsequent great expansion of the Thoth-Nepenthes system of canals, and the advent of a new dark area which developed to great prominence near Nodus Lacoontis at the 1954 opposition. This region [1,2,3] has long been the scene of numerous frost and cloud formations, which, on occasions, have concealed the Syrtis Major from view, (see No. 3, Plate XXI); while further to the south the Hellas region has often been temporarily shrouded in white, first strikingly photographed at Lowell on August 1 and 2, 1909. Numerous examples of drifting clouds have been observed in the Isidis-Libya region.

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[1]Slipher, E. C., Pop. Ast., *29*, 2, 1921.
[2]————, P.A.S.P., *33*, 193, 1921.
[3]Slipher, V. M., Ibid, *39*, 147, 1927.

PLATE I

LOWELL'S GLOBE OF MARS 1907

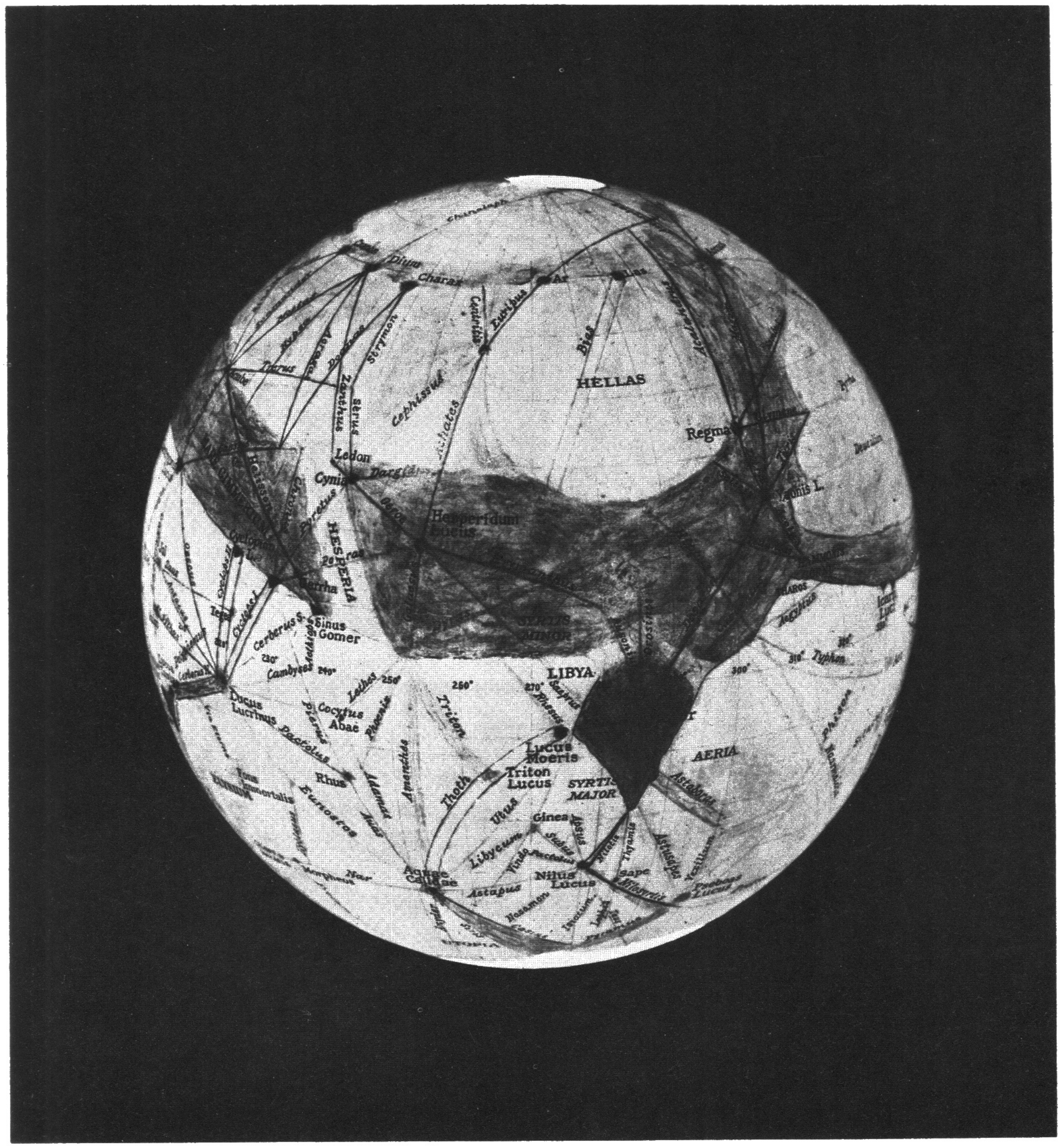


Plate II

The cameras used to obtain all Lowell photographs are equipped with specially figured negative lenses mounted in a movable carriage inside the tube. The internal mechanism is operated from the outside by dials for setting the lens for different magnifications and for focusing. Each camera is equipped with a double-slide plate carriage to enable the observer to make successive images quickly across the plate and to take several rows of images on a single plate. Mounts are provided for holding the color filter just in front of the negative lens. Ordinarily the camera is set to produce equivalent focal lengths of 160 to 220 feet. For blue, violet or ultra-violet photographs, it is necessary, of course, to employ a special blue-corrector lens ahead of the camera. The eyepiece attachment and camera can be interchanged easily in about one minute.

PLATE II

PLANETARY CAMERA ATTACHED TO THE 24-INCH LOWELL REFRACTOR

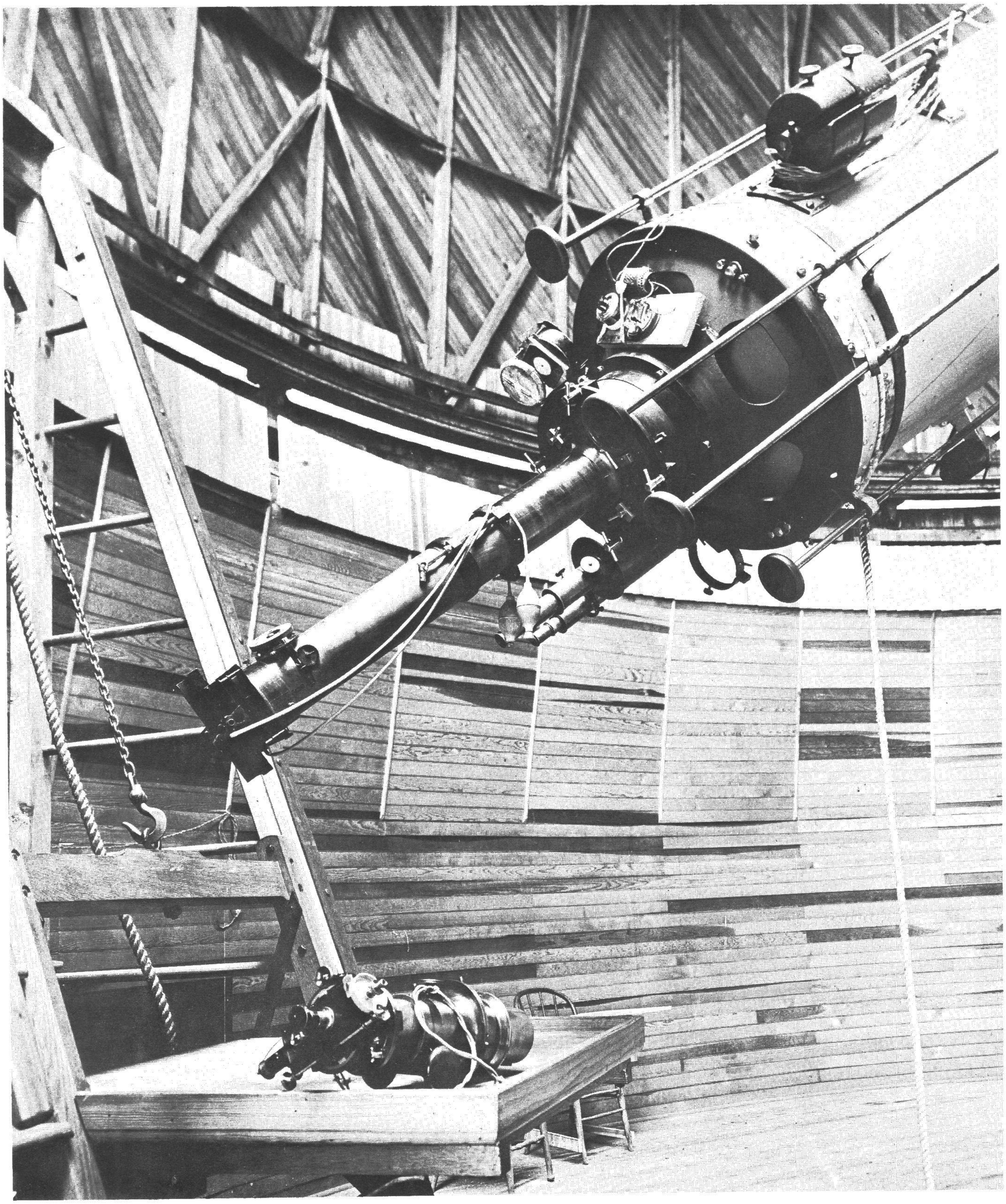


Plate III

This photograph, taken only a few days before opposition, December 4, 1911, shows the disk of Mars just after occultation by the moon. It reveals that, even at a better-than-average opposition, the planet's apparent disk is no larger in area than a medium-to-small crater on the moon. This serves to emphasize the meticulous care necessary to discover the hundreds of details that have been recorded on Mars and which confirm the numerous changes that have been observed.

PLATE III

OCCULTATION OF MARS BY THE MOON

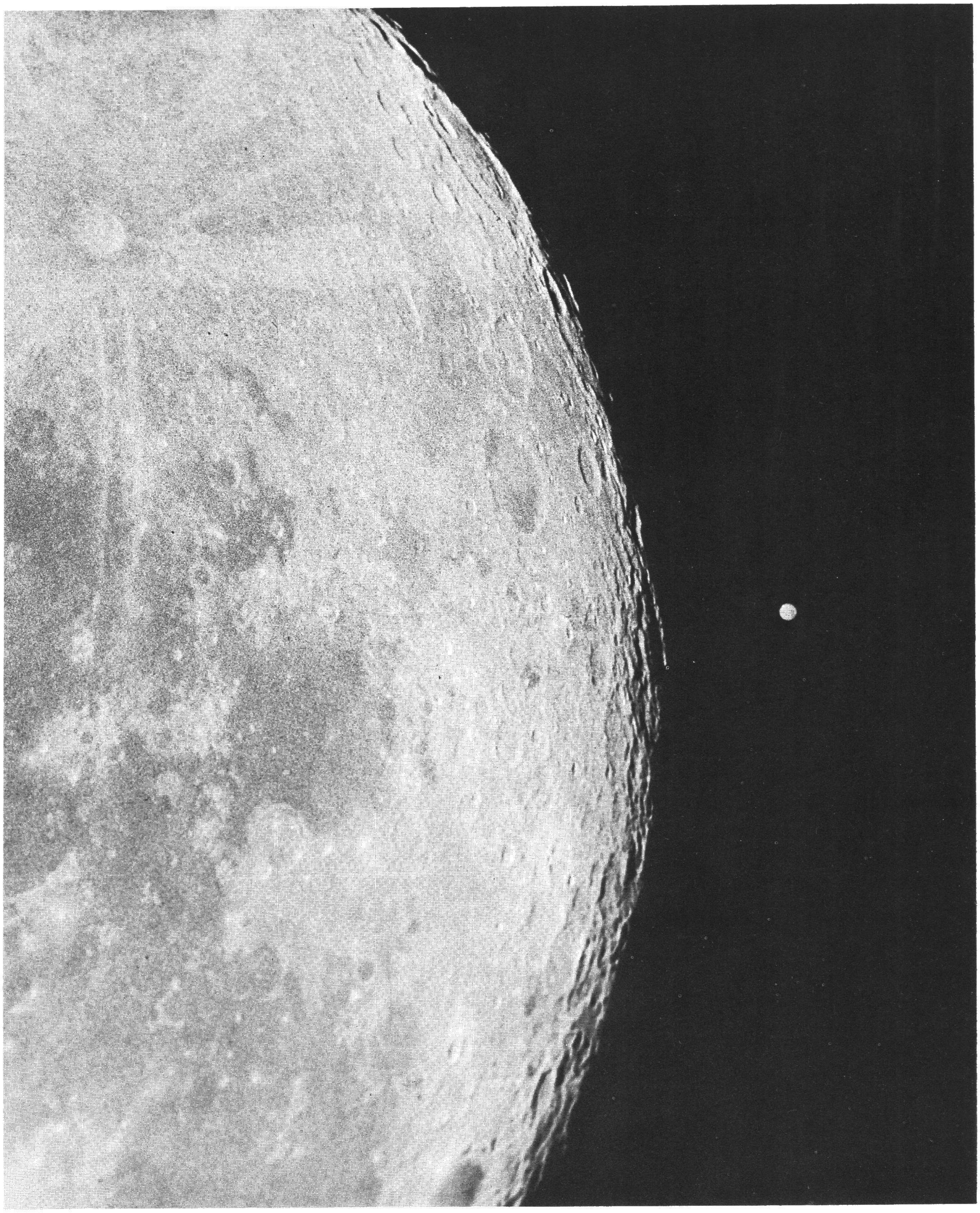
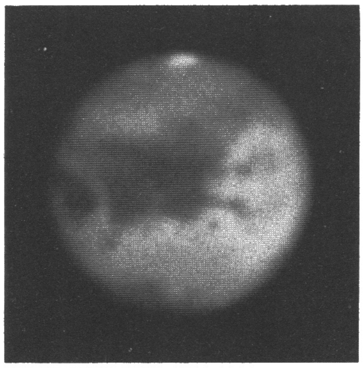


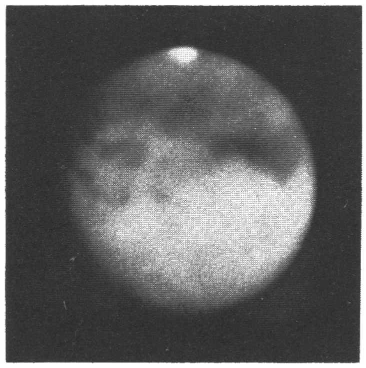
PLATE IV

REFERENCE MAP OF MARS AND ASSOCIATED PHOTOGRAPHS OF PRINCIPAL REGIONS

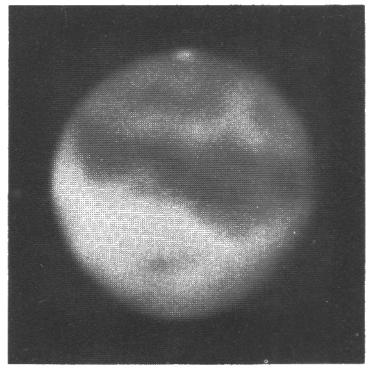
To facilitate the identification of markings referred to in the text, an annotated map of Mars by Lowell is here surmounted by a series of photographs covering a complete circuit of the planet.



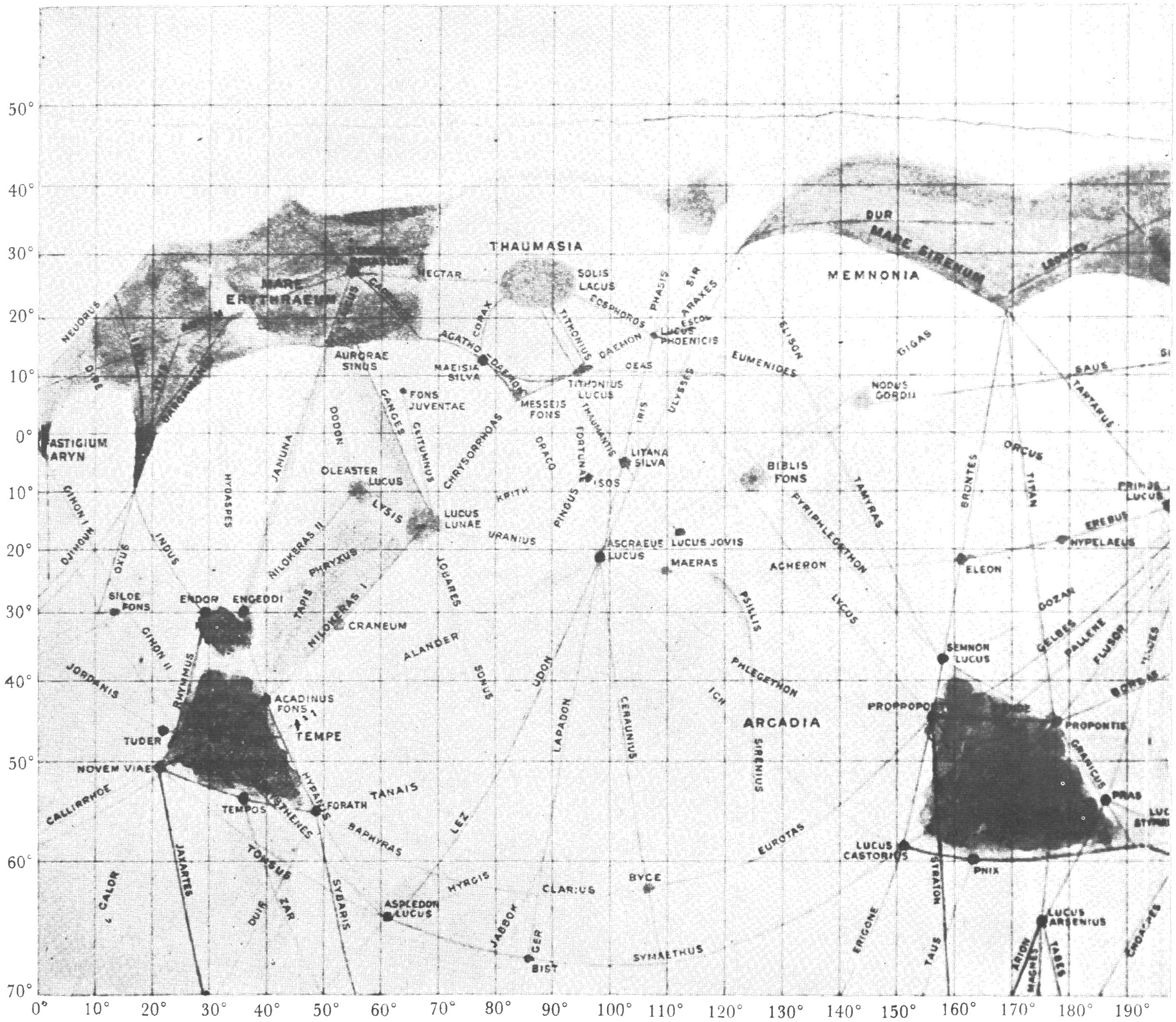
1. 1941 Oct 7 λ48°
U.T. 10:45 R
July 9 M.D.



2. 1941 Sept. 25 λ116°
U.T. 8:09 O
July 1 M.D.



3. 1941 Oct 23 λ208°
U.T. 6:37 Y
July 19 M.D.

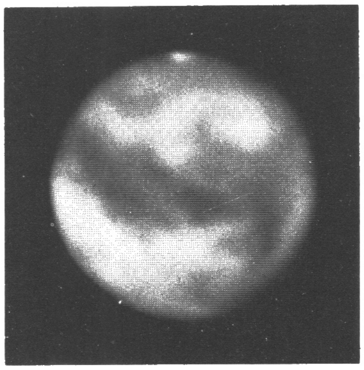


This annotated map of Mars, made by Lowell from visual observations in 1905, is intended to aid the reader in identifying certain markings referred to in the text. Since Mars presents to the Earth different tilts of its axis from one opposition to another, no one map

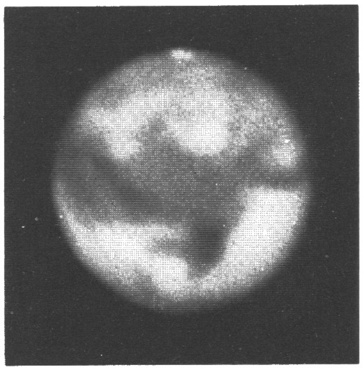
PLATE V

REFERENCE MAP OF MARS AND ASSOCIATED PHOTOGRAPHS OF PRINCIPAL REGIONS

Obviously the photographs and the map represent different oppositions, therefore, in making comparisons, allowance should be made for different tilts of the axis and other changes that occur with time.

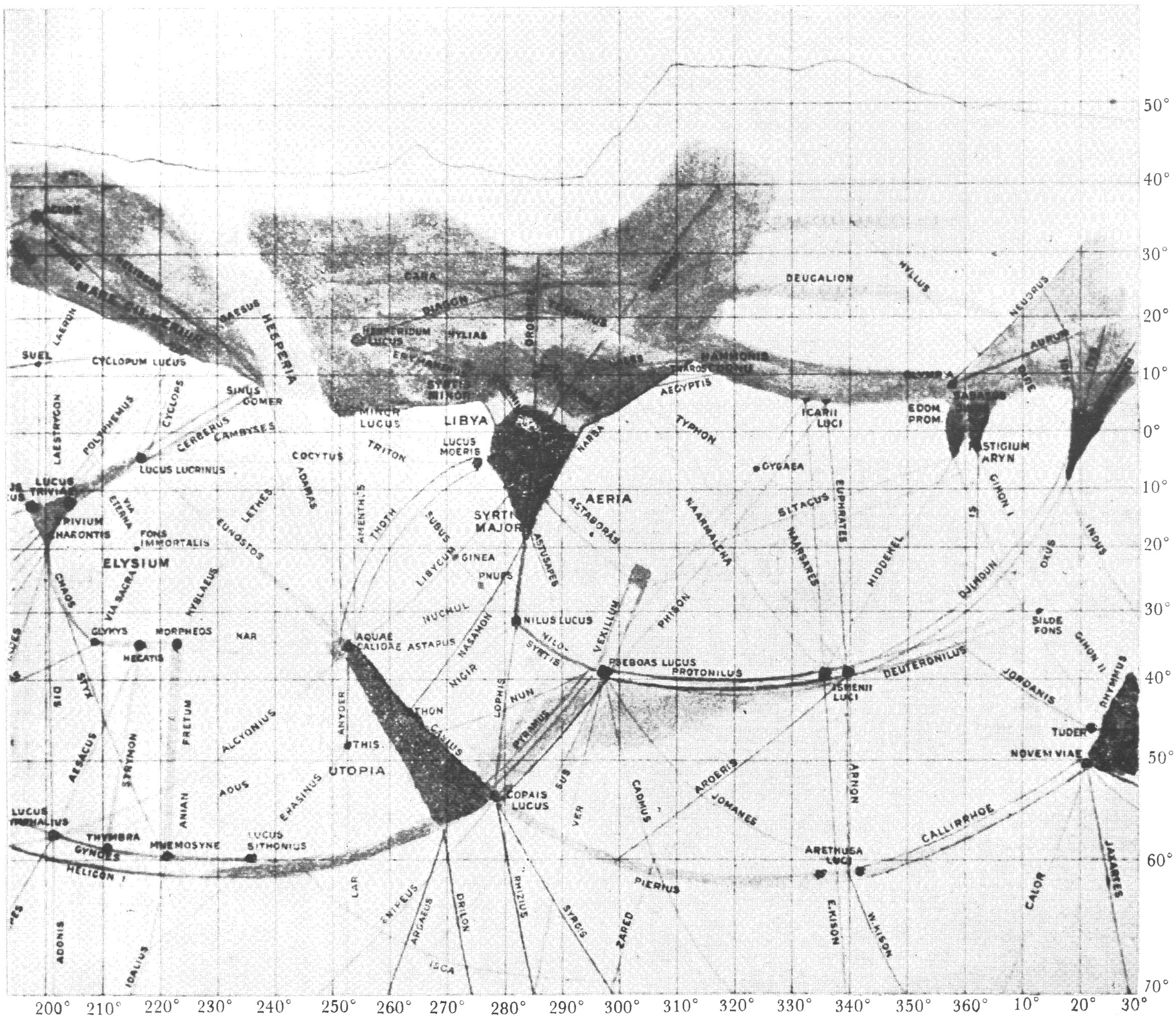


1. 1941 Oct. 17 λ259° U.T. 6:27 Y July 15 M.D.



2. 1941 Oct 17 λ284° U.T. 8:25 R July 15 M.D.

3. 1941 Oct 7 λ328° U.T. 5:16 R July 9 M.D.



will suffice to show all its markings. Above the map is a series of 1941 photographs which corresponds to about every 60° of longitude on the map. These were made when the southern regions of Mars were well presented to view.

Plate VI

In 1907 Mars was more favorably placed for observation than it had been for more than a dozen years. The earth in its "stern chase" around the sun, caught up with Mars on July 12, 1907, and found it in the part of its orbit nearest the sun. The distance at opposition was 38,500,000 miles, not far from its smallest possible value. However, it was 25° south of the equator during the favorable time for observations; therefore it was unfavorably low in the southern sky for good observations from northern sites. Lowell, inspired by the initial success in photographing some of the canals at Flagstaff in 1905[1], and anxious to make full use of the next favorable opposition to continue the work, sent an expedition[2] to the Andes to observe Mars where it would culminate near the zenith each night. Fortunate in obtaining the loan of the excellent 18-inch refractor of Amherst College, the expedition set out from New York, by way of Panama on May 11 for an outdoor station at Alianza, Chile. The station was situated on the Tarapaca desert, elevation 4000 feet, in south latitude 20°30′, and inland about 70 miles from Iquique and beyond the coast range of the Andes. Here in this rainless and almost cloudless desert waste, the seeing was exceptionally fine.

The accompanying photographs are representative examples from over 13,000 taken by the expedition. They have been prepared by optically superimposing about a half-dozen images from each plate into one composite picture, in order to minimize the effect of plate grain, but at the cost of losing much of the finer detail. Here the photographs are arranged in order of Martian longitudes of the disk, and cover one complete circuit of the planet.

The photographs show many interesting features on the disk and temporary atmospheric phenomena. Among these are: 1) temporary mists and clouds obscuring dark regions, (see veiled dark regions in Nos. 12 and 14); 2) night-to-night disappearance and reappearances of the canopy at the north pole demonstrating it consisted then chiefly of cloud; 3) the slow, gradual shrinking of the south cap with its fixed dark rifts and bright spots, revealing that it was a fixed deposit on the solid surface as contrasted with the cloud character of the north cap; 4) the temporary clouds in Southern Tharsis region near Lacus Phoenicis (these clouds have been much observed in later years especially in 1926 and 1954 when the configuration was referred to as the "W" cloud group); 5) morning limblight preceding Syrtis Major (see No. 20); and 6) definite traces of the majority of all canals shown in 108 complete drawings made from visual observations during the same period. On some of the best images, the original plates show as many as twenty-six of these delicate lines and oases. The Gehon, which was strong in 1907, and the Euphrates were shown to be double beyond doubt. This early series of photographs, supplemented by 4000 to 5000 secured at Flagstaff, have proved of great value in providing comparisons with later photographs. Note the great strength of Nilosyrtis in Nos. 17 and 18.

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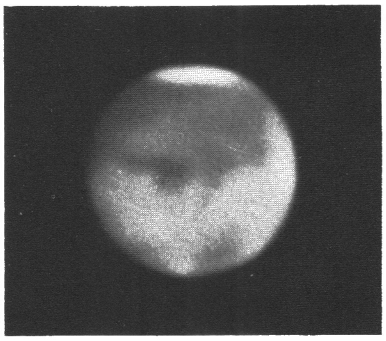
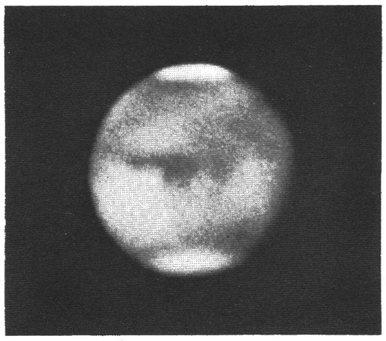
[1]Lowell, P., Lowell Obs. Bull., *1*, 21, 1905.

[2]Members of the Expedition included Dr. David P. Todd, in charge; Mrs. Todd; A. G. Ilse, engineer of the Alvan Clark Corp.; R. G. Eaglesfield, electrician and general assistant; and the writer as observer.

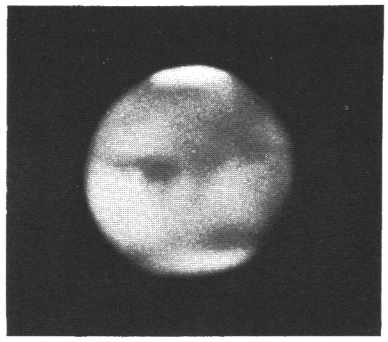
PLATE VI
1907 CIRCUIT OF MARS



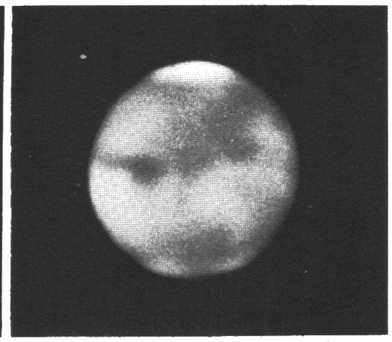
1. June 27 λ15°
U.T. 7:50 Apr 4 M.D. Y



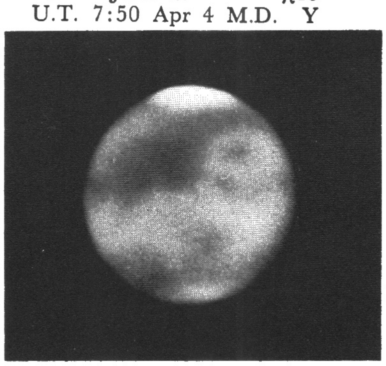
2. July 28 λ16°
U.T. 0:55 Y



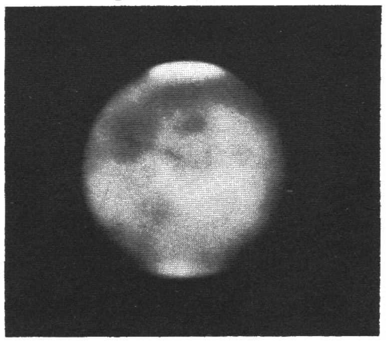
3. July 27 λ22°
U.T. 1:57 Y



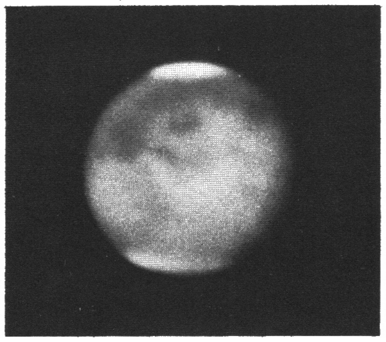
4. July 26 λ27°
U.T. 1:45 Y



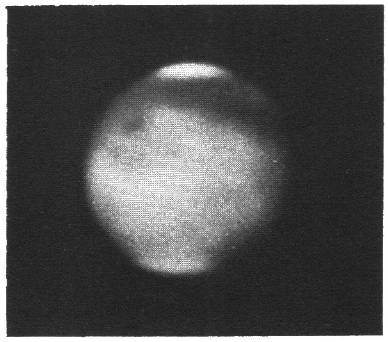
5. July 24 λ56°
U.T. 2:35 Y



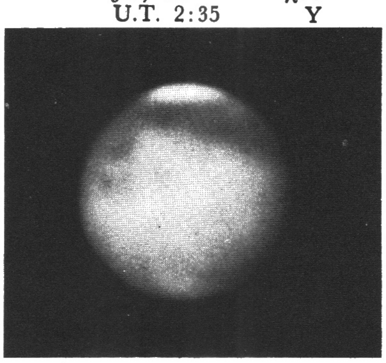
6. July 28 λ79°
U.T. 6:23 Y



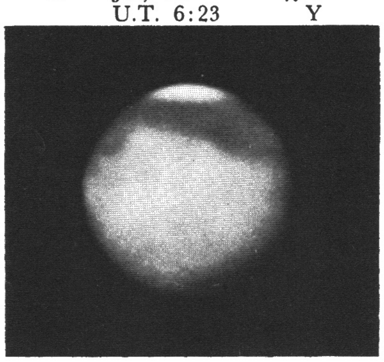
7. July 27 λ97°
U.T. 6:26 Y



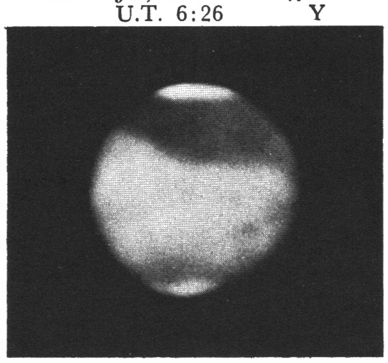
8. July 26 λ120°
U.T. 8:13 Y



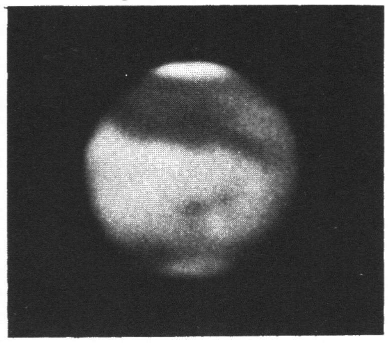
9. July 23 λ122°
U.T. 6:20 Y



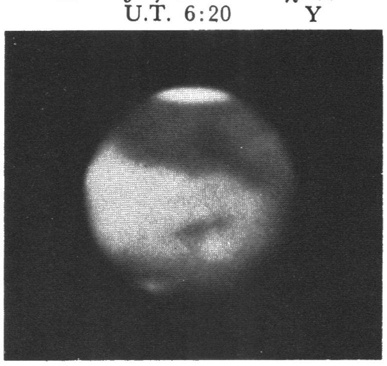
10. July 20 λ149°
U.T. 6:25 Y



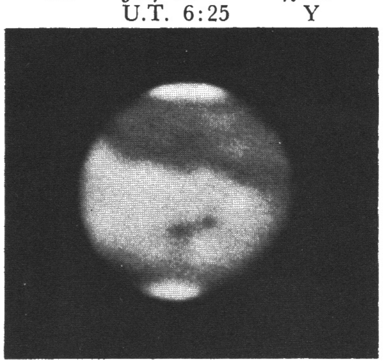
11. July 16 λ173°
U.T. 5:42 Y



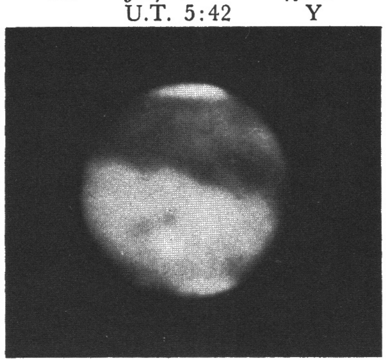
12. July 17 λ196°
U.T. 7:45 Y



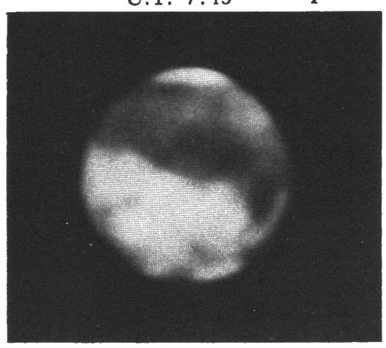
13. July 16 λ202°
U.T. 7:44 Y



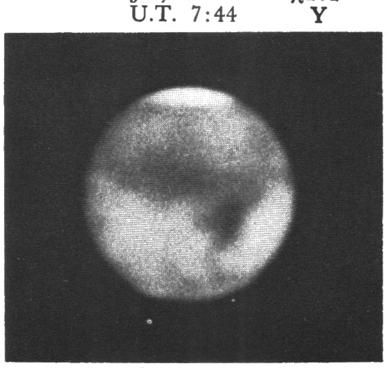
14. July 15 λ205°
U.T. 7:40 Y



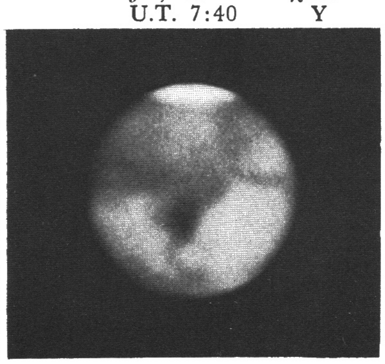
15. July 13 λ236°
U.T. 7:27 Y



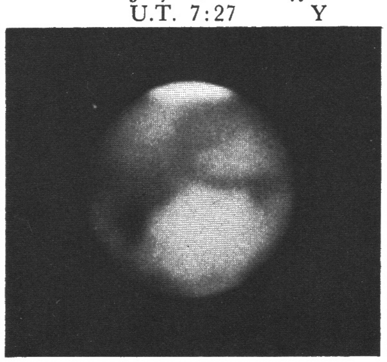
16. July 12 λ250°
U.T. 6:39 Y



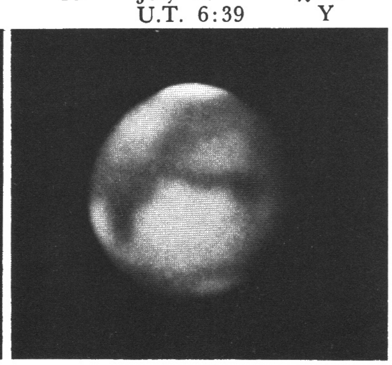
17. July 3 λ270°
U.T. 4:21 Y



18. July 3 λ294°
U.T. 5:56 Y



19. July 3 λ323°
U.T. 7:42 Y



20. July 30 λ331°
U.T. 0:56 Apr 23 M.D. Y

Plate VII

Following the initial efforts at Flagstaff to secure successful photographs of the planet in yellow light from 1903 to 1907, attempts to obtain photographs in other regions of the spectrum were begun in 1909 by making tri-color exposures in red, green and blue. The first row of images shows early examples of such tri-color photographs made in 1909. Results with the 42-inch reflector disclosed the surprising observations that blue images were completely blank, showed none of the permanent dark markings, and yet clearly enhanced the cloud cap and cloud areas. The green tri-color filter, which passed both green and blue light, (compensated filters were then not available) recorded the surface markings weakly as compared to the redder image which showed these in strongest contrast. Since similar tri-color photographs of paintings by Howard Russell Butler, N. A. gave identical results (second row), it was reasonable at that time to conclude that the explanation lay in the effect of selective reflection between the blue-green dark areas and the reddish deserts. This resulted in a complete leveling-out of the two in the blue photographs; the thought was that the thin atmosphere of Mars could have little or no effect.

The cause of the disappearance of the surface markings on the blue photographs, however, is less simple—there are at least two possibilities. One is that the actual colors of the reddish surface of the planet and its greenish-gray markings are such that in red light the first is much brighter than the second, while in blue light the red has lost much of its brightness and little contrast remains. The other is that the atmosphere of Mars, though transparent to red and fairly so to yellow, is very thick and hazy to blue light, and hence obscures the surface details.

No definite conclusion between these two alternatives seemed possible until 1937[1], when photographs by the writer revealed a state of blue clearing on May 20-23 so striking that the blue images revealed the surface details almost as clearly as ordinary yellow photographs. This example of blue clearing in the atmosphere of Mars led to the detection of others both before and since, with the result that the explanation of the *"violet layer"* and its temporary clearings has become a much discussed problem. A considerable number of explanations have been offered by physicists and physical chemists but none of these is free from serious objection. These are summarized elsewhere in this history.

The last row of images shows typical examples of modern tri-color photographs when the atmosphere of Mars was opaque to violet light. It is important to note here that there is no limb darkening in the blue photograph. Limb darkening is the fundamental requirement of the new theory announced recently by Opik[2] that carbon monoxide in the Martian atmosphere accounts for the violet layer.

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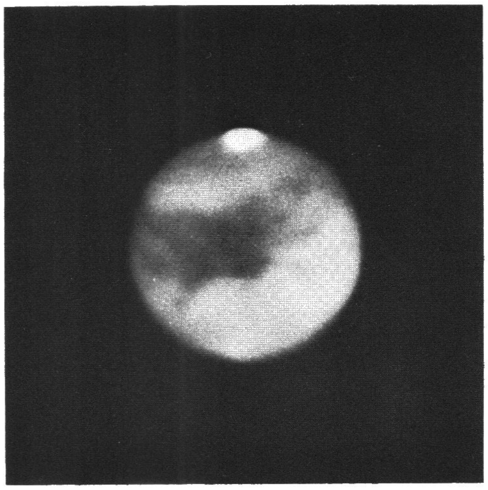
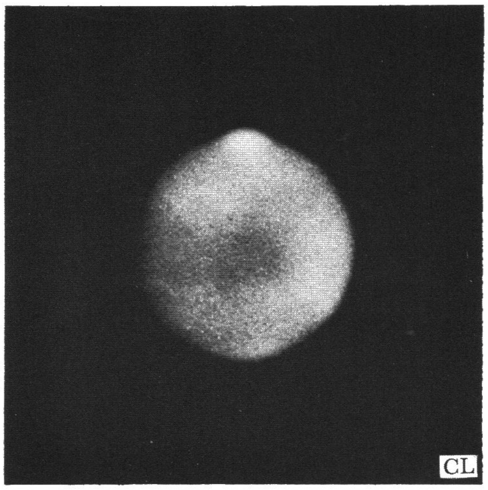
[1]Slipher, E. C., P.A.S.P., *49,* 289, p. 137, 1937.
[2]Opik, E. J., Jrnl. of Geo. Res., *65,* 10, p. 3057, 1960.

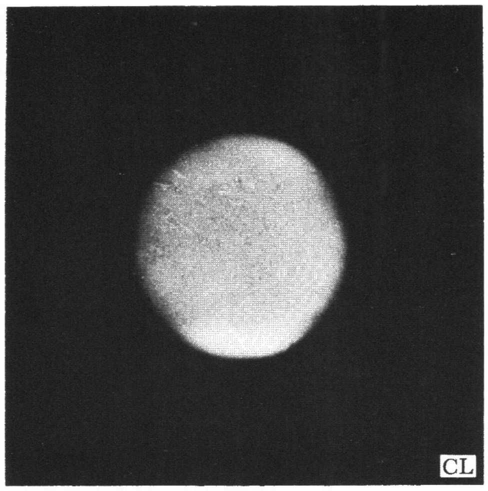
PLATE VII
EARLY TRI-COLOR EXPERIMENTS



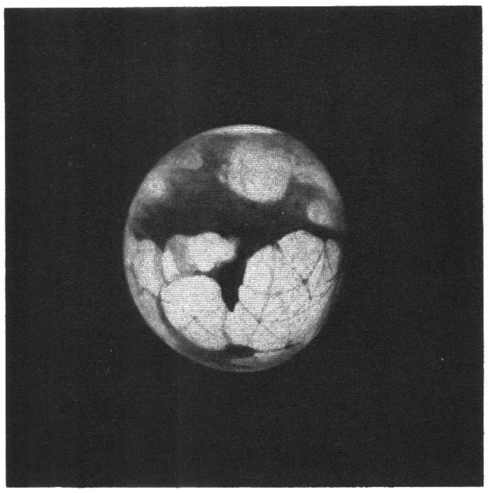
1. 1909 Sept 24 R



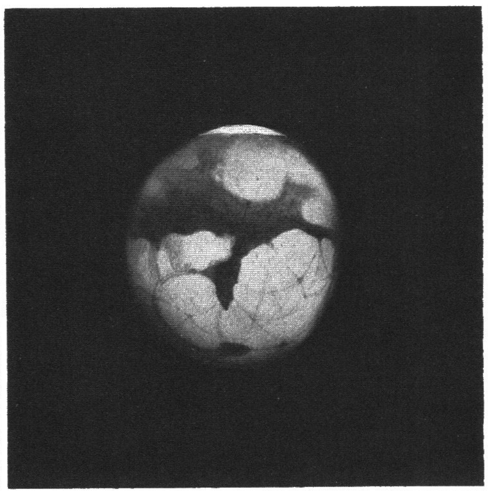
2. 1909 Sept 24 G-B



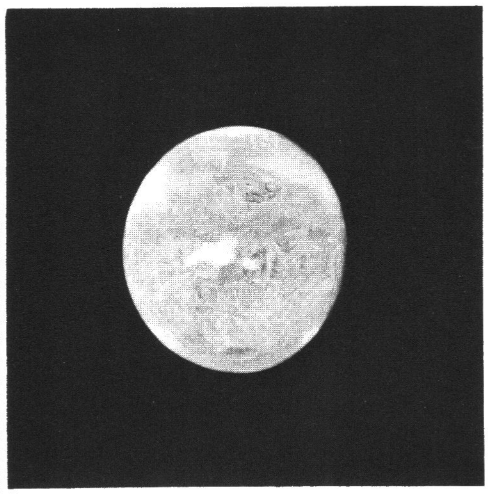
3. 1909 Sept 24 B



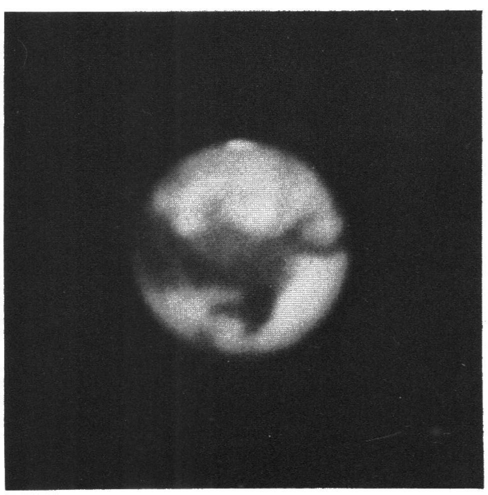
4. Butler Painting R



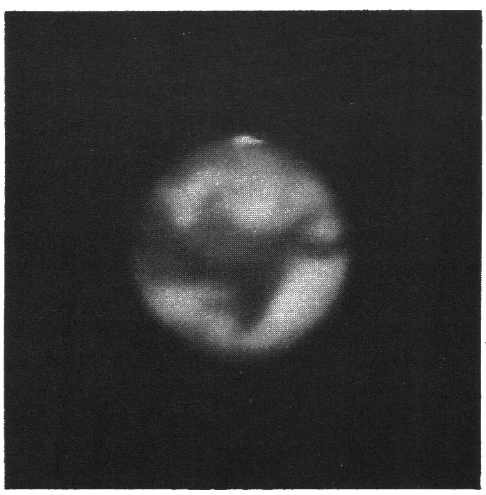
5. Butler Painting Y



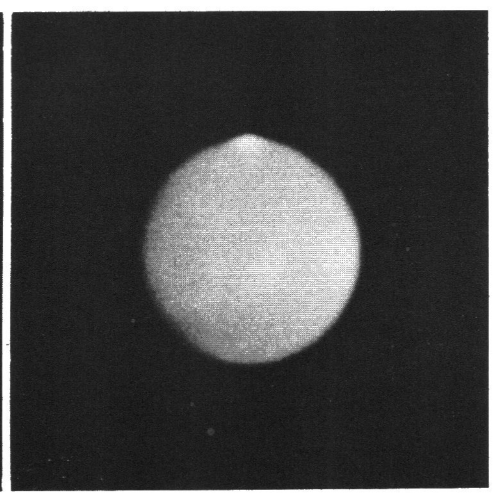
6. Butler Painting B



7. 1941 Oct 11 U.T. 4:44 λ285° R



8. 1941 Oct 11 U.T. 5:00 λ289° Y



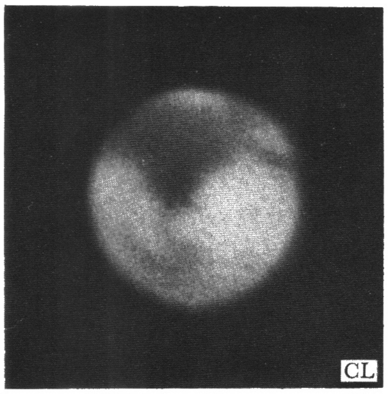
9. 1941 Sept 29 U.T. 10:27 λ114° B

Plate VIII

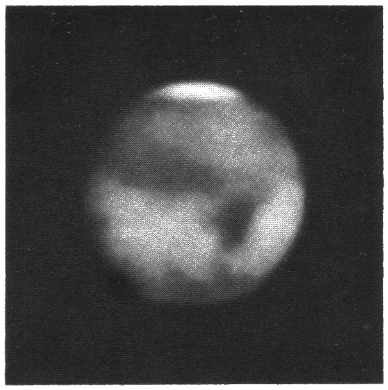
Typical examples of yellow photographs from 1905 to 1928 show changes of various features over the Syrtis Major region of Mars. Most of these changes are so self-evident that they hardly need description. However, attention may be called to some of the more outstanding ones. First note the great difference between the 1907 and 1909 photographs where the former in its springtime shows the maria (Mare Tyrrhenum, Ionium, Hadriaticum, Hellespontus and Hellas) as a rather uniform gray up to the south cap. In Martian summer in 1909, however, these same features have strikingly darkened, but the Hellas and the islands preceding it have definitely brightened. In 1909 the Syrtis itself appears narrower than in 1907, but the Lucus Moeris shows extensive development in the preceding direction, although the Thoth was even fainter than at the previous opposition. In 1911 to 1920 especially, the Thoth and other desert features developed considerable strength. In 1918 the Syrtis appears appreciably smaller and weaker as compared to its strength in 1920 and 1922. In 1922 dense yellow clouds appeared over Hellas with a faint fringe reaching well down toward southern Syrtis at times. In 1924 the Syrtis again became abnormally narrow but the maria again shows considerable darkening (Martian date May 17). The Thoth was again darker in 1926. In 1928 it became one of the grosser features of the disk and dark markings developed strongly in the Aethiops region. Aside from these major changes many minor ones occurred in this period.

The virtual disappearance of the Thoth in 1909, coupled with its strong development at the later oppositions, clearly suggests that it is not a natural feature but is due to something which develops on the surface.

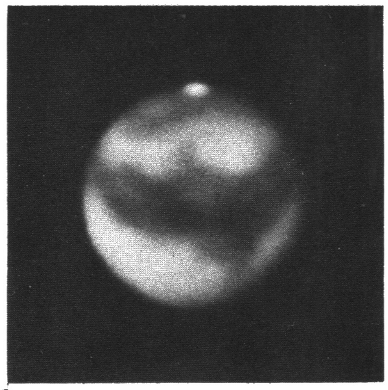
PLATE VIII
CHANGES IN THE SYRTIS MAJOR REGION



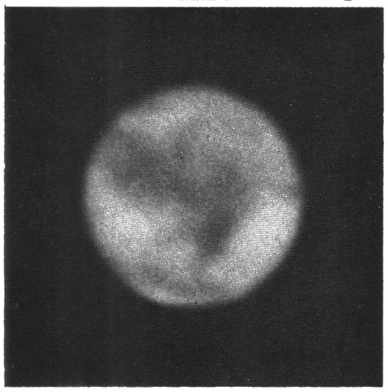
1. 1905 May 12 λ310°
Feb. 13 M.D. Y



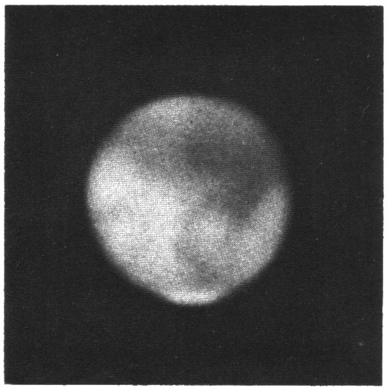
2. 1907 July 3 λ270°
U.T. 4:21 Apr 7 M.D. Y



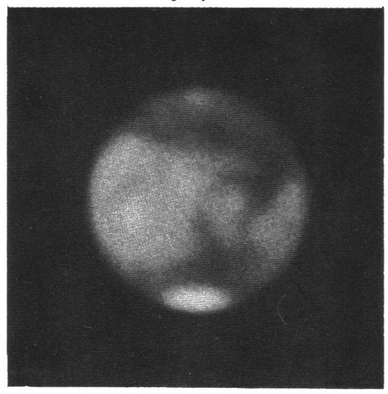
3. 1909 Oct 4 λ270°
U.T. 7:08 July 1 M.D. Y



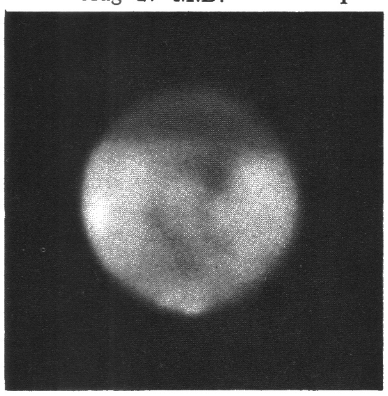
4. 1911 Nov 26 λ275°
Aug 27 M.D. Y



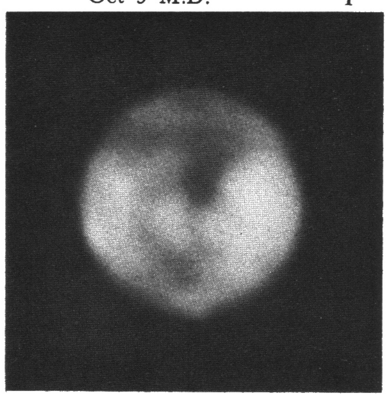
5. 1914 Jan 21 λ254°
Oct 9 M.D. Y



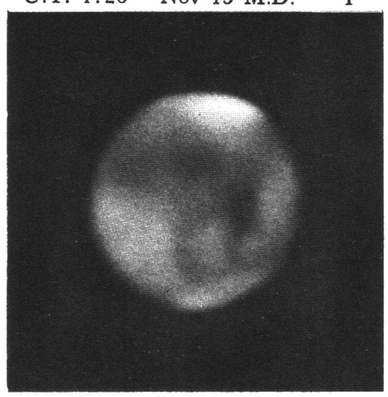
6. 1916 Feb 12 λ250°
U.T. 4:26 Nov 15 M.D. Y



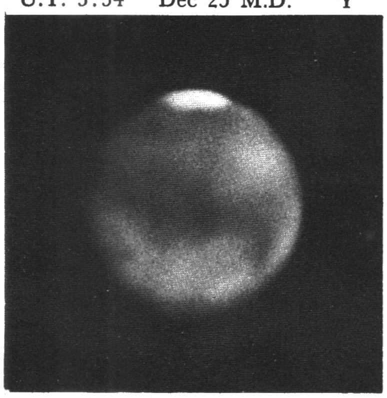
7. 1918 Mar 31 λ284°
U.T. 3:34 Dec 25 M.D. Y



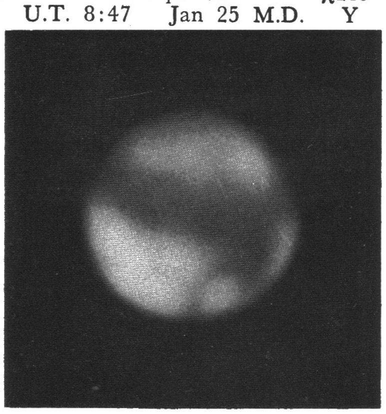
8. 1920 Apr 23 λ285°
U.T. 8:47 Jan 25 M.D. Y



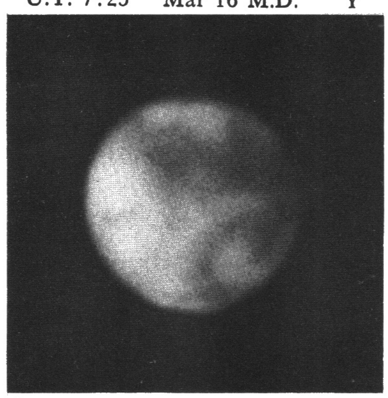
9. 1922 June 18 λ260°
U.T. 7:25 Mar 16 M.D. Y



10. 1924 Aug 31 λ250°
U.T. 9:34 May 17 M.D. Y



11. 1926 Nov 6 λ255°
U.T. 5:19 Aug 6 M.D. R



12. 1928 Dec 29 λ245°
Sept 28 M. D. Y

Plate IX

The large bright region between Elysium and Syrtis Major has revealed the greatest array of striking changes during the past 55 years of any part of the desert areas of Mars.

This series of yellow and red photographs, like those for the earlier years in Plate VIII, shows the varied aspects of the region preceding the Syrtis Major for different oppositions from 1931 to 1961 and displays numerous changes in the markings that have occurred there in the last thirty years. The different tilts of the planet's axis are evident, and the appearance of the northern and southern hemispheres in the different Martian seasons is indicated roughly in each case by the dimensions of the polar caps. Each opposition of the planet is represented except those of 1933, 1948 and 1950, here omitted for want of space.

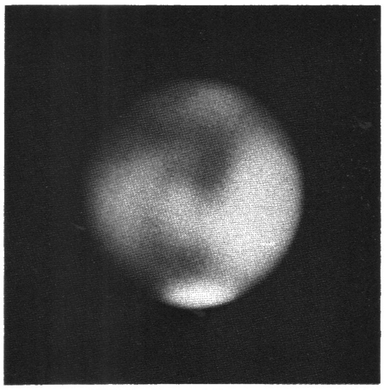
Photographs Nos. 1, 2, 3, 6, 7, 8 and 12 were made near aphelion and the others were made at perihelion. The reader should make due allowance for the fact that the areas originally photographed at these positions are in the ratio of about 3.5 to 1 and that the photographs at aphelion have been enlarged to the same size as the others. However, in every case enough is recorded in the photographs to provide valid comparisons and to determine many differences in the markings and interesting changes in the various areas. In 1931 and 1935 it is evident that the Thoth-Nepenthes system of canals, as well as all the markings over the Aethiops region, was much weaker than usual. In 1937 these markings were still weak, but had been strengthened appreciably. In 1939 and 1941 these same markings had been greatly strengthened by an amount greater than can be explained by the change in the planet's distance. In October 1941 a strange and unexpected gap appeared about half way along the Thoth canal, a break which appeared complete for a distance of four or five degrees or more as if obliterated by cloud, but none was detected. Referring back to the 1939 photographs, we note that they also show the Thoth unusually weak below Lucus Moeris as compared to the other years especially 1954 and 1956. In the red photograph, No. 9, the Thoth-Nepenthes-Triton system is by far the darkest of any time during this period and fully as prominent as it was in 1922, 1926 and 1928 (Plate VIII).

Perhaps the most extraordinary change in this region occurred around Nodus Lacoontis in 1954 just preceding the left base of the Thoth. An embryonic kernel appears to have existed there since 1952 when a small dusky patch first appeared. In 1954 this area burgeoned into a large dark area about the size of France. In most of the photographs and drawings it appeared as a fairly uniform dark shading, but when critically studied visually it was found to contain numerous details and was striated by several canals including the Eunostos, Adamas, Aethiops and Amenthes. Like the other dark areas on Mars it was not merely a uniformly shaded area but contained many lines and spots darker than itself.

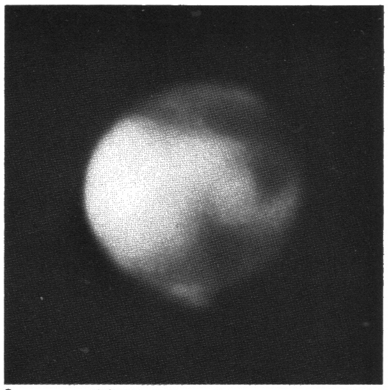
Many of these developments in this region hardly belong to the ordinary seasonal type but were more irregular in character or secular in nature. In some cases the development involved the expansion of existing weak markings and in some others the development of a new dark area, not previously mapped. As is evident from the photographs, the newly developed dark markings were not of any particular type, but aside from Thoth and other areas, they were very complex in structure consisting of a maze of dark spots and striae of several kinds.

The matter of paramount importance in connection with these new dark areas, is the fact that what was once a desert region may become a dark region.

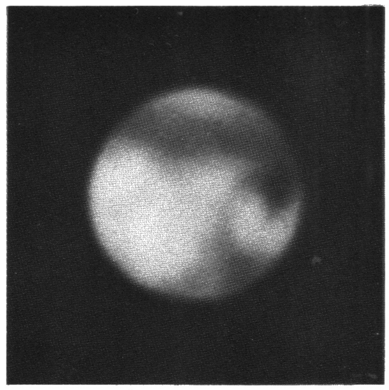
PLATE IX
CHANGES IN THE SYRTIS MAJOR REGION



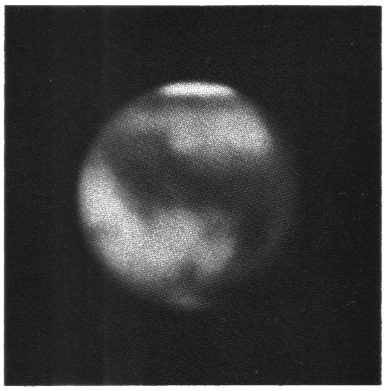
1. 1931 Jan 16 λ279°
U.T. 7:05 Oct 28 M.D. Y



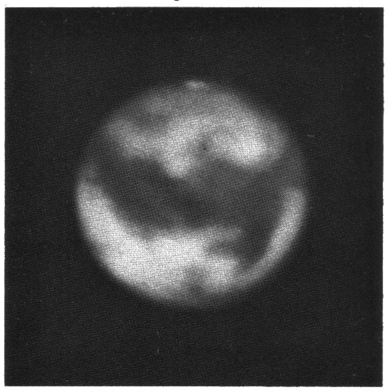
2. 1935 May 6 λ260°
U.T. 3:29 Jan 22 M.D. Y



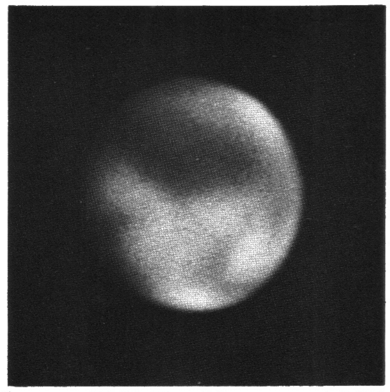
3. 1937 May 26 λ246°
U.T. 6:02 Feb 22 M.D. R



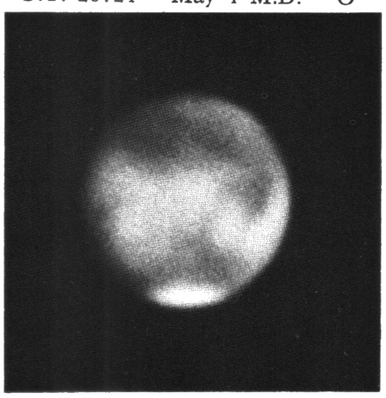
4. 1939 Aug 10 λ260°
U.T. 20:24 May 4 M.D. O



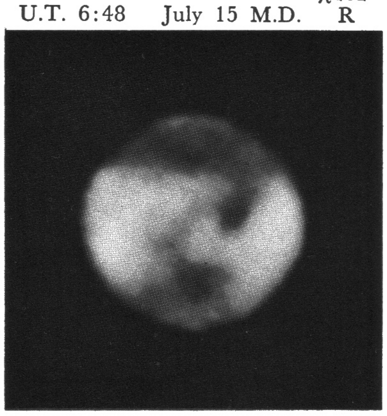
5. 1941 Oct 17 λ262°
U.T. 6:48 July 15 M.D. R



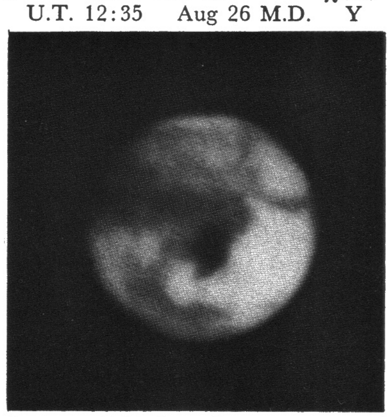
6. 1943 Nov 12 λ242°
U.T. 12:35 Aug 26 M.D. Y



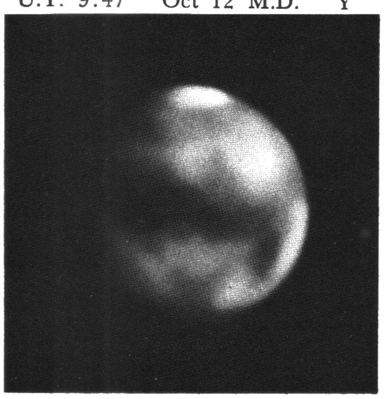
7. 1946 Jan 1 λ235°
U.T. 9:47 Oct 12 M.D. Y



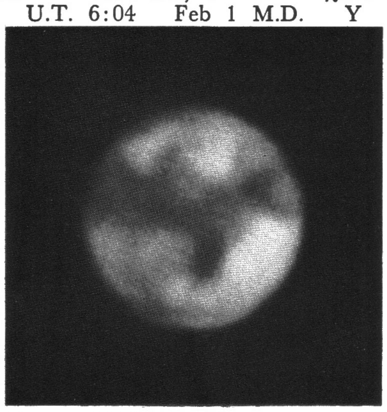
8. 1952 May 1 λ271°
U.T. 6:04 Feb 1 M.D. Y



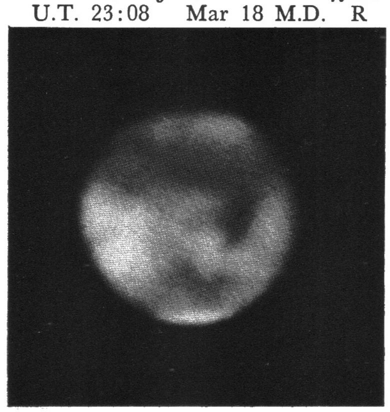
9. 1954 June 11 λ282°
U.T. 23:08 Mar 18 M.D. R



10. 1956 Aug 6 λ249°
U.T. 23:54 May 18 M.D. R



11. 1958 Nov 13 λ282°
U.T. 5:28 Aug 17 M.D. Y



12. 1961 Jan 9 λ266°
U.T. 5:20 Oct 9 M.D. Y

Plate X

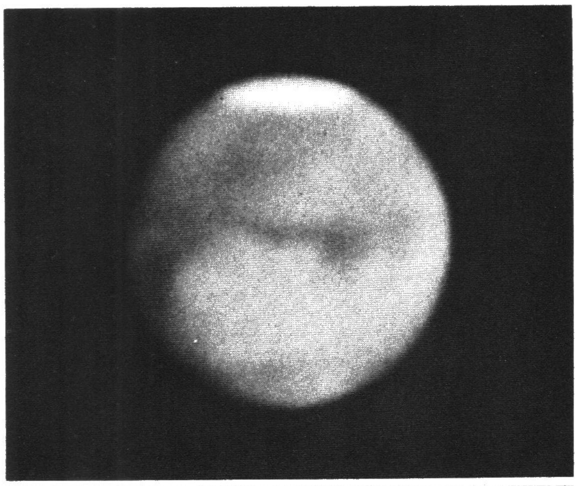
Undoubtedly the outstanding revelation of the photographs is the undeniable record of seasonal darkening of vast blue-green regions in Martian summer. In 1907 we see Sabaeus Sinus standing alone in the Martian spring, but in the summer of 1909, it is seen darkly flanked by the great Pandorae Fretum in the form of a broad, dark band covering millions of square miles. Obviously if such a development occurred only once, it might be considered merely a strange coincidence. However, in 1924, with the planet again in its early spring, we note that the dark band has completely vanished into ochre desert, leaving the weak Sabaeus Sinus standing quite alone again. Also in the summer of 1926 we note that the great dark band has returned once more as a complete replica of what it was in 1909. In 1939, the dark Pandorae Fretum has disappeared again and Sabaeus Sinus stands alone, but in 1941 the summer darkening is shown returning over the Pandorae, although not to the full extent of the previous examples. In 1954, the customary winter-spring aspect is also evident. In 1956, during late Martian spring, save for a partial veiling due to haze and clouds from the widespread dust storm over most of Mars at the time, we see the customary darkening of the Pandorae Fretum region just as it has appeared in the other summer photographs.

Although not described in connection with the foregoing series of seasonal changes, the Hellespontus, Mare Ionium, Mare Tyrrhenum also were partly involved.

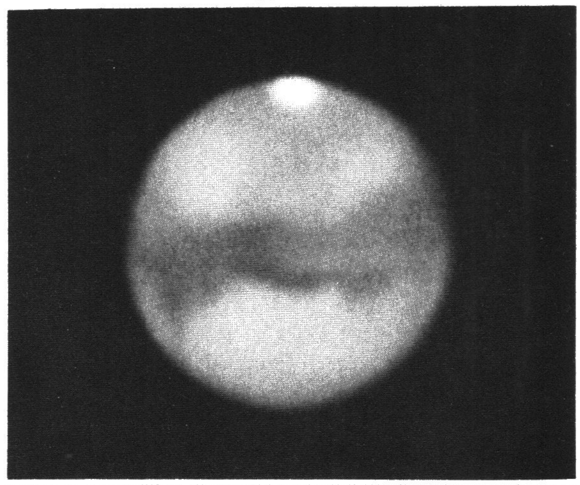
In a similar manner the series of dark regions in the southern hemisphere of the planet undergo a summer darkening. However, the Pandorae Fretum stands so completely alone on the planet that its appearance and disappearance with the seasons is most obvious and the fact that it completely vanishes into the ochre desert in winter makes it by far the easiest seasonal change to recognize.

PLATE X
SEASONAL DEVELOPMENT OF THE DARK MARKINGS

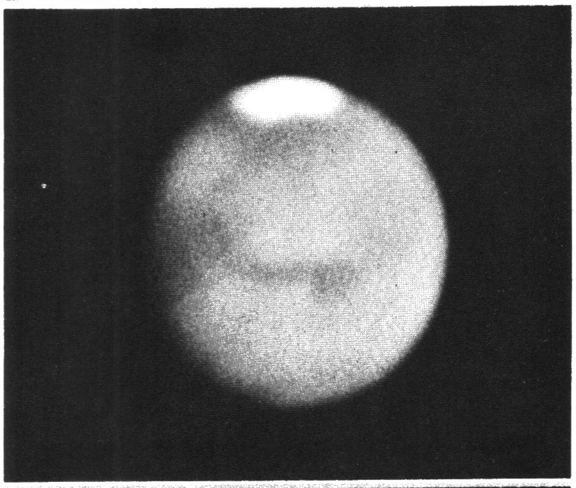
SPRING | SUMMER



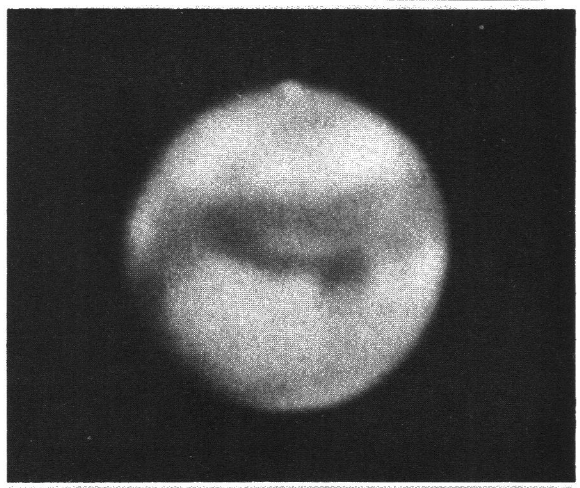
1. 1907
Apr 17 M.D.
λ344°



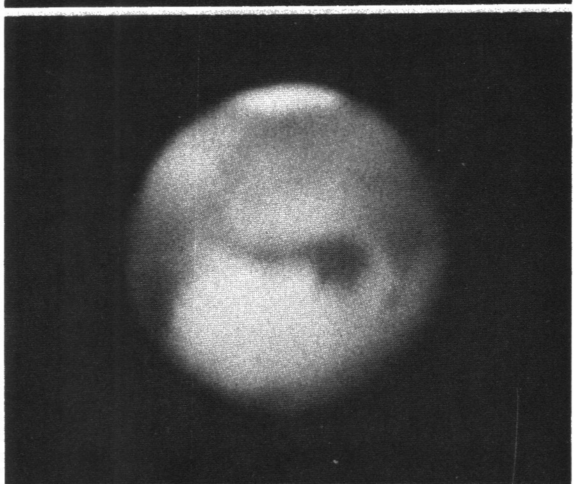
2. 1909
June 29 M.D.



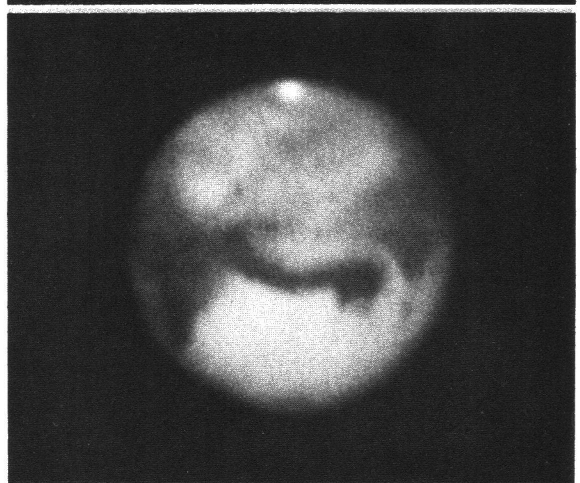
3. 1924
May 11 M.D.



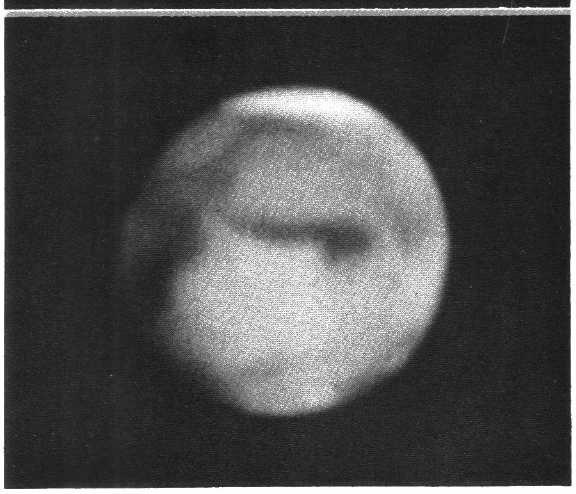
4. 1926
Aug 1 M.D.



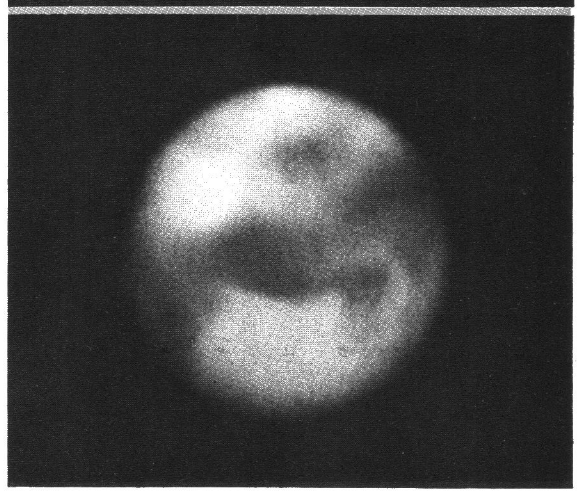
5. 1939
May 2 M.D.



6. 1941
July 11 M.D.



7. 1954
Mar 15 M.D.



8. 1956
June 7 M.D.
λ336°

Plate XI

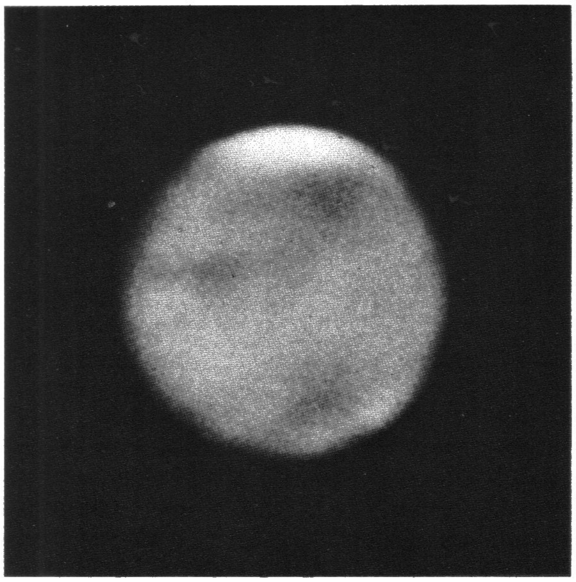
This series of photographs of the same face of Mars at various seasonal intervals displays stages in the progressive darkening of the blue-green regions as the cap gradually recedes towards the pole in unison with Martian spring and summer. The darkening of the maria and the southern tropics is striking from mid-May to mid-June when it appears to reach maximum intensity, and then it remains practically stationary until early September. The same general pattern of development takes place all around the planet every Martian year with remarkable regularity. In fact, at the same seasonal date the size and shape of the polar cap and other details repeat themselves with unfailing fidelity. Observers always on the lookout for diversions from the systematic seasonal behavior rarely find any anomalies in the seasonal melting of the polar cap or the darkening of the dark regions. As summer advances, and the tropics darken, the polar regions and higher latitudes grow a little lighter in tone than they were in the spring.

The gradual darkening of certain regions of the planet in its summer season and their subsequent fading in winter seem best explained by attributing the dark areas to vegetation.

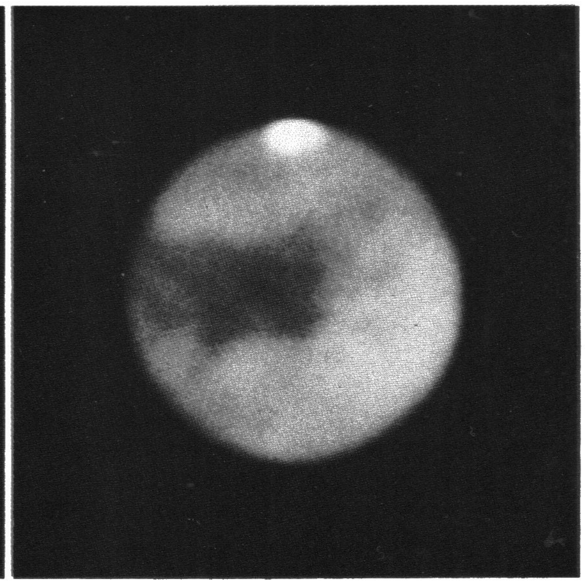
PLATE XI

SEASONAL CHANGES IN THE SOUTH CAP AND DARKENING OF THE BLUE-GREEN AREAS

Mar 10
M.D.



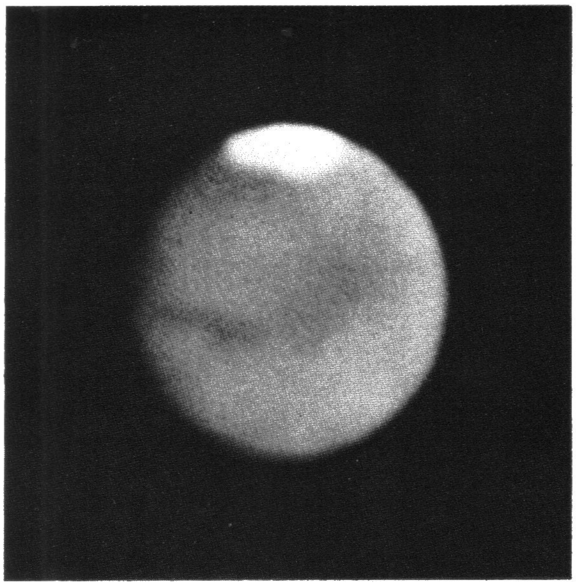
1. 1922 June 7 λ21°
U.T. 9:05 Y



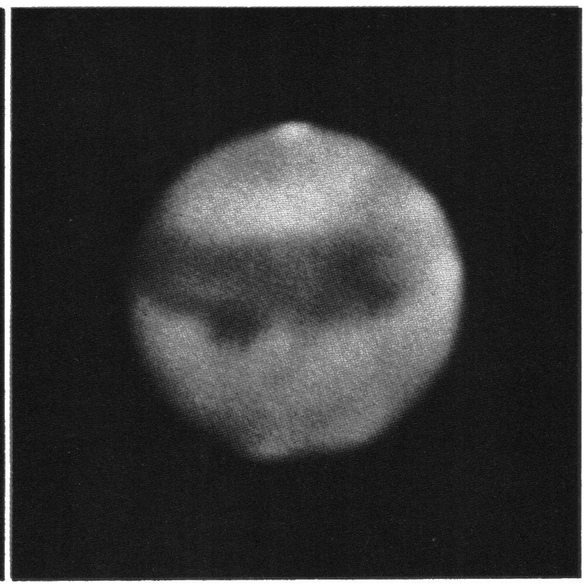
4. 1909 Sept 24 λ55°
U.T. 9:30 Y

June 23
M.D.

May 11
M.D.



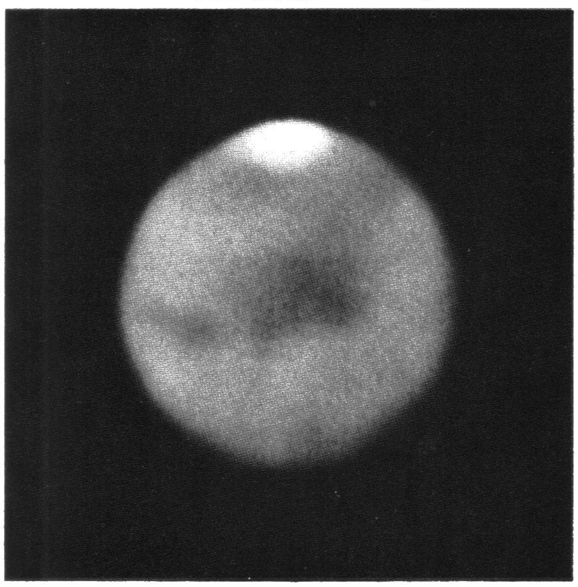
2. 1924 Aug 3 λ13°
U.T. 11:40 Y



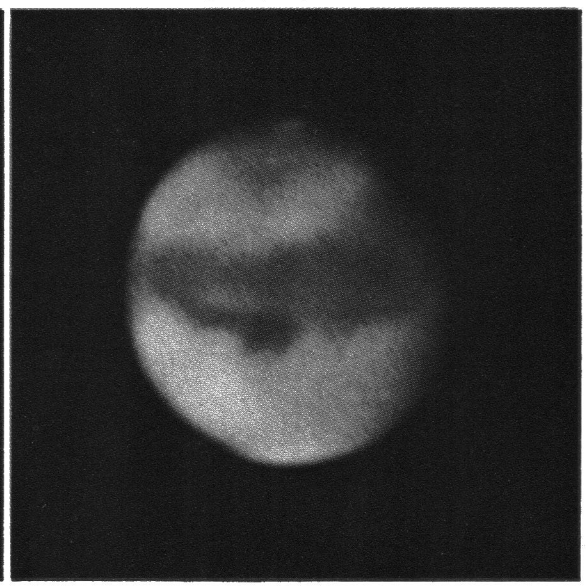
5. 1926 Oct 27 λ18°
U.T. 7:42 Y

Aug 1
M.D.

May 30
M.D.



3. 1924 Sept 1 λ34°
U.T. 6:15 Y



6. 1926 Dec 1 λ22°
U.T. 4:27 Y

Aug 22
M.D.

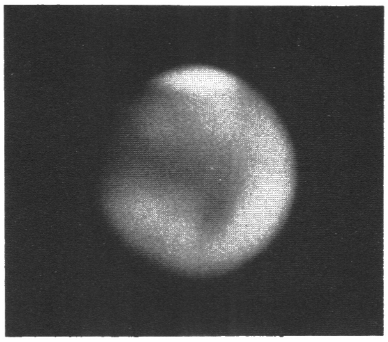
Plate XII

The first 8 photographs illustrate further the various shapes and sizes the cap undergoes every Martian spring and summer in its retreat to the pole and the orderly precision with which it recedes with the advance of summer.

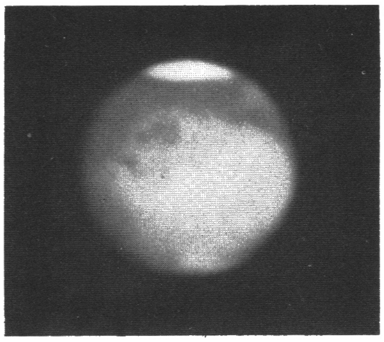
It has long been observed that as the snow cap melts it is always outlined by a dark collar which hugs the cap as it recedes. In order to show that this dark band is not merely a contrast effect, we have added a series of photographs from 1918 to 1952 showing the north cap in mid-summer. Contrast obviously plays no part in the appearance of the dark band, because in the red pictures the snow is no brighter than the surrounding desert. The dark band common to both caps in season has always been explained as being caused by moisture released by the melting cap. Thus the photographs fully confirm what has been known from visual observation, although contested by some, for half a century.

PLATE XII

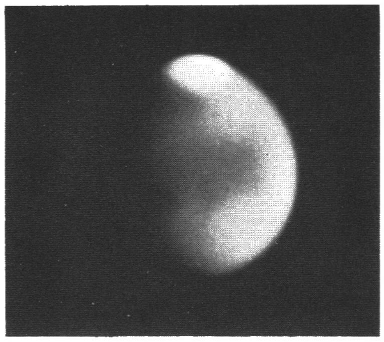
SEASONAL MELTING OF THE SOUTH POLAR CAP, AND THE 'DARK COLLAR' WHICH ALWAYS HUGS THE POLAR CAPS AS THEY RECEDE TOWARDS THE POLES DURING MARTIAN SUMMERS.



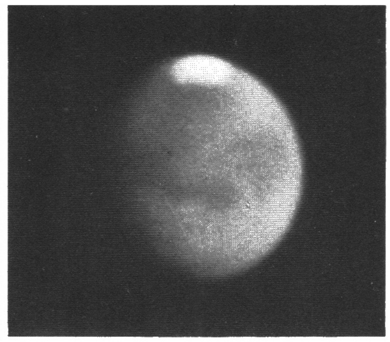
1. 1939 Apr 11 M.D. Y



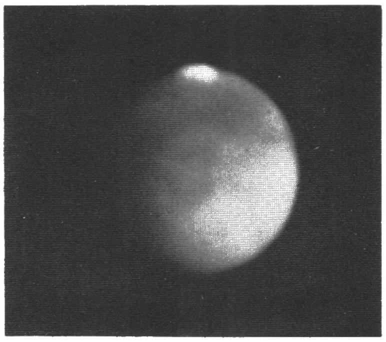
2. 1939 Apr 21 M.D. Y



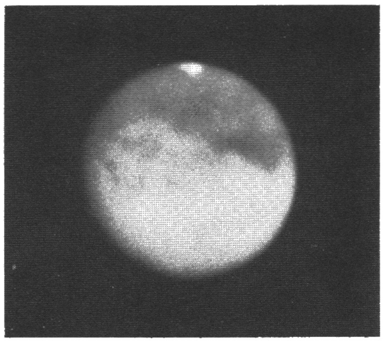
3. 1941 May 8 M.D. Y



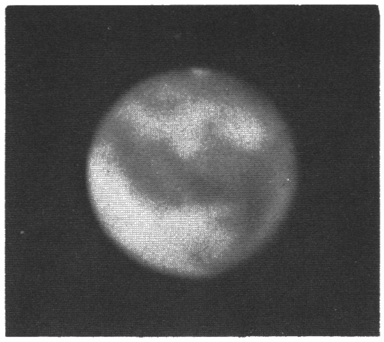
4. 1941 May 26 M.D. Y



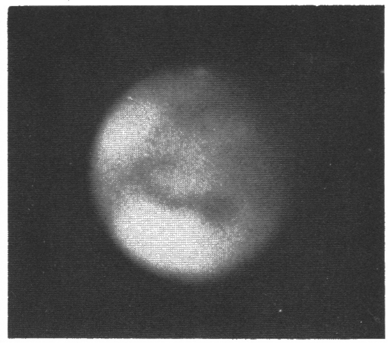
5. 1941 June 12 M.D. Y



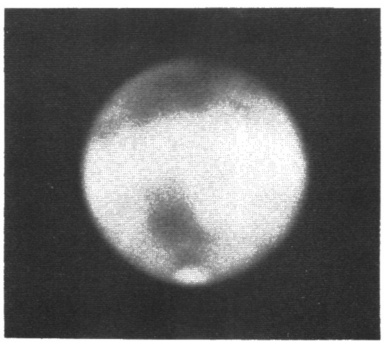
6. 1941 July 1 M.D. O



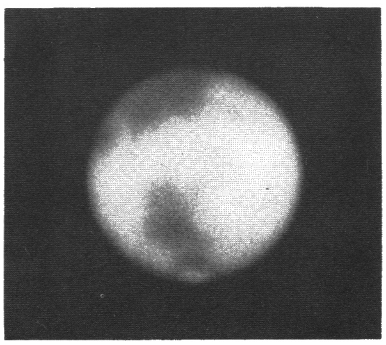
7. 1941 July 15 M.D. Y



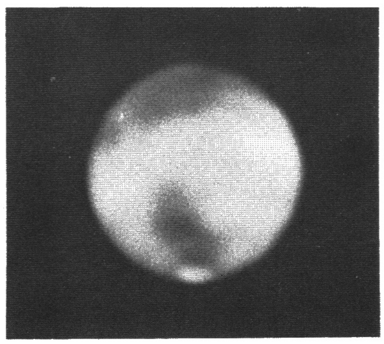
8. 1941 Aug 3 M.D. R



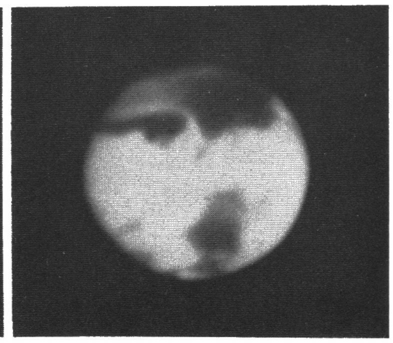
9. 1918 Mar 24 λ51°
U.T. 8:20 Y
Dec 22 M.D.



10. 1935 Apr 20 λ52°
U.T. 4:06 Y
Jan 15 M.D.



11. 1950 Mar 31 λ56°
U.T. 6:14 R
Dec 29 M.D.



12. 1952 May 22 λ15°
Feb 13 M.D. R
200-in. Mt. Wilson-Palomar Photograph

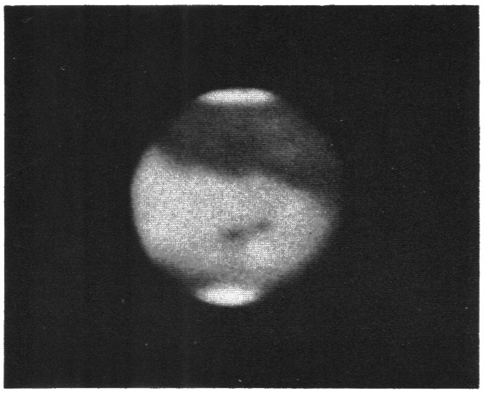
Plate XIII

Since 1907 when photographic observations of Mars became a regular part of our observational program, the behavior of the polar caps has proved to be one of pertinent significance. These representative yellow photographs clearly portray the persistent character of the south snow cap in Martian springtime as it slowly shrinks toward the pole. At the same time they reveal sudden changes in the north cap in autumn when that cap consists of clouds of intermittent character. One can see in Nos. 1, 2 and 3, taken on July 15, 16 and 17 in 1907, the stability of the waning south snow cap. During the same period the waxing north cap formed of cloud, was large on the first night, had all but disappeared on the second, but on the third had returned again to much the same size as on the first. The marked difference in the brightness and behavior in the two caps strongly indicates that the brighter one was a bright substance, such as snow, ice or frost deposited on the surface, which only gradually changes with the season. The duller one, however, at the autumn pole formed and dissipated from night to night and denotes clouds in the atmosphere.

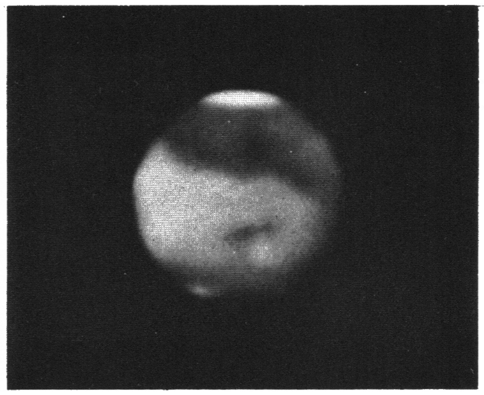
Photographs 4, 5 and 6, in 1939, show the notably different character of the two polar caps—a solid deposit on the surface in the one case, and atmospheric clouds in the other. Nos. 7, 8 and 9 taken on successive nights and showing the same face of the planet, reveal a repetition of the behavior of the two types of polar caps. The same may be said of the last three prints. The Lowell collection of photographs of Mars over a period of 54 years portrays this same performance of the summer and winter caps many times.

PLATE XIII

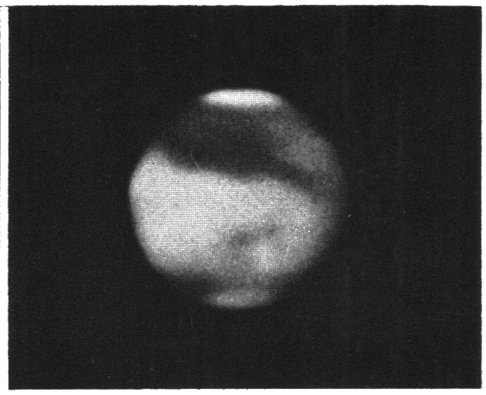
SERIES SHOWING PERSISTENT QUALITY OF SOLID CAP IN ITS SPRINGTIME AT THE SOUTH POLE AND THE QUICK CHANGES IN THE CLOUD CANOPY AT THE AUTUMN POLE (NORTH) FROM NIGHT TO NIGHT.



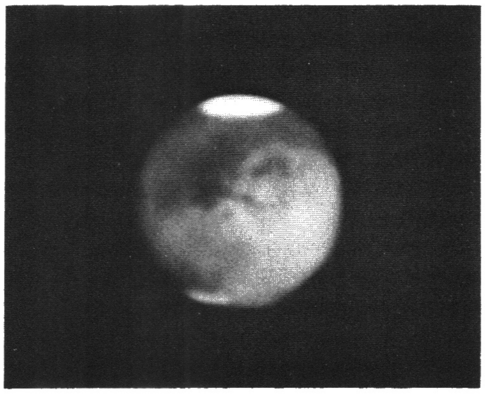
1. 1907 July 15 λ205°
U.T. 7:40 Apr 15 M.D. Y



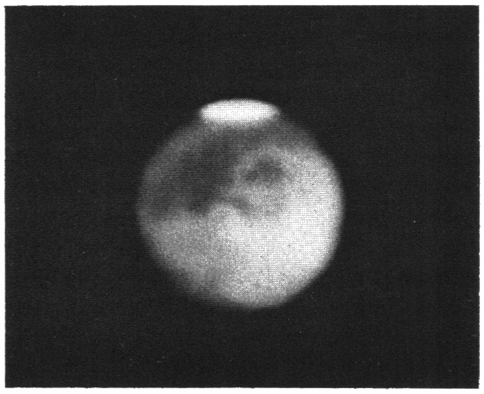
2. 1907 July 16
U.T. 7:44 Y



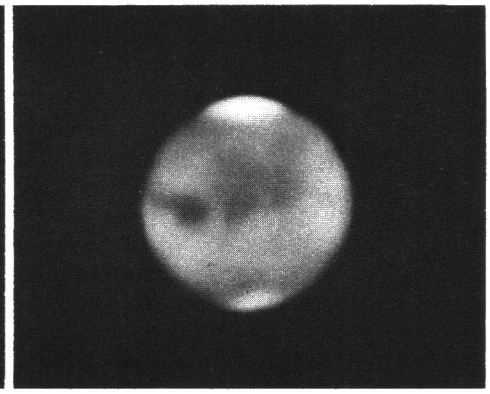
3. 1907 July 17
U.T. 7:28 Y



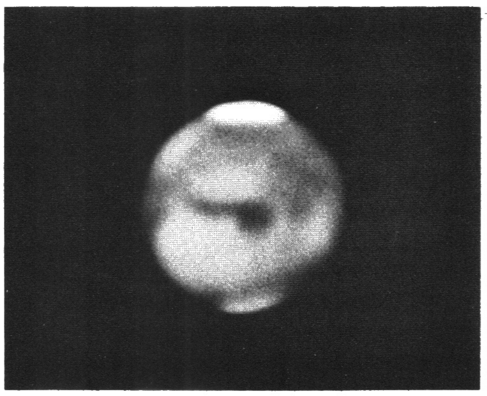
4. 1939 July 23 λ72°
U.T. 21:15 Oct 26 M.D. Y



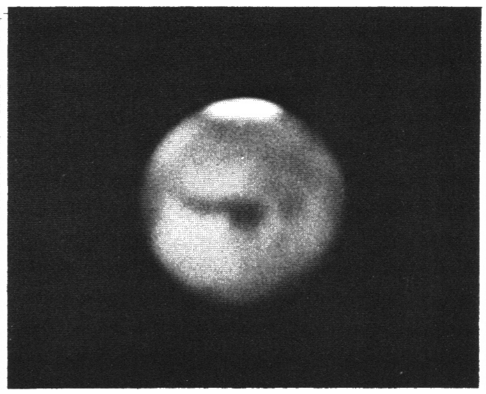
5. 1939 July 25
U.T. 22:26 Y



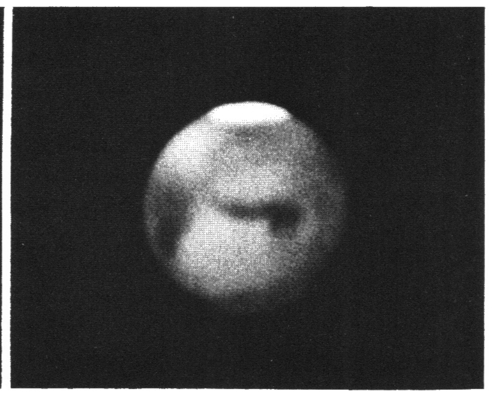
6. 1939 July 30 λ42°
U.T. 22:46 Y



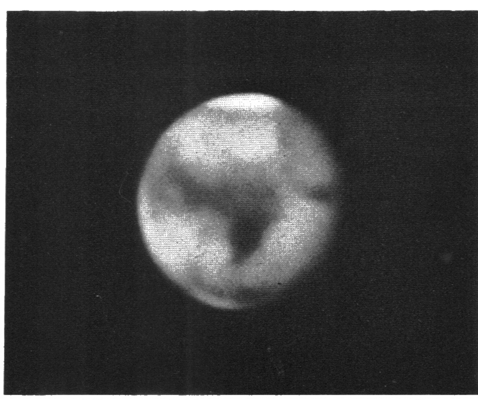
7. 1939 Aug 1 λ353°
U.T. 21:19 Oct 31 M.D. Y



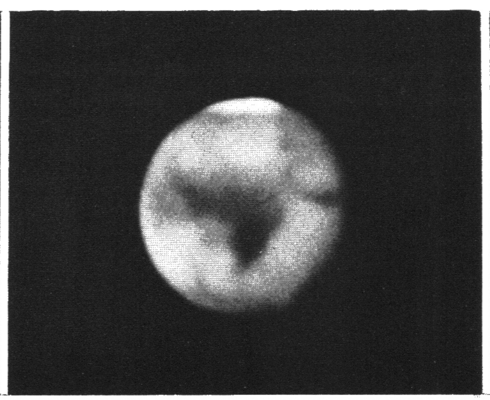
8. 1939 Aug 2
U.T. 22:23 R



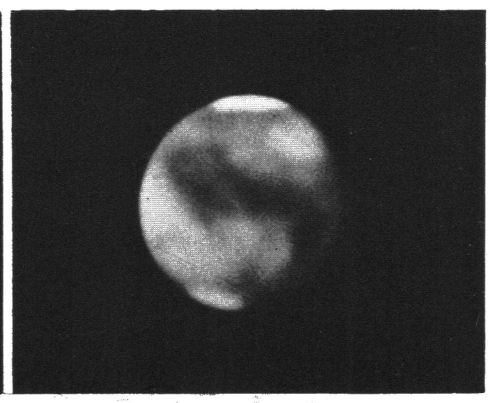
9. 1939 Aug 3
U.T. 21:50 R



10. 1939 Aug 10 λ272°
U.T. 22:31 Nov 6 M.D. O



11. 1939 Aug 11
U.T. 23:10 R



12. 1939 Aug 13 λ240°
U.T. 22:10 Y

Plate XIV

The monochromatic photographs are intended to show a very fundamental fact concerning the snow caps as revealed by blue and violet light. The blue photographs selected here for comparison represent Mars under various types of conditions of its atmosphere: No. 2, completely opaque; No. 4, virtually transparent; No. 6, semi-transparent.

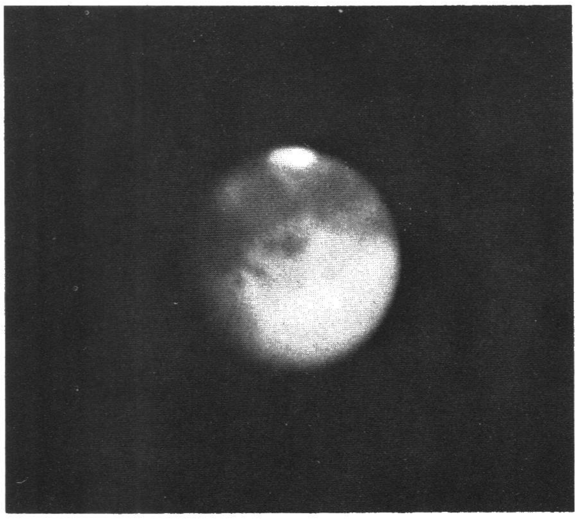
Since 1909 Lowell Observatory photographs taken in blue and violet light have strongly recorded the snow cap even when the planet's atmosphere was so opaque to the blue rays as to totally obscure all the other surface features. Later observers who obtained the same results were puzzled at this seeming paradox and therefore postulated a high cloud canopy over the cap to explain its appearance in the blue photographs. It had long been known that the polar caps are sometimes seen divided and broken by rifts or bright and dark patches. They often show irregular outlines and divisions which have been observed to occur repeatedly at the same places and at the same seasons.

Since 1922, observations at Flagstaff with blue filters have revealed these details in blue light, but convincing photographs of them have been very difficult to obtain. Blue photographs, however, have always shown the shape, size and contour of the cap to be the same as they appeared in yellow pictures made at the same time. This is illustrated by Nos. 3, 4, 5 and 6. It was also found that this close resemblance was maintained from spring to late summer with a constancy hardly to be expected of a cloud cap. This was especially so in view of the spectacular variations continually occurring in the cloud cap at the opposite pole which sometimes covered several millions of square miles on one night and had vanished completely on the next. Finally near the end of August 1956, under favorable circumstances for such observations, the cap was caught undergoing rapid disintegration near the time of opposition. The blue pictures revealed the broken, divided character of the cap like that shown by yellow images Nos. 1 and 2. This had often been seen visually. The results clearly and definitely proved that the blue cap was in fact the same object as that observed in red and yellow light—an actual deposit on the planet's surface. A comparison of Nos. 1 and 2 discloses that the left-hand one-third of the cap is fainter, broken, and more irregular than the larger, brighter, right-hand portion and that a dark rift, too fine to show clearly in the composite photographs, divides the two sections.

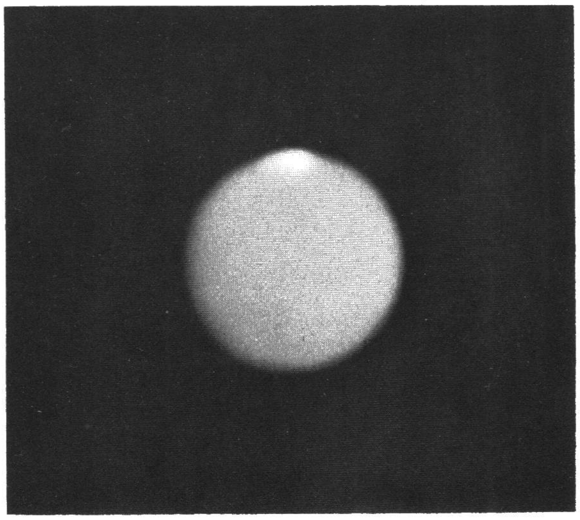
Hundreds of photographs taken at Bloemfontein support these facts. All of the other surface features were completely obscured in August, 1956, so the planet's air was quite opaque and therefore the case is unequivocal. (For experiments on terrestrial features supporting this disclosure, see Plate XLVIII, Nos. 4 and 5.)

PLATE XIV

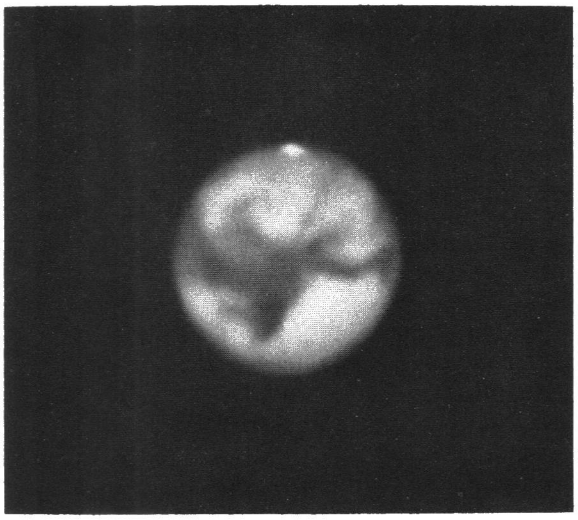
COMPARISONS OF YELLOW AND BLUE PHOTOGRAPHS TO SHOW THAT THE CAP RECORDED IN BLUE LIGHT IS THE SAME IN EVERY DETAIL AS THAT DISPLAYED IN RED AND YELLOW LIGHT.



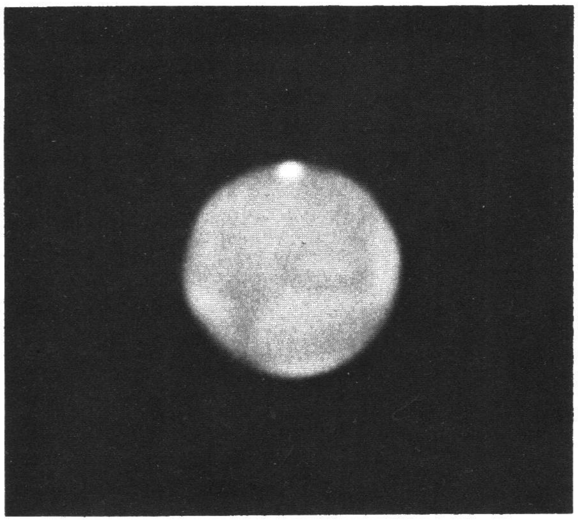
1. 1956 Aug 24 λ84°
U.T. 23:49 R
May 30 M.D.



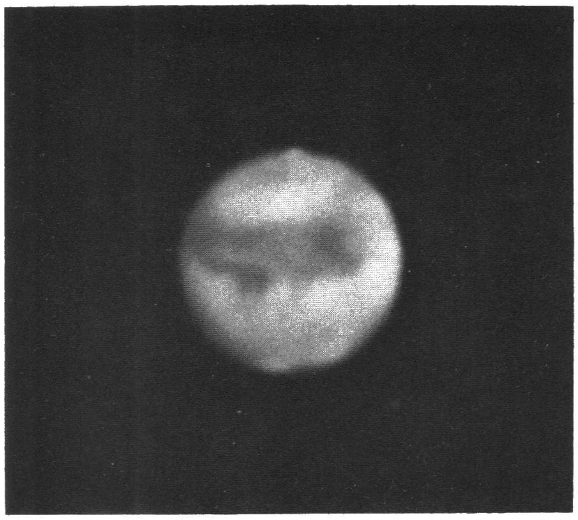
2. 1956 Aug 24 λ79°
U.T. 23:27 B
May 30 M. D.



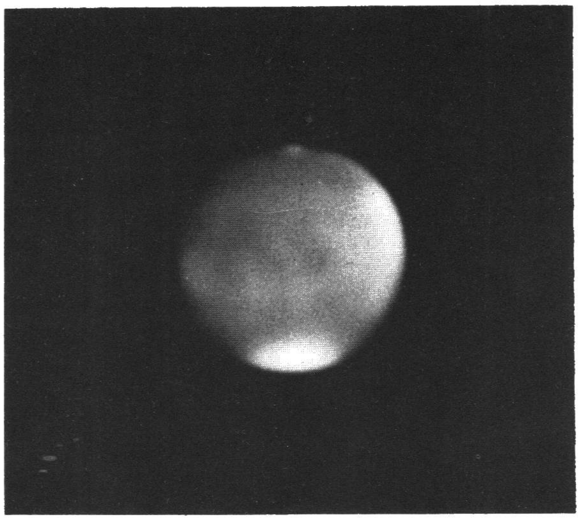
3. 1941 Oct 11 λ305°
U.T. 6:00 O
July 11 M.D.



4. 1941 Oct 11 λ320°
U.T. 7:07 B
July 11 M.D.



5. 1926 Oct 27 λ10°
U.T. 6:48 Y
Aug 1 M.D.



6. 1926 Oct 27 λ22°
U.T. 8:06 B
Aug 1 M.D.

Plate XV

These photographs display three stages in the seasonal behavior of the south cap. The yellow photograph (No. 1) shows the winter cloud cap on March 6 extending down nearly to the Solis Lacus (dark spot upper right). This extension, nearly 100° in breadth, means that if the polar canopy were symmetrical, its maximum diameter (measured along the surface) exceeded 3,500 miles. However, in this instance, as is generally the case in winter, the cloud cap far exceeds the actual size of the ice cap when it later is exposed to our view after the vernal equinox. After the longer, colder winter in the south of Mars, the snow cap there reaches 70° in breadth, while the shorter, warmer winter in the northern hemisphere produces a snow cap scarcely more than 53° across. More than a century of observations show that the caps at the two poles always maintain this same angular ratio. On the other hand, the short, hot summers in the southern hemisphere always melt the southern cap to a smaller compass, sometimes completely melting it away (1894 and 1908). The longer, cooler summers in the northern hemisphere never reduce its cap to a smaller compass than 5½°.

No. 2 is a yellow photograph portraying the south cap on Martian August 17 when it is nearing its minimum size (compare edge of cap with Solis Lacus in No. 1) and measured scarcely 100 miles across.

No. 3 is a blue photograph showing the planet near its equinoxes; the southern hemisphere is just past its autumnal equinox, while the northern one is just passing the vernal equinox. Here the cloud canopies over both poles reach down the disk to latitudes below 40°.

Monochromatic photographs of the same face of Mars made in red (4), orange (5), yellow (6), and blue (7) demonstrate the redness of the disk and the blueness of its snow cap. In No. 4 the albedo of the snow in red light (6200-6600A) is so low as compared to the disk that the cap appears scarcely as bright as the desert areas. In orange light (5600-6200A), the brightness of the cap rises slightly above that of the desert regions. In the yellow-green (5500-5700), the snow cap greatly exceeds the rest of the disk in brightness, while in violet light (3900-4600A), the snow cap far outshines anything on the disk and is rivaled only by the cloud canopy over the north polar region.

These images from four regions of the spectrum show the high color-index of Mars, the bluish tint of the snow cap, and readily explain why the spectrum of the disk reveals a low albedo toward the shorter wave lengths as is shown by all spectrographic observations. On the other hand, the snow cap is so brilliant in blue and ultra violet light that absorption by the Martian atmosphere registers no appreciable effect. Obviously here the snow cap is observed through the equivalent of many atmospheres yet it progressively brightens toward the shorter wave lengths.

This brightening is of major importance. It argues strongly against the new theory[1] that nitrogen dioxide and nitrogen tetroxide explain the clouds, polar caps and the changes in the dark markings. It appears that the sole evidence for the new theory rests on the assumption that the weakness of the spectrum of the disk of the planet toward the violet is due to absorption of nitrogen dioxide; on the contrary, these observations show that this weakening must be due to selective reflection from the red disk of Mars.

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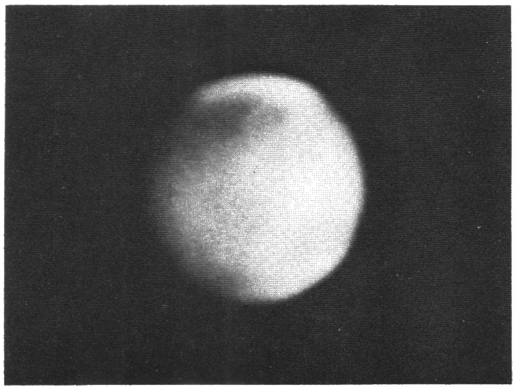
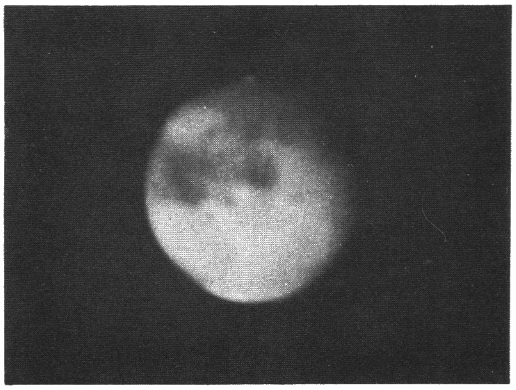
[1]Kiess, C. C., Karrer, S. and Kiess, H. K., P.A.S.P., *72*, 427, p. 256, 1960.

PLATE XV

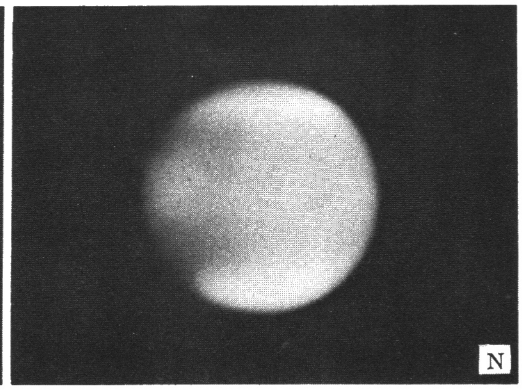
EXTREMES OF SOUTH POLAR CAP



1. 1922 May 30 λ65°
U.T. 5:09 Y
Mar 6 M.D.



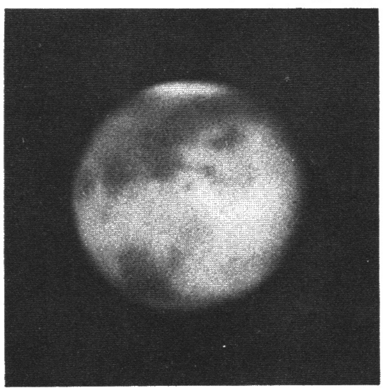
2. 1926 Nov 22 λ96°
U.T. 4:12 Y
Aug 17 M.D.



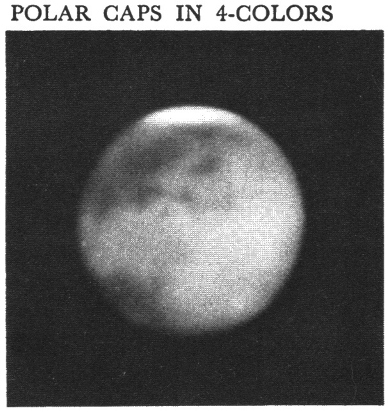
3. 1960 Dec 19 λ95°
U.T. 5:41 B
Sept 28 M.D.

RELATIVE BRIGHTNESS OF POLAR CAPS IN 4-COLORS

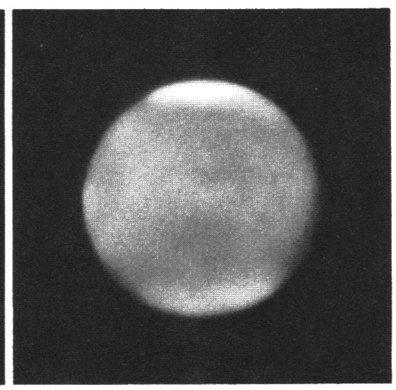
4. 1954 July 4 λ69°
U.T. 22:32 R
Mar 31 M.D.



5. 1954 July 2 λ65°
U.T. 21:01 O



6. 1954 July 3 λ74°
U.T. 22:16 Y



7. 1954 July 4 λ74°
U.T. 22:53 B

Plate XVI

The adjoining photographs display one of the most revealing events in the retreat of the south cap to the pole. I refer to the small bright spot to the left of the main cap, a detached patch of snow which is left behind as the dwindling cap recedes toward the pole during summer. Circumstances of Martian seasons and occurrence of opposition are such that this event can only be observed at intervals of about 15 years. First observed by Mitchel at Cincinnati in 1845, it has occurred with remarkable coincidence on practically the same seasonal date at every opposition.

The following table shows all the available observations since its discovery.

OBSERVATIONS OF THE MTS. OF MITCHEL

Observer	Date	Corresponding Martian Date
Mitchel	Aug. 30, 1845	May 31
Green	Sep. 1, 1877	June 3
Brett	Sep. 1, 1877	June 3
Lowell	Aug. 6, 1894	June 4
W. W. Campbell	Aug. 7, 1894	June 4.5
Barnard	Aug. 6, 1894	June 4
W. H. Pickering	Aug. 6, 1894	June 4
Douglass	Aug. 8, 1894	June 5
E. C. Slipher	Aug. 21, 1909 Photo	June 2
E. C. Slipher	Sep. 7, 1924 Photo	June 3
Trumpler	Sep. 7, 1924	June 3
E. C. Slipher	Aug 1, 1941 Photo	May 31
E. C. Slipher	Aug. 31, 1956 Photo	June 3

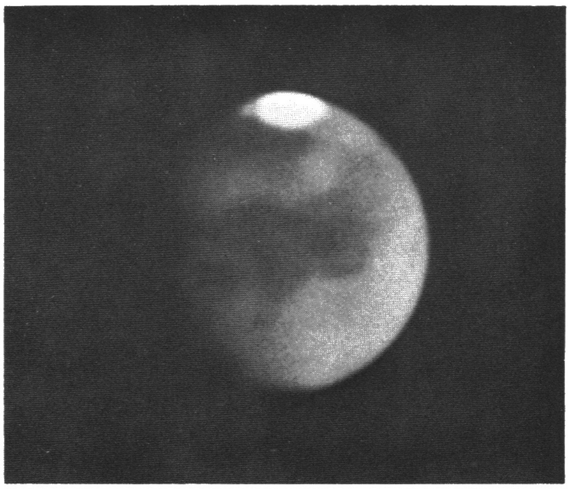
The slight discrepancy in the seasonal dates of the 1845 and the 1941 observations, as compared to the others, is because these were made at an earlier stage in the development of the spot. During my observations of 1941 the patch had not reduced to the same degree as at the oppositions cited in the table, and it was not possible to observe the planet at this stage before it was lost in the daylight sky.

Besides the interest in this remarkable event itself, the importance lies in the precise mile post it provides in the systematic retreat of the south cap, arriving on practically the same Martian date year after year.

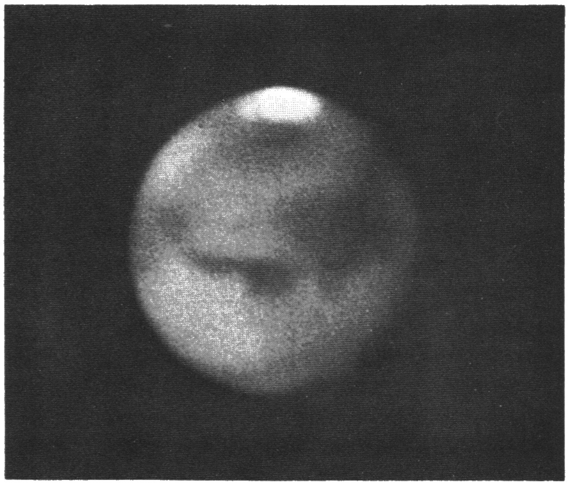
Another phenomenon connected with the site of this snow patch is that on several occasions, as for example in November, 1909, and in October, 1941, approximately three months after the snow on the Mts. of Mitchel had disappeared, a patch of temporary mist or cloud of the same size and shape appeared over the same area. (See No. 6, Plate X.)

PLATE XVI

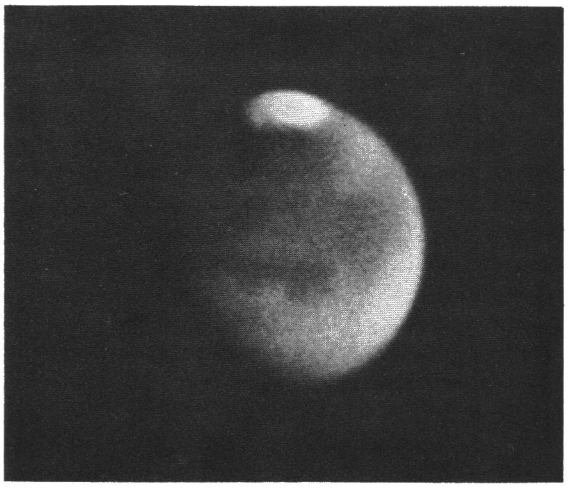
FOUR APPEARANCES OF THE MOUNTAINS OF MITCHEL FROM 1909 TO 1956.



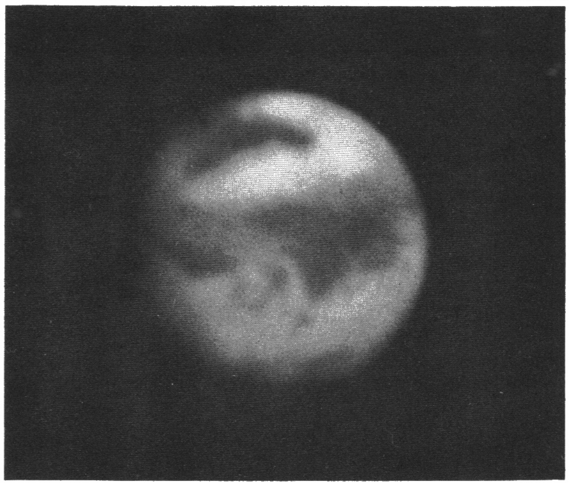
1. 1909
Aug 21 Y
U.T. 10:25
λ17°
June 2 M.D.



2. 1924
Sept 8 Y
U.T. 8:04
λ358°
June 3 M.D.



3. 1941
Aug 1 Y
U.T. 13:38
λ342°
May 27 M.D.



4. 1956
Aug 30 R
U.T. 22:05
λ6°
June 3 M.D.

Plate XVII

This unusual set of fine photographs was made by Finsen[1] in Johannesburg during the opposition of 1956. The photographs were obtained from composite enlargements of selected frames of experimental exposures on 16mm Kodachrome film.

In obtaining the original exposures, the aperture of the 26½-inch visual refractor was stopped down by Finsen to 13¼ inches. A Goerz Telenegative lens was used to provide a scale of 8″.0 per mm. The exposure times at the telescope, on Kodachrome daylight-type film, were about 1^s. A specially-built enlarger was used in making the composite negatives. These were, with the exception of No. 11, based on 25 selected exposures.

Detailed information regarding each of these 48 photographs is summarized in the following table:

Finsen Observations

No.	Date	U.T.		No.	Date	U.T.	
1	1956 Jul. 31	1^h14^m	332°	25	1956 Sep. 2	20^h20^m	314°
2	Aug. 1	0 41	315	26		21 24	330
3		22 22	272	27		22 39	348
4	2	0 31	303	28	4	22 23	326
5		1 35	319	29	5	20 44	293
6	8	1 45	266	30	6	20 48	285
7	15	21 38	134	31	7	20 36	274
8	17	1 24	179	32		22 36	303
9		21 27	113	33		22 59	308
10		23 19	140	34		23 33	317
11		23 52	148	35	9	22 33	285
12	22	23 12	94	36	19	20 5	160
13	24	21 22	49	37	25	19 9	93
14	25	20 48	31	38	26	18 32	75
15	26	0 17	82	39		19 46	93
16	29	20 39	354	40		20 48	108
17		21 43	9	41		21 52	124
18		23 24	34	42	27	19 40	83
19	30	21 56	4	43	Oct. 2	18 22	19
20		22 2	5	44		19 33	36
21		23 46	31	45		20 30	50
22	31	22 4	357	46	4	17 55	354
23	Sep. 1	21 46	344	47	5	18 32	354
24	2	19 59	309	48	8	18 10	322

A careful study of this sequence of photographs will reveal many of the Martian phenomena described elsewhere in this volume.

[1]Finsen, W. S., Union Observatory Circular, No. 116, 1957.

PLATE XVII

PHOTOGRAPHIC OBSERVATIONS OF MARS MADE BY W. S. FINSEN AT THE REPUBLIC OBSERVATORY

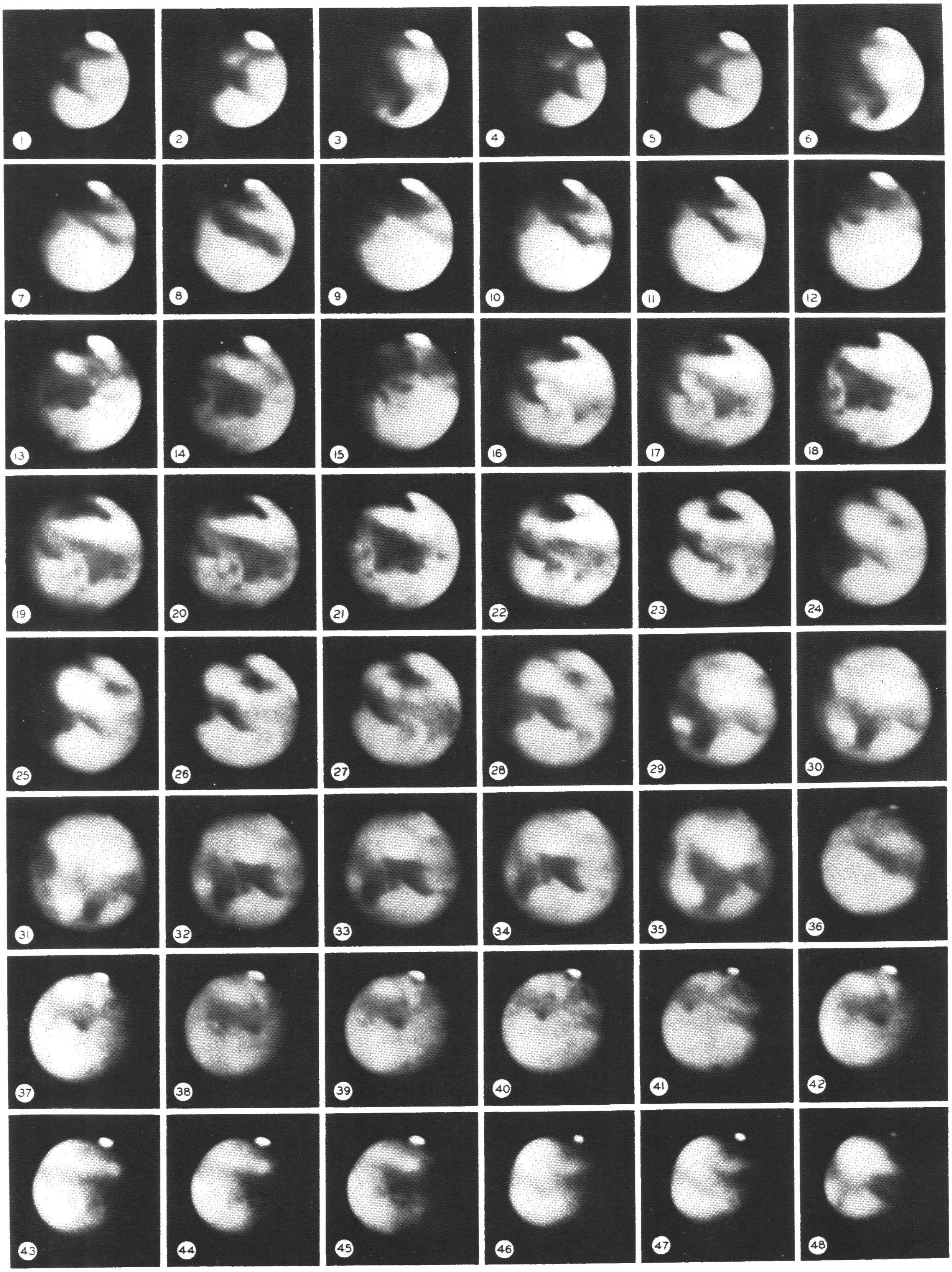


Plate XVIII

This sequence of photographs was secured with the Lick 36-inch telescope during the 1956 opposition of Mars.

Jeffers' technique differs considerably from that of Slipher and Finsen in several respects. The exposure times were of several seconds duration and fine-grain V-G plates were used. The plates were placed at the focus of the 36-inch lens the aperture of which was sometimes reduced to 28 or 23 inches. A yellow Schott OG-1 filter and the G-type emulsion combined to limit the effective energy range to a spectral band near 5600A.

This particular selection of excellent photographs show interesting cloud developments, which characterized this opposition and impeded the study of the more stable surface features of the planet.

PLATE XVIII

PHOTOGRAPHS OF MARS MADE BY H. M. JEFFERS WITH THE LICK 36-INCH REFRACTOR

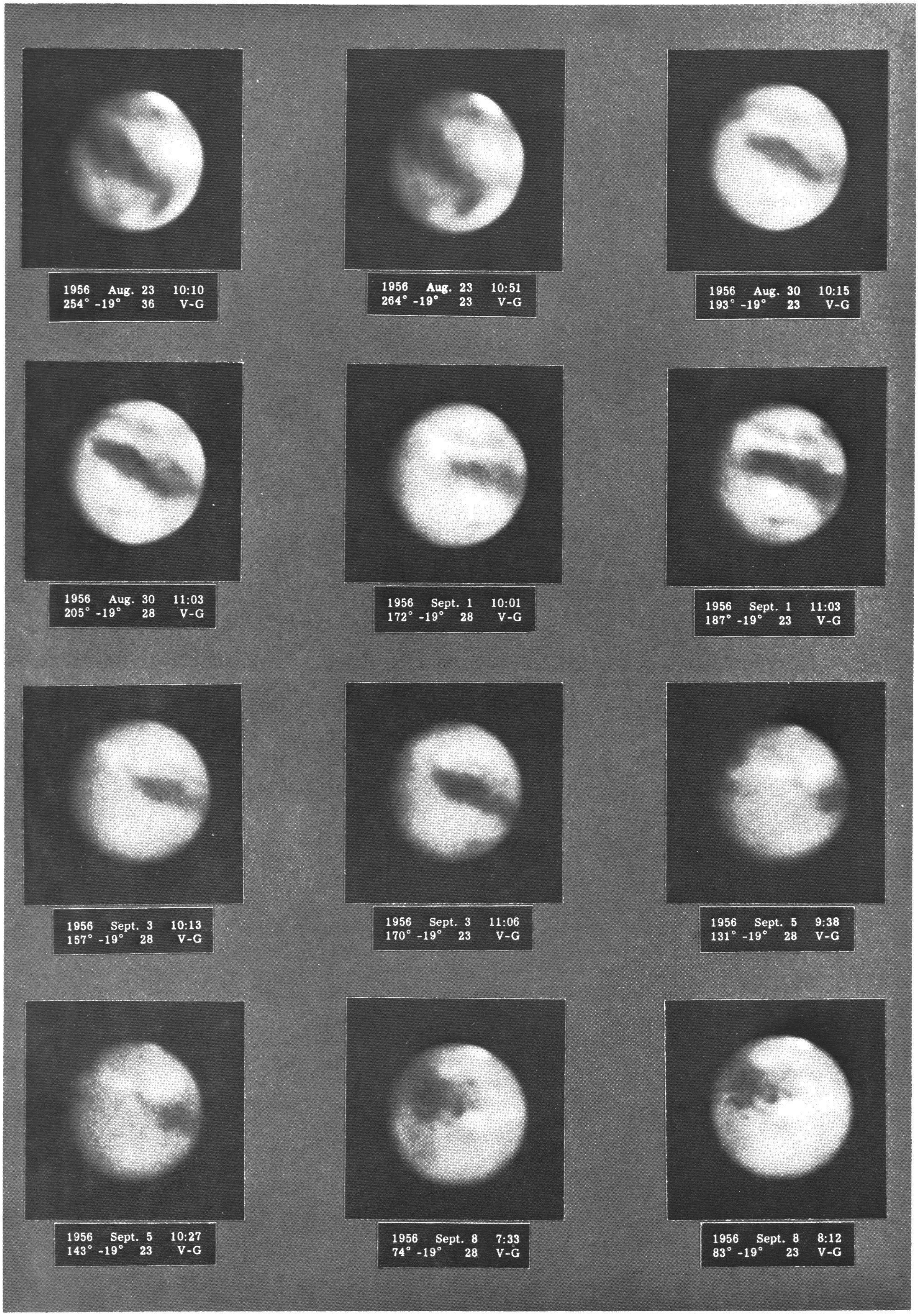


Plate XIX

These observations are arranged to display the life history of a remarkable storm over the Martian tropics (bright area near center of disk), embracing about 400,000 square miles. It appeared first on July 9, 1922, as a nearly rectangular-shaped bright spot. It stood out brilliantly at the first look at the planet where nothing unusual had been observed on the night before. Photographs on the first night revealed that the cloud was nearly as bright in the yellow as was the polar cap. Blue filter photographs made at the same time with the 42-inch reflector by Lampland showed it to be no brighter than the rest of the disk. This indicated a strong yellowish tint of the cloud, which by selective reflection reduced its albedo in blue to that of the general background of the blue photograph (note here how much larger and brighter the polar caps appear in the blue image because of their strong blue color).

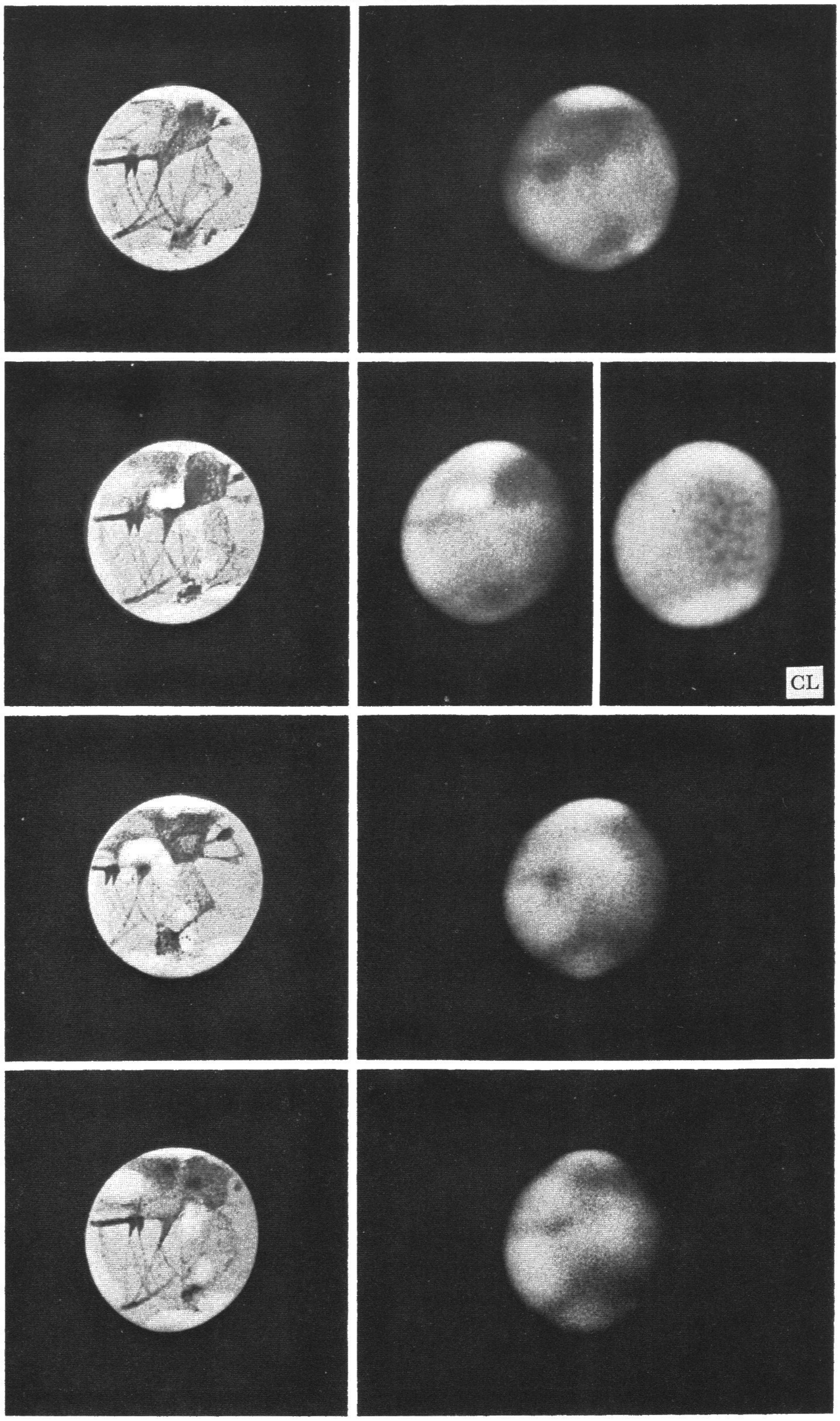
On July 10 and cloud area had moved appreciably towards the northwest and had also expanded very considerably in that direction, showing a thinning and flaring out over the desert area to the north. Photographs on the 11th (not included here) revealed further expansion and disintegration into small spots over a considerable area with the whole storm still moving slowly to the northwest. It was not then possible to identify with certainty the original cloud center. On July 12, the cloud area had so generally dissipated and scattered that it showed only as a thin, faint veil obscuring the coast line and desert northeast of the base of Margaritifer Sinus. This storm lasted for four days, the longest period of any the writer had observed until that time.

The motion of this storm was abnormally slow—6 to 12 miles per hour. The precise value would depend upon what expansion factor is applied. On the first night, before expansion was observed, it was barely possible to detect motion, estimated at 6 miles per hour. But on the second night, July 10, the expansion and the drift of the cloud area are clear and distinct in the photographs. Unfortunately this outstanding storm was not observed anywhere else in the world, so our knowledge of its life history is confined to the Flagstaff observations.[1]

[1]Slipher, E. C., P.A.S.P., *34,* 22, 1922.

PLATE XIX

THE GREAT STORM OF 1922



1. June 7 λ30°

2. June 7 λ21°
U.T. 9:05 Y

3. July 10 λ25°

4. July 10 λ36°
U.T. 5:35 Y
Mar 29 M.D.

5. July 10 λ40°
B

6. July 11 λ50°

7. July 11 λ22°
U.T. 5:11 Y

8. July 13 λ25°

9. July 13 λ23°
U.T. 6:26 Y

Plate XX

On rare occasions temporary yellow clouds have been observed which cover large areas of the planet and conceal vast regions of the surface for a day or two. Three outstanding examples of such clouds are pictured in the yellow photographs taken at the opposition of 1941. The upper row of images displays the normal appearance of three different faces of the planet; below are yellow photographs taken on later dates when its atmosphere was invaded by widespread yellow clouds. There is a striking difference between the upper and lower rows of photographs due to obscuration of vast areas of the dark maria by clouds, so much so that they are hardly recognizable as the same features.

Infrequent storms are usually quite transistory. The cloud systems of November 15 and 25 appeared suddenly without any visible sign of disturbance on the preceding nights and they both dissipated rapidly so that on the next night only a faint tenuous haze remained. The cloud system of November 15 was exceptional in that the bright cloud centers were separated by several hundred miles. As the photograph reveals, however, the whole area was suffused with an extensive blanket of haze. Neither of the cloud systems of November 15 and 25 showed prominently in blue photographs, a fact which denotes their yellowish tint. The cloudy area of November 25 was of a different type and apparently belonged to the class of clouds which are present only in the Martian morning hours. The clouds of November 15 and 25 resembled those of 1922, Plate XIX. They differed generally from those of 1918[1] and 1920[2] which tended to dissipate toward midday and they also differed widely from the "W" type observed only in the afternoon in 1907, 1926 and 1954 (Plate XXIV). They resembled, however, except for their duration those of 1956.

Unfortunately these cloud areas covering vast regions were not observed at any other station so there is no way of knowing what transpired during the hours preceding or following these observations. On November 15 spectrograms were made at Lowell of the same face of the planet as shown in No. 4 but they failed to disclose anything unusual.

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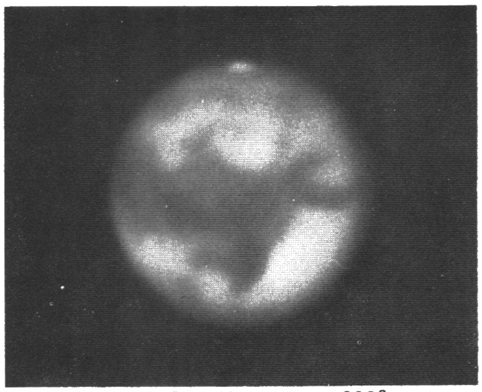
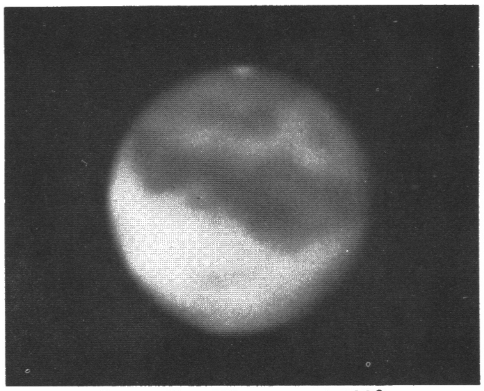
[1]Hamilton, G. H., Lowell Obs. Bull., *3,* No. 82, 1918.
[2]Slipher, E. C., Pop. Astr., *29,* No. 2, 1921.

PLATE XX

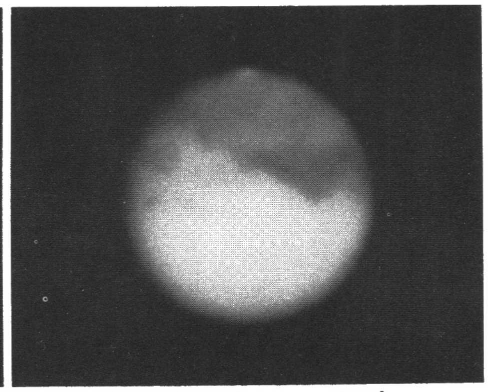
YELLOW-FILTER PHOTOGRAPHS IN 1941 SHOWING NORMAL ASPECT OF THREE DIFFERENT FACES OF THE PLANET (TOP) WITH THE SAME REGIONS OBSCURED BY 'YELLOW' CLOUDS (BOTTOM).



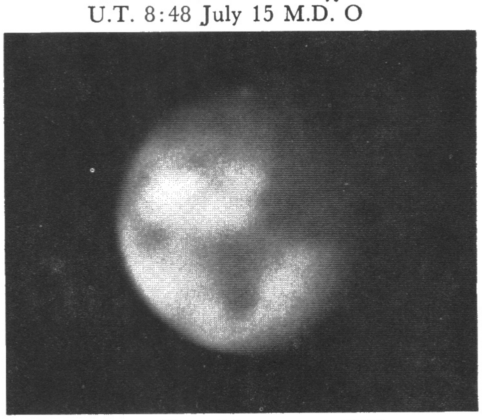
1. Oct 17 λ293°
U.T. 8:48 July 15 M.D. O



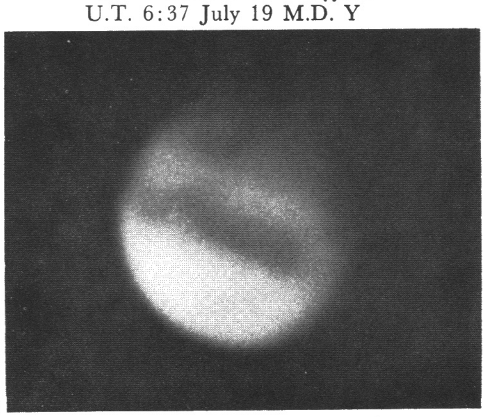
2. Oct 23 λ208°
U.T. 6:37 July 19 M.D. Y



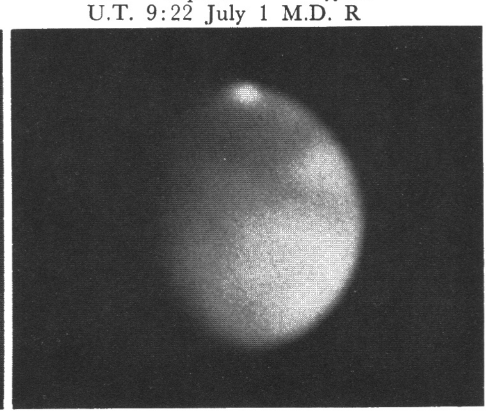
3. Sept 25 λ134°
U.T. 9:22 July 1 M.D. R



4. Nov 15 λ302°
U.T. 2:43 Aug 2 M.D. Y



5. Nov 25 λ229°
UT. 4:05 Aug 8 M.D. Y



6. Aug 24 λ116°
U.T. 12:55 June 11 M.D. Y

Plate XXI

A few examples of yellow photographs from 1907 to 1958 show specimens of temporary limblight and yellow clouds. Obviously these early examples in 1907 and 1911 of haze and limblight furnish objective proof of a Martian atmosphere at a time when its existence was an actively debated point. The manner in which these patches of limb clouds varied from night to night demonstrated quite clearly that they were in the atmosphere itself. Spectrographic observations have failed to identify water vapor, oxygen or any other constituent except carbon dioxide on the planet. These direct photographs recording clouds that condense in the mornings and evenings of the planet only to completely evaporate around Martian noonday become important in clearly showing the existence of a substance which quickly condenses and as quickly evaporates into invisibility. This provides objective evidence of an otherwise undetected substance in the planet's atmosphere — water vapor.

No. 3 shows a large part of Syrtis Major and of the Nepenthes-Thoth entirely concealed beneath morning clouds which 3^h45^m later, (see No. 8, Plate VI), had completely disappeared.[1] This phenomenon can best be explained by water vapor clouds because experience shows that dust could not have settled out of the atmosphere in such a brief period. The bright areas in the other photographs, except No. 7, show similar types of yellow clouds which form and dissipate in a day or two and behave in a like manner. The cloud cover in No. 7 is of a different nature, is long-lived, and was due to the great dust pall which encompassed the planet for several weeks during 1956.

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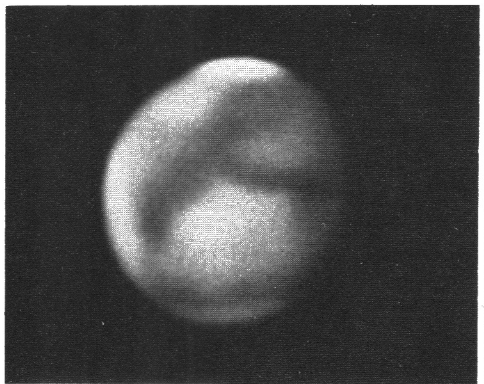
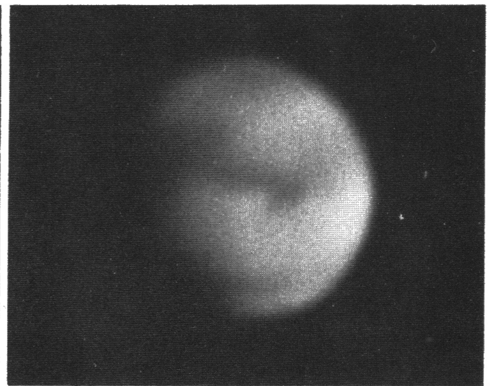
[1]Slipher, E. C., Pop. Astr., *29*, No. 2, 1921.

PLATE XXI

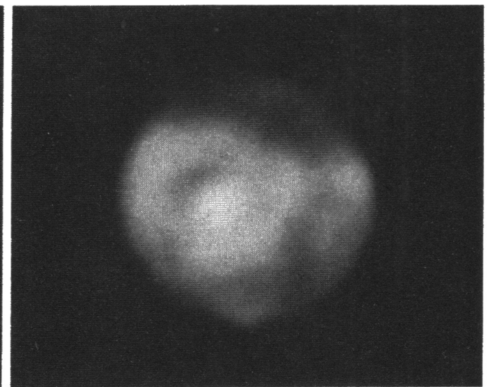
EXAMPLES OF YELLOW CLOUDS, 1907 - 1958



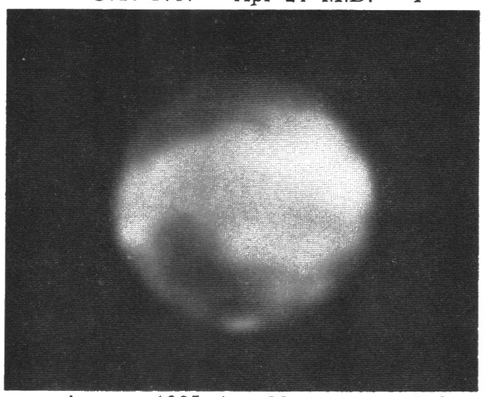
1. 1907 Aug 1 λ328°
U.T. 1:17 Apr 24 M.D. Y



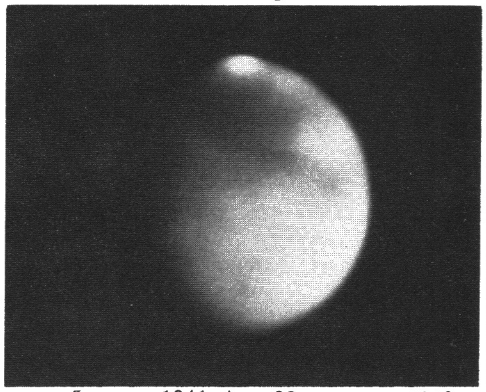
2. 1911 Oct 12 λ349°
U.T. 6:38 Aug 1 M.D. Y



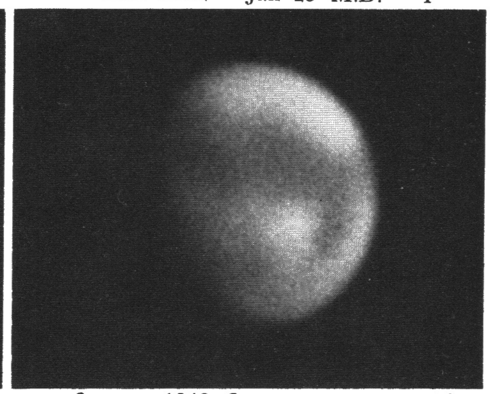
3. 1920 Apr 23 λ230°
U.T. 5:02 Jan 25 M.D. Y



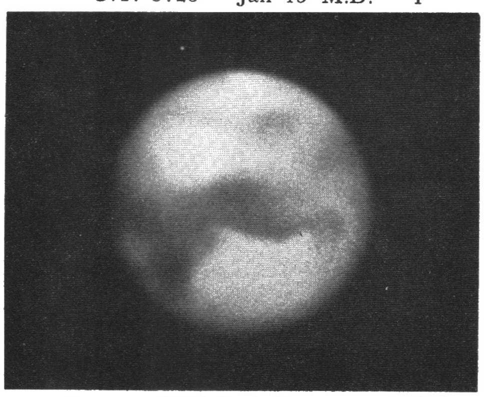
4. 1935 Apr 20 λ71°
U.T. 5:28 Jan 15 M.D. Y



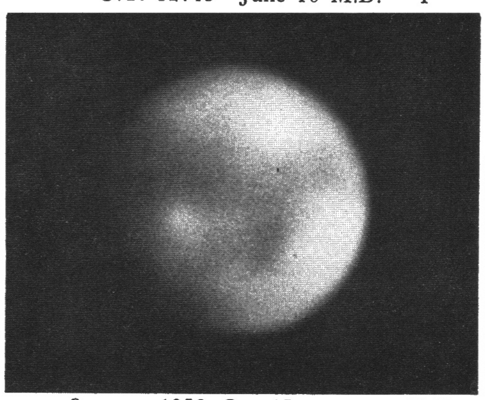
5. 1941 Aug 23 λ122°
U.T. 12:43 June 10 M.D. Y



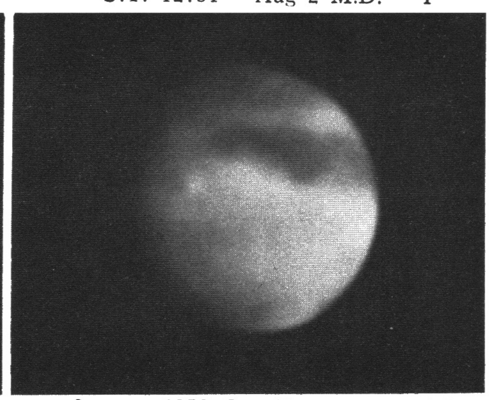
6. 1943 Oct 3 λ247°
U.T. 12:51 Aug 2 M.D. Y



7. 1956 Sept 5 λ321°
U.T. 22:37 June 7 M.D. R



8. 1958 Oct 15 λ274°
U.T. 11:45 July 29 M.D. Y



9. 1958 Oct 23 λ145°
U.T. 7:46 Aug 4 M.D. Y

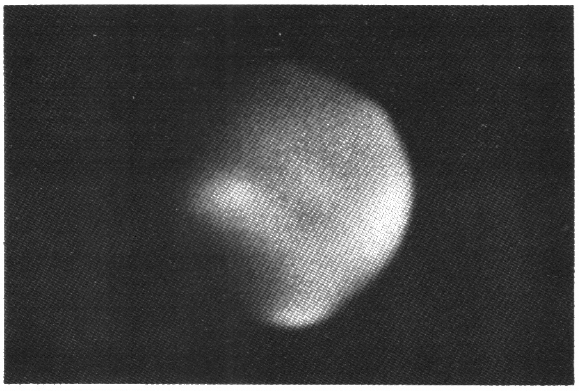
Plate XXII

This series of blue photographs shows the typical appearance of Mars from time to time. Through the years the blue photographs have exhibited no tendency for limb darkening, contrary to the opinion of some workers (see Plate VII). The tendency is for the planet to show limb *brightening*, not darkening, due to limblight, haze and clouds around the morning and evening edges. Generally the blue images show morning clouds which never last until noonday, and afternoon clouds which appear to condense and brighten toward the sunset edge of the disk.

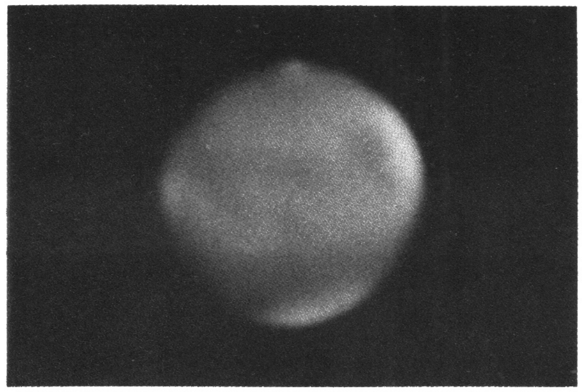
The preponderance of the evidence seems to indicate that morning haze and clouds are the more prevalent; however, in certain localities the opposite effect is often the case. An example is the "W" group of clouds (see Plates XXIV and XLV) in the Tharsis region near Phoenicis Lacus which has always proved to be entirely an afternoon event. When partial blue clearing occurs, the Martian atmosphere is almost invariably more transparent in the afternoon than on the morning side of the disk. Invariably the polar caps, while in the cloud stage, are very strong in blue light (see Plate XV), while in yellow and green photographs they show moderately bright. At the same time they are so completely penetrated by red light that they fail to show in the red.

PLATE XXII

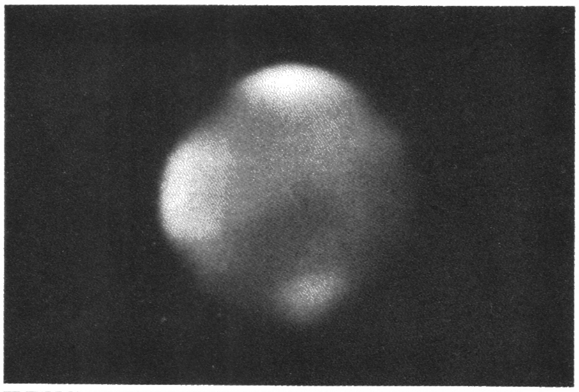
BLUE SERIES SHOWING LIMBLIGHT AND CLOUDS



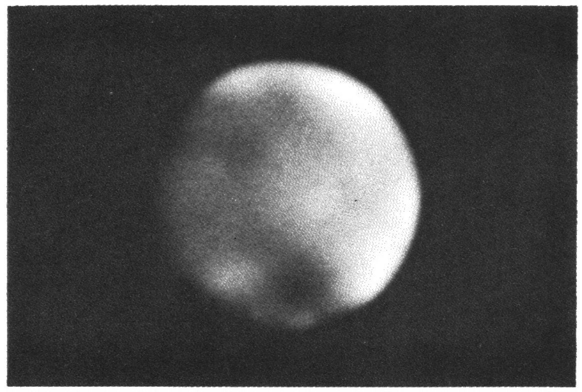
1. 1926 Oct 13
U.T. 7:36 λ139°
July 24 M.D.



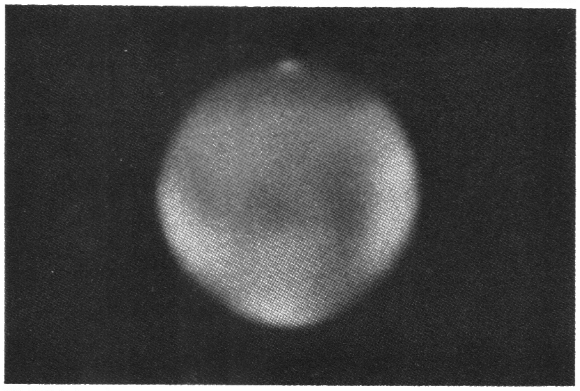
2. 1926 Oct 27
U.T. 6:27 λ358°
Aug 1 M.D.



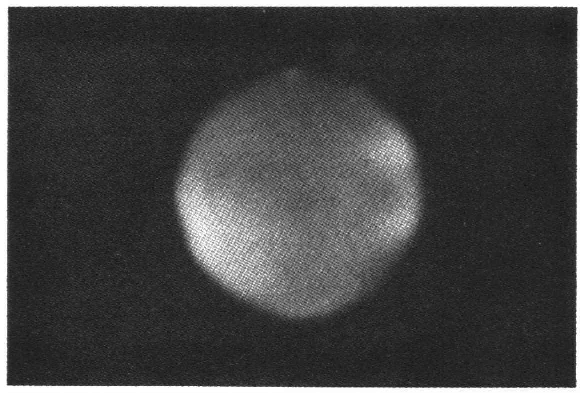
3. 1937 June 4
U.T. 6:31 λ174°
Feb 27 M.D.



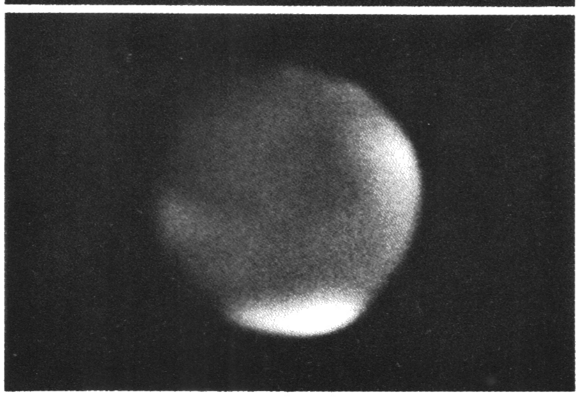
4. 1937 May 14
U.T. 7:21 λ11°
Feb 16 M.D.



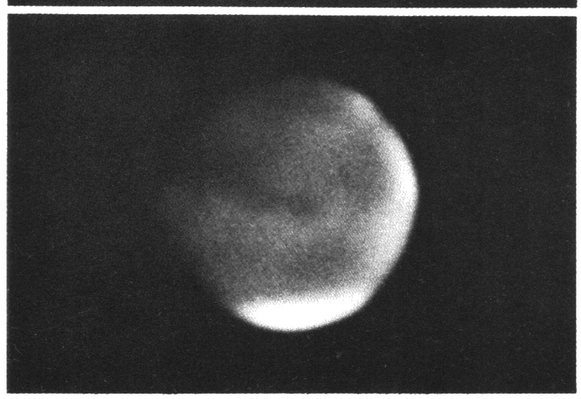
5. 1941 Oct 17
U.T. 7:20 λ270°
July 15 M.D.



6. 1941 Oct 23
U.T. 7:18 λ217°
July 19 M.D.



7. 1958 Nov 7
U.T. 7:58 λ13°
Aug 13 M.D.



8. 1958 Nov 8
U.T. 6:38 λ345°
Aug 14 M.D.

Plate XXIII

Here are blue and violet photographs showing the aspect of the Martian atmosphere during periods of opacity. In some cases, as at the oppositions of 1922 and 1935, the opacity of the planet's atmosphere appears partly due to blue clouds and haze patches, while at other times as in 1926, 1941 and 1956 it is practically uniform. An exception is the snow cap, which is seldom accompanied by patches of blue haze and clouds. This last fact is of special importance in connection with certain theories advanced to explain the violet layer on Mars.[1]

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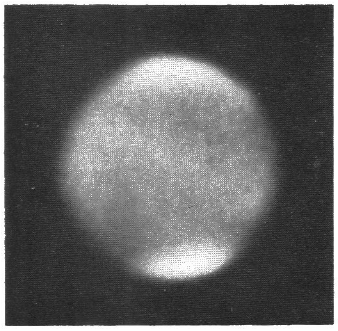
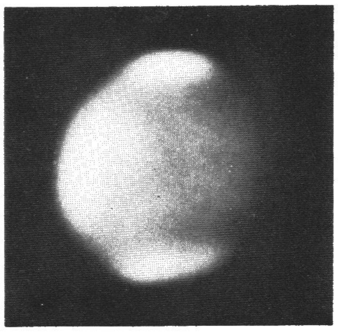
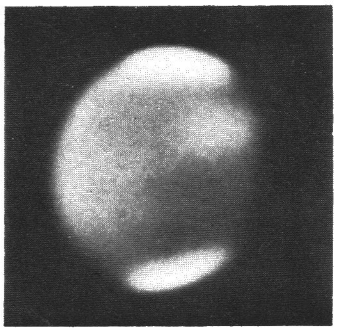
[1]Opik, E. J., J. Geophys, Research, *65,* No. 10, p. 3057, 1960.

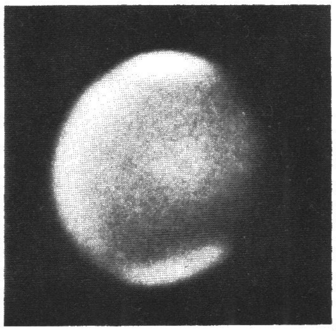
PLATE XXIII
SERIES SHOWING OPACITY OF MARTIAN ATMOSPHERE

1922

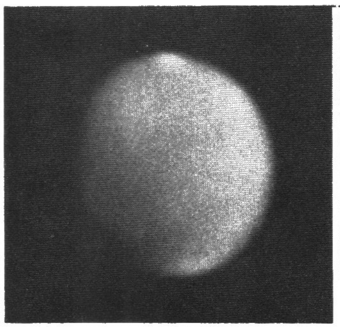

1. June 18 λ218°
U.T. 4:34 Mar 16 M.D. B

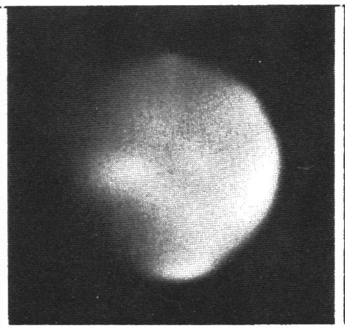

2. July 11 λ57°
U.T. 7:35 Mar 29 M.D. B

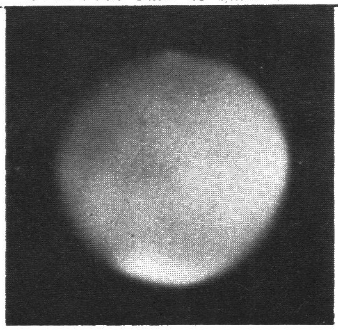

3. July 11 λ359°
U.T. 3:37 Mar 29 M.D. B

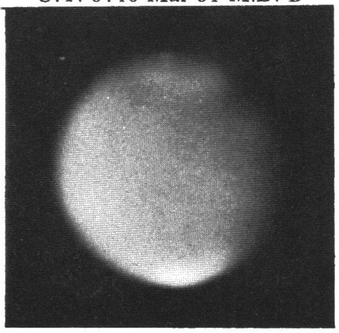

4. July 14 λ333°
U.T. 3:40 Mar 31 M.D. B

1926

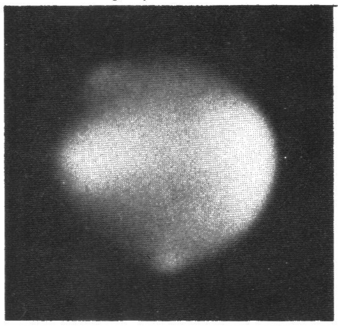

5. Sept 25 λ314°
U.T. 8:28 July 12 M.D. B

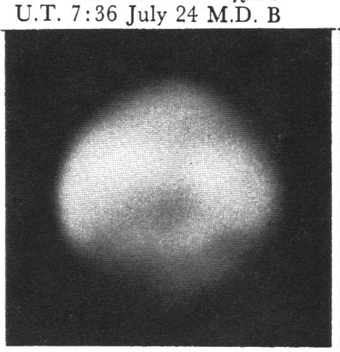

6. Oct 13 λ139°
U.T. 7:36 July 24 M.D. B

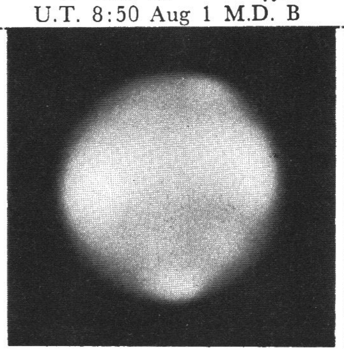

7. Oct 27 λ32°
U.T. 8:50 Aug 1 M.D. B

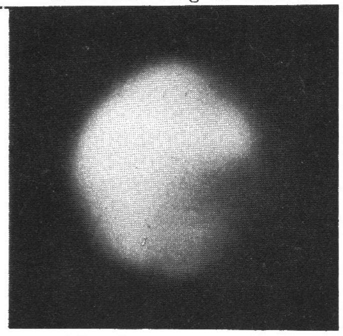

8. Dec 1 λ355°
U.T. 2:52 Aug 22 M.D. B

1935

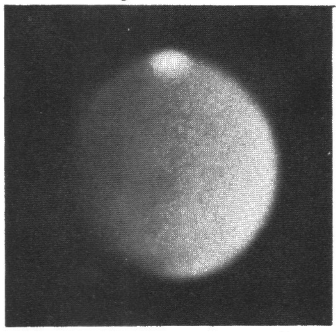

9. Mar 23 λ336°
U.T. 6:57 Jan 2 M.D. B

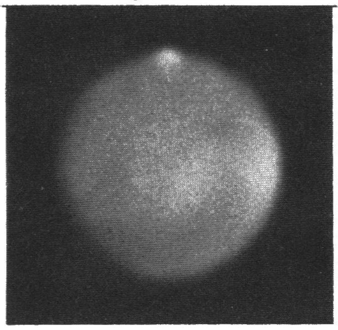

10. Apr 20 λ101°
U.T. 7:33 Jan 15 M.D. B

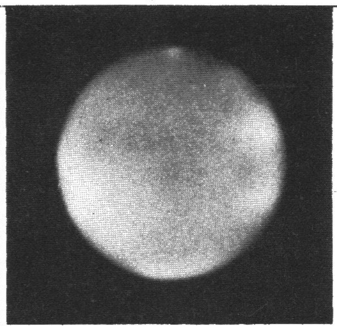

11. May 7 λ265°
U.T. 3:50 Jan 23 M.D. B

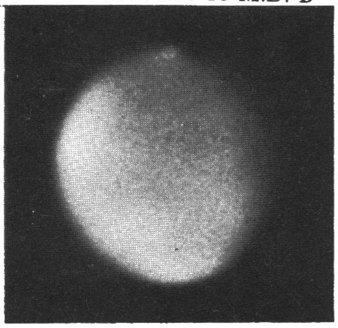

12. June 15 λ250°
U.T. 3:30 Feb 10 M.D. B

1941

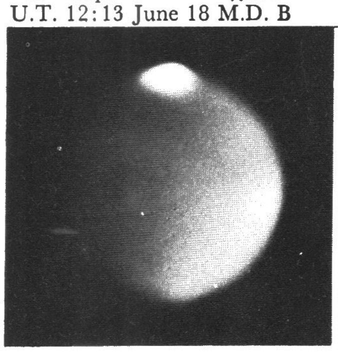

13 Sept 5 λ355°
U.T. 12:13 June 18 M.D. B

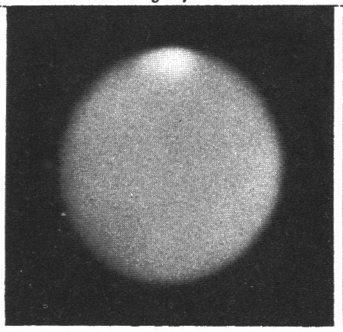

14. Sept. 29 λ114°
U.T. 10:27 July 4 M.D. B

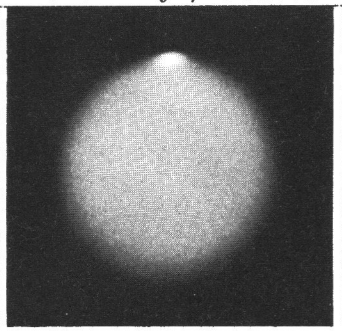

15. Oct 23 λ217°
U.T. 7:18 July 19 M.D. B


16. Nov 16 λ1°
U.T. 7:25 Aug 3 M.D. B

1956


17. Aug 20 λ136°
U.T. 0:15 May 27 M.D. B


18. Aug 24 λ79°
U.T. 23:27 May 30 M.D. B


19. Sept 19 λ155°
U.T. 19:42 June 16 M.D. B

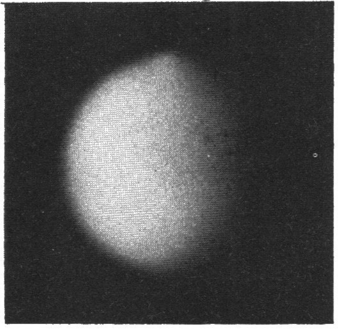

20. Oct 26 λ174°
U.T. 19:22 July 10 M.D. B

Plate XXIV

A photographic history of one of the most remarkable meteorological phenomena ever observed on Mars. It was first observed visually and photographed by the writer at the opposition in 1907. A similar cloud group has been repeatedly observed in the same locale, the Tharsis region near Lacus Phoenicis. During later oppositions, as for example in October, 1926, and June, 1954, the configuration received the designation "the W clouds". Similar blue photographs of the same face of the planet in 1956, made in late Martian May and early June, failed to show the brilliant cloud group present in 1954.

The most remarkable peculiarity of these clouds is that they are strictly an afternoon event. They appear faintly first around two o'clock and gradually develop and brighten during the afternoon until, toward the sunset limb, they become so prominent and bright as to rival the snow cap in brilliance. On the next morning, they are entirely gone, only to reappear in the early afternoon and gradually repeat themselves in the same place and in the exact same pattern during the afternoon. Sometimes, as in 1954, this cloud group repeats itself each afternoon for a period of three weeks or more. The configuration appears the same each day and no shift in the cloud masses has been observed; the whole pattern rotating with the planet.

Another remarkable feature of this phenomenon is that the main stems of the cloud pattern appear to coincide with the main canals in the area.

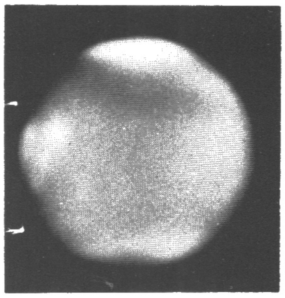
A marked tendency for clouds to recur for several decades over one part of the planet's surface has been observed since 1907. One such area lies near Phoenicis Lacus and particularly on its following side, as well as above and below it. The writer has observed temporary clouds in this vicinity many times in the past half century and while he has not made an exhaustive search of the files to form a complete list, a partial list shows examples in 1907, 1909, 1920, 1924, 1926, 1935, 1954, 1956 and 1958. On August 18, 1941, (M.D. = June 6) Truman photographed at Mt. Wilson a 350-mile cloud near Phoenicis Lacus (latitude $-17°$ and longitude $116°$) which is the approximate location of one of the strong clouds in the "W" group of 1954. The prevalence of recurrent clouds in this general area suggests that they may owe their origin to some geographical conditions or physical process associated with this location on the planet's surface. McLaughlin (1954) believes that the explanation may lie in his hypothesis of volcanic activity there.[1] However, the temporary and even seasonal character of these clouds obviously militate against the volcanic origin idea.

[1]McLaughlin, D. B., Sky and Tele., *13,* No. 11, p. 372, 1954.

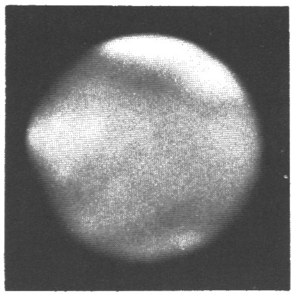
PLATE XXIV

SERIES SHOWING W-SHAPED CLOUD BELOW LACUS PHOENICIS

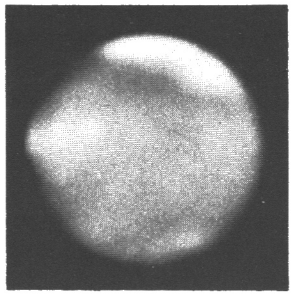
1954



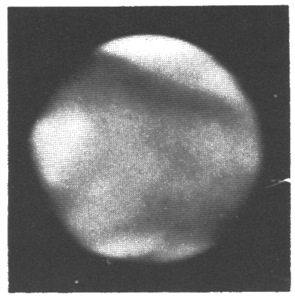
1. June 20 λ161° U.T. 20:22 B Mar 23 M.D.



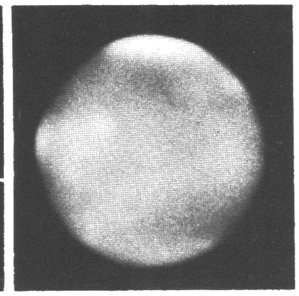
2. June 22 λ147° U.T. 20:35 B



3. June 26 λ147° U.T. 23:01 B

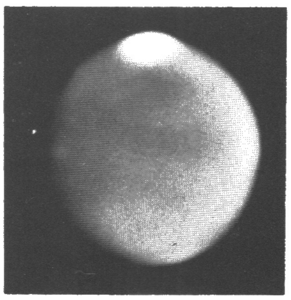


4. June 28 λ157° U.T. 0:19 B

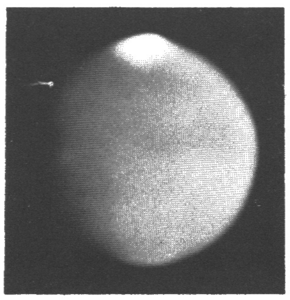


5. June 29 λ146° U.T. 0:09 B

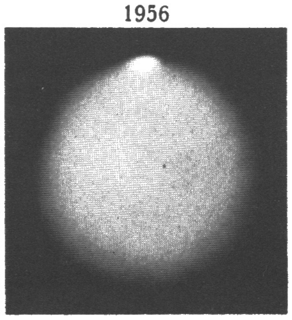
1956



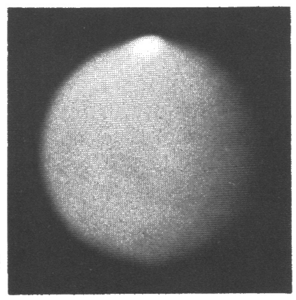
6. Aug 16 λ171° U.T. 0:14 B May 24 M.D.



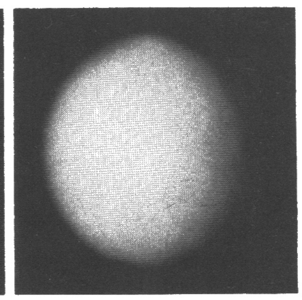
7. Aug 20 λ162° U.T. 2:02 B May 27 M.D.



8. Sept 19 λ155° U.T. 19:41 B June 16 M.D.

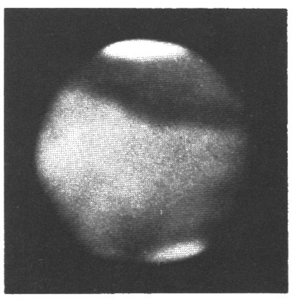


9. Sept 26 λ141° U.T. 23:01 B June 21 M.D.

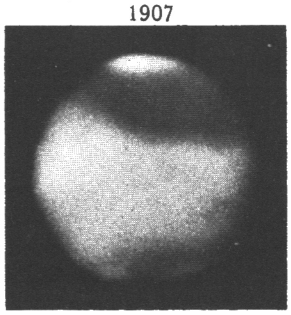


10. Oct 27 λ155° U.T. 18:43 B July 11 M.D.

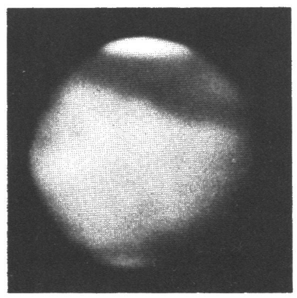
1907



11. July 15 λ163° U.T. 4:10 Y Apr 15 M.D.



12. July 17 λ168° U.T. 5:53 Y



13. July 19 λ167° U.T. 7:00 Y

Plate XXV

On the whole disk of Mars, no region is so frequently invaded by yellow clouds as the Libya and Isidis region on the preceding side of the Syrtis Major. The photographs illustrate the behavior of three separate examples of temporary cloud areas in this region in the 1924, 1943 and 1958 apparitions.

In 1920 the clouds were observed on three successive nights and the cloud area was sufficiently well defined to show not only the direction of its motion but the rate of motion as well. If we exclude the expansion factor, which usually becomes quite large after a period of about 48 hours, in all three examples the motion was southeasterly at a rate of 20 to 30 miles per hour.

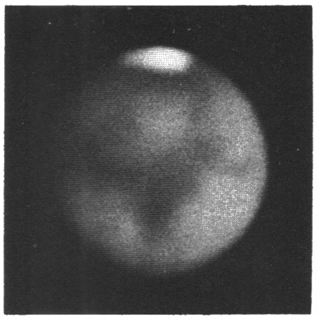
In 1924 (upper row) the cloud area appeared first as a small spot near the edge of the Syrtis Major and was seen to be moving southward; on the following night it was situated just south of the Thoth over the Libya. Since it showed no appreciable expansion, its rate of motion of 22 miles per hour is probably a good determination of the wind velocity.

In 1943 a cloud area was first observed in the Libya region (see second row), moved mostly eastward and expanded considerably on the second night, while on the third night its expansion and motion had carried it southwesterly over the southern portion of the Hesperia strait.

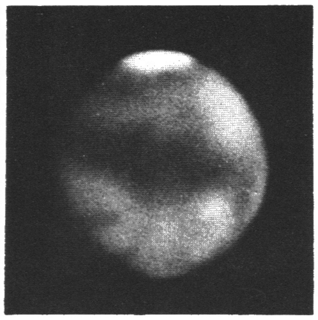
In 1958 a cloud appeared first in the Isidis region on October 13th and moved into the northern Libya on the 14th. On the 15th it had expanded considerably which, with its motion, had carried it mostly eastward. On the 16th its further expansion and motion had carried the forward portion over the southern part of the Hesperia. Thus the motion of these clouds, allowing for expansion, turned out to be from 22 to 30 miles per hour in a southeasterly direction.

PLATE XXV

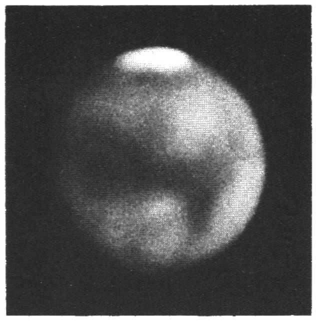
SERIES SHOWING YELLOW CLOUDS IN ISIDIS AND LIBYA REGIONS, 1924 — 1943 — 1958.



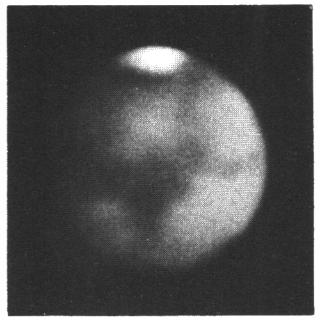
1. 1924 Aug 9 λ287° U.T. 9:40 May 14 M.D. Y



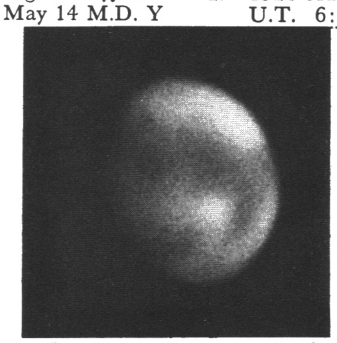
2. 1924 Aug 10 λ237° U.T. 6:49 Y



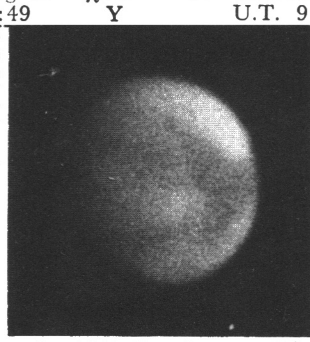
3. 1924 Aug 10 λ278° U.T. 9:34 Y



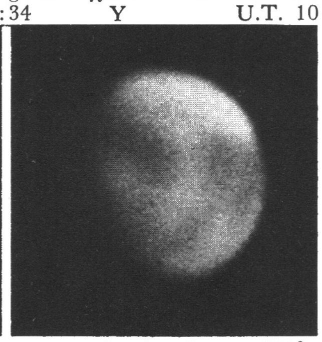
4. 1924 Aug 10 λ291° U.T. 10:40 Y



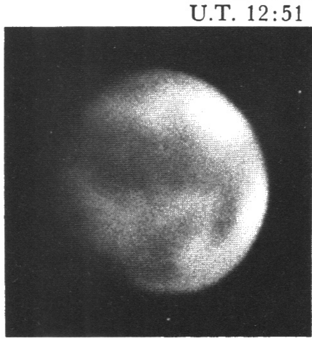
5. 1943 Oct 3 λ247° U.T. 12:51 Aug 2 M.D. Y



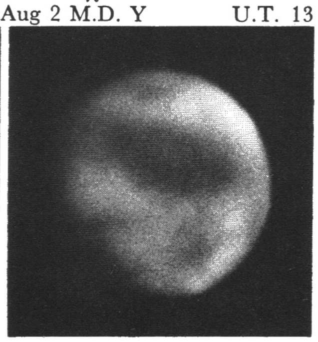
6. 1943 Oct 4 λ66° U.T. 13:28 Y



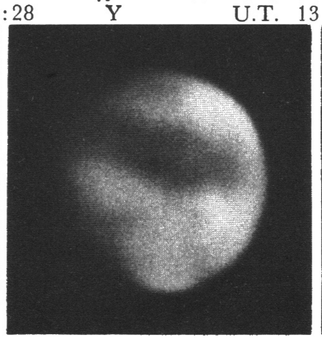
7. 1943 Oct 5 λ235° U.T. 13:20 Y



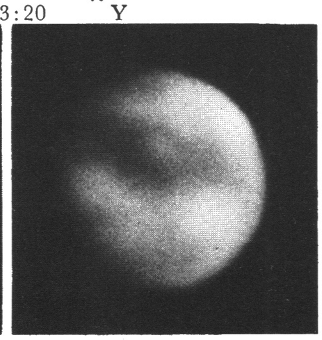
8. 1958 Oct 13 λ247° U.T. 8:47 Y July 29 M.D.



9. 1958 Oct 14 λ229° U.T. 8:04 Y



10. 1958 Oct 15 λ224° U.T. 8:18 Y



11. 1958 Oct 16 λ229° U.T. 9:23 Y

Plate XXVI

Photographs made in red or yellow light in 1956 are compared with those obtained in 1941 when the Martian atmosphere was normally clear. The missing dark markings in the 1956 photographs result from the obscuration by atmospheric clouds. In some instances there is only a general weakening of the dark areas, but in other cases, (as in No. 2), they are completely concealed or broken up into irregular patches. It will be noted in Nos. 1, 2, 3 and 7, that the south snow cap is all but hidden from view by the heavy cloud cover. In Nos. 8 and 9 the obscuring veil over the cap has become more tenuous and the cap itself begins to approach its normal appearance.

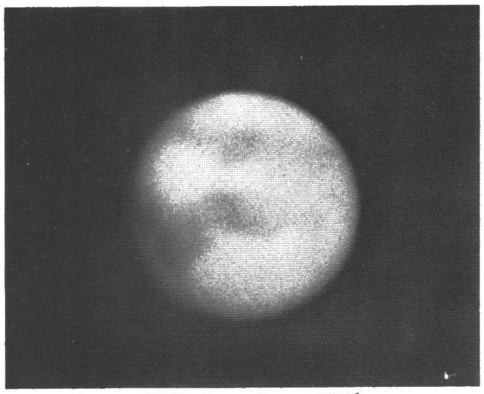
Accompanying the storm clouds there were numerous cases of abnormal darkening of certain areas, as for example near Aurora Sinus and the dark spot to the left of the Solis Lacus as in No. 8.

In general there were more cloud areas in the southern hemisphere; but in photographs 2, 3 and 9 the clouds invaded the northern hemisphere and concealed familiar markings there. The density, expanse, and duration of this storm was undoubtedly the greatest ever observed during the recorded history of the planet.

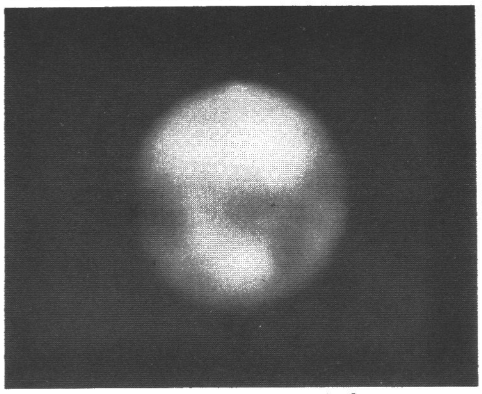
A more detailed discussion appears elsewhere in the text.

PLATE XXVI

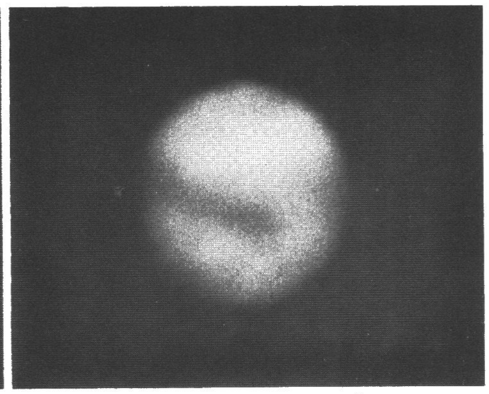
PHOTOGRAPHS DURING DUST STORM 1956 AND COMPARATIVE 1941 NORMAL SERIES



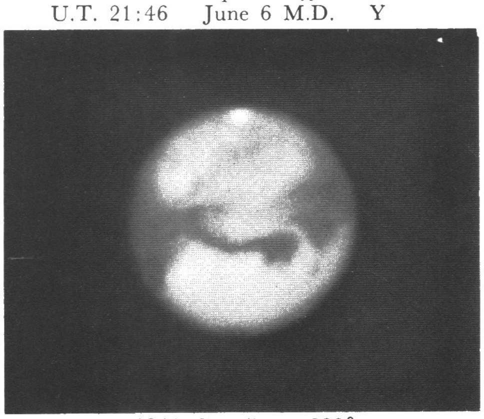
1. 1956 Sept 3 λ325°
U.T. 21:46 June 6 M.D. Y



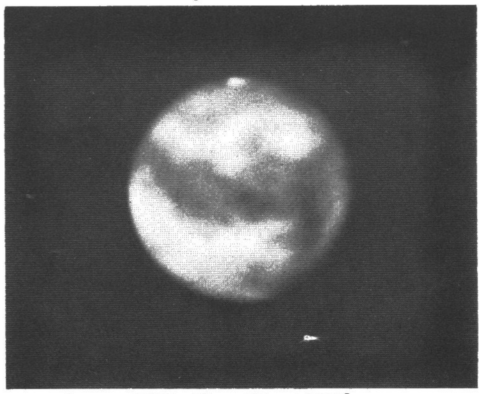
2. 1956 Sept 12 λ271°
U.T. 23:27 June 12 M.D. R



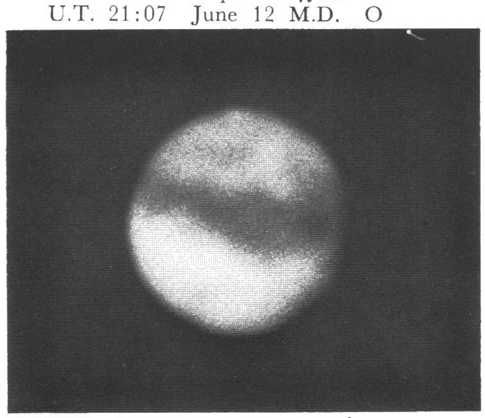
3. 1956 Sept 13 λ228°
U.T. 21:07 June 12 M.D. O



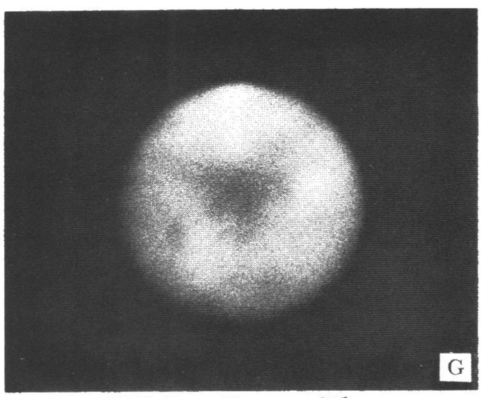
4. 1941 Oct 7 λ328°
U.T. 5:16 July 9 M.D. R



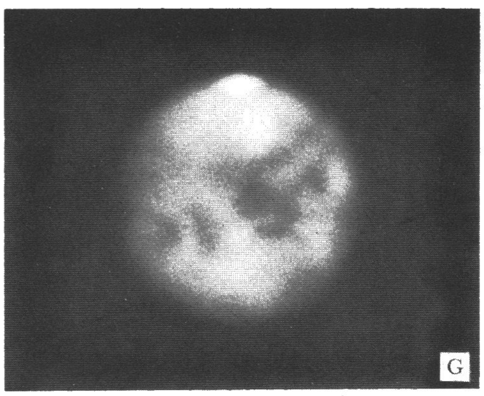
5. 1941 Oct 17 λ259°
U.T. 6:27 July 15 M.D. Y



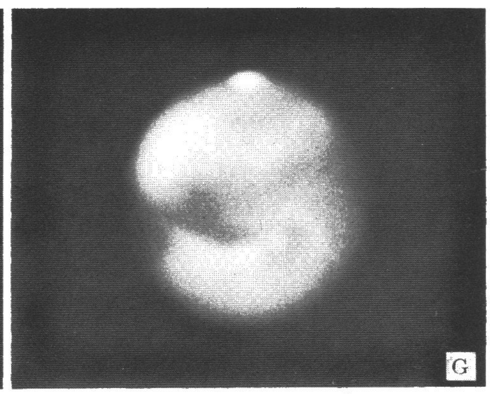
6. 1941 Oct 18 λ225°
U.T. 4:45 July 16 M.D. R



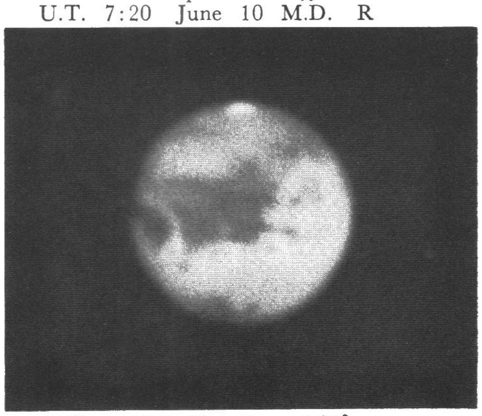
7. 1956 Sept 10 λ53°
U.T. 7:20 June 10 M.D. R



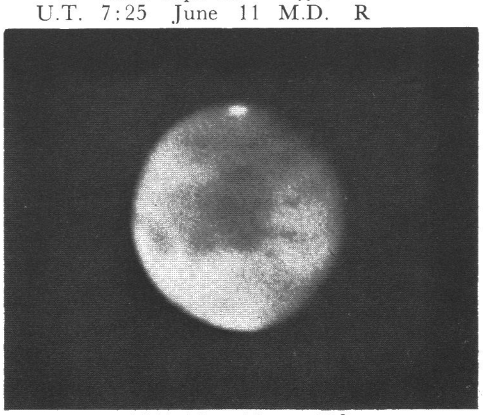
8. 1956 Sept 12 λ37°
U.T. 7:25 June 11 M.D. R



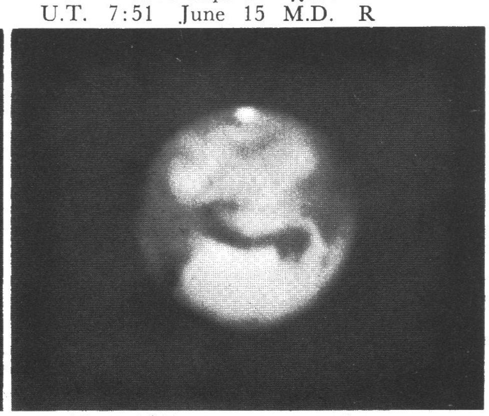
9. 1956 Sept 18 λ350°
U.T. 7:51 June 15 M.D. R



10. 1941 Oct 7 λ48°
U.T. 10:45 July 9 M.D. R



11. 1941 Nov 10 λ62°
U.T. 7:07 July 30 M.D. Y



12. 1941 Oct 11 λ338°
U.T. 8:26 July 11 M.D. R

Plate XXVII

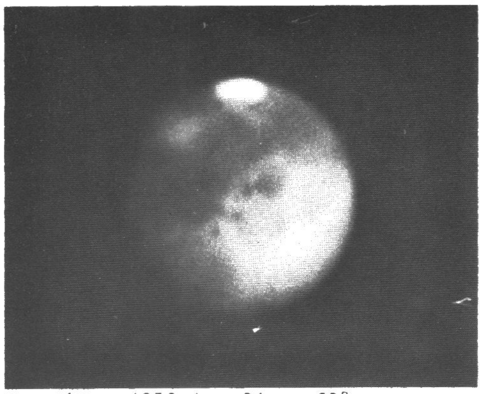
At Bloemfontein, we noted the first evidence of cloud over Argyre I on August 24; it was accompanied by a fainter streak of cloud running down from the left end of the south cap toward the Solis Lacus (No. 1). By the 28th a large, brilliant, orange-colored cloud had also developed over Noachis and the forward (left) side of the south cap began to show veiling by yellow haze.

On August 29 (No. 2) yellow clouds spread over much of southern latitudes and across the disk from Hellespontus to the limb beyond the longitude of Solis Lacus and southward over the cap, and the northern parts had invaded the Deucalionis R., Meridiani Sinus and vicinity. By September 3 the clouds had temporarily subsided markedly and, except for clouds over the 'islands' the maria here again showed nearly normal appearance. Later photographs show that this was only temporary. On August 25, No. 7, except for thin clouds over northern Hadriaticum and Hellas toward the morning limb, this longitude was nearly free of cloud.

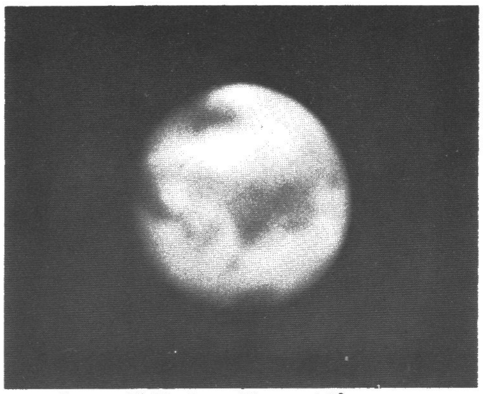
By September 2, however, clouds had spread around the planet and the whole of Mare Sirenum is concealed as well as the southern part of the disk and the south cap. No. 9, taken September 9, shows various cloud patches over the disk and the region of the Solis Lacus area is hidden by bright cloud. However, it is surprising to note that the ordinarily bright Thaumasia has suddenly turned intensely dark all along the upper left margin of the cloud. This sudden darkening of the Martian surface around heavy cloud areas is very amazing and strongly suggests that the soil was dampened by moisture released by the clouds.

PLATE XXVII

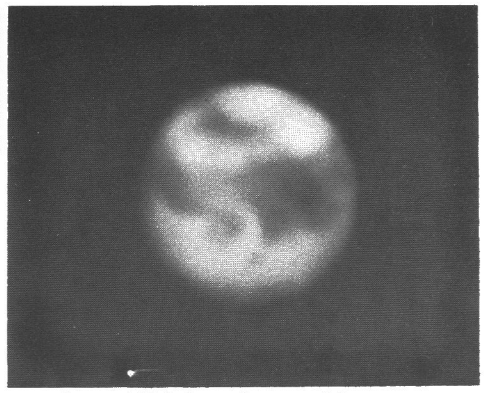
PHOTOGRAPHS DURING DUST STORM 1956 AND COMPARATIVE NORMAL SERIES 1941



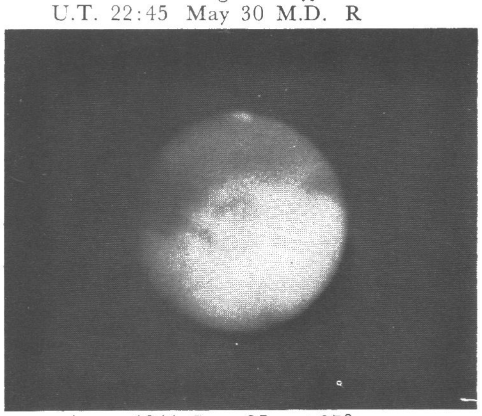
1. 1956 Aug 24 λ69°
U.T. 22:45 May 30 M.D. R



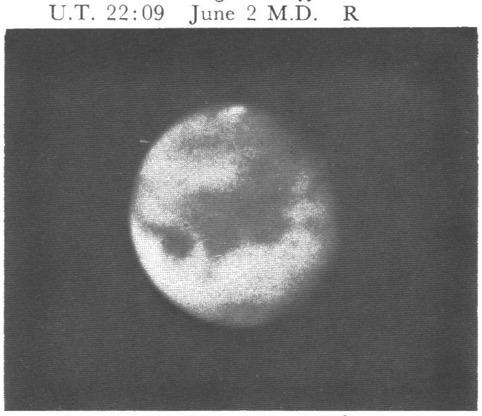
2. 1956 Aug 29 λ16°
U.T. 22:09 June 2 M.D. R



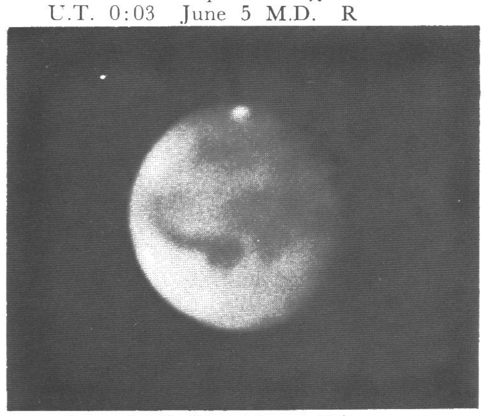
3. 1956 Sept 3 λ8°
U.T. 0:03 June 5 M.D. R



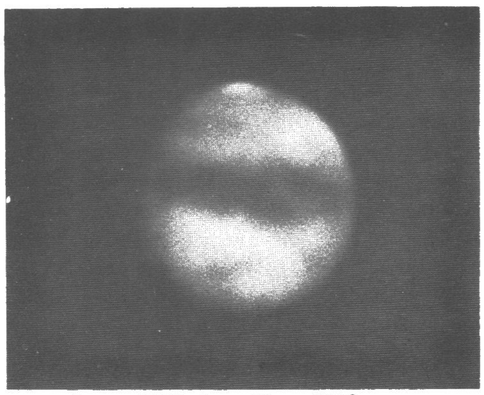
4. 1941 Sept 25 λ87°
U.T. 6:02 July 1 M.D. R



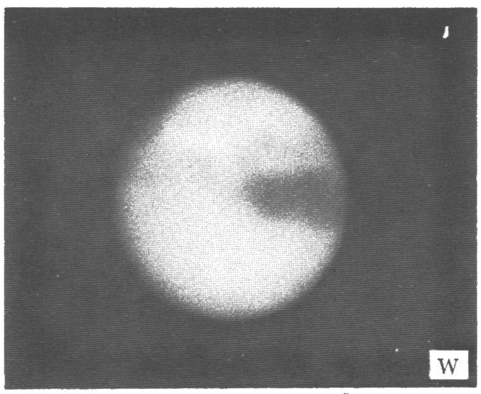
5. 1941 Nov 10 λ38°
U.T. 6:09 July 30 M.D. R



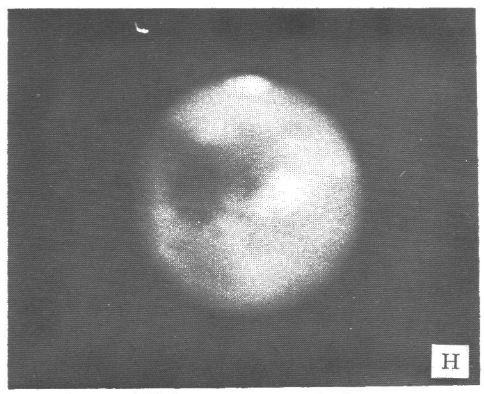
6. 1941 Nov 10 λ11°
U.T. 4:20 July 30 M.D. Y



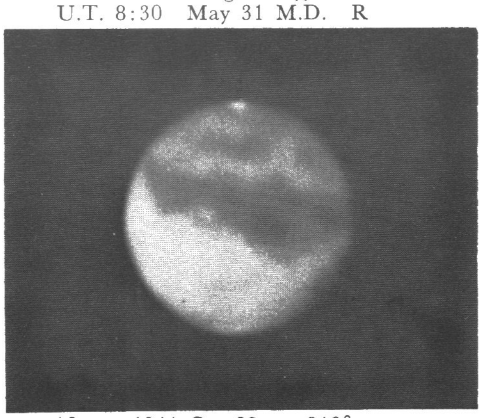
7. 1956 Aug 25 λ212°
U.T. 8:30 May 31 M.D. R



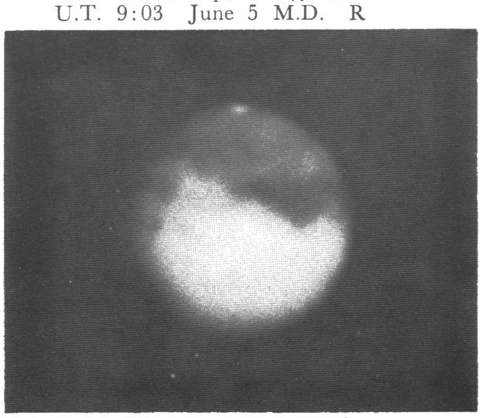
8. 1956 Sept 2 λ148°
U.T. 9:03 June 5 M.D. R



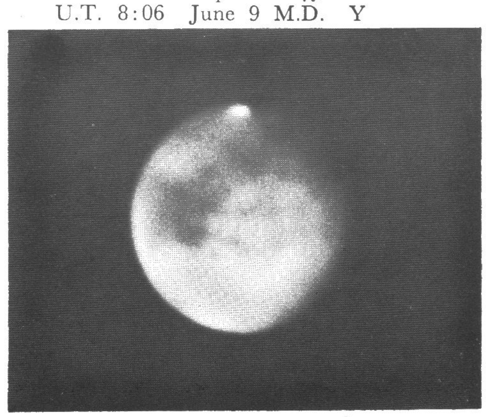
9. 1956 Sept 9 λ73°
U.T. 8:06 June 9 M.D. Y



10. 1941 Oct 23 λ212°
U.T. 6:54 July 19 M.D. O



11. 1941 Sept 25 λ134°
U.T. 9:22 July 1 M.D. R



12. 1941 Nov 4 λ82°
U.T. 5:22 July 28 M.D. Y

Plate XXVIII

During the past 34 years the Martian atmosphere, usually opaque in blue light, has often cleared suddenly so that for three or four days the surface features are remarkably distinct. Several times between 1926 and 1958 periods of transparency coincided quite closely with opposition. These blue images (only two or three for each occasion) illustrate the more remarkable examples of outstanding blue clearing. Nos. 1, 2 and 3 show the region from Syrtis Major to Meridiani Sinus, with Pandorae Fretum above, as revealed from November 1 to 5, 1926.[1,2] Familiar dark markings are almost as prominent as in a mediocre yellow photograph. Allowing for selective reflection in reducing the contrast between dark areas and deserts in blue light as shown in Plate VII, we conclude that the atmosphere was almost completely transparent to blue light. Since blue clearing seems more prevalent near opposition, it is noteworthy that this outstanding blue clearing exactly coincided with the planet's opposition on Nov. 4.

Nos. 4 and 5 show unusual blue clearing on December 29, 1928, eight days after opposition. Nos. 6 and 7, taken two and three days respectively after the 1937 opposition, show Syrtis Major remarkably clear except for patches of misty bluish clouds. Blue photographs compare favorably with yellow photographs made at the same time.

At the next opposition in 1941, Nos. 8, 10 and 11 show extraordinary blue clearing on October 9, 10 and 11. Again this example of blue clearing, like those in 1926 and 1937, was centered precisely with the opposition date of October 10. On this occasion the blue clearing was estimated as 4 to 5 on a scale 0-5 with 5 perfectly clear. The only real difference between the showing of the surface markings in simultaneous blue and yellow photographs is caused by selective reflection. On June 14, 1954, No. 12 shows another example of maximum blue clearing where the Syrtis Major and Mare Tyrrhenum are so clearly recorded as to rival the best yellow photographs. This occurred ten days before opposition. No. 13 taken within one day of opposition, shows the atmosphere completely opaque again and it remained essentially so for the remainder of the apparition. During the earlier part of the 1954 opposition there were numerous instances of strong or partial blue clearing.

In the first half of the opposition of 1956 the blue photographs showed that the atmosphere was continually opaque up to the advent of the great dust storm near the end of August. Nos. 14 and 15, however, show blue photographs taken on September 1 and 3, respectively, which reveal an abnormal amount of blue clearing although they were made at the very height of the greatest dust storm ever recorded on the planet. Although the photographs are heavily mottled by patches of heavy clouds, enough of the Syrtis Major, Sabaeus Sinus, Pandorae Fretum, Hellespontus and Mare Australe are revealed between clouds to show that better-than-average blue clearing was present. The fact that blue clearing could occur during the height of such an enormous dust storm clearly demonstrates that dust is not the medium which produces the violet layer as some authors have theoretically concluded. In 1958 blue photographs on November 13 and 14 (Nos. 16 and 17) show the best blue clearing during the whole apparition. This again occurred within four days of opposition on November 17.

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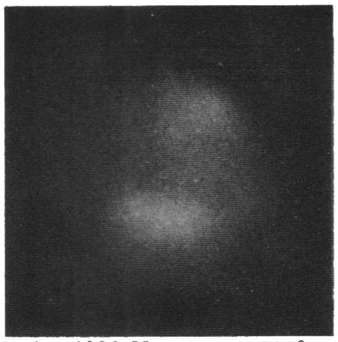
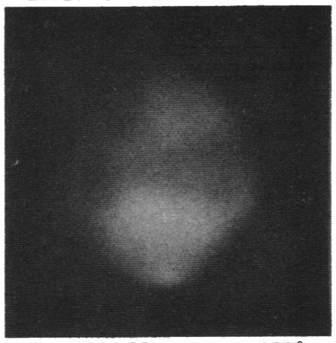
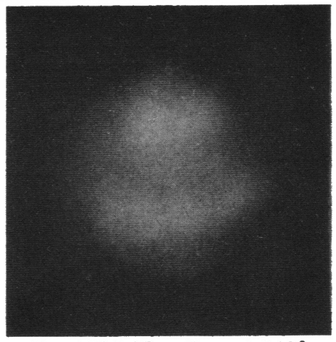
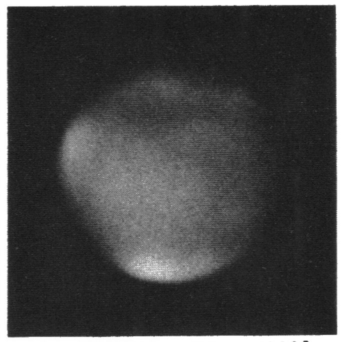
[1] Slipher, E. C., P.A.S.P., *39,* No. 230, 1927.
[2] ————, Proc. Amer. Phil. Soc., *79,* No. 3, 1938.

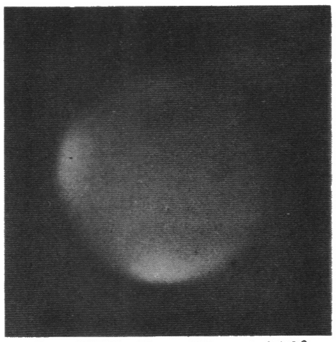
PLATE XXVIII
BLUE CLEARING NEAR OPPOSITIONS FROM 1926 TO 1958

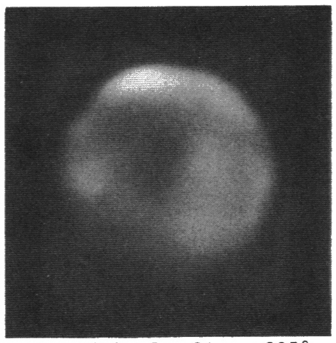

1. 1926 Nov 1 $\lambda 333°$
U.T. 7:43 Aug 4 M.D. B

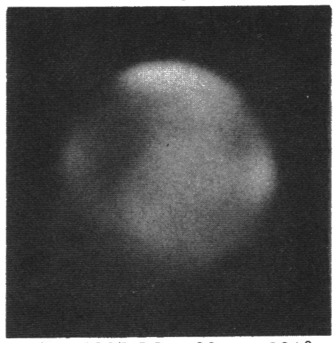

2. 1926 Nov 3 $\lambda 329°$
U.T. 8:41 Aug 6 M.D. B

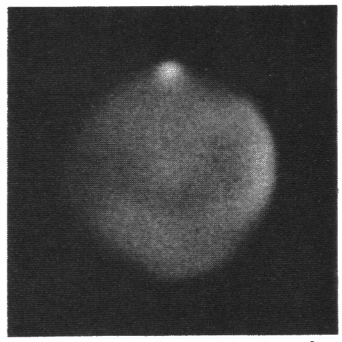

3. 1926 Nov 5 $\lambda 342°$
U.T. 10:44 Aug 7 M.D. B

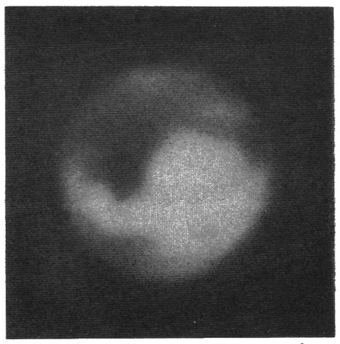

4. 1928 Dec 29 $\lambda 330°$
U.T. 9:33 Sept 28 M.D. B

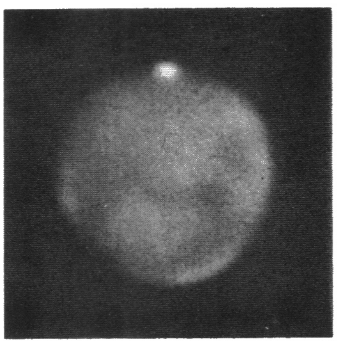

5. 1928 Dec 29 $\lambda 336°$
U.T. 9:57 Sept 28 M.D. B

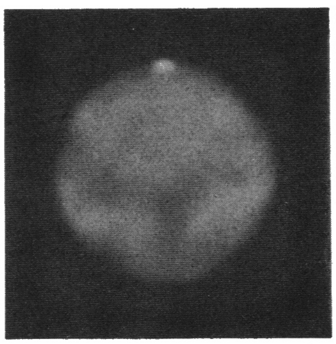

6. 1937 May 21 $\lambda 295°$
U.T. 6:20 Feb 20 M.D. B

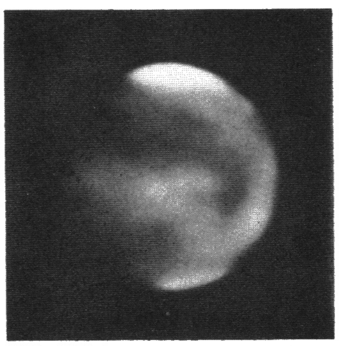

7. 1937 May 22 $\lambda 321°$
U.T. 8:43 Feb 20 M.D. B

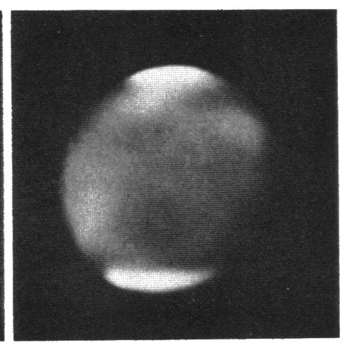

8. 1941 Oct 9 $\lambda 346°$
U.T. 7:46 July 10 M.D. B

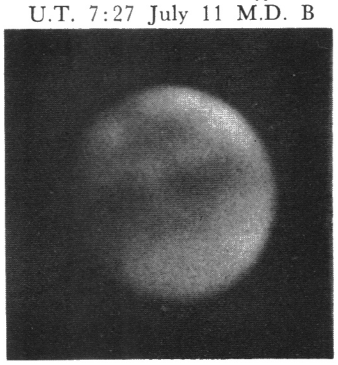

9. 1937 May 21 $\lambda 305°$
U.T. 7:41 Feb 20 M.D. Y

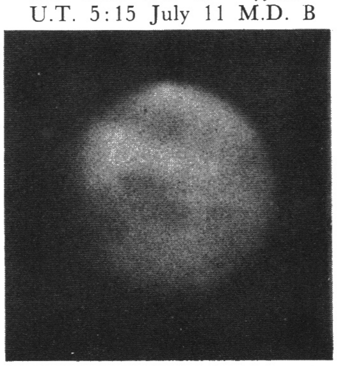

10. 1941 Oct 10 $\lambda 334°$
U.T. 7:27 July 11 M.D. B

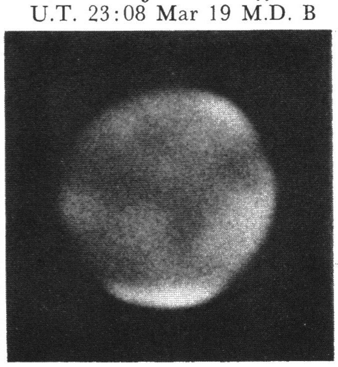

11. 1941 Oct 11 $\lambda 293°$
U.T. 5:15 July 11 M.D. B


12. 1954 June 14 $\lambda 255°$
U.T. 23:08 Mar 19 M.D. B


13. 1954 July 25 $\lambda 219°$
U.T. 21:02 Apr 13 M.D. B


14. 1956 Sept 1 $\lambda 345°$
U.T. 21:52 June 4 M.D. B


15. 1956 Sept 3 $\lambda 331°$
U.T. 22:07 June 6 M.D. B


16. 1958 Nov 13 $\lambda 279°$
U.T. 5:08 Aug 17 M.D. B

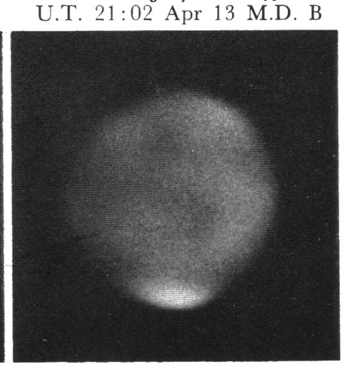

17. 1958 Nov 14 $\lambda 273°$
U.T. 5:18 Aug 17 M.D. B

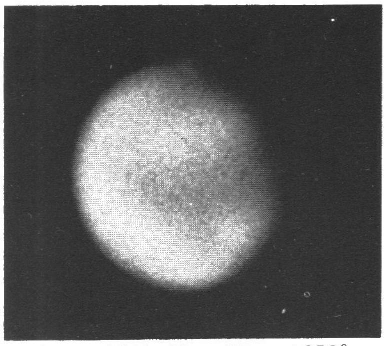
Plate XXIX

If we compare blue photographs taken far from opposition with corresponding yellow or red examples of the identical face of Mars (Plates IV and V), it will be evident that they show a fairly high degree of blue clearing and much of the maria are visible. In some cases the atmospheric transparency was estimated to be three to four. Such extraordinary blue clearing, so far from opposition, came as a surprise because all the early examples of unusual blue clearing had occurred at opposition time, namely 1926, 1928, 1937 and 1941. This seemingly well-established relation between blue-clearing and opposition date led to attempts to explain the phenomena on the basis of circumstances existing only at the time of opposition. Such examples as these, however, and similar ones observed here and elsewhere, strongly indicate that circumstances existing at opposition are not necessarily a prerequisite to blue clearing.

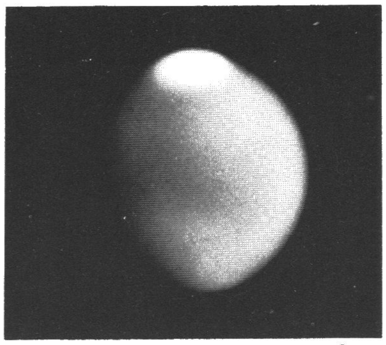
Naturally at opposition when sun and Earth are in line with Mars, the incident and reflected light transverse the minimum possible atmospheric path, a condition which is conducive to a clearer view of the surface. If the surface of the planet had been observed through the minimum path it seems probable that these photographs might have been so enhanced as to rival the remarkable examples of blue clearing observed at the oppositions of 1937 and 1941.

PLATE XXIX

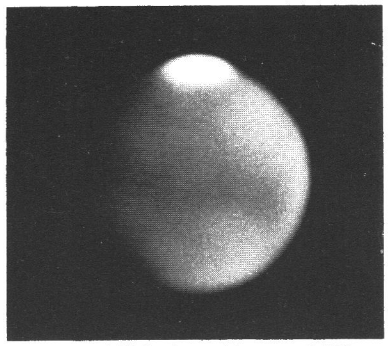
EXAMPLES OF BLUE CLEARING FAR FROM OPPOSITION



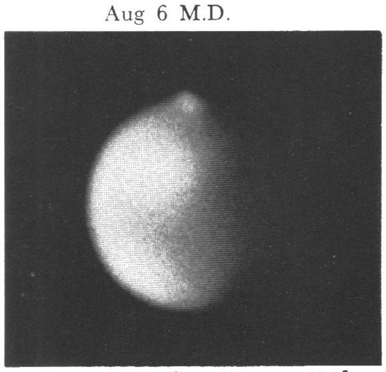
1. 1941 Nov 22 λ250° B
U.T. 3:38
Aug 6 M.D.



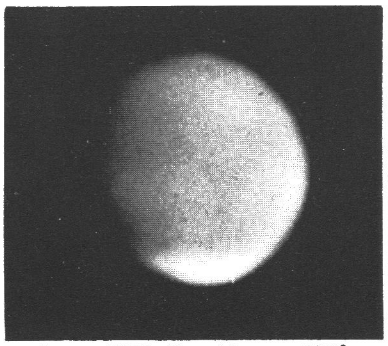
2. 1956 Aug 7 λ264° B
U.T. 0:59
May 19 M.D.



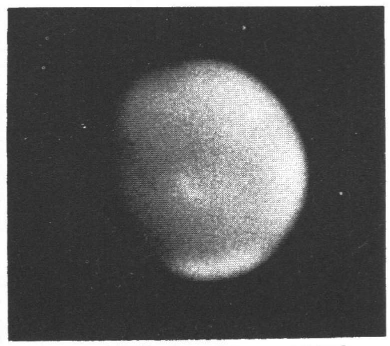
3. 1956 Aug 11 λ245°
U.T. 2:11
May 21 M.D.



4. 1956 Oct 26 λ311° B
U.T. 4:09
July 10 M.D.



5. 1958 Oct 13 λ271° B
U.T. 10:18
Aug 17 M.D.



6. 1958 Oct 15 λ255° B
U.T. 10:30
July 31 M.D.

Plate XXX

These blue photographs were made on the same dates with identical plates and filters at Flagstaff and in South Africa. They reveal striking differences in the opacity of the Martian atmosphere between observations separated by about nine hours. Obviously the observers at the two stations, observing at the same local time on the same night, would be viewing faces of the planet which differ by approximately 130° in longitude. However, if the same conditions existed all around the planet the photographs should appear the same. The fact that they do not demonstrates that the blue layer may be opaque on one side while quite transparent over another on the same night.

A comparison of No. 1 with its counterpart No. 2 shows a high degree of blue clearing in the first but an opaque condition in the second. No. 3, Flagstaff, also shows good blue clearing while its companion No. 4 is uniformly opaque. The same relation is true of Nos. 5 and 6. In No. 7 the Mare Cimmerium is easily recognized although it is mottled by a number of dark patches which all fall on bright areas of the planet and merely represent dark clouds in the planet's atmosphere. Thus all the Flagstaff photographs exhibit marked blue clearing while on the same dates all the Bloemfontein images are, strangely enough, essentially opaque.

Meanwhile, de Vaucouleurs[1] at Mt. Stromlo, Australia, eight hours east of Bloemfontein and seven hours west of Flagstaff, obtained results on blue clearing at variance with the other observers. He observed the atmosphere to be virtually opaque on August 23rd and 24th while on the 25th and 26th he estimated the blue clearing to be 3. On the 28th and 29th he found the transparency to be up to 4–5. No. 9, made at Bloemfontein on August 28th shows opacity over the whole disk, there being no sign of the solid surface showing through, while at Mt. Stromlo the blue clearing was rated almost perfect.

This series of photographs demonstrates for the first time two important facts about the blue layer, to wit: 1) on a given date it may be opaque over one face of the planet and remarkably transparent over another; 2) the blue layer was generally quite opaque prior to the advent of the dust pall over Mars in 1956 but in its presence blue clearing was observed. (Compare Nos. 9, 10, 11 and 12.)

It is clear that the introduction of dust particles into the planet's atmosphere would not in itself directly make the Martian air more transparent to any color. However, it was clearer in the blue as Nos. 10, 11 and 12 plainly show. To account for this the only reasonable explanation seems to be that the dust pall acted as a filter which cut out the shorter wave lengths and caused the image to become one made up largely of the greener-blue rays which more readily reached the solid surface of the planet.

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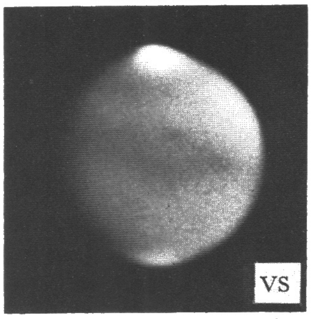
[1]de Vaucouleurs, G., P.A.S.P., *69,* No. 411, 1957.

PLATE XXX

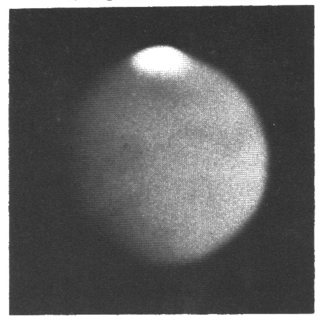
COMPARISON OF BLUE PHOTOGRAPHS SECURED AT FLAGSTAFF
AND AT BLOEMFONTEIN ON LIKE DATES

FLAGSTAFF

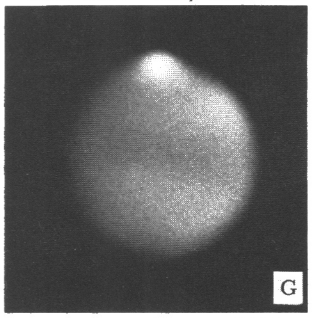
SOUTH AFRICA



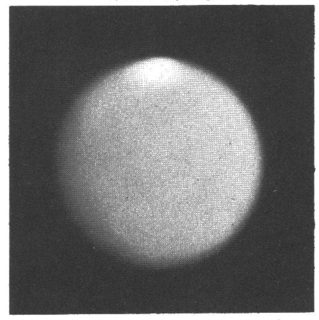
1. Aug 23 λ229°
U.T. 8:27 May 29 M.D.



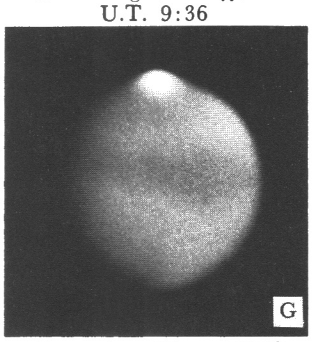
2. Aug 24 λ128°
U.T. 2:09



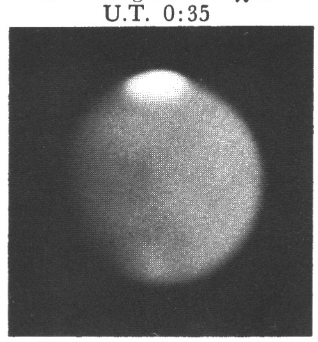
3. Aug 24 λ237°
U.T. 9:36



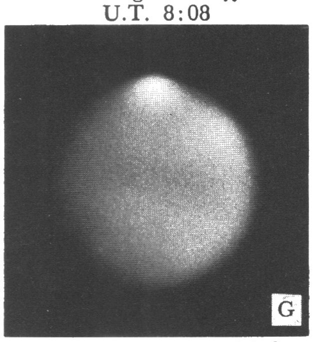
4. Aug 25 λ96°
U.T. 0:35



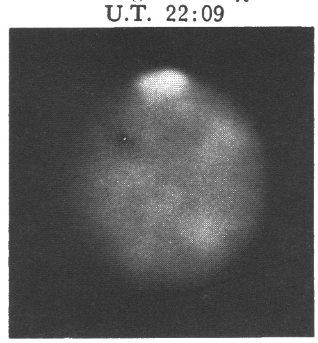
5. Aug 25 λ206°
U.T. 8:08



6. Aug 25 λ51°
U.T. 22:09

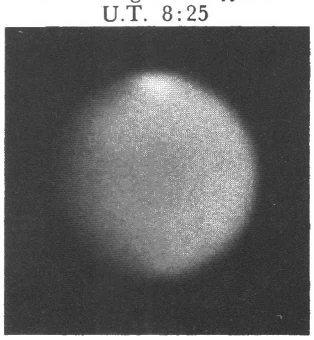


7. Aug 26 λ201°
U.T. 8:25

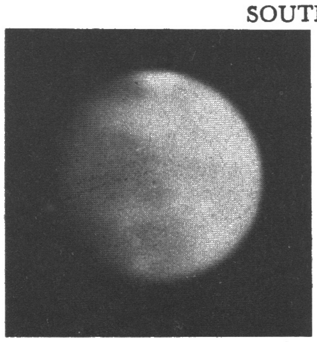


8. Aug 26 λ56°
U.T. 23:05

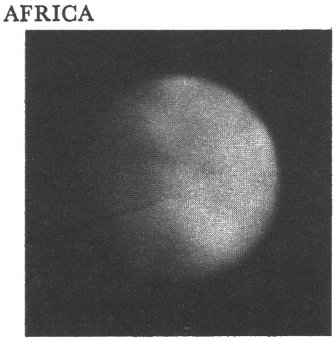
SOUTH AFRICA



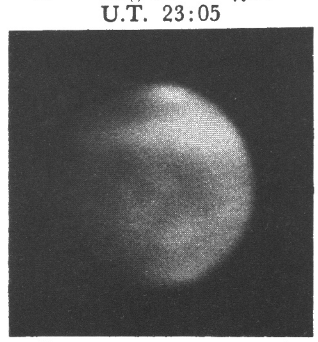
9. Aug 28 λ24°
U.T. 22:06



10. Aug 30 λ45°
U.T. 0:09



11. Aug 31 λ61°
U.T. 1:55



12. Aug 31 λ14°
U.T. 23:14
June 4 M.D.

Plate XXXI

Further comparative blue photographs made on the same dates at Flagstaff and Bloemfontein show different faces of the planet during a period of one month. Despite the 9-hour difference in longitude, almost all faces of the planet are included in this series. A graphical study of all our blue photographs of the planet over a period of thirty years has revealed that the dark regions show better near the meridian 270° than on the opposite side of the planet (see Plate XLIV). Since the majority of the Flagstaff photographs present this view of the planet, it is to be expected that they would tend to show slightly more blue clearing than their Bloemfontein counterparts. Some of them, however, also show the more favorable side. Nevertheless, the pair-by-pair comparisons from August 23 to September 23 consistently show greater blue clearing on the Flagstaff photographs than those made at Bloemfontein, and this by a considerable factor. Because of the similar methods used in securing the photographs, the wide difference in the opacity of the Martian atmosphere is quite puzzling.

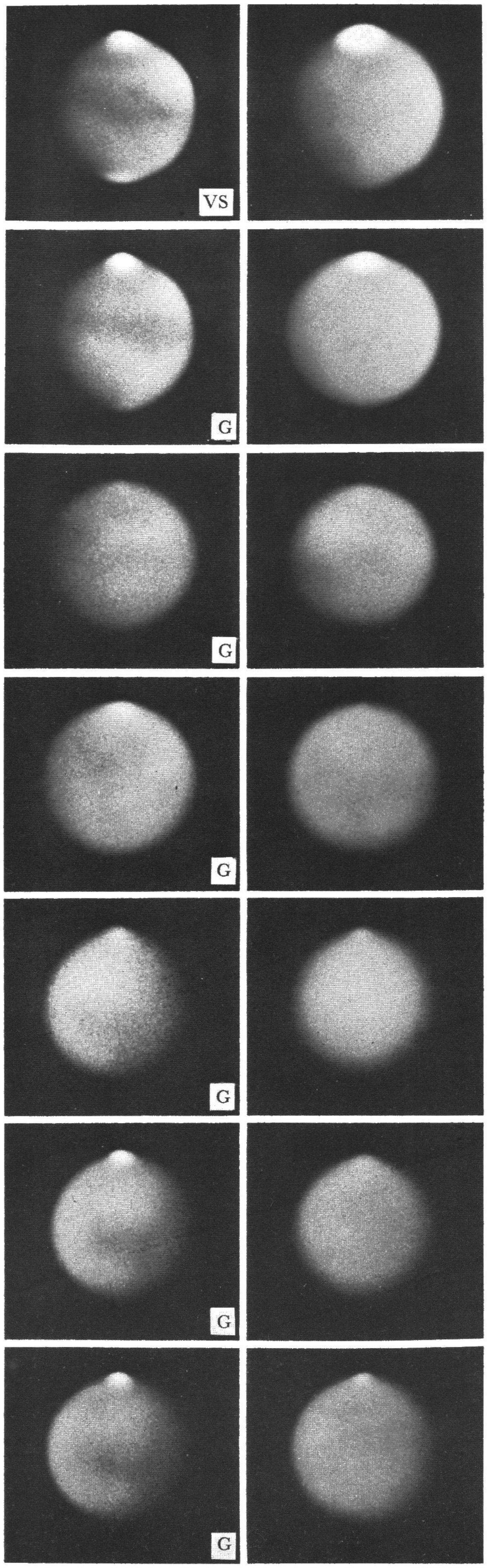
Naturally it may occur to some readers to question whether the two telescope objectives might differ in their capacity to transmit the shorter wave lengths. However, my experience with the two telescopes convinces me that the advantage, if any, certainly lies with the Lowell telescope in this respect. There is another reason which might account for the observed differences. It is well known that as one goes toward the shorter wave lengths the opacity of the Martian atmosphere increases. The declination of Mars was 10° south of the equator during this period. Therefore, because of the difference in the latitude of the two observatories, the zenith distances of Mars at culmination were 19° and 45° in South Africa and Flagstaff, respectively. For this reason more greenish-blue light would be effective at Flagstaff than at Bloemfontein where more of the violet light would get through the earth's atmosphere. As a result the South African photographs should be richer in the shorter wave lengths of violet light and therefore show less blue clearing. This apparently accounts for the main difference between the two sets of photographs.

PLATE XXXI

BLUE PHOTOGRAPHS MADE AT FLAGSTAFF COMPARED WITH THOSE MADE AT BLOEMFONTEIN.

1956

FLAGSTAFF SOUTH AFRICA



1. Aug 23 λ229°
U.T. 8:27
May 29 M.D.

2. Aug 22 λ77°
U.T. 22:06

3. Aug 25 λ206°
U.T. 8:08
May 30 M.D.

4. Aug 25 λ96°
U.T. 0:35

5. Sept 5 λ103°
U.T. 7:46
June 7 M.D.

6. Sept 4 λ318°
U.T. 21:50

7. Sept 10 λ58°
U.T. 7:43
June 10 M.D.

8. Sept 9 λ291°
U.T. 23:01

9. Sept 21 λ296°
U.T. 5:59
June 17 M.D.

10. Sept 20 λ146°
U.T. 19:43

11. Sept 22 λ284°
U.T. 5:47
June 18 M.D.

12. Sept 21 λ167°
UT. 21:45

13. Sept 23 λ281°
U.T. 6:12
June 19 M.D.

14. Sept 22 λ163°
U.T. 22:04

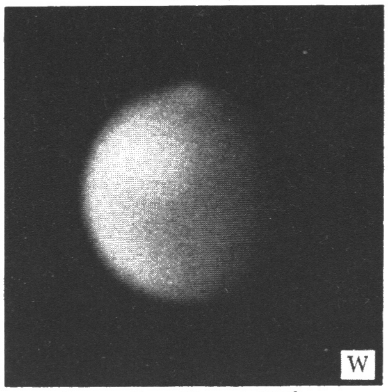
Plate XXXII

Other comparative blue photographs which were taken during a period when the planet was far from opposition, as the large phase defect reveals, show that blue clearing does occur sometimes regardless of opposition and the phase angle. A comparison of the various pairs shows again, as did Plate XXXI, that the Flagstaff photographs consistently exhibit greater blue clearing than do the South African observations. These examples involve surface areas having equally conspicuous markings and could not have been caused by differential extinction in the earth's atmosphere.

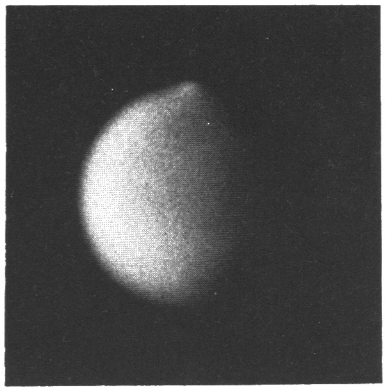
PLATE XXXII

BLUE CLEARING COMPARISONS IN OCTOBER 1956, FLAGSTAFF VS. SOUTH AFRICA

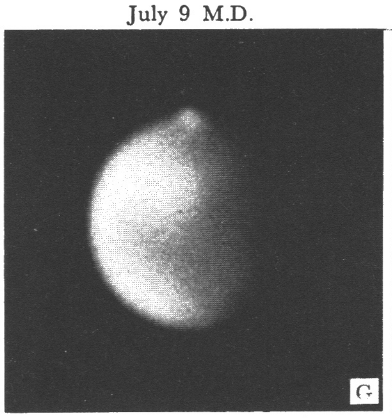
FLAGSTAFF | SOUTH AFRICA



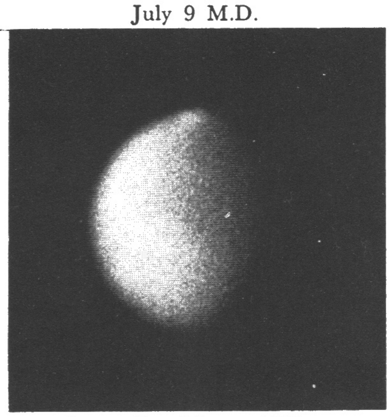
1. Oct 25 λ312°
U.T. 3:34
July 9 M.D.



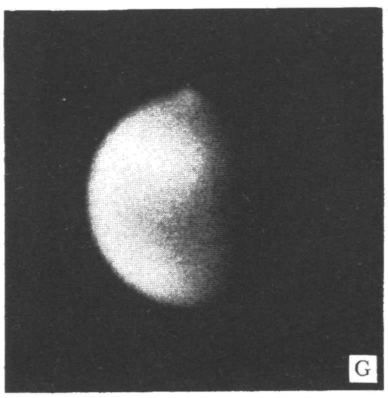
2. Oct 24 λ210°
U.T. 20:32
July 9 M.D.



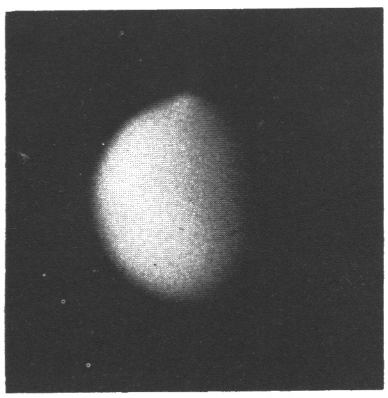
3. Oct 26 λ311°
U.T. 4:09



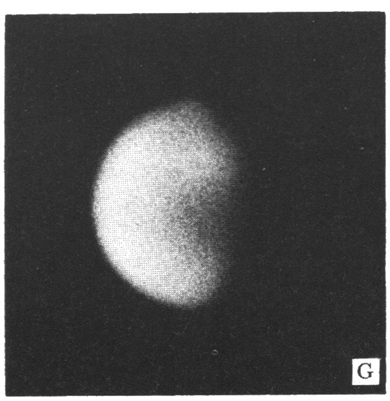
4. Oct 25 λ175°
U.T. 18:46



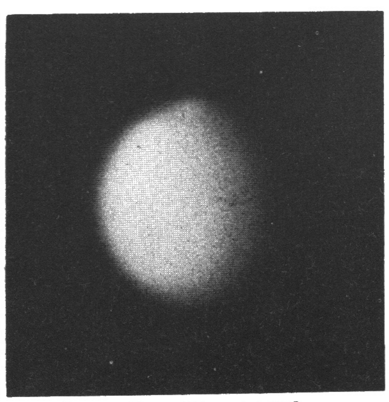
5. Oct 27 λ305°
U.T. 4:23



6. Oct 26 λ174°
U.T. 19:21



7. Oct 28 λ277°
U.T. 3:06
July 11 M.D.



8. Oct 27 λ155°
U.T. 18:43
July 11 M.D.

Plate XXXIII

Previous plates have shown changes in the transparency of the planet's atmosphere as observed on the same night from different stations separated by seven to nine hours in longitude.

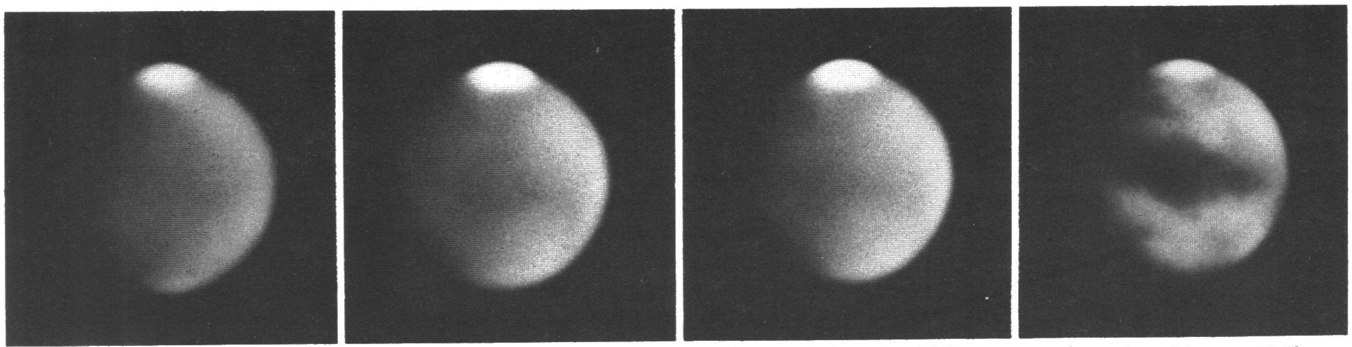
The photographs shown here reveal similar variation between images obtained early and late on the same night with the same telescope. The first three photographs were made in blue light, at different times. No. 4 was obtained in orange light a little later and is included for purposes of comparison. This is one of the best examples of a rapid change in the blue layer found by two investigators working independently on a study of more than 60,000 blue photographs obtained during the past 38 years. One of these estimated the transparency of the violet layer in No. 1 to be 0.5 while the writer derived 0.3; on No. 2, the estimates were 2.0 and 1.7 and on No. 3 they were 1.5 and 1.6, respectively.

These estimates show that an appreciable change in the violet layer occurred in less than three hours. Some of the change might be attributed to rotational effect but the change in the central meridian amounted to only 41° from beginning to end of the observations. This is too small to modify appreciably the whole picture; therefore most of the difference must have occurred in the planet's atmosphere itself. The next night and the two following ones, the atmosphere was again opaque and was rated by both observers as 0.0 to 0.3.

Such sudden changes are of course rare. But the fact that they can occur at all has a very significant bearing on the nature of the violet layer. For example, according to Stokes law, dust particles could not appear and fall out quickly enough to be consistent with these short-period changes in the violet layer. These sudden changes in the violet layer strongly suggest the existence there of some volatile medium.

PLATE XXXIII

CHANGE IN THE TRANSPARENCY OF MARTIAN AIR DURING SINGLE NIGHT 1956



1. Aug 10 λ209° U.T. 23:40 B May 21 M.D.

2. Aug 11 λ245° U.T. 2:11 B

3. Aug 11 λ249° U.T. 2:26 B

4. Aug 11 λ226° U.T. 0:53 O

Plate XXXIV

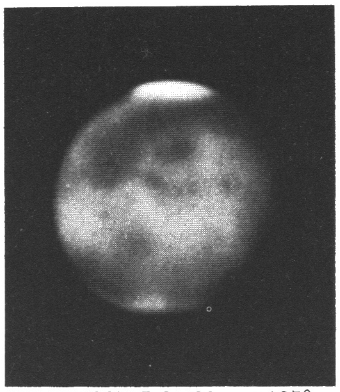
These photographs show changes in the size and form of the Solis Lacus region from 1907 to 1956. In Plates VI, VII, VIII and IX we have seen various stages in the seasonal changes in the polar caps and dark markings as well as striking secular changes in the Syrtis Major region. In No. 1, taken in 1907, the Solis Lacus consisted of two contiguous dark spots and the following component was more than three times the size of the preceding one, both being nearly circular in shape. In 1909 the north-south width of the Solis became quite slender and hung from the canals Nectar, Tithonius and Bathys something like a hammock.

Two years later the Solis had much the same shape, but as the photograph shows, had darkened considerably. At the 1926 opposition it had become greatly enlarged and its shape had strikingly changed. It had developed markedly towards the north with the darkest portion being to the north and much below its position in the earlier oppositions. In 1939 and 1941 the dark northern portion had completely disappeared and returned again to about the brightness of the desert leaving the Solis in the shape of a crown of three or four condensations above what was the darkest area of 1926. In 1954 and 1956, the Solis again resembled its appearance in 1909 and 1911 but differed noticeably in the arrangement of the three or four condensations of which it was composed.

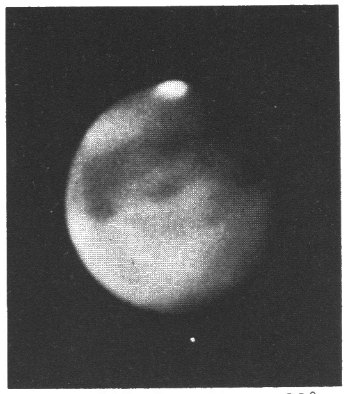
In the intervening oppositions the region has otherwise varied in form and size. These variations show that, from time to time, various portions of the Solis Lacus may fade from very intense spots to the same brightness as the surrounding desert area.

PLATE XXXIV

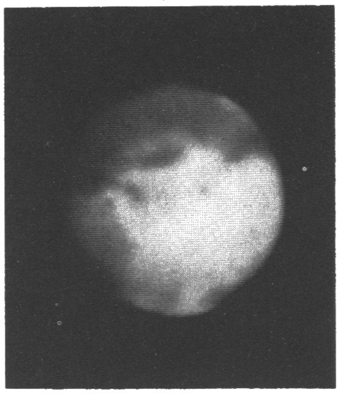
CHANGES IN SOLIS LACUS



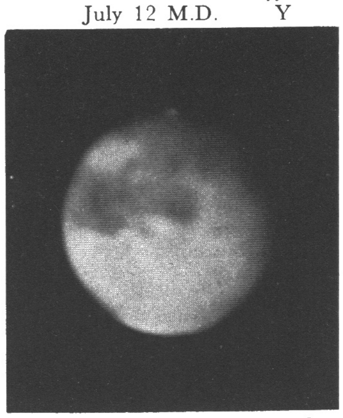
1. 1907 July 28 λ107°
U.T. 8:25 Apr 22 M.D. Y



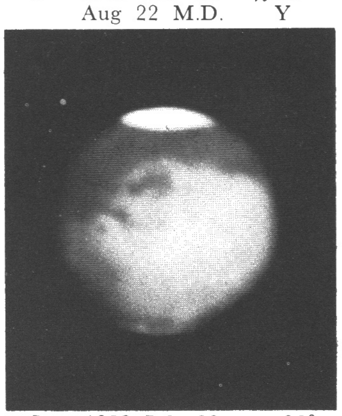
2. 1909 Oct 21 λ93°
July 12 M.D. Y



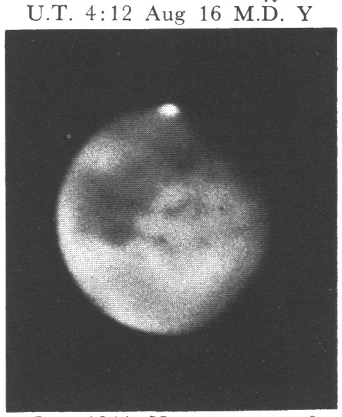
3. 1911 Nov 15 λ100°
Aug 22 M.D. Y



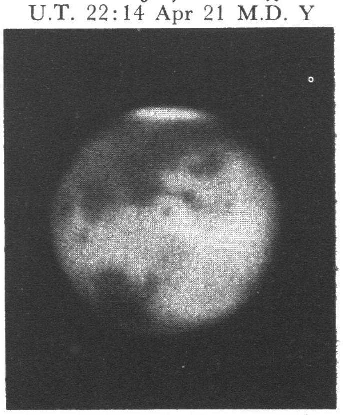
4. 1926 Nov 22 λ96°
U.T. 4:12 Aug 16 M.D. Y



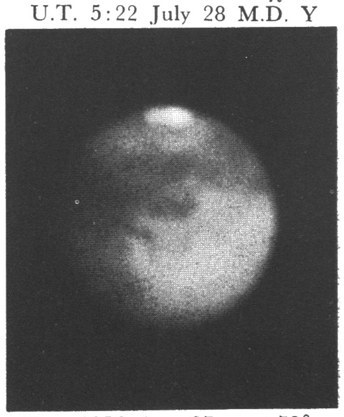
5. 1939 July 22 λ96°
U.T. 22:14 Apr 21 M.D. Y



6. 1941 Nov 4 λ82°
U.T. 5:22 July 28 M.D. Y



7. 1954 July 2 λ65°
U.T. 21:01 Mar 30 M.D. O



8. 1956 Aug 27 λ78°
U.T. 0:35 May 31 M.D. R

Plate XXXV

In addition to the seasonal development of the dark markings from time to time during the last half century or more, various features have sometimes undergone striking changes which bear little or no relation to the planet's season and are purely secular in nature. A few examples of this type of change are illustrated by this series of images.

During the early part of this century photograph No. 1 accurately represented the normal coastline of the Mare Cimmerium and Mare Tyrrhenum but in 1924 a dark area began to develop in the desert below Sinus Gomer between the Mare and the Elysium. This development was rather weak at first but grew stronger in 1926 and by 1939, as shown in No. 2, the dark area took on the aspect of permanency and has continued, with some variations, ever since. Likewise the Nepenthes-Thoth system on the forward side of the Syrtis Major was very weak and difficult to see in 1907 but from 1911 on it has been an easy object. From 1916 to the present time this system of canals generally has been so strong as to rival the grosser features of the disk.

Nos. 3 and 4 demonstrate a change of a different type around Laestrygonum Sinus. The Cimmerium above the Laestrygonum has brightened with the bay standing out as a small island connected to the Mare above by two or three canals. Above and to the left near Atlantis is another bright patch on a 1939 photograph which proved to be temporary and evidently represented a cloudy area.

Nos. 5 and 6 show the aspect of the Nepenthes-Thoth in 1909 and in 1928. In 1909 the Nepenthes and Lucus Moeris were strong and dark next to the Syrtis Major, but the Thoth canal itself was weak and nearly invisible. However, in 1928 the Thoth appears extremely broad and dark, consisting of a series of recognizable markings. Running through the mass of detail and a little to the right of the center is a canal-like core bordered on the outside by a series of spots and irregular details, while the inside edge is lined by a hazy border. At the base are two oases with two short canals running northward into the polar collar.

The southern Aethiopis shows a V-shaped mass of intricate dark markings too complex to decipher in detail. Comparative photographs of other oppositions from 1916 to the present reveal that many changes are occurring in this general area.

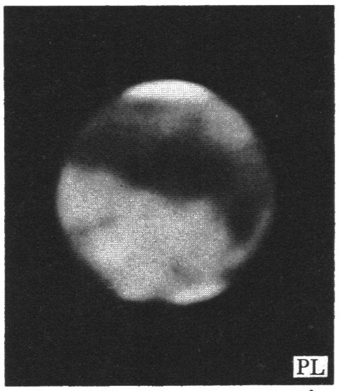
The three photographs at the bottom of the page, taken in 1907, 1939 and 1954, demonstrate quite clearly the enormous changes which have taken place in the desert region from the Syrtis Major to the Elysium. In addition to the development below Sinus Gomer, we see changes in 1939 in the Thoth-Nepenthes system and to the left of the Wedge of Casius. We also see in 1954 the development of a large irregular dark area to the left of the Thoth in the general region of the Nodus Lacoontis. Early symptoms of this change were indicated by photographs of the region taken in 1952, but this new dark area reached its maximum development 2 years later. Except for slight variations, it is still present.

From this series of changes we are forced to conclude that regions which appear to belong to maria and are therefore dark areas may change into desert areas, and by the same token, areas which first become familiar as desert regions may at another time become dark regions.

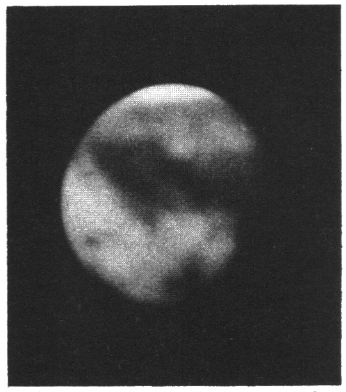
PLATE XXXV

PHOTOGRAPHS DISPLAYING SECULAR CHANGES IN THE DARK MARKINGS

Apr 13
M.D.



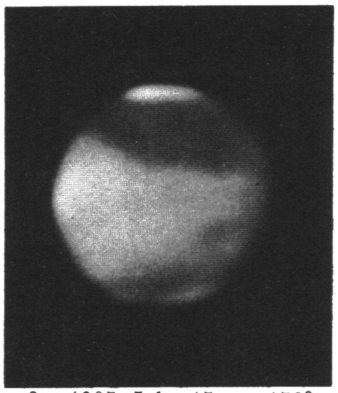
1. 1907 July 12 λ250°
U.T. 6:39 Y



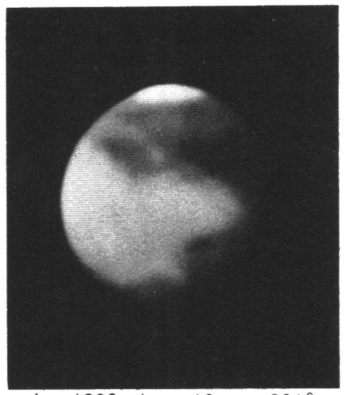
2. 1939 Aug 13 λ250°
U.T. 21:38 R

May 6
M.D.

Apr 17
M.D.



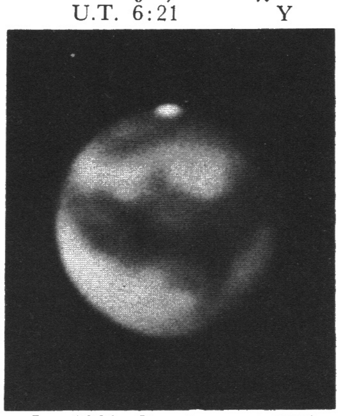
3. 1907 July 17 λ176°
U.T. 6:21 Y



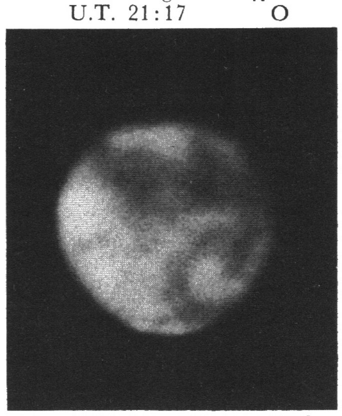
4. 1939 Aug 18 λ201°
U.T. 21:17 O

May 9
M.D.

June 31
M.D.

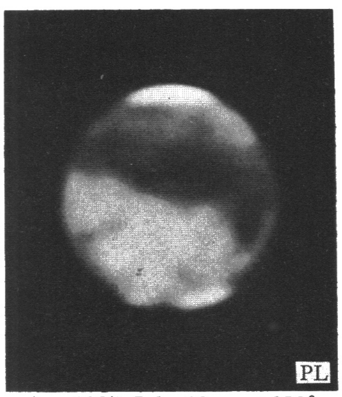


5. 1909 Oct 4 λ270°
U.T. 7:08 Y

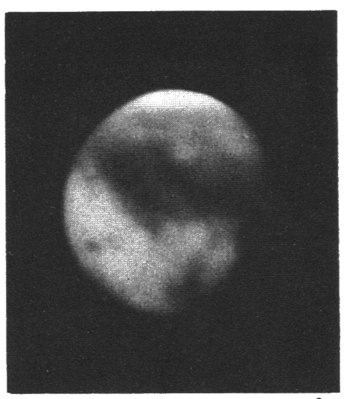


6. 1928 Dec 29 λ245°
Y

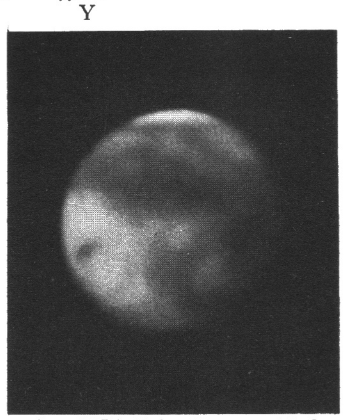
Sept 28
M.D.



7. 1907 July 12 λ250°
U.T. 6:39 Y
Apr 13 M.D.



8. 1939 Aug 13 λ250°
U.T. 21:38 R
May 6 M.D.



9. 1954 July 22 λ258°
U.T. 21:50 O
Apr 11 M.D.

Plate XXXVI

These photographs, including one drawing, illustrate examples of temporary darkening of small spots in the Martian deserts. They may be compared with the matching photographs displaying the normal appearance of the same region.

No. 1 shows the normal aspect of Mars in July 1907 with no conspicuous dark markings over the vast expanse of desert from the Mare Sirenum to the north pole. On August 9 to 14, 1909, there suddenly appeared in the place of the Biblis Fons oasis a very dark spot nearly circular in form and of a size and intensity far greater than anything observed there in the last 50 years. This spot was relatively large and so intensely dark as to appear like the shadow of a large satellite. It had not been there at the previous view of this part of the disk in July, nor was it observed at the next opportunity in September.

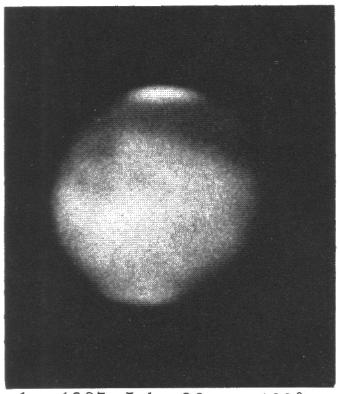
Photograph No. 3 shows the normal markings in the desert region between the Syrtis Major and Elysium as they appeared from 1905 through 1924, but on No. 4 there is an abnormal darkening to the left of the base of the Thoth in the region of Nodus Lacoontis. This dark area was of considerable size, approximately 30,000 square miles, and appeared for several days around October 5, 1926. It also was observed during only one presentation of the disk. However, about 26 years later in the 1952 and 1954 oppositions and ever since, a large new dark area of more permanent character has been observed in this same general locality.

Nos. 5 to 10 deal with the variable appearance of the oasis Ferentinae L. In 1939 (No. 5) the oasis was practically invisible, but on August 22, 1941, it shows clearly (No. 6) near the north pole. Again on November 29, 1941, it is barely recorded. On August 24, 1955 (No. 8) it is inconspicuous, but on September 25 (No. 9) it appears prominently as a much enlarged dark spot standing out conspicuously near the north rim of the disk. It was last photographed on October 6, 1956 when it was still an abnormally prominent oasis.

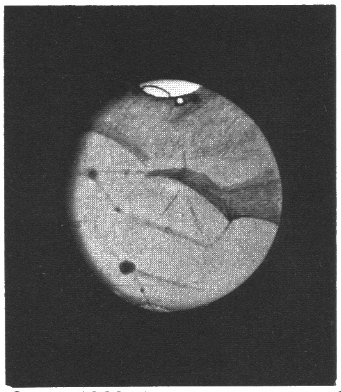
The sudden and temporary enlargement and darkening of normally inconspicuous oases present one of the most significant and puzzling mysteries of Mars. None of these examples showing development and growth of dark areas in the desert regions can be construed as belonging to the planet's seasonal changes. The only explanation that can be offered is that they result from a temporary abnormal moist condition. They have occurred at oppositions when an abnormal amount of cloudiness has been present.

PLATE XXXVI

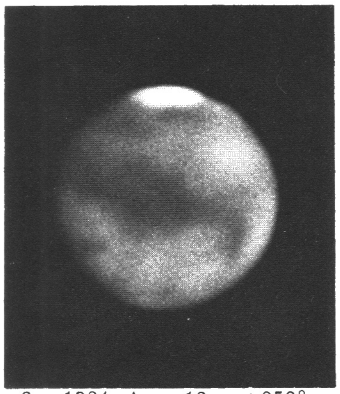
EPHEMERAL DARK MARKINGS AND MATCHING NORMAL PHOTOGRAPHS



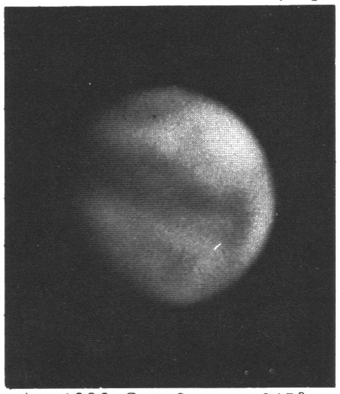
1. 1907 July 26 λ122°
U.T. 8:13 Apr 22 M.D. Y



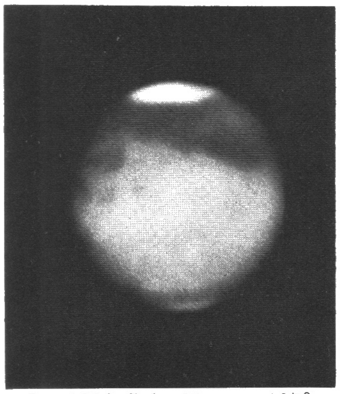
2. 1909 Aug 13 λ145°
U. T. 12:30 May 27 M.D. (Slipher)



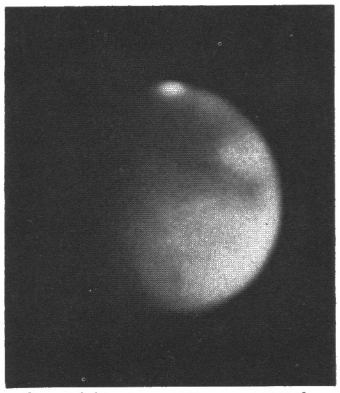
3. 1924 Aug 13 λ250°
U.T. 9:34 May 17 M.D. Y



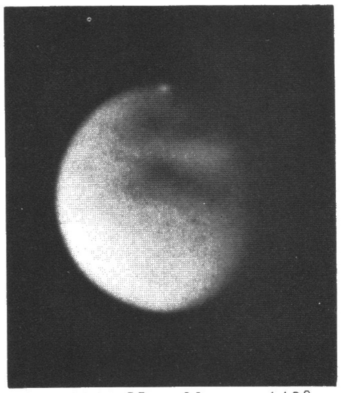
4. 1926 Oct 6 λ245°
U.T. 10:37 July 19 M.D. Y



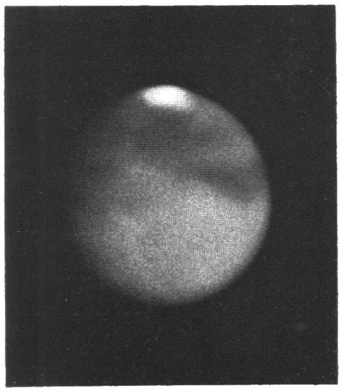
5. 1939 July 21 λ127°
U.T. 23:45 Mar 28 M.D. O



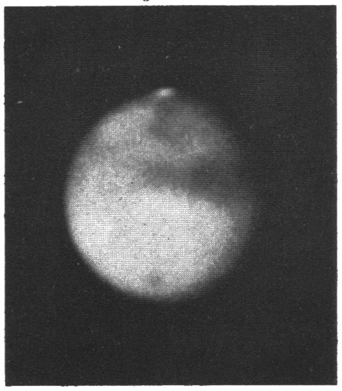
6. 1941 Aug 22 λ122°
U.T. 12:43 June 10 M.D. Y



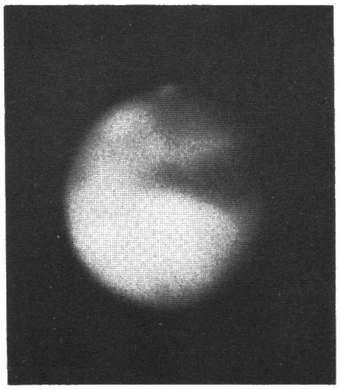
7. 1941 Nov 29 λ142°
U.T. 1:03 Aug 10 M.D. Y



8. 1956 Aug 24 λ122°
U.T. 1:46 May 29 M.D. Y



9. 1956 Sept 25 λ150°
U.T. 23:03 June 20 M.D. O



10. 1956 Oct 6 λ149°
U.T. 5:08 June 27 M.D. R

Plate XXXVII

These drawings made from visual observations may readily be compared with photographs of the same faces of the planet. The drawings were made at the Lick, Meudon and Lowell Observatories and the photographs were made at Lowell. Careful comparison of the five different sets of observations will disclose remarkable agreement between the best photographs and the drawings and also notable disagreements when the seeing was poor.

For the first pair (Nos. 1 and 2) Mars was near aphelion (apparent diameter 12″.95) and the magnification of the image was equivalent to 1800 diameters. Despite the severe loss of detail resulting from image composition to reduce graininess, enough remains to verify the existence of most of the details in the drawings. Careful study of the original plate shows virtually everything seen visually.

Drawing No. 3 by Trumpler using the Lick 36-inch refractor on October 23 is substantially confirmed by my photograph, No. 4, of the same general region on November 22. Close comparison discloses that traces of most of the canals and oases on the drawing are corroborated by traces of similar detail in the photograph.

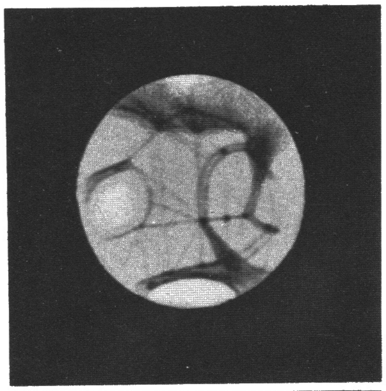
Comparison of the Antoniadi drawing, No. 5, with my photograph of the same region, No. 6, (magnification 1700 diameters) reveals that all the numerous details in the photograph to the left of and above the Thoth, namely in the Aethiopis and Elysium regions, are not recorded in his drawing. However, his representation of the aspect of the Thoth itself is not supported by the photograph. Examples are the short double canal running downward from the base of the Thoth, and also the dark, core-like medial line through the center of the Thoth flanked by diffuse irregular shadings on each side.

No. 7, is a circular section copied from Trumpler's 1924 map of the planet which is compared with our 1941 photograph, No. 8. A careful comparison should disclose that many of the finer details of his map are identifiable in the photograph, in particular many of the details in the southern part of the disk above the Sabaeus Sinus. The many fine traceries and spots in his map are faintly revealed in the original photograph.

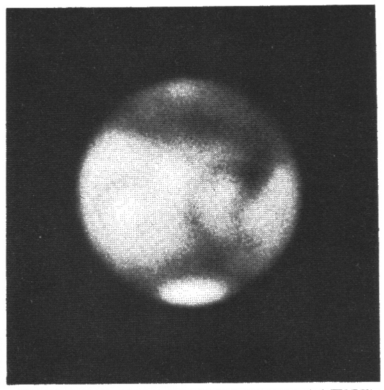
No. 9 is a drawing by the author. Photograph No. 10 was made a little later and shows the same face of the planet as Nos. 5 and 6. Here the agreement between drawing and photograph is more satisfactory and the one corroborates the other in a substantial manner. The markings missing in Antoinadi's drawing should be apparent in our drawing and photograph. Astronomers who observe the planet both visually and photographically know that nearly every detail observed visually can be found on some of the photographs, but the latter may show only a trace of something without clearly revealing its character or appearance. The visual observations have been of great help in the representation of the fine structure, such as sharpness, width and regularity of boundary lines or canals. On the other hand many markings are quite satisfactorily shown by the photographs which were not noticed in the visual observations. Those experienced in both types of observations fully realize the photograph may not show the precise character of extremely minute markings, but with regard to the reality of controversial markings, the evidence of the photograph is undeniable.

PLATE XXXVII

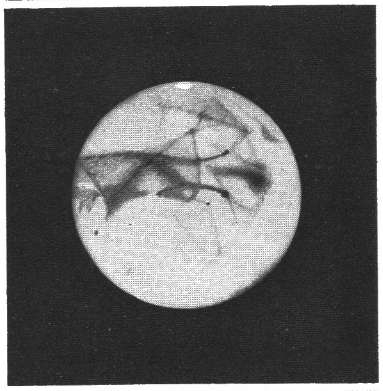
COMPARISON OF DRAWINGS AND PHOTOGRAPHS



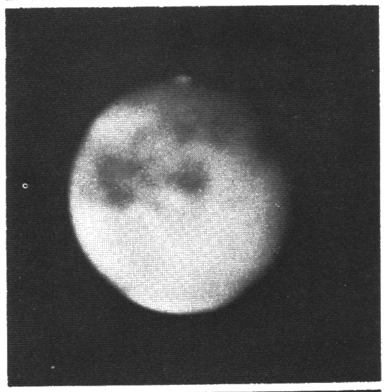
1. 1916 Feb 11
(Slipher drawing)
Nov 15 M.D.



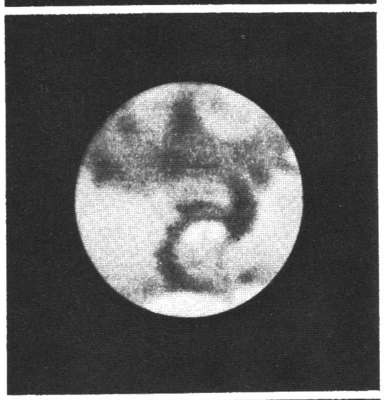
2. 1916 Feb 12 λ250°
U.T. 4:26 Y
Nov 15 M.D.



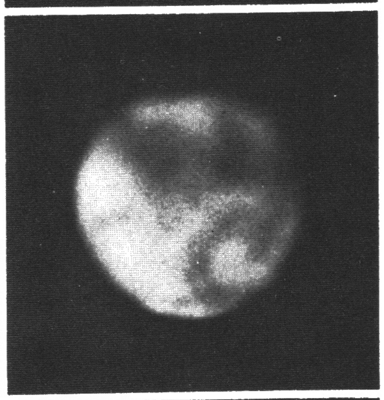
3. 1926 Oct 23
(Trumpler drawing)
July 30 M.D.



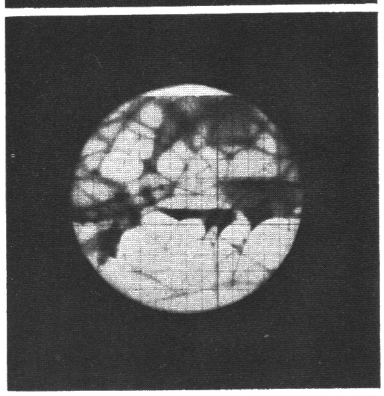
4. 1926 Nov 22 λ96°
U.T. 4:12 Y
Aug 16 M.D.



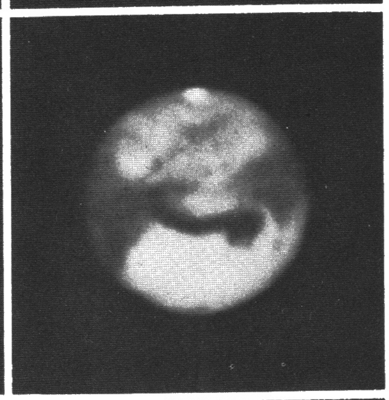
5. 1928 Dec 15
(Antoniadi drawing)
Sept 21 M.D.



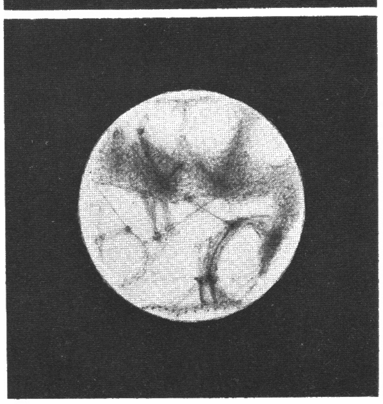
6. 1928 Dec 29 λ245°
Sept 28 M.D. Y



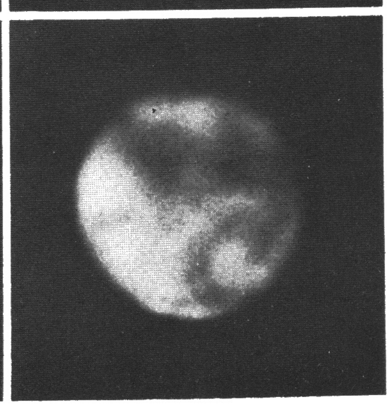
7. 1924 Trumpler Map



8. 1941 Oct 11 λ338°
U.T. 8:06 R
July 11 M.D.



9. 1928 Dec 28
(Slipher drawing)
Sept 28 M.D.



10. 1928 Dec 29 λ245°
Sept 28 M.D. Y

Plate XXXVIII

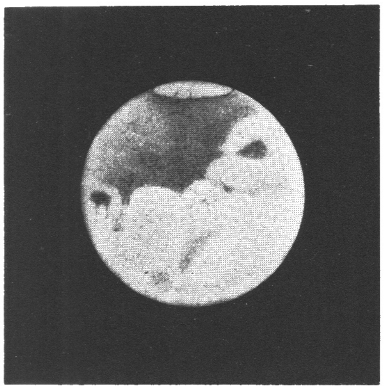
Direct photographs are compared with some of the better drawings made on the same dates by four different visual observers.[1] Detailed comparisons reveal the clear superiority of the photograph in precisely recording the grosser dark maria, their form and intensity. If one compares carefully the various areas of the disk, he sees on the photograph that the vast dark regions, instead of consisting of vague indiscriminate shadings, actually consist of numerous tiny oasis-like spots and equally numerous tenous streaks or canals. Even grosser markings appear considerably more precisely, as for example the Solis Lacus, which is actually a sort of crown consisting of a series of contiguous, tiny condensations with an open area to the north rather than a vague shading. The exact form and appearance of the Syrtis Major, the Mare Tyrrhenum, the Hadriaticum, the Mare Ionium and Hellespontus regions with their various component spots, so readily seen in the photographs, are entirely missing in the drawings.

Absent in the drawings are other important markings: the short, stubby beginnings of the Hydraotes and Jamuna canals leading downward from the coastline between the Margaritifer S. and Aurora S. The Maeisia Silva atop the Agathodaemon and the Tithonius Lacus, and many other fine markings revealed in the upper photograph are also completely missing in these visual observations. The new oasis just to the right of the tip of Syrtis, which stands out clearly in the photographs, also escaped detection by the visual observers. Whatever visual observations disclose concerning existence or non-existence of the more difficult canals and oases is obviously of little value. Finally, if one wishes to record changes in the polar caps and in the dark markings, either of a seasonal, secular or temporal nature, it is evident that the photographic technique provides more reliable and precise information than the visual method.

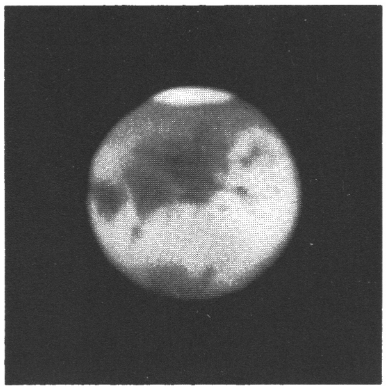
[1]Roy, L., l' Astronomie, *54*, No. 4, p. 79-83, 1940.

PLATE XXXVIII

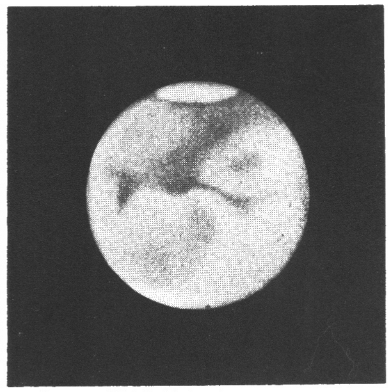
CONTEMPORANEOUS DRAWINGS AND PHOTOS OF DARK MARKINGS



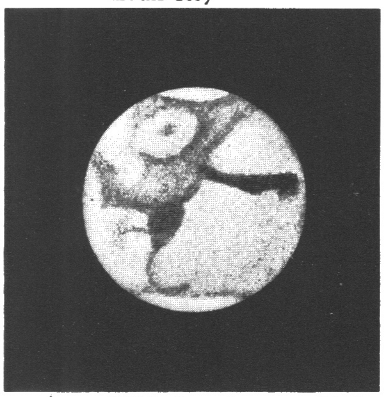
1. 1939 July 28 λ62°
Louis Roy



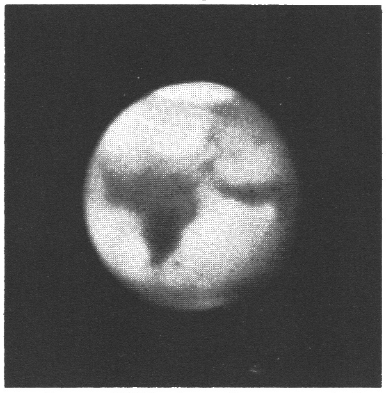
2. 1939 July 27 λ48°
U.T. 22:02 Apr 25 M.D. R



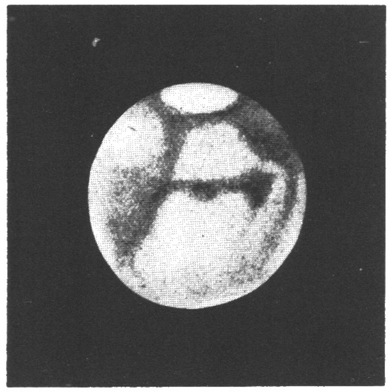
3. 1939 July 28 λ68°
R. Schlumberger



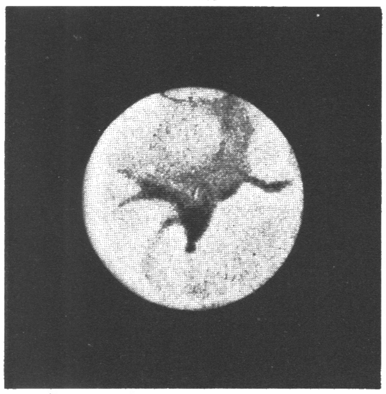
4. 1939 Aug 8 λ310°
M. Gentili



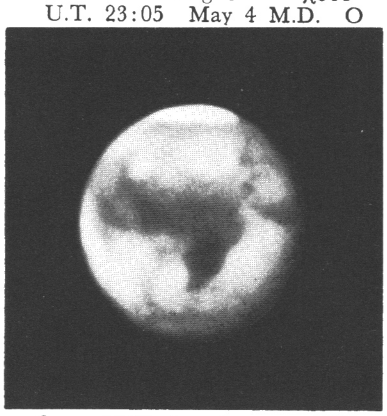
5. 1939 Aug 9 λ308°
U.T. 23:05 May 4 M.D. O



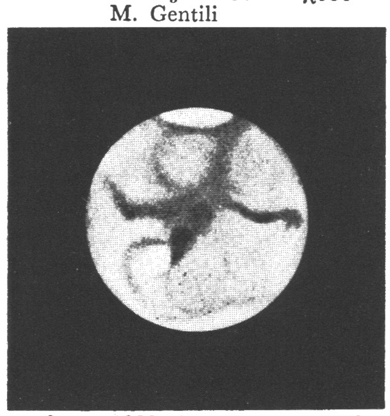
6. 1939 June 30 λ330°
M. Gentili



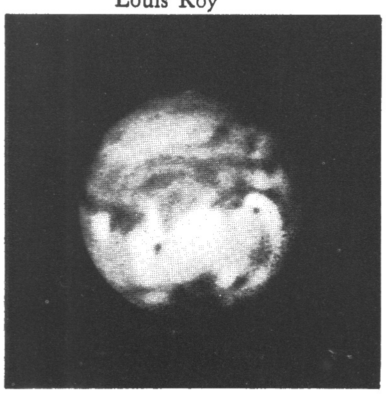
7. 1939 Aug 8 λ285°
Louis Roy



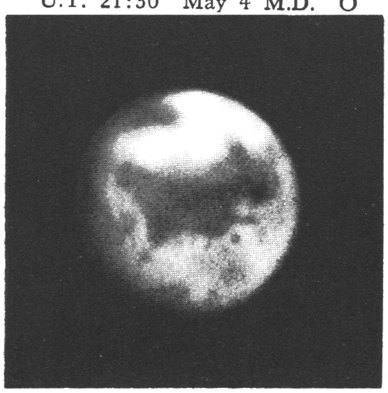
8. 1939 Aug 9 λ285°
U.T. 21:30 May 4 M.D. O



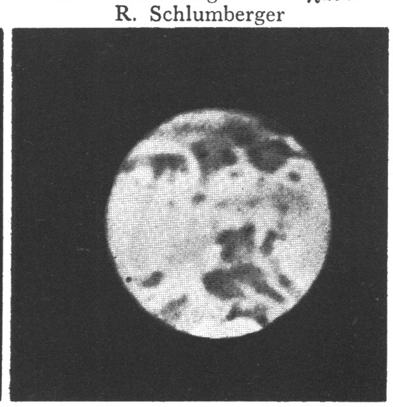
9. 1939 Aug 9 λ295°
R. Schlumberger



10. Drawing by
A. Dollfus
(From North American
Aviation Inc.)



11. 1956 Aug 29 λ36°
U.T. 23:35 O
June 3 M.D.



12. Drawing by A. Dollfus
Plate 17 Fig. b
(From Planets and Satellites
Ed. by G. P. Kuiper)

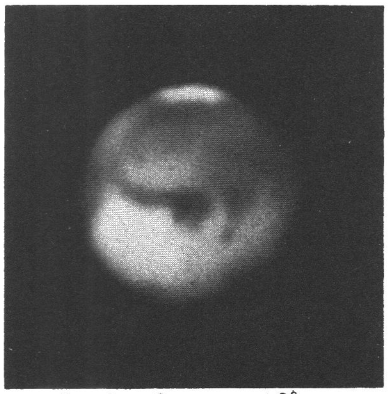
Plate XXXIX

This series of yellow photographs shows a complete circuit of the planet's disk in 1939 at intervals of about 30° in longitude. As the size of the south snow cap indicates, the season in the south was springtime, ranging from April 19 to May 9. Meanwhile in the northern hemisphere autumn was setting in and sometimes the photographs show patches of clouds or frost near the northern pole. Except for a few patches of cloud on two or three images, the sky was quite clear when these photographs were taken so that the various pictures show about the normal appearance of the dark regions. The photographs contain many details and hundreds of markings and shadings, including canals and oases, such as the tiny new oasis at the right of the tip of Syrtis Major in No. 11.

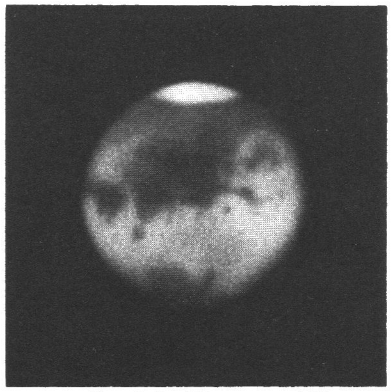
PLATE XXXIX

PHOTOGRAPHS SHOWING COMPLETE CIRCUIT OF MARS

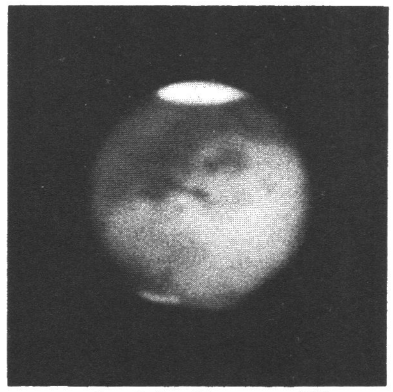
1939



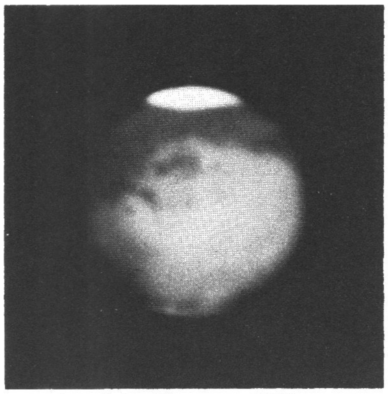
1. Aug 2 λ0°
U.T. 22:23 R



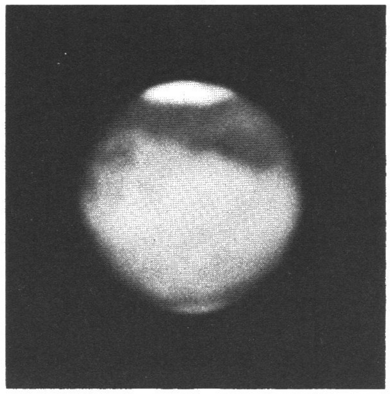
2. Julv 27 λ48°
U.T. 22:02 R



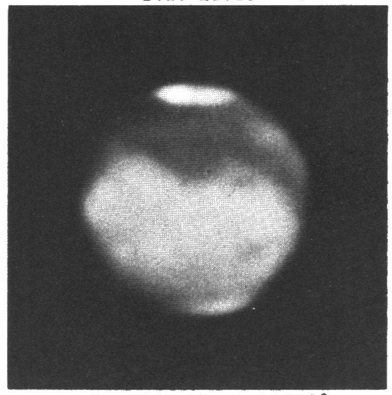
3. July 23 λ72°
U.T. 21:15 Y



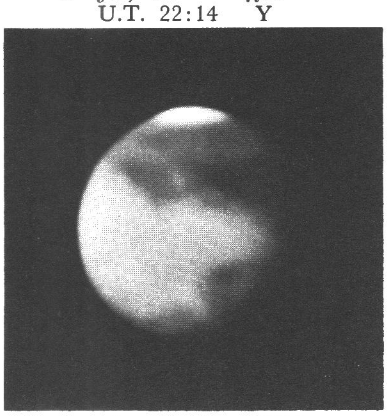
4. July 22 λ96°
U.T. 22:14 Y



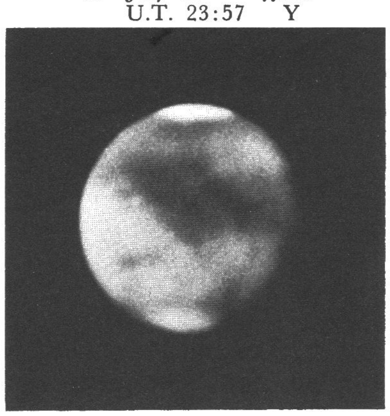
5. July 21 λ128°
U.T. 23:57 Y



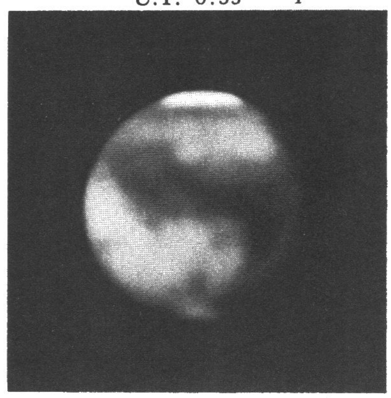
6. July 19 λ169°
U.T. 0:53 Y



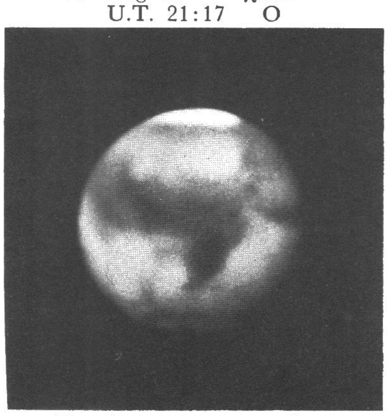
7. Aug 18 λ201°
U.T. 21:17 O



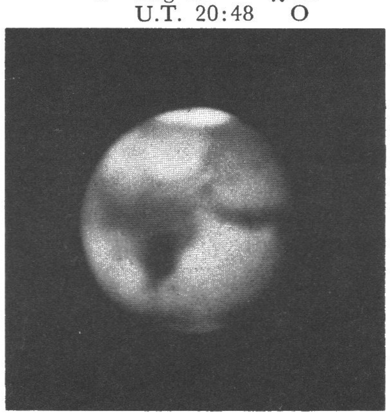
8. Aug 13 λ239°
U.T. 20:48 O



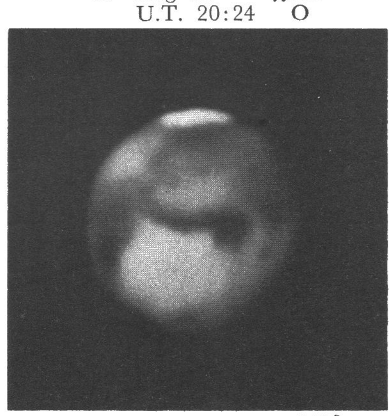
9. Aug 10 λ260°
U.T. 20:24 O



10. Aug 9 λ285°
U.T. 21:30 O



11. Aug 9 λ308°
U.T. 23:05 O



12. Aug 2 λ348°
U.T. 20:57 Y

Plate XL

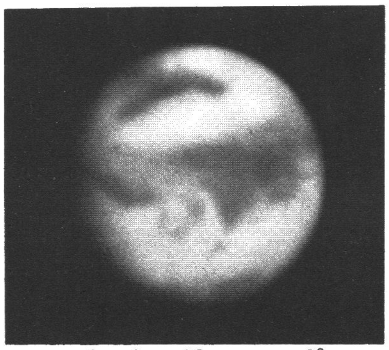
A group of eight red photographs taken at the 1956 opposition of Mars show the appearance of various faces of the planet. In some of these, clouds covered parts of the southern hemisphere and greatly altered the normal appearance of the familiar dark areas while in others, such as Nos. 4, 5 and 6, the Martian sky was nearly clear so that the dark regions appeared nearly normal. In Nos. 1, 2 and 3 a heavy cloud canopy covered much of the southern hemisphere with its lower boundary consisting of a series of semicircular curves or scallops. This canopy concealed the surface and also nearly hid the south cap. At the same time, however, an unusual dark spot stood out at a different place and with a different shape each night. (These ephemeral dark areas and their significance will be further discussed in connection with Plate XLI.)

In No. 1 it will be seen that cloud over Fastigium Aryn makes Dawes Bay almost unrecognizable while thin haze over Pandorae Fretum veils it remarkably. In No. 2 scattered clouds in this same region cause a broken appearance to Dawes Bay and to that general area. No. 7, taken before the cloudy period began, represents about the normal aspect of the Syrtis Major region as can be judged by the clarity of the south cap. No. 8 shows heavy obscuration from Sabaeus Sinus southward due to haze and clouds; even the south cap is all but concealed, while the Pandorae Fretum and the Mare Erythraeum on the right are markedly dimmed. Hellas is completely cloud covered and stands out as the brightest region on the whole disk.

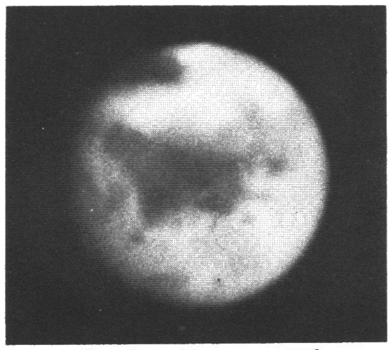
PLATE XL

SERIES SHOWING COMPLETE CIRCUIT OF MARS

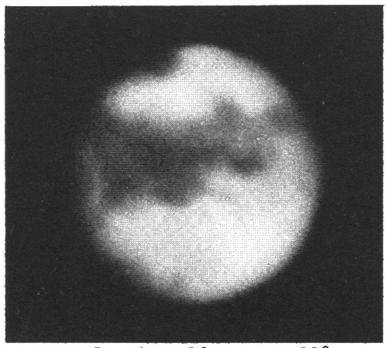
1956



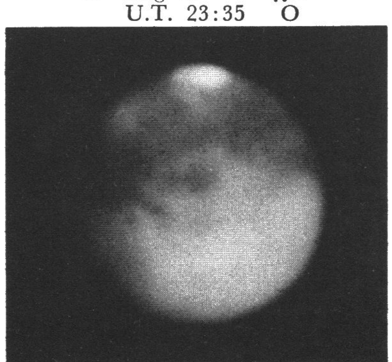
1. Aug 30 λ6°
U.T. 22:05 R



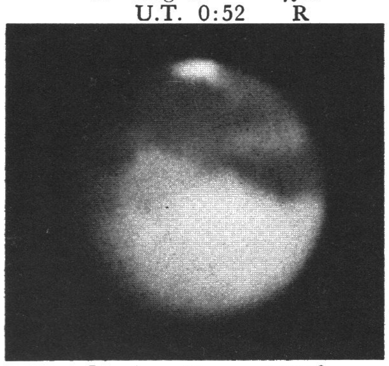
2. Aug 29 λ37°
U.T. 23:35 O



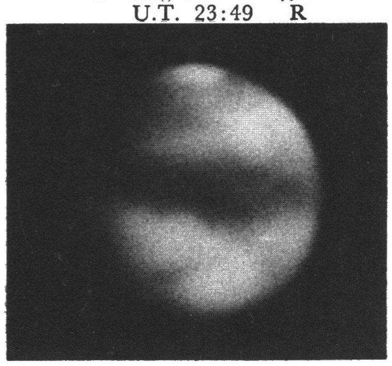
3. Aug 30 λ60°
U.T. 0:52 R



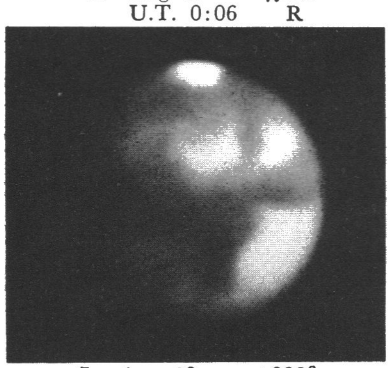
4. Aug 24 λ85°
U.T. 23:49 R



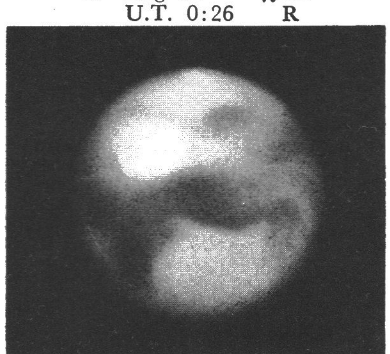
5. Aug 21 λ124°
U.T. 0:06 R



6. Aug 12 λ210°
U.T. 0:26 R



7. Aug 19 λ283°
U.T. 9:42 R



8. Sept 5 λ321°
U.T. 23:37 R

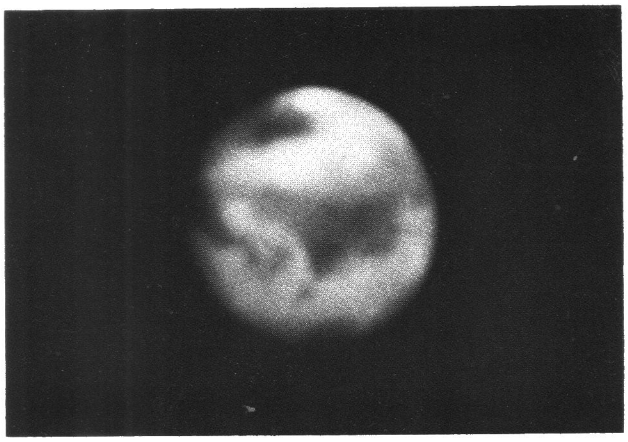
Plate XLI

The new type of markings discussed on this page are among the most interesting phenomena observed since the discovery of seasonal changes on Mars. During the height of the great storm in 1956 a series of extraordinary dark spots were observed to be associated with some of the denser masses of clouds. At first most observers did not attach any special significance to the phenomenon. Visual observers, who made reference to them, appear to have attributed the dark spots merely to areas of the surface showing through gaps between the cloud cover. However, the photograph clearly shows that the dark areas are darker than the bare surface would appear and are in fact darker than any other markings on the disk, even Sabaeus Sinus, Dawes Bay or the Mare Erythraeum.

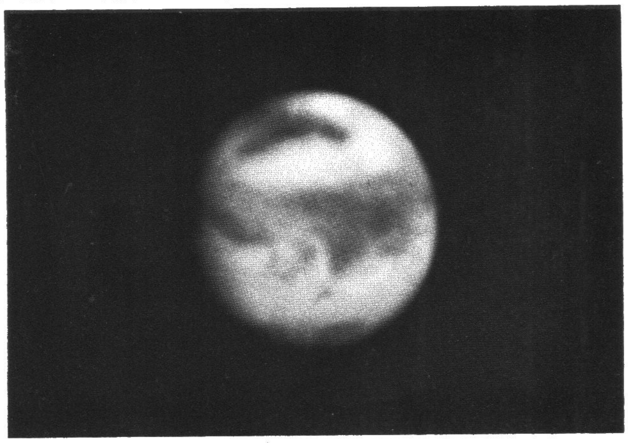
The first six photographs on the page vividly display the changing form and location of a series of such temporary dark areas in the southern part of the disk on August 29, 30 and 31 and on September 1, 3 and 5. In the first four the dark patch was distinctly darker than the rest of the disk, and therefore represented something different from ordinary markings. In photographs 5 and 6 the intensity of the temporary dark areas was not greater than it would be if they were seen between clouds. Their association with the dark areas on the other photographs, however, suggests that they too owed their existence to the same origin. The two photographs, Nos. 7 and 8, show the normal appearance of the same faces of Mars without the storm clouds and without the strange dark areas. These two photographs do not reveal any suggestion of the intense isolated dark spots in the first six images. The intimate association of the variable dark areas with storm clouds and their ephemeral nature strongly indicates that they came from something released by the clouds. The close resemblance between these dark patches and the dark collar (Plate XII) which always borders the melting polar caps suggests a like origin, the presence of water and moistened soil. The short-lived character of this series of dark spots, lasting only a matter of hours at most, does not militate against this hypothesis.

But whatever the true explanation of these temporary features of the surface, their peculiar character and close resemblance to the other dark markings stamps them of special significance.

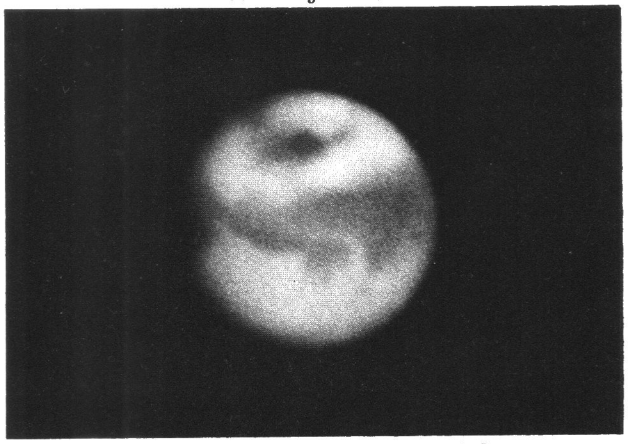
PLATE XLI
NEW TYPE TEMPORARY DARK MARKINGS



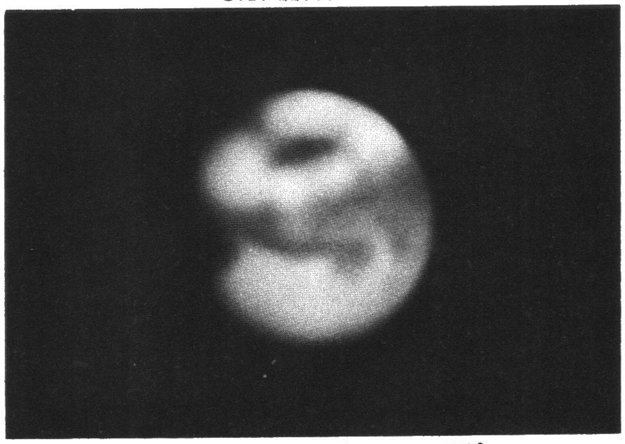
1. 1956 Aug 29 λ16°
U.T. 22:09 June 2 M.D. R



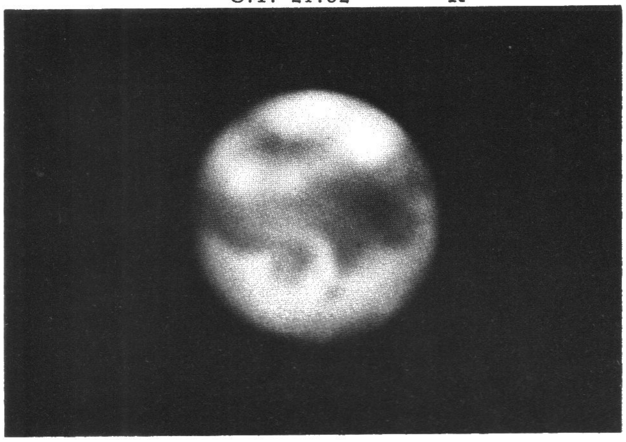
2. 1956 Aug 30 λ6°
U.T. 22:05 R



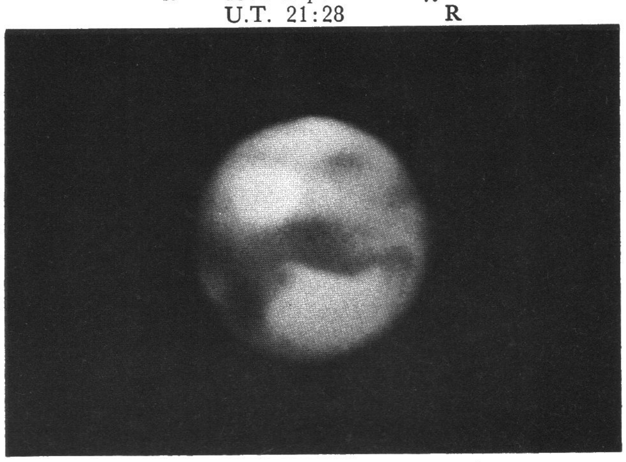
3. 1956 Aug 31 λ349°
U.T. 21:32 R



4. 1956 Sept 1 λ339°
U.T. 21:28 R

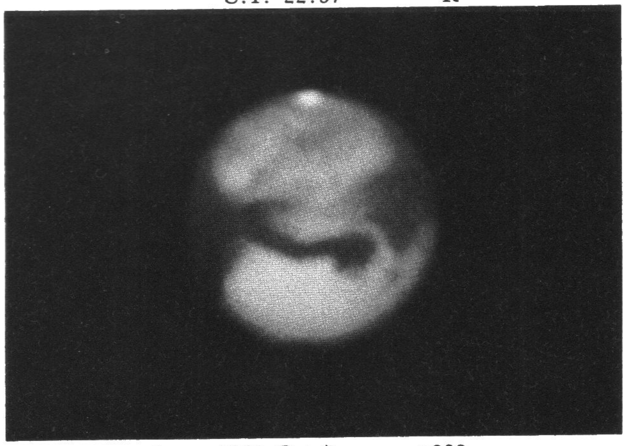


5. 1956 Sept 3 λ8°
U.T. 0:03 R



6. 1956 Sept 5 λ321°
U.T. 22:37 R

7. 1958 Nov 4 λ27°
U.T. 7:02 Aug 11 M.D. Y



8. 1941 Oct 7 λ328
U.T. 5:16 July 9 M.D. R

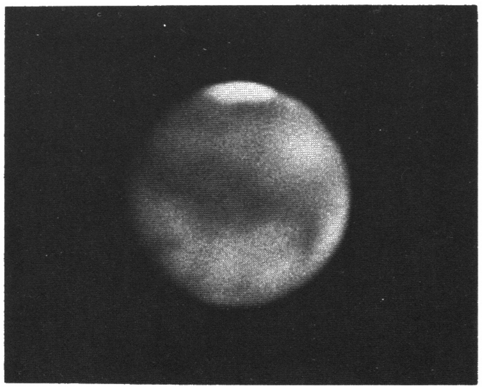
Plate XLII

Occasional photographs display markings which distort both the limb and terminator of the planet. One must, of course, exercise great caution in deciding between purely photographic effects and planetary markings. After making ample allowance for these, one finds that there are numerous occasions when real distortions of the outline of the disk occur. In many cases one first detects these distortions visually and then attempts to photograph them. Numerous examples of projections due to faint clouds standing out in the twilight arc and often separated from the visible disk have been observed, but all these have proved too faint relative to the disk to be caught in a photograph. There are, however, various other types of irregularities of the disk that have been photographed from time to time as this series shows.

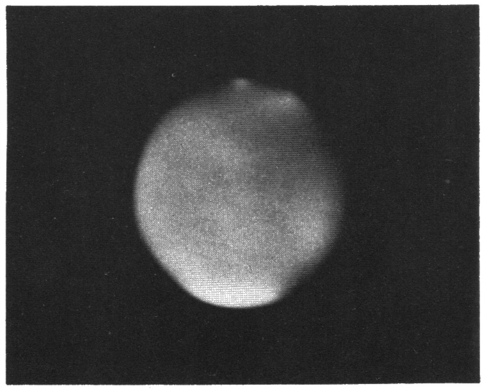
In No. 1, taken August 13, 1924, a small cloud near the south cap was seen to protrude beyond the actual limb of Mars and was caught in many photographs. In No. 2, in a series of blue photographs, a white cloud near the south pole was found to project beyond the actual terminator. On May 21, 1937 (No. 4), a bluish cloud over the Libya-Syrtis region was photographed well beyond the terminator (compare with No. 3, May 17). With due allowance for spurious photographic effects it is estimated that the height of this cloud was greater than thirty miles. In 1941, the yellow and blue photographs, shown in Nos. 5 and 6, display another type of terminator marking, a dark wedge-shaped marking which *indented* the outline of the disk. This, like all markings which distort the planet's natural outline, was only temporary. In No. 7, the blue photographs, reveal a large, dark notch on the left edge of the disk which hid the edge completely. Numerous photographs showed this dark notch in the terminator but its actual outline was invisible. In No. 8, made two nights later, there is a bright blue white cloud in the same general location, but the top of this cloud is distinctly flattened giving a straight-edge appearance.

Blue photographs, No. 9, show a small cloud to the left of the north pole which clearly extends beyond the normal outline of the disk, and by an amount considerably in excess of any reasonable allowance for photographic irradiation. This, and other similar examples, occur occasionally and represent clouds high enough to catch the sun after it has vanished over the adjacent surface. The blue photograph in No. 10 illustrates the irregular character of the terminator which occasionally occurs. Here the twilight margin of the disk is scalloped by a series of lighter and darker spots all the way from the north to the south polar cap. Obviously this condition results from the uneven reflection of the Martian atmosphere.

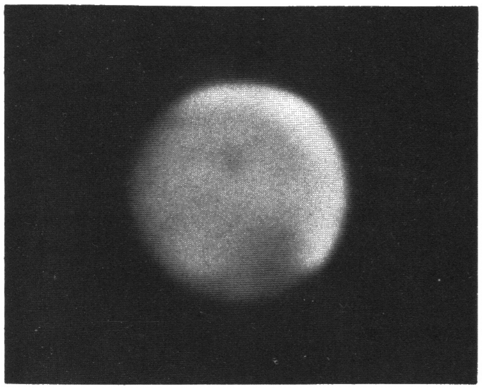
PLATE XLII
IRREGULARITIES OF LIMB AND TERMINATOR



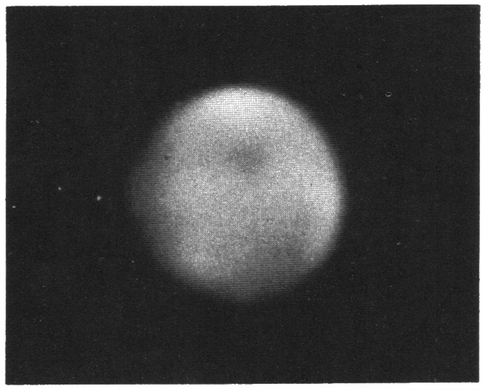
1. 1924 Aug 13
U.T. 9:34
λ250° Y
May 17 M.D.



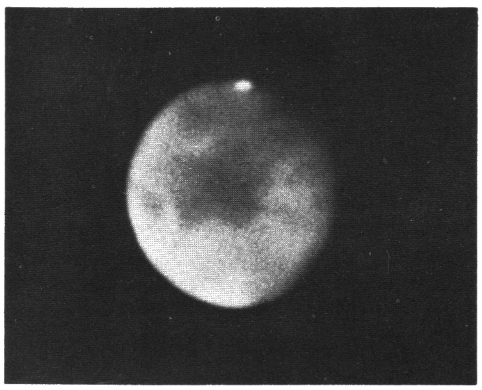
2. 1926 Nov 22
U.T. 3:16
λ82° B
Aug 16 M.D.



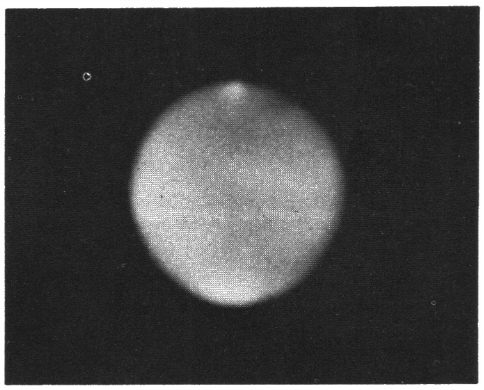
3. 1937 May 17
U.T. 8:18
λ358° B
Feb 18 M.D.



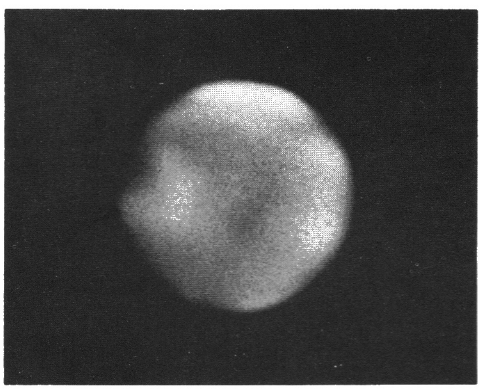
4. 1937 May 21
U.T. 9:49
λ346° B
Feb 20 M.D.



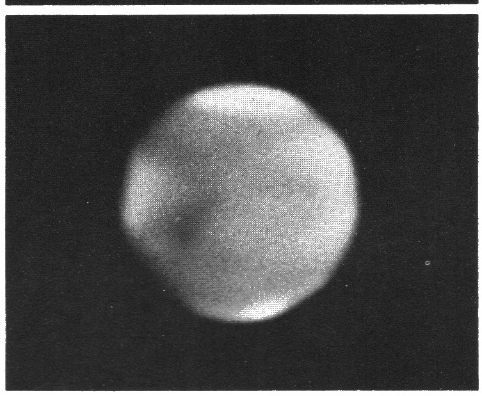
5. 1941 Nov 10
U.T. 7:07
λ58° Y
July 30 M.D.



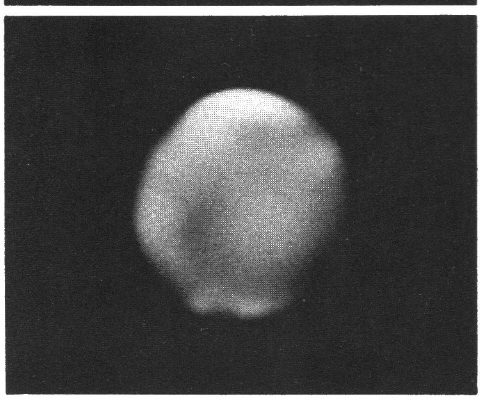
6. 1941 Nov 10
U.T. 7:30
λ62° B
July 30 M.D.



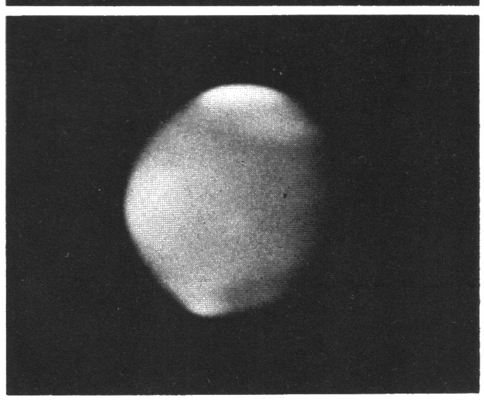
7. 1954 June 10
U.T. 22:30
λ284° B
Mar 17 M.D.



8. 1954 June 12
U.T. 1:13
λ312° B
Mar 18 M.D.



9. 1954 July 13
U.T. 20:22
λ317° B
Apr 6 M.D.



10. 1954 July 28
U.T. 19:19
λ167° B
Apr 15 M.D.

Plate XLIII

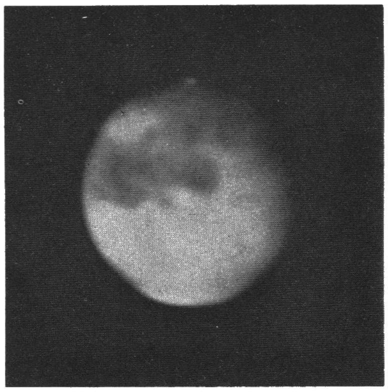
From time to time our blue photographs have recorded dark, cloud-like patches over various portions of the Martian disk which have no counterpart on the body of the planet. Since they are also very temporary, they must be atmospheric in origin. These dark clouds are not confined to any particular locality but may be observed over any portion of the disk.

The plate shows four pairs of yellow and blue photographs illustrating typical examples of this peculiar type of atmospheric phenomenon which generally consists of vaguely outlined dark areas of great extent. In each instance the yellow photographs show no unusual markings in the area while the blue photograp show strong evidence that the blue rays are heavily absorbed or trapped by the atmosphere. In extreme cases the albedo falls to only 50% of that of other blue photographs.

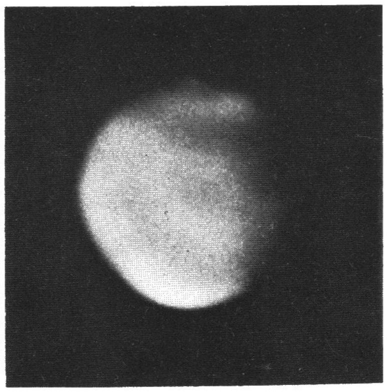
It is not easy to understand the nature of the medium which causes the depletion of the blue rays in these dark areas without revealing evidence of absorption in the yellow photographs. Perhaps widely scattered dust particles of large size, as compared to the wave lengths of light, are floating at the level of the violet layer. These might produce a yellowish surface which would reflect little of the blue rays while at the same time it would not perceptibly affect the yellow photographs.

PLATE XLIII

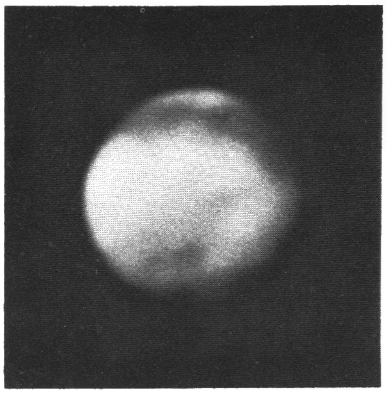
DARK CLOUDS IN THE ATMOSPHERE OF MARS



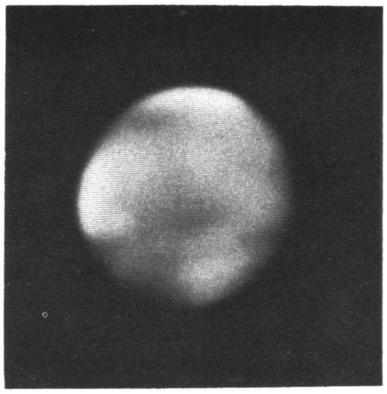
1. 1926 Nov 22 λ96°
U.T. 4:12 Y
Aug 16 M.D.



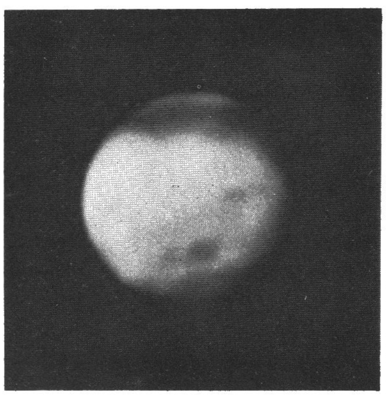
2. 1926 Nov 30 λ73°
U.T. 7:32 B
Aug 21 M.D.



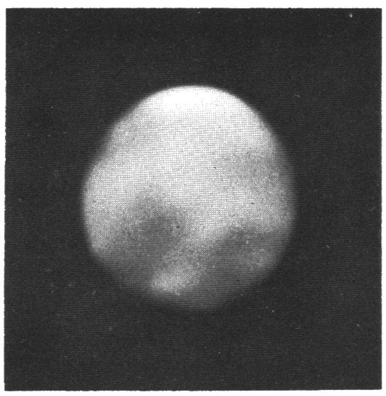
3. 1937 June 1 λ192°
U.T. 5:56 Y
Feb 26 M.D.



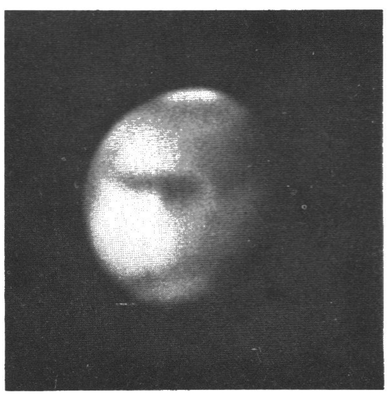
4. 1937 June 2 λ172°
U.T. 5:10 B
Feb 26 M.D.



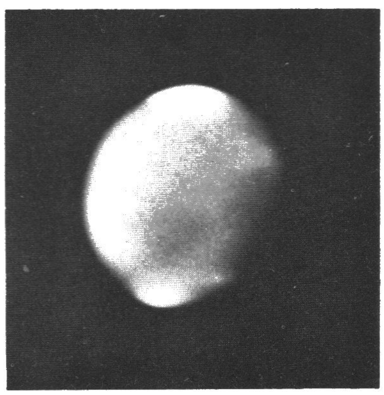
5. 1937 June 2 λ183°
U.T. 5:45 R
Feb 26 M.D.



6. 1937 June 1 λ209°
U.T. 7:05 B
Feb 26 M.D.



7. 1954 Aug 14 λ18°
U.T. 19:12 O
Apr 25 M.D.



8. 1954 Aug 15 λ28°
U.T. 21:08 B
Apr 26 M.D.

Plate XLIV

Although band-like streaks of haze have sometimes appeared faintly on our blue photographs, photographs on June 14 and July 18, 1954, surprisingly showed five or six alternate bright and dark bands across the face of the planet. This belted pattern is clear over much of the disk, but shows especially well across the large bright area on the forenoon (right) side of No. 1. This position indicates that the belted pattern is at a higher level than the bright area. On the afternoon side of the disk the pattern appears disrupted and destroyed, as if by convection in the region of the equator. Photograph No. 2 displays a similar set of belts when the same face of the planet came into view about a month later. Surface features shown in Nos. 1 and 2 include the Syrtis Major and much of the dark maria. Significantly these surface features are visible in the dark bands but are concealed by the bright belts.

"Weather bands" in Nos. 1 and 2 roughly parallel the planet's equator. In Nos. 3 and 4, the haze bands angling steeply across the planet's equator are more in line with the motions of yellow clouds (which have been observed) over the Martian tropics. These novel weather bands, or similar ones, appear faintly for several nights in our 1954 blue photographs around longitude 210°. Later in this opposition the Martian air became more or less uniformly opaque over these regions.

In 1926, when No. 3 was taken, some faint bands running at a 45° angle with the equator were detected near longitude 20°. In 1952 an excellent blue photograph near longitude 180°, obtained by Humason with the Palomar 200-inch reflector, displays striking parallel streamers across the disk tilted 135° to the equator.

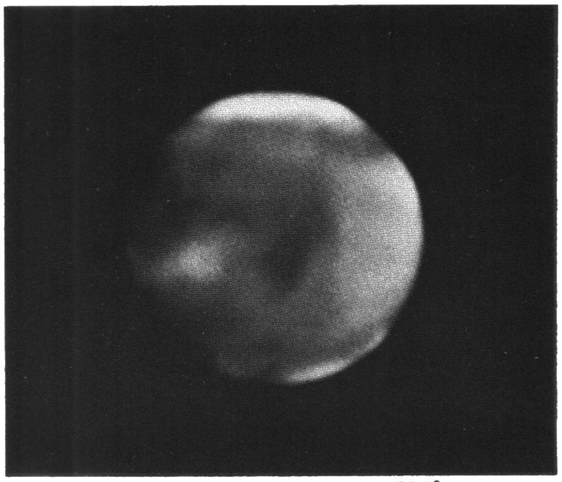
In No. 5 the blue photograph shows a unique aspect of the violet layer. All of Mars, except the polar caps, was masked by a peculiar mosaic mottle somewhat like a mackerel sky. This pattern is in strong contrast to the long streamers and weather bands exhibited in the photographs above. Whether this banded effect was present around longitude 290° we have no way of knowing because that region was inaccessible at Bloemfontein and the Flagstaff observations were then centered around 190°.

The blue photograph in No. 6 shows still another typical example of the behavior of the planet's atmosphere. The violet layer is here so opaque to blue light as to obscure all the surface except the snow cap at the south pole.

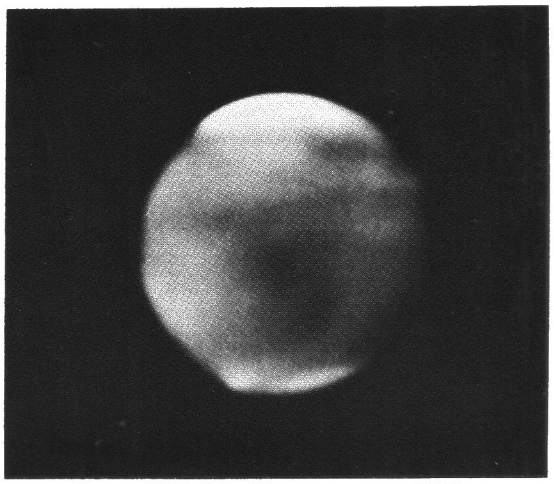
The various phenomena pointed out here, being solely atmospheric features, are readily penetrated by the longer wave lengths of light and therefore become invisible in red photographs.

PLATE XLIV

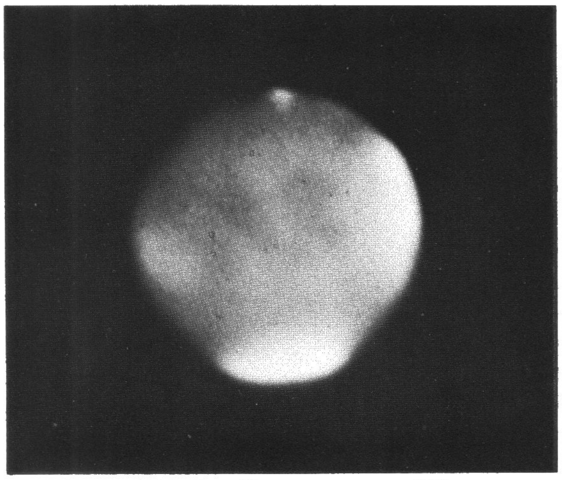
MARS FOR THE FIRST TIME REVEALS ATMOSPHERIC BELTS



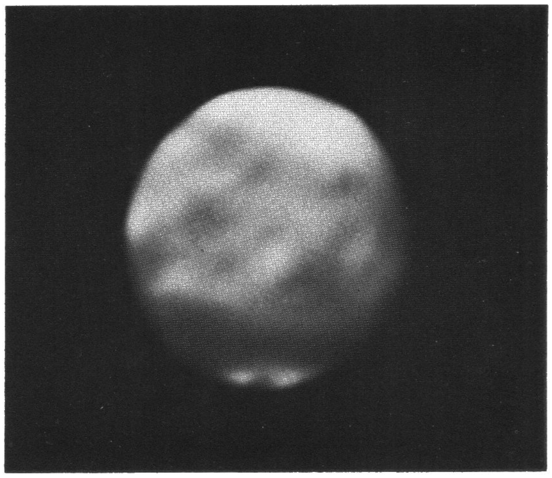
1. 1954 June 14 λ284°
U.T. 0:31 Mar 19 M.D. B



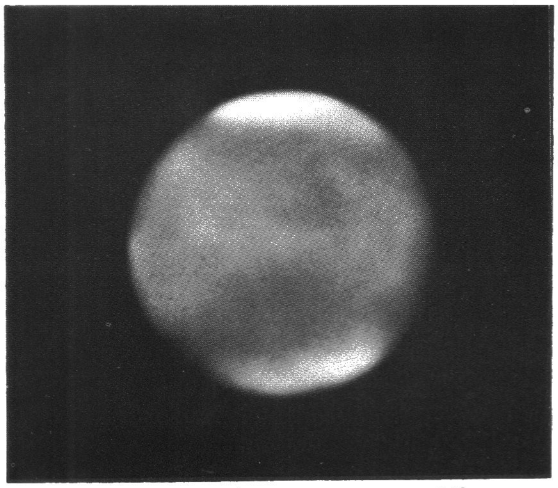
2. 1954 July 18 λ297°
U.T. 22:01 Apr 9 M.D. B



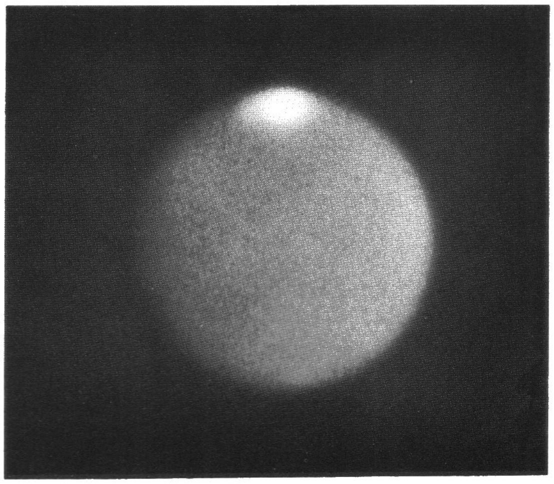
3. 1926 Oct 27 λ22°
U.T. 8:06 Aug 1 M.D. B



4. 1952 May 20 Feb 12 M.D. B
200-in. Mt. Wilson Palomar Photograph



5. 1954 July 4 λ74°
U.T. 22:53 Mar 31 M.D. B



6. 1956 Aug 23 λ75°
U.T. 23:09 May 30 M.D. B

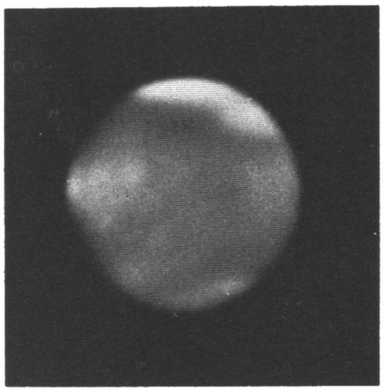
Plate XLV

Ever since 1907 our photographs of Mars around longitude 120° have shown a group of evening clouds below and to the right of Lacus Phoenicis usually for a few weeks near the time of the vernal equinox of the southern hemisphere. Not only is this a seasonal event, but more significantly it is only an afternoon affair, never appearing in Martian morning. A comparison of Nos. 1 and 2 here plainly shows this to be the case because, if present in Martian forenoon, the clouds should be visible on the right side of No. 2. Generally this group of clouds show more prominently in blue light (see Plate XXIV). In 1954 these "W" clouds were prominently displayed for about a month and have appeared also in the photographs of 1907 and 1926. It is revealed that at least three stems of the W coincide with the position of well known canals.

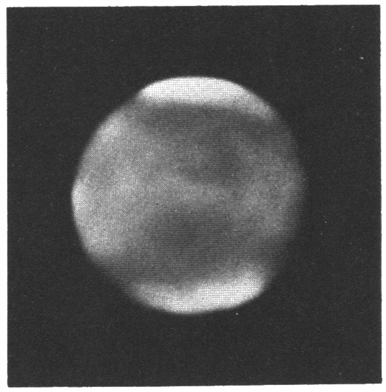
The behavior of this phenomenon strongly indicates the condensation of something in the atmosphere of the planet rather than a deposit on the surface. Another conspicuous event in the history of this region occurs about two months after the clouds have disappeared. For example, on August 24 and 25, 1939, seemingly as an aftermath of the clouds, the canals and oases in the areas take on a very extraordinary darkening. (Compare Nos. 3 with 4, 5 with 6, and 7 with 8.) In each case the right-hand picture shows an abnormal darkening of the area formerly occupied by the clouds, including the canals, Eumenides and Ulysses and the oases with which they connect down to Ferentinae L. The darkening appears of the same type as the other dark regions undergo when the polar caps melt. This suggests a common cause. And if the darkening of the other regions of the planet results from moisture released by the polar cap, by the same token it seems reasonable to assume that the darkening of these features may have come from moisture released by these clouds.

PLATE XLV

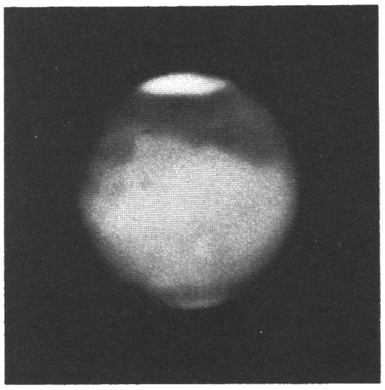
UNUSUAL DEVELOPMENTS OF CANALS AND OASES IN THE SOUTHERN THARSIS REGION WHERE EARLIER "W" CLOUDS EXISTED.



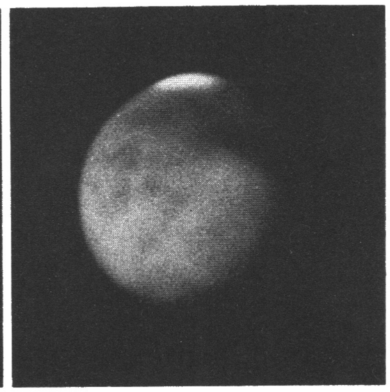
1. 1954 June 26 λ147°
U.T. 23:01 B
Mar 27 M.D.



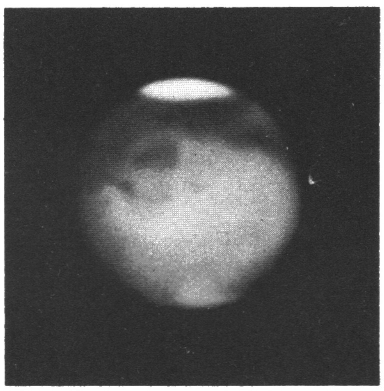
2. 1954 July 4 λ74°
U.T. 22:53 B
Mar 31 M.D.



3. 1939 July 21 λ127°
U.T. 23:45 Y
Apr 21 M.D.

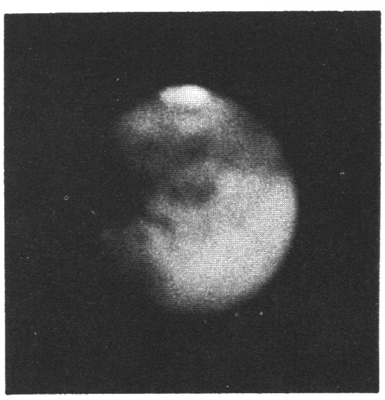


4. 1939 Aug 24 λ128°
U.T. 20:00 R
May 13 M.D.

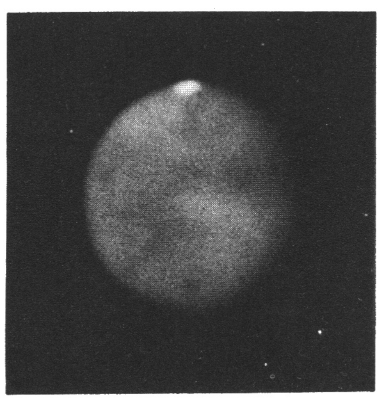


5. 1939 July 20 λ104°
U.T. 21:35 Y
Apr 20 M.D.

6. 1939 Aug 25 λ112°
U.T. 19:34 O
May 14 M.D.



7. 1956 Aug 27 λ78°
U.T. 0:35 R
May 31 M.D.



8. 1956 Sept 24 λ144°
U.T. 22:38 Y
June 20 M.D.

Plate XLVI

This group of yellow and red photographs displays striking examples of sudden darkening of certain bright desert regions of Mars. See also Plates XIX and XLI. Photographs in the top row exhibit the planet's normal appearance around the Solis Lacus and Thaumasia regions, while those below reveal unprecedented darkenings during the extraordinary cloud period in September, 1956.

Photographs Nos. 2, 3, and 4 show that as late as August 29 the clouds had not descended as low as the latitude of Thaumasia and Solis Lacus. The Jeffers' photograph, however, reveals that on September 8, when the clouds invaded the Thaumasia region around the Solis Lacus, an elliptical dark area of great intensity appeared over the Nectar, extending downward in the vicinity of the Coryx and beyond. The Flagstaff photograph by Hess discloses that the dark area, which had been present the night before, on September 9 was a little higher up (southward) and showed a long, curved extension into the southern Thaumasia. This extension of the dark area bounded the left edge of a vast cloud which concealed the Solis Lacus and all the northern Thaumasia, including the Tithonius, Lucus Tithonius, and the Daemon.

No. 7 shows the main dark spot centered over the Nectar on September 12, and topped by two dark arms, one extending across the southern Thaumasia and the lower branch running downward across the Agatho-Daemon into the upper part of the Ophir region and thence off to the left below the Aurora Sinus. In addition, in No. 7, an intense dark spot that is not present in the normal photographs of this region stands out in the Mare Erythraeum above the Aurora Sinus.

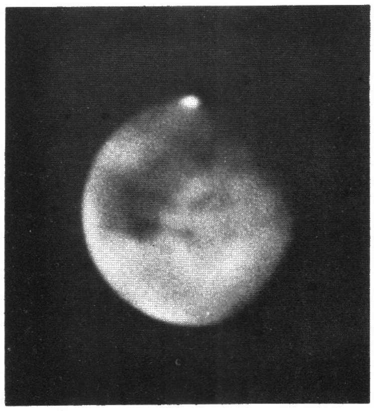
After September 12 the Solis Lacus region passed off the disk of the planet and was no longer available for study until early in October. On September 16, however, an anomalous somber area was observed in the desert region of Eden (not illustrated here) about 18 degrees northeast of Fastigium Aryn, in a place never before seen to be occupied by a dark area.

On October 1, when the longitude of the Solis Lacus turned into our view at Bloemfontein, the region appeared nearly normal again (see No. 8) except that the southern Thaumasia seemed perhaps a little more somber than in the normal pictures in the top row.

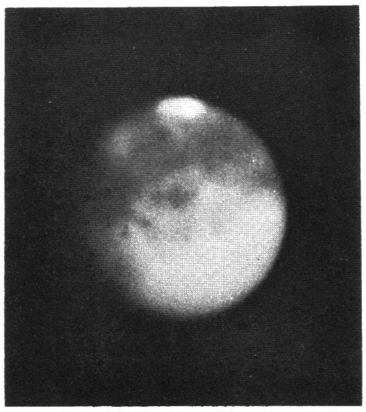
At no time in our 55-year photographic record of the planet do we find any previous hint of a darkening of these areas and no such visual observations has been recorded during nearly a century. Thus such darkenings must be rare indeed.

PLATE XLVI

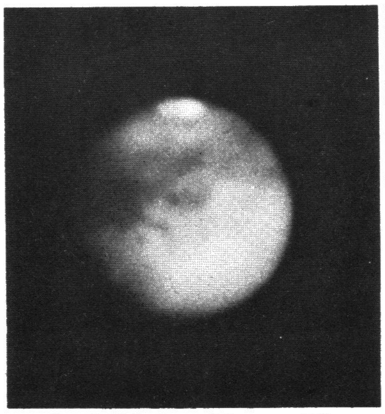
DARKENING OF BRIGHT DESERT AREAS AT THE BORDER OF DENSE CLOUDS



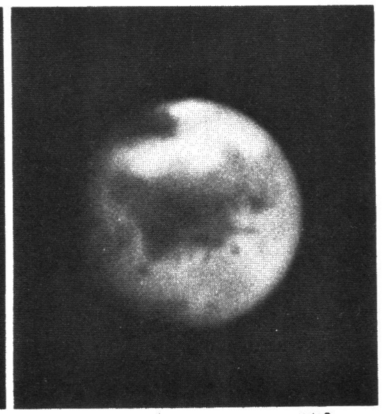
1. 1941 Nov 4 λ82° U.T. 5:22 Y July 28 M.D.



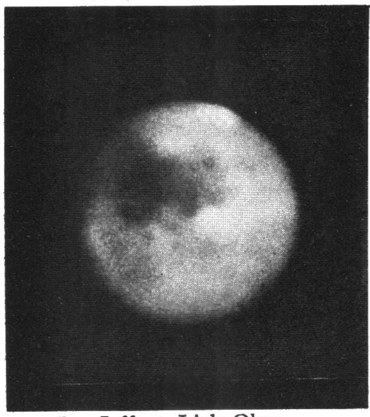
2. 1956 Aug 24 λ84° U.T. 23:48 R May 31 M.D.



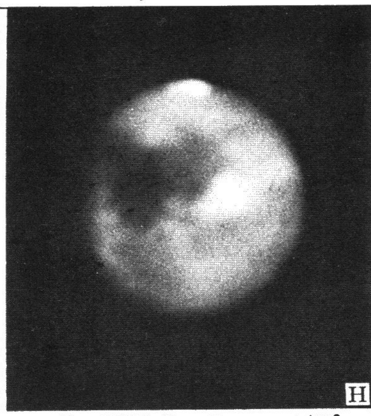
3. 1956 Aug 27 λ78° U.T. 0:35 R June 1 M.D.



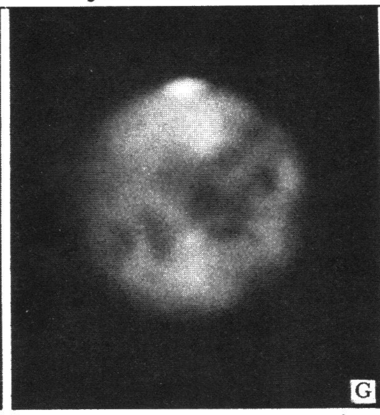
4. 1956 Aug 29 λ37° U.T. 23:35 O June 2-3 M.D.



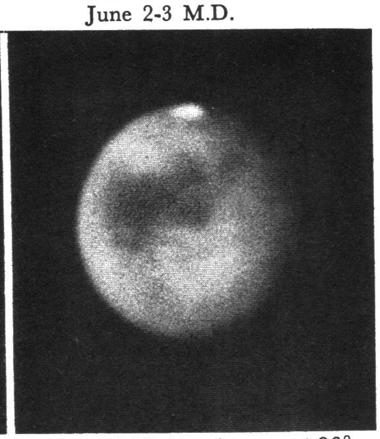
5. Jeffers, Lick Obsy. 1956 Sep 8 λ74° U.T. 7:33 Y June 9 M.D.



6. 1956 Sep 9 λ73° U.T. 6:53 Y June 10 M.D.



7. 1956 Sep 12 λ37° U.T. 7:24 R June 12 M.D.



8. 1956 Oct 1 λ86° U.T. 22:18 R June 25 M.D.

On August 29 and 30, 1956, our visual observations at Bloemfontein revealed, almost hour by hour, that the cloud front which subsequently obscured the south snow cap was moving from left to right across the disk. Whether the clouds in south latitude 30° – 35° moved likewise was not certain because of the many cloud areas present and because of rapid changes from day to day. If we assume, however, that the clouds in the latitude of the Solis Lacus were also moving from left to right, as seems fairly certain, then all these temporary dark areas, occurred along the *following* boundaries of the cloud areas. This would mean that as the clouds passed across the planet some desert areas darkened enormously, to such an extent that they rivaled the intensity of the darkest features on Mars. The whole process took place in a day or two at most.

The intimate association between these transistory darkenings of the Martian desert and the equally changeable cloud areas, marks a new and significant event in Martian observations. At least, this was our first observation of large-scale darkenings in the desert regions which could not possibly be connected with former oases, canal systems, or older dark areas.

The uniqueness of these ephemeral dark areas, their close association with the extraordinarily dense cloud formations prevalent in 1956, and the fact that the photographs provided the means to trace out the behavior of these phenomena in considerable detail, seem to justify the special attention given them here.

Plate XLVII

Plate XLVII is published here as a direct photographic reproduction in order to provide each reader with the best possible opportunity to distinguish the fine lines and to judge their reality for himself. It is suggested that a number of discriminating observers independently plot the positions of lines for several of the photographs and then compare their results.

Doubtless the latitude of the observer has had much to do with seeing the canals. Since all the closest approaches of the planet occur near perihelion when the declination of Mars is far south of our equator, averaging around $-26^{\circ}\!.5$, it is evident that for stations in high northern latitudes such as in England, Germany and northern France the zenith distance of Mars may well be 75° or more. Common experience in astronomical observation has shown the great difficulty in making any kind of trustworthy observations on celestial bodies which rise, even at culmination, only a matter of 15° above the horizon. Observations of Mars made under such difficult conditions are hardly comparable with those made near the zenith. It is for this reason that one or more Lowell astronomers observed Mars in Chile in 1907 and in Bloemfontein, South Africa, in 1939, 1954 and 1956.

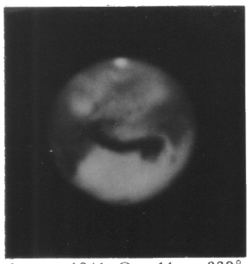
History of the canal problem shows that every skilled observer who goes to the best available site for his observations has had no great difficulty of seeing and convincing himself of the reality of the canals. I am not aware of a single exception to this. Even some with small telescopes, when they journeyed to suitable places in the proper latitudes of the Earth, have met with convincing success.

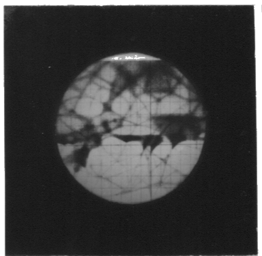
Photographs have recorded traces of so many of the canals and oases in the same position, form, and character as drawn on the Lowell and Lick Observatory maps of the planet, that they should remove all doubt of the reality of this class of markings. The photographs disprove a recent contention that the canals are essentially real surface features and exist only by virtue of being merely divisions between areas of unequal shading and therefore appear solely as contrast effects. Inspection of many examples of such photographs do not reveal a single case where the surface brightness on the two sides of a canal shows any visible difference. Another objection to their linear aspect has been the contention that the canals can be resolved into a series of disconnected spots, and are not truly line-like in character. However, the authors of this idea have as basis of their argument used the Thoth-Nepenthes system as it has appeared in recent years after it had become one of the grosser features of the disk. Our observations and photographs also readily reveal that this marking has become very complicated and can readily be resolved into various components. It no longer can be truly termed a canal. Around 1907 it was a faint and difficult canal seen by only the most meticulous observer and did not show the slightest condensation or spot throughout its length from the tip of Aquae Calidae to the Lucus Moeris near the Syrtis.

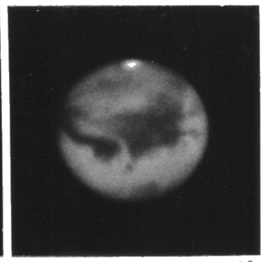
While there is room for difference of opinion as to the interpretation of the canals, their existence as true markings on the planet has been clearly established. They are revealed by our photographs and have been seen by nearly all skilled observers who have studied the planet with powerful instruments. The Lick astronomers, Schaeberle, Campbell, Barnard and Hussey of the early observers and Trumpler more recently, all drew the canals. In recent years, too, Pettit and Richardson at Mt. Wilson have observed them.

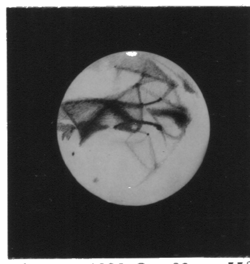
PLATE XLVII

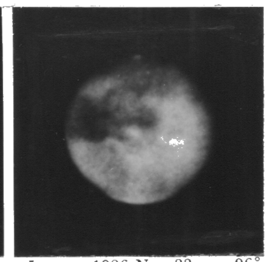
PHOTO EVIDENCE OF LINES (CANALS) ON MARS.

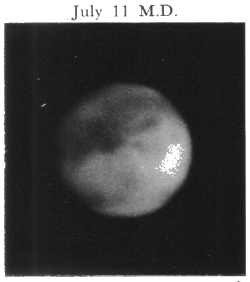

1. 1941 Oct 11 338° July 11 M.D.

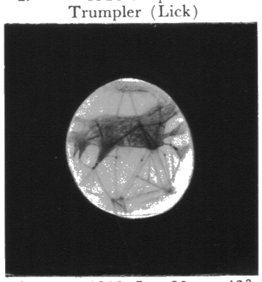

2. 1924 Map 340° Trumpler (Lick)


3. 1941 Oct 7 19° July 9 M.D.

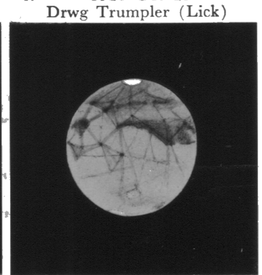

4. 1926 Oct 23 55° Drwg Trumpler (Lick)

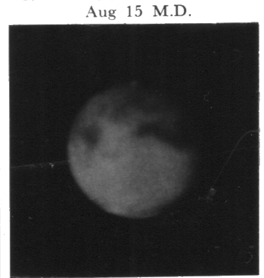

5. 1926 Nov 22 96° Aug 15 M.D.

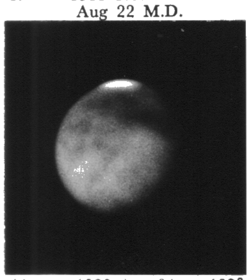

6. 1911 Nov 15 65° Aug 22 M.D.

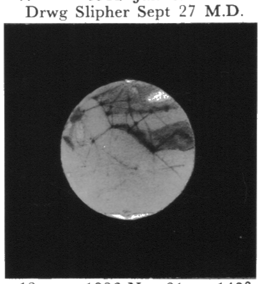

7. 1912 Jan 23 43° Drwg Slipher Sept 27 M.D.

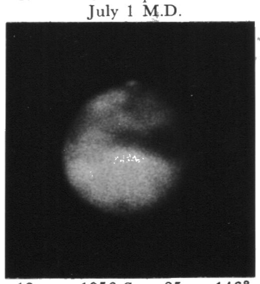

8. 1941 Sept 25 116° July 1 M.D.

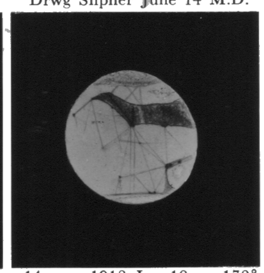

9. 1924 Sept 26 137° Drwg Slipher June 14 M.D.

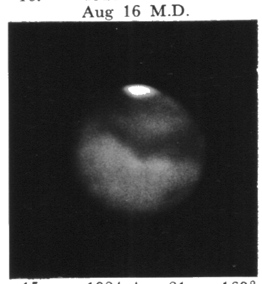

10. 1926 Nov 22 135° Aug 16 M.D.

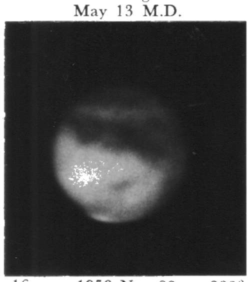

11. 1939 Aug 24 128° May 13 M.D.

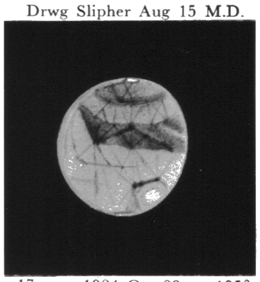

12. 1926 Nov 21 142° Drwg Slipher Aug 15 M.D.

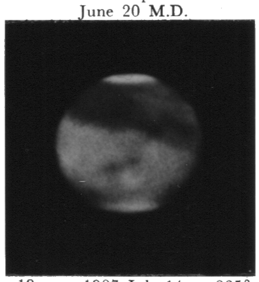

13. 1956 Sept 25 146° June 20 M.D.

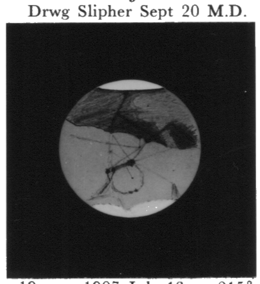

14. 1912 Jan 10 170° Drwg Slipher Sept 20 M.D.

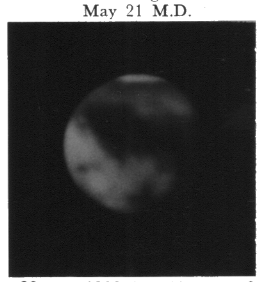

15. 1924 Aug 21 168° May 21 M.D.

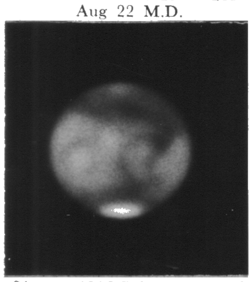

16. 1958 Nov 23 203° Aug 22 M.D.

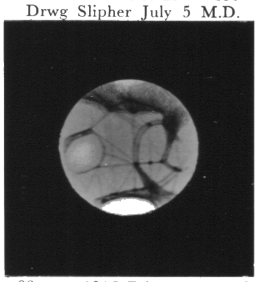

17. 1924 Oct 28 195° Drwg Slipher July 5 M.D.

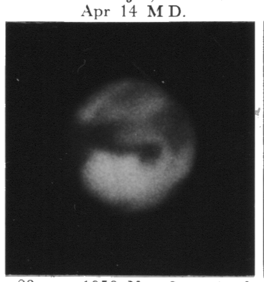

18. 1907 July 14 205° Apr 14 M D.

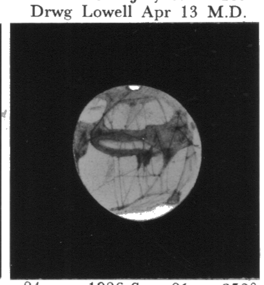

19. 1907 July 13 215° Drwg Lowell Apr 13 M.D.

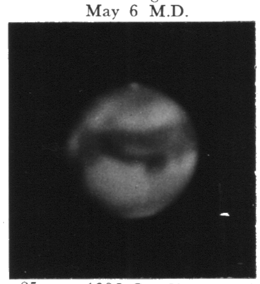

20. 1939 Aug 13 250° May 6 M.D.

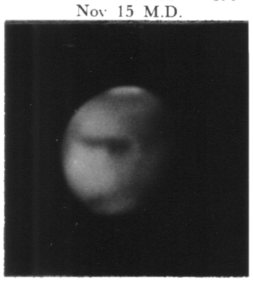

21. 1916 Feb 12 250° Nov 15 M.D.

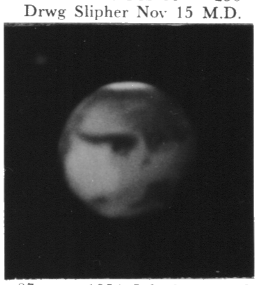

22. 1916 Feb 11 250° Drwg Slipher Nov 15 M.D.

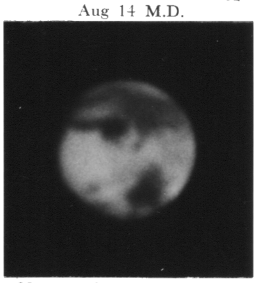

23 1958 Nov 9 342° Aug 14 M.D.

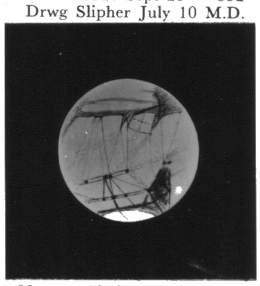

24. 1926 Sept 21 352° Drwg Slipher July 10 M.D.


25. 1926 Oct 27 338° Aug 1 M.D.


26. 1954 Aug 14 9° Apr 25 M.D.


27. 1954 July 9 6° Apr 4 M.D.


28. 1937 May 14 6° Feb 16 M.D.


29. 1916 Mar 3 2° Drwg Lowell Nov 24 M.D.

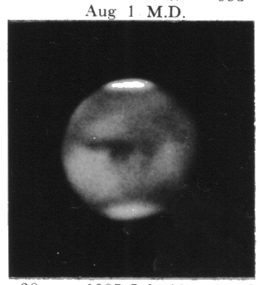

30. 1907 July 28 16° Apr 22 M.D.

Plate XLVIII

Numerous terrestrial experiments and monochromatic photographs have been made at the Lowell Observatory during the last fifty years in a special effort to obtain significant data and empirical results to aid in understanding the phenomena recorded in the Mars observations.

Consequently, when the extraordinary storm clouds appeared over the southern hemisphere of Mars late in August 1956, the phenomenon recalled our photographs of a unique dust pall which invaded northern Arizona in April, 1935 from the "dust bowl" of western Kansas and Texas. The red and violet photographs of the San Francisco Peaks shown in pictures Nos. 2 and 3 were made through a maximum of 10 miles of atmosphere. In comparison the Mars photographs, examples of which are shown in Plate XLI, Nos. 1 to 6, reveal that the denser Martian clouds (shown as bright areas) were more opaque than the terrestrial dust pall but that the haze veil over Mars outside the heavy clouds was only about one-third to one-half as opaque as the terrestrial dust pall. This difference is not surprising, however, considering the fact that the equivalent of nearly two atmospheres was involved in the terrestrial photograph. The most surprising feature of the terrestrial photographs is the fact that the mountains were about equally obscured in both the red and violet photographs. Based on the law of molecular or small-particle scattering, the short-wave violet photograph should have exhibited much greater scattering and opacity. The fact that it did not indicates that the scattering medium consisted of comparatively large solid particles rather than of gaseous molecules. In contrast to these terrestrial photographs the "violet" layer on Mars is generally transparent to yellow and red rays but opaque to blue rays.

During June, July and up to August 26, 1956, the blue photographs showed that the Martian air was virtually opaque. By August 29 when the dust storm nearly reached maximum and extended over almost all of the southern hemisphere of Mars (see Nos. 1 to 6, Plate XLI), considerable blue clearing set in for the first time during the opposition (see Nos. 10, 11 and 12, Plate XXX). This fact strongly militates against the theory that dust particles account for the "violet layer" on Mars, a theory recently stressed by Goody.[1]

Nos. 4 and 5 are red and ultra-violet photographs, respectively, of the San Francisco Peaks taken when our air was clear and from a distance equivalent to about three terrestrial atmospheres. In the ultra-violet photograph, the snow-capped mountains show conspicuously through this long air-path, showing conclusively that surfaces of high albedo in violet light, such as snow, could be similarly photographed through several terrestrial atmospheres. This seems to account for the snow caps showing in blue and violet photographs (Plate XIV), even near the margin of the disk, when are areas of low albedo, 5 to 16 percent, vanish completely. The fact that the "blue" cap is always of the same size and form and contains the same identical markings as those recorded in the yellow and red images, seems to clearly demonstrate that the cap recorded in the blue photographs is in fact on the true surface of the planet just as it must be in case of the yellow and red photographs. It is therefore unnecessary to postulate cloud canopies[2] to explain these results.

Photographs Nos. 6 and 7, October 19, 1925, show the San Francisco Peaks in yellow light (Wallace yellow filter) and in blue light through a tri-blue (Ilford) filter respectively, at an airline distance up to 10 miles, and when our air was normally transparent. The blue photographs not only show the snow capped summits clearly, but also, contrary to results on Mars, show the forested and the yellowish grass-covered areas. A companion photograph of the Peaks made at the same time with ultra-violet light of wave lengths from 3700 to 4000A (Wratten No. 18 filter, not reproduced here) reveals about the same degree of opacity in this distance (7-10 miles) through the Earth's atmosphere as that generally recorded in the ordinary blue pictures taken of Mars. The snow areas higher up are quite clearly revealed. These and numerous other comparative photographs of terrestrial landscapes have indicated that the Martian atmosphere is generally about two to three times as opaque to blue rays as is the Earth's atmosphere.

Photograph No. 8 is to demonstrate the wide differences in the reflectivity of snow according to its age and stage of melting. From photometric measures of the south snow cap in our yellow photographs at the extremely favorable opposition in 1924, it was found that the albedo of the cap was only about 0.55 to 0.60 as compared to 0.80 to 0.85 for fresh snow. This is probably caused by the age of the snow cap with consequent effects of melting and accumulation of dust. One patch in No. 8 is only slightly brighter than the adjacent dead grass, and can be contrasted with snow in the intermediate stage which is also shown in 8. Thus the albedo of the polar caps of Mars during the summer melting period is about as to be expected of snow of a similar age and condition.

Still other photographs of snow patches (see arrows) in the "painted desert" northeast of Flagstaff (Nos. 9 and 10) revealed that snow areas on the red sandstone and ochre soil showed no brighter in red photographs (9) than did the adjacent rocks and soil. This empirical result explains why the snow caps appear no brighter than the reddish deserts of Mars in the red photographs (No. 9 in Plate IX). Selective reflection is the contributing factor in equalizing the albedo of the Martian snow cap and the desert areas of the planet in the red photographs. These and other experimental color-filter photographs indicate that the surface of the "painted desert" closely resembles the ochre-red deserts of Mars in albedo and color.

In Nos. 11 and 12 are sunlit red (Wratten 29F filter) and blue (WR, 47A filter) photographs of five assorted colored rocks displayed against a solid background of comparatively fresh snow. As these monochromatic photographs strikingly show, the ochre and reddish rocks, selected because their color simulated the deserts of Mars, appear as bright as the snow in red photographs while the gray or neutral-colored specimens remained almost unchanged. In blue light (No. 12), however, the same specimens show about equally and nearly black compared to snow. (The white specks on rocks are magnesium carbonate placed there for control purposes.) This experiment makes it clearly apparent why reflection spectra of Mars would be far brighter in the red than in the blue region. Many spectrograms of the planet from 1903 to more recent times have consistently recorded this difference in brightness between the red and blue. Also, the spectrum[3] of the snow cap, which shows much brighter in the blue than in the red, is in complete agreement with these photographic results.

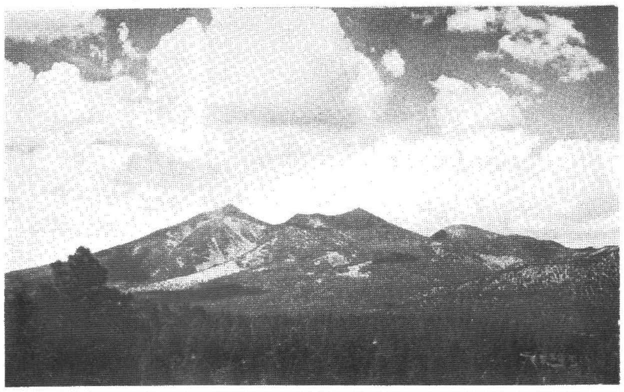
Failure to recognize the overwhelming influence of selective reflection on spectrograms of Mars has led certain spectroscopists to erroneously attribute the low albedo in blue to absorption by NO_2 in the Martian atmosphere. But spectrometric observations in the infrared by Sinton at Lowell showed no evidence of the presence of NO_2 or N_2O_4. His results further revealed that if NO_2 were present in excess of one part in a million, it would be evident in his observations.

These experimental studies strongly indicate: (1) That dust in the Martian atmosphere has little or nothing to do with the violet layer; (2) that the Martian air is far more opaque to blue rays than is the Earth's; (3) that the snow cap shows in blue images because of its high albedo in short wave lengths, when the Martian atmosphere is opaque to the dark surface markings; (4) that the age of the snow cap greatly reduces its albedo; (5) that in red photographs snow is no brighter than the reddish-ochre desert areas; (6) that red rocks and soils of our deserts give photographic results closely resembling the photographs of Mars.

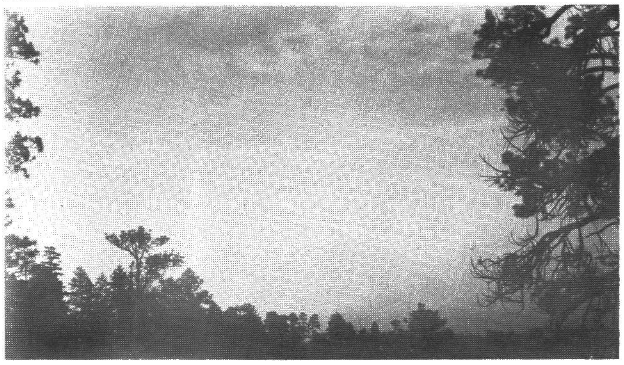
[1,2,3]Wright, W. H., Lick Bull., No. 366, p. 60, 1925.

PLATE XLVIII

PHOTOGRAPHIC STUDIES OF THE BEHAVIOR OF THE TERRESTRIAL ATMOSPHERE WITH SPECIAL REFERENCE TO BLUE CLEARING, THE SNOW CAPS, AND OTHER PHENOMENA OF THE MARTIAN ATMOSPHERE



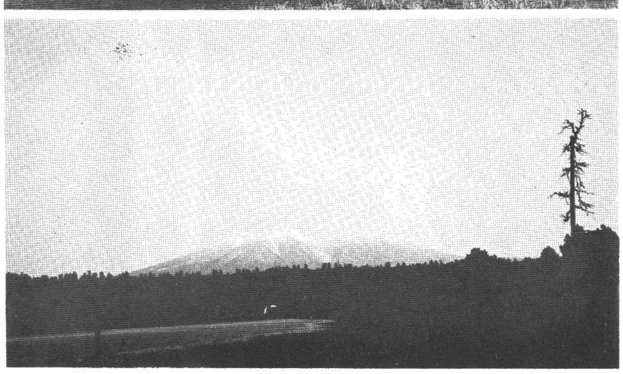
1. RED



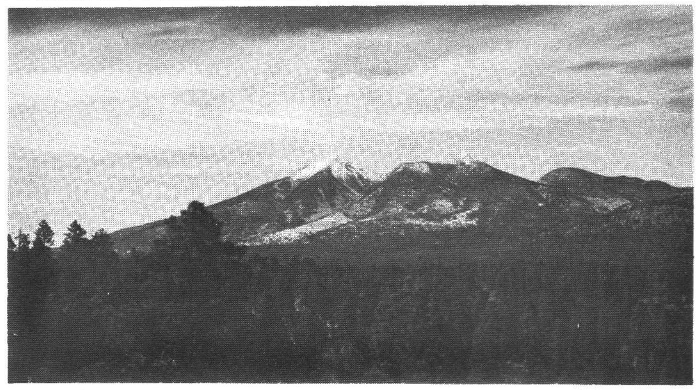
2. RED

3. VIOLET

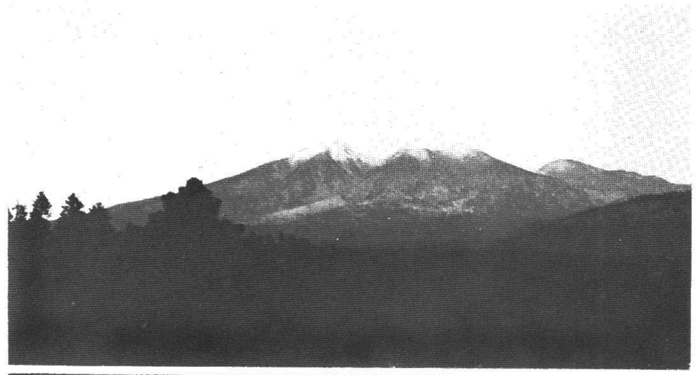
4. RED



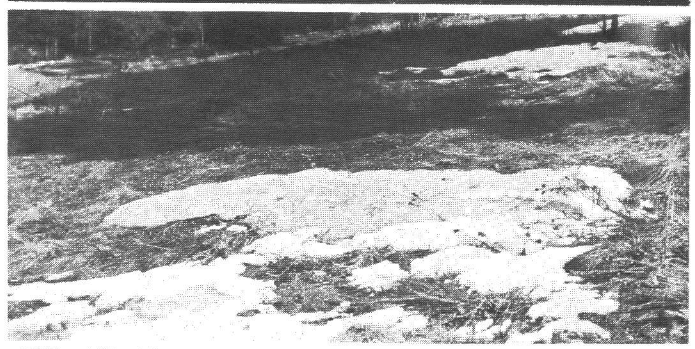
5. ULTRA-VIOLET



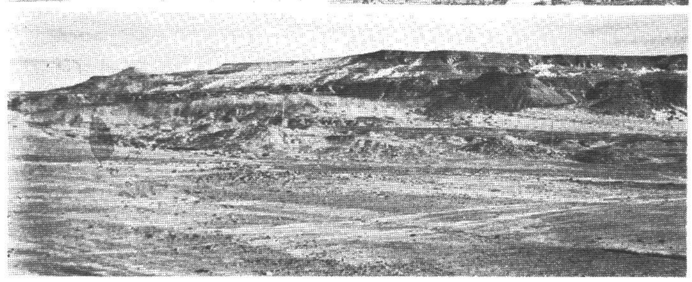
6. YELLOW



7. BLUE

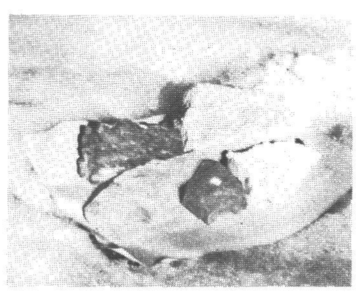


8.

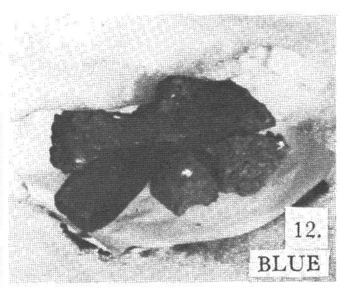


9. RED

10. BLUE



11. RED



12. BLUE

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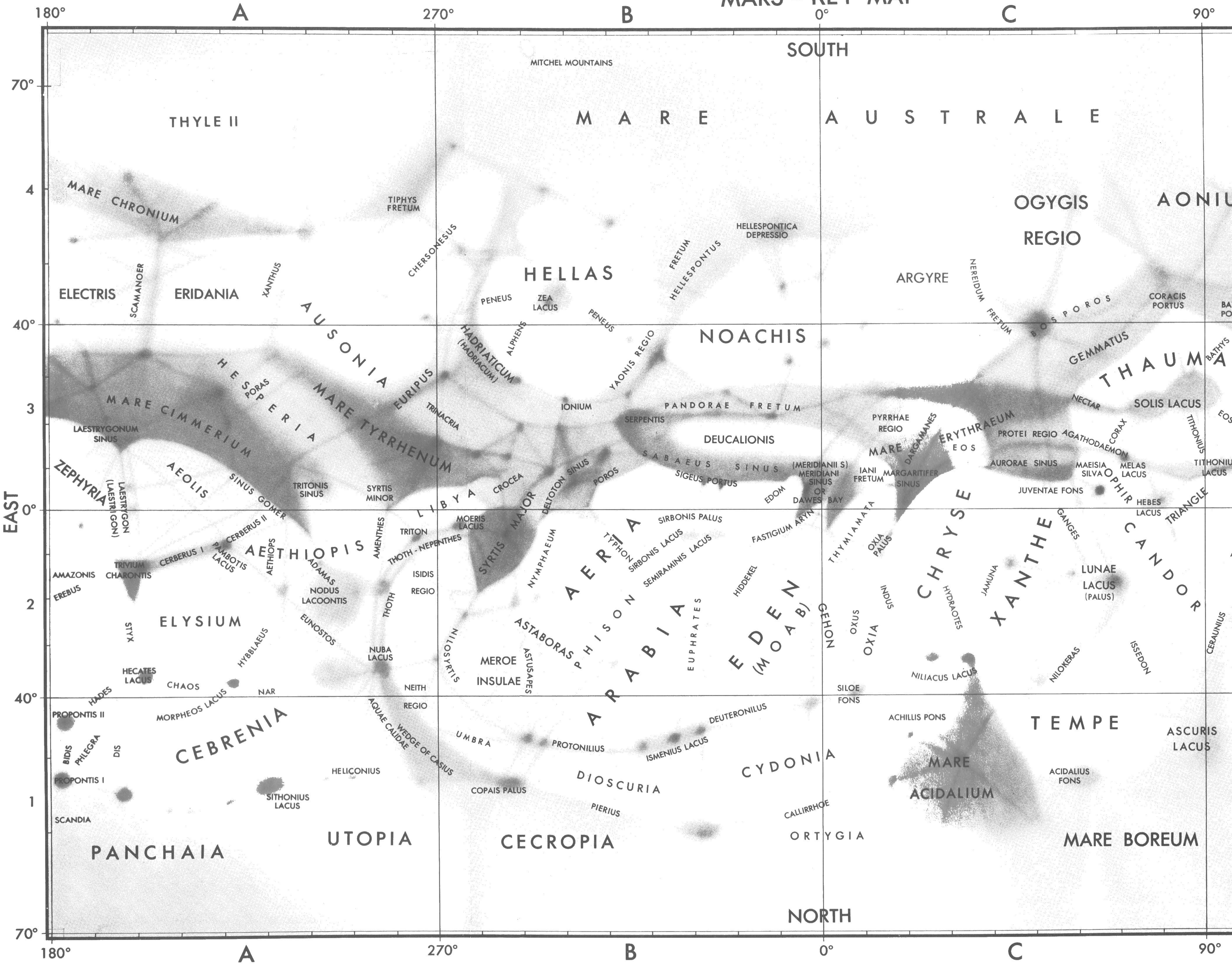
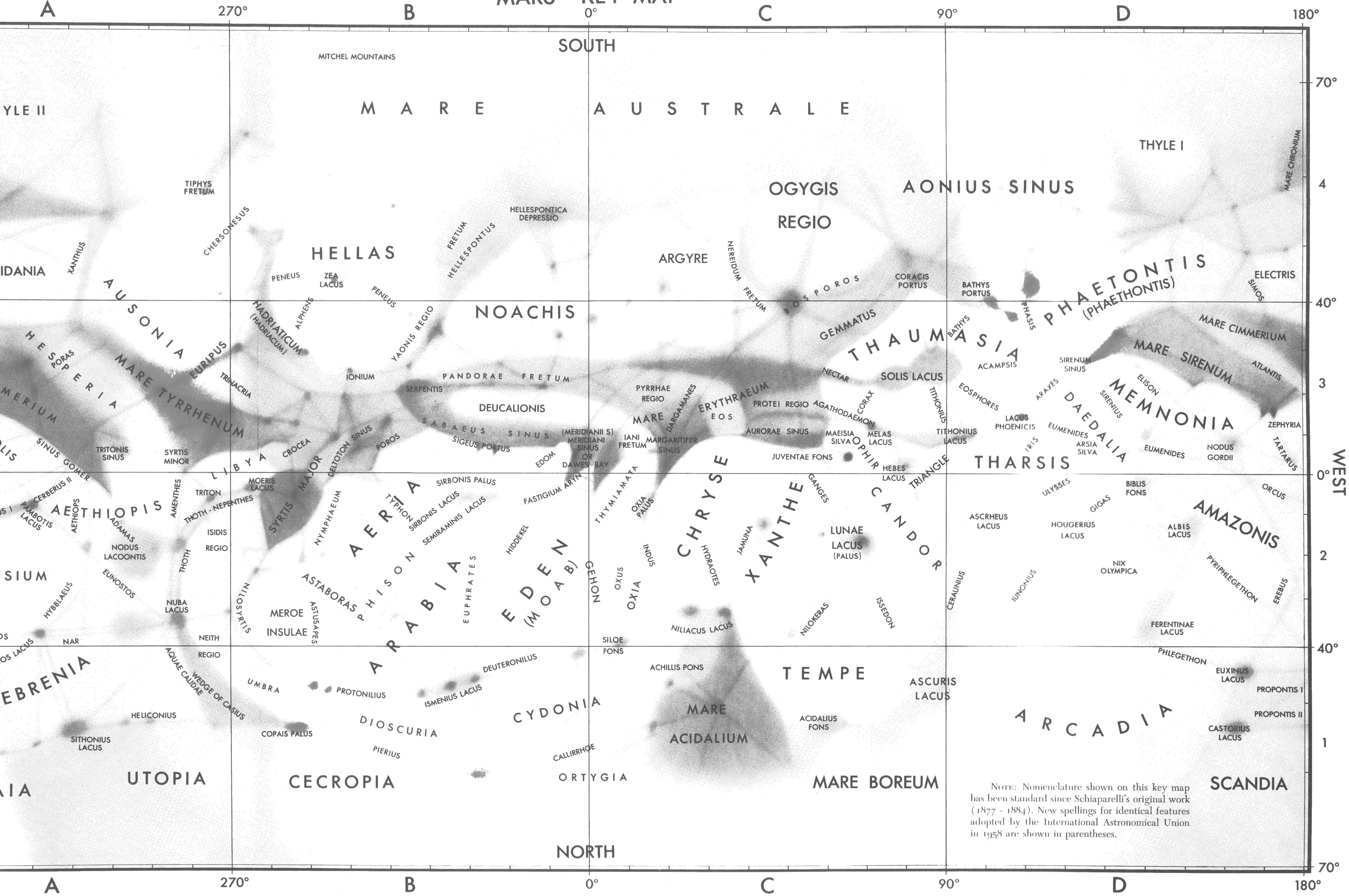
- Adamas A2
- Aethiopis A2
- Aethiops A2
- Agathodaemon C3
- Amenthes A2
- Aquae Calidae A1
- Argyre I C4
- Arsia Silva D3
- Astaboras B2
- Astusapes B2
- Atlantis D3
- Aurora Sinus C3
- Bathys D3
- Biblis Fons D2
- Casius A1
- Cimmerium A3
- Corax C3
- Daemone C3
- Dawes Bay B3
- Deucalion B3
- Deucalionis R B3
- Eden B2
- Elysium A2
- Eumenides D3
- Eunostos A2
- Euphrates B2
- Fastigium Aryn B2
- Ferentinae Lucus D2
- Gehon C2
- Hadriaticum B3
- Hellas B4
- Hellespontus B4
- Hesperia Strait A3
- Hydraotes C2
- Ionium B3
- Isidis-Libya A2
- Isidis Regio A2
- Jamuna Canal C2
- Lacus Phoenicis D3
- Laestrygon A3
- Laestrygonum Sinus A3
- Libya A2
- Libya-Syrtis B2
- Lucus Moeris B2
- Maeisia Silva C3
- Mare Acidalium C1
- Mare Australe B4 C4
- Mare Cimmerium A3
- Mare Erythraeum C3
- Mare Sirenum D3
- Mare Tyrrhenum A3
- Margaritifer Sinus C3
- Meridiani Sinus B3
- Mts. of Mitchel B4
- Nectar C3
- Nepenthes-Thoth A2
- Noachis B3
- Nodus Lacoontis A2
- Nuba Lacus A2
- Ophir C3
- Pandorae Fretum B3
- Phoenicis Lacus D3
- Poras A3
- Sabaeus Sinus B3
- Sinus Gomer A3
- Solis Lacus C3
- Syrtis Major B2
- Tharsis D3
- Thaumasia C3
- Thoth A2
- Thoth-Nepenthes A2
- Thoth-Nepenthes-Triton A2
- Tithonius C3
- Tithonius Lacus C3
- Ulysses D2

MARS – KEY MAP



MARS – KEY MAP



NOTE: Nomenclature shown on this key map has been standard since Schiaparelli's original work (1877 - 1884). New spellings for identical features adopted by the International Astronomical Union in 1958 are shown in parentheses.