THE EVIDENCE FOR LIFE ON MARS: NATURE AND UNCERTAINTIES

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For decades life on Mars has been a topic of considerable speculation. In the scientific press the most imaginative has been the "canali" of Schiaparelli which evolved in the hands of Lowell into an intricate system of irrigation canals bearing water from the polar caps to the thirsty Martians in the temperate and equatorial regions. This has been largely discredited, and the current scientific consensus is that if life does exist on Mars it is in the form of simple organisms such as lichens, small plants, bacteria, etc. However the possibility of even such low forms of life is very exciting, and acts as the major spur to much contemporary work in exobiology. Mars is the centerpiece of the exobiology program.

A discussion of the present evidence for life on Mars must necessarily be subjective, since the observational data are not definitive. The bias which I will introduce is a conservative one. I believe that every effort should be made to find an abiological explanation for each observation, and for their sum. Furthermore the lack of a reasonable abiological explanation should <u>not</u> be used to argue for life, if there is not at the same time a reasonable biological explanation for the datum. The understandable human desire to find a Martian biota should not prejudice one to make positive statements which are not justified by the facts.

In this presentation I will defer a discussion of the question of Martian life till the second half, reserving the first half for a review of the current knowledge of the Martian environment. This will serve as a background not only for my subsequent comments but also for other papers in this series.

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The Physical Environment

The simplest starting point is a picture of the planet. In figure 1 several of its characteristic features are displayed. The overall color of the planet is reddish and is dominated by the bright areas, concentrated in the northern hemisphere (at the bottom of the picture since this was taken on an astronomical telescope). The very dark area near the center of the disc is Syrtis Major, the darkest area on the planet. It is mainly south of the equator, but its tip extends over into the northern hemisphere. At the top of the picture is a bright, white spot -- the south polar cap, at the other pole is a semi-transparent white haze.

The important physical characteristics are summarized in Table 1. In preparing this table, and in the ensuing discussion, I have relied heavily on the excellent book by de Vaucouleurs, Physics of the Planet Mars (de Vaucouleurs, 1954). Despite its age it is a most valuable component of a Martian library. I have also drawn greatly from Mars, The Photographic Story, by Slipher (Slipher, 1962).

The mass of Mars has been determined precisely by measuring the orbits of its two satellites Phobos and Deimos. Both are very small and their diameters have been estimated from their observed brightness, assuming their reflecting power to be similar to their parent planet, to be 23 - 30 and 11 - 14 km respectively. Their orbital radii are respectively 9,340 and 23,500 km, and Phobos is distinguished by having its orbital period, 7 hours 39 minutes, shorter than the rotational period of the parent.

The equatorial and polar diameters of Mars are somewhat controversial. The most recent determinations, by Dollfus using a birefringent micrometer (Dollfus, 1962) give D_{eq} = 6790 km and D_{pol} = 6710 km, the optical flattening, $(D_{eq} - D_{pol})/D_{eq}$, then being .0117. He observed no

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difference in diameters for red and blue light. Previous work gave values within 100 km of these, but W. H. Wright and others detected a difference in the diameters for red and blue light. Wright was the first to detect this phenomenon, where the diameter is 2 - 3 percent greater in the blue than in the red. This was interpreted as an atmospheric effect, suggesting there is a blue scattering and/or absorbing haze layer at an altitude of about 60 - 100 km. Some investigators have suggested the effect is merely due to greater limb darkening in the red than in the blue, and Dollfus' most recent work reveals no difference at all. The variety of opinions on the subject testify to the difficulty of obtaining the diameter of a planet which possesses an appreciable atmosphere. While the diameter is not of importance to exobiologists, any information about the transmission properties of the atmosphere which accrue from the diameter studies will be of direct and immediate value.

The actual value is also of some significance when considering the possible presence of a magnetic field. For an equatorial diameter < 6670 km an iron core seems improbable whereas for higher values its existence is quite probable (MacDonald, 1963). Since it is believed that an iron core is necessary for a planet to possess a magnetic field, this in turn is dependent on the actual diameter.

Another interesting question related to the observed diameters is also discussed by MacDonald (MacDonald, 1963). All observers are in agreement in reporting the optical flattening as .012. However the flattening calculated from the satellite orbits is only .0051 assuming the planet is in isostatic equilibrium. If the rocks on Mars have a strength 10x our rocks then a flattening of .007 could be sustained. Greater strengths are improbable so that the high optical flattening can evidently not reflect the true effect but must be due to an atmospheric effect. Such an explanation has been proposed by Kuiper, and it appears reasonable although it requires further experimental confirmation.

The orbital characteristics differ somewhat from Earth's. The mean distance from the Sun is 228 x 10^6 km compared to 150 x 10^6 km for Earth, resulting in a mean solar constant at Mars which is 0. 43 that at Earth. In the course of a Martian year of 687 days the planet travels an elliptic orbit with an aphelion of 248 x 10^6 km and a perihelion of 208 x 10^6 km. The seasons are accordingly unequal in length, and since the tilt of the rotational axis is such that summer in the southern hemisphere occurs near perihelion this season is shorter and hotter than summer in the northern hemisphere. The seasons however are essentially similar to ours since the inclinations of the rotational axes of Mars and Earth to their respective orbital planes are similar.

The times when we can observe Mars at its closest approach to Earth are called oppositions and occur 25 to 26 months apart. Because of the ellipticity of Mars' orbit all oppositions are not equally favorable. The last most favorable opposition was in 1956, the next won't occur until 1971. In 1965 the apparent size of the Martian disc will be only 14. 0" compared with 24. 9" in 1971. A further consequence of the ellipticity is that phenomena occuring during the southern summer and northern winter have been studied best since at the corresponding oppositions Mars is the closest to the Earth.

A parameter of great importance to life is the temperature. It is generally assumed that any Martian life will use water as a solvent and the acceptable temperature regime will be dictated by this fact. The most extensive measurements were carried out at Lowell Observatory between 1926 and 1943 by Lampland. His data have been reduced and collated by Gifford (Gifford, 1956) who has presented the data in graphical form. In figure 2 is shown a set of noon-time isotherms obtained for summer in the southern hemisphere. More refined temperature measurements have been made by Sinton and Strong (Sinton and Strong, 1960) using the 200 inch telescope at Mt. Palomar. In general they agree well with Lampland, although some differences such as the diurnal temperature variation are present. The variation found by Sinton and Strong for a point on the equator is given in figure 3 and reveals a daily temperature variation amplitude of about 100° C. Both studies indicate that for the equatorial regions the temperatures for the dark areas are ca 8° higher than for the bright areas, roughly what one would expect from the difference in albedos.

An apparent discrepancy is present in the earlier data. Figure 4 shows the temperature along the noon meridian for the different seasons and does not reveal the expected effect of the ellipticity of the orbit. The solar constant at perihelion is 1.42 that at aphelion so that the noon temperature at the equator should be ca 27° C higher during southern summer than during southern winter. This effect has been noted by Pettit and Nicholson (Pettit, 1961) but is not evident in Gifford's isotherms, suggesting there may be a rather large internal error in Lampland's data. Since the measurements of Sinton and Strong cover only a very limited time period Lampland's data must still be used for many Mars studies. However the inconsistency between the expected and observed seasonal temperatures at the equator suggests they be used with some reservation.

Typical of the problems encountered is the determination of the atmospheric pressure. Many investigators have measured the brightness and polarization of the reflected visible radiation as a function of phase angle, wavelength and position on the disc. After certain assumptions were made pressures between 25 and 125 mb (1 bar = 10^{6} dynes cm^{-2} = 0.987 atmo) were calculated. The assumptions are so gross that de Vaucouleurs (p. 124 of Physics of the Planet Mars) characterizes most of the results as "doubtful", "rejected" and "illusory". The results that have been regarded with the greatest favor were obtained by Dollfus (Dollfus, 1951) and fell between 80 and 90 mb. However even these are highly uncertain since among his assumptions are 1) there is no wavelength dependence of the [redacted] polarization of the surface reflected light, all of the observed wavelength dependence being due to atmospheric scattering, 2) all of the scattering by the atmosphere is molecular, with no contribution from particles, 3) there is no true absorption by the atmosphere. Unfortunately the observed brightness and polarization involve the interaction of many independent variables and the data are not sufficient to permit a determination of any one of them without invoking certain assumptions such as these. This introduces a large uncertainty into the derived results.

Quite recently a new approach has been used to find the atmospheric pressure. Kaplan et al (Kaplan et al, 1964) have measured the intensities of two CO_2 bands and used them to obtain the CO_2 abundance and the total pressure. From the equivalent width of the $5\nu_3$ band at 8700A, figure 5, they directly obtained an abundance, since for very weak lines the pressure has no effect. The CO_2 abundance was found to be 55 ± 20 m atmo. Then the total pressure was found using this, the intensity of the 2.06μ band, and the laboratory obtained curve of the dependence of the equivalent width on the product of the abundance and the effective pressure, figure 6. The derived pressure was 25 ± 15 mb. This method is inherently more direct than the others used and its result should be given the greatest weight.

The atmospheric pressure is of critical importance to engineers changed with the responsibility of placing a soft-landed biological laboratory on the Mars' surface. It is also of direct interest to exobiologists since it limits the temperature range within which water can exist in the liquid state. The phase curve of water, figure 7, is such that if the surface pressure is 25 mb liquid water can exist only in the range 0 - 20° C. As the pressure is lowered the upper temperature limit is also reduced, being only 8° C for a pressure of 11 mb. This discussion applies strictly to pure water; for aqueous solutions of electrolytes the upper temperature will be raised and the lower one decreased. Yet the point is still valid, and will be particularly germane if the uptake of water by Martian organisms (assuming they exist) occurs only during those brief periods when water is present on the surface in the liquid phase.

Of the various gases suspected to be present in the Martian atmosphere only CO_2 and H_2O have been detected. The former was first noted by Kuiper, and, as mentioned previously, is currently estimated to have an abundance of 55 $\pm$ 20 m atmo. The study of Kaplan et al, which gave this number together with the low value of the pressure, was actually designed to detect H_2O vapor. Observations were made when the relative velocity of Mars to Earth was at a maximum, ca 14 km sec^{-1}. This gives any absorption lines on Mars a Doppler shift, so that their centers are displaced from the centers of the corresponding telluric lines. The one photographic plate which they succeeded in obtaining showed H_2O lines displaced by the calculated amount, figure 8. From the intensities of these weak lines and the pressure of 25 $\pm$ 15 mb they derived an H_2O abundance, averaged over the disc, of 14 $\pm$ 7 microns of precipitable H_2O. If the H_2O is assumed to have a constant mixing ratio in the Martian atmosphere this abundance corresponds to a partial pressure at the surface of 5.2×10^{-4} mb. The relative humidity at 273° K would be 8.5×10^{-5}, and at 300° K 1.4×10^{-5}. It should be emphasized that these are averages and that in localized areas considerably higher values may occur. In the same study they looked without success for Doppler shifted O_2 lines and concluded that the upper limit on the O_2 abundance is 70 cm atmo. Other components have not been discovered, but they must be present since the CO_2 forms only a fraction, estimated to be 7 - 60 percent of the total pressure. By analogy with the Earth it is considered that the remainder of the pressure is made up by N_2 and Ar.

The solar ultraviolet radiation flux at the surface is a vital factor of the ecology, but it is poorly known. The CO_2 and H_2O in the atmosphere will absorb effectively radiation with $\lambda < 1850A$ (Kellogg and Sagan, 1961). The transmission properties of the atmosphere for longer wavelength radiation is at present only guessed at. Transmissions have been derived from observed brightness and polarization data but they cannot be regarded seriously because of the gross assumptions used. On a qualitative basis it is reasonable to state that in general the radiation flux with $\lambda < 4400A$ is low at the surface. This follows from the observation that in general there is a haze which obscures the planet for these wavelengths, figure 9. The low violet albedo (ca .05) and the limb darkening commonly observed (but limb brightening is also noted) suggest the haze has an absorbing component. But the haze is not invariable, and it frequently clears sufficiently for surface details to be clearly visible in the blue, figure 9. This in turn suggests that periodically the surface will be exposed to solar radiation in the 1850 - 4400A range which is only partially attenuated by the atmosphere. The ozone layer which is so effective an absorber in our atmosphere must be very thin, if present at all, on Mars due to the very low O_2 abundance which may be present. Kuiper (Kuiper, 1952) has put the upper level of O_3 at .05 cm atmo, but this is still enough to act as an effective absorber of radiation with $\lambda < 2875A$, using the data of Inn and Tanaka (Inn and Tanaka, 1953) the transmission between 2190 and 2880A is found to be 10 percent or less. However the O_3 abundance may be much less and its absorption may be ineffective in shielding the surface from solar ultraviolet radiation.

Clearly the inadequate knowledge of the ultraviolet transmitting properties of the Mars atmosphere introduces a considerable uncertainty into attempts to simulate the Martian environment.

The smaller atmospheric mass on Mars results in a considerably larger surface particle flux than on Earth (Yagoda, 1963). Assuming a pressure of 41 mb he estimates the dose rate as 6.7×10^{-4} rads hr^{-1} during a galactic sunspot minimum, 5.3×10^{-4} rads hr^{-1} during a galactic sunspot maximum, and 0.6 rads hr^{-1} during unusual solar flares such as that on February 23, 1956. For pressures in the 10 - 25 mb range these numbers should probably be multiplied by a factor of 2.5 - 3. By comparison the normal dose rate on Earth is ca 4×10^{-6} rads hr^{-1} and may rise to only 4×10^{-5} rads hr^{-1} during exceptional solar flares. This high radiation dosage may affect significantly any Martian life and should be considered in Mars simulation experiments.

Finally one should consider the nature of the inorganic surface with which life must be in contact. It is well known that the bright areas are covered with dust, since dust storms of similar color are frequently observed, figure 10. From the spectrum and polarization curve, figure 11, of the bright areas Dollfus has concluded that they are composed of limonite, $Fe_2O_3 \cdot 3/2\,H_2O$. At the same time Kuiper from the spectrum throughout the visible and near infrared believes that felsitic rhyolite, an igneous potassium aluminum silicate, is the best candidate. This disagreement emphasizes the difficulty in determining surface composition solely from the polarization and intensity of reflected radiation. The extensive laboratory data of Dollfus (Dollfus, 1957b) reveal a complex interaction of several factors in producing the polarization. The absorption coefficient, particle size, and presumably the refractive index of the material, and the departure of the powdery surface from smoothness are critically important.

On the last point the angle of inversion shifts to higher phase angles as the surface is stirred up, with the following displacements observed -- antimony - 19 $\rightarrow$ 27°, carborundum - 10 $\rightarrow$ 14°, emery - 16 $\rightarrow$ 20°. Moreover the polarization observed is the net polarization produced by the surface and the atmosphere. Dollfus has estimated the atmospheric contribution and has corrected the observed data accordingly to produce figure 11, which should then apply to the surface. There are however doubts about the validity of the correction since they apply to a Rayleigh scattering atmosphere with a surface pressure of 90 mb, while the pressure may be only 25 mb (Kaplan et al, 1964). If the discrepancy is due to some of Dollfus' approximations other than that of Rayleigh scattering then the appropriate correction would be only about 30 percent of that used. But if the difference is due to the presence of small particles in the atmosphere the correction may even be opposite in sign to that employed. This follows from the fact that Rayleigh scattering is always positively polarized whereas scattering by particles can have an initial strong negative wing. The negative branch for the surface may then be less pronounced than that observed, and the inversion angle will occur at a smaller angle. All of these considerations indicate that the arguments for limonite are weak and that other possibilities should be examined in detail.

The Evidence for Life

One of the most intriguing and controversial points is the question of the canals. In 1877 Schiaparelli detected a network of straight lines which he named "canali". In subsequent years Lowell (Lowell, 1908) observed them repeatedly and drew a very complex picture of canals intersecting at small dark spots which he called oases, figure 12. The canals were sometimes double and in time totaled over 400, being present in both the bright and dark areas. They were on or close to great circles, a regularity which Lowell considered highly significant. He rejected natural phenomena on the basis that no such features of comparable length (up to 5600 km) are present on Earth or the Moon. The regularity then is a product of intelligent beings who constructed canals to carry water from the polar caps to the dry areas towards the equator. The dark lines result from vegetation growing on irrigated land along the canals.

As mentioned initially this imaginative hypothesis is no longer accepted and the reality of the unbroken lines has frequently been questioned (e.g. Dollfus, 1961). At the Pic du Midi, a site which possesses excellent seeing conditions, the lines have been detected but they are resolved during the best seeing into a series of irregular areas.

These comments on the canals all refer to visual observations. Recording the canals on plates is difficult since the resolution attainable with photography is considerably poorer than with the eye, and only the more pronounced ones have been successfully photographed (Slipher, 1962).

The most frequent explanation for the canals is that they are depressed linear features such as graben, whose floors have a lower albedo than the surroundings. The reason for the lower albedo may be the presence of vegetation (Fielder, 1963). However it seems strange that small depressions would be maintained for long periods of time in view of the recurring dust storms. It is logical to believe the dust would settle in the low areas and eventually fill any valleys which had existed at some time in Mars' history. Any low areas which are still present should be dust-covered, and hence be bright and not dark. A more reasonable explanation for the origin of the dark canals is that they are indeed associated with faulting of the Martian crust, but are elevated features such as crater chains or ridges. Such features are present both on Earth and on the Moon, although not to the same extent as appears to be the case on Mars. It would appear rash though to reject this proposal merely because we have no other exact counterpart at hand.

A feature that is in certain ways characteristic of vegetation is the range of colors reported for the dark areas. These change with the seasons, and a variety of blues, browns, greens and other shades have been noted. The reality of these colors is however questionable since there are no objective measurements of colors other than reddish in the literature. Dollfus' spectra of the bright and dark areas (Dollfus, 1957a), figure 13, show the dark areas to be brighter in the red than in the blue, although the difference is less than for the bright areas. In view of the lack of objective corroboration it appears preferable to be conservative and to attribute the various colors to aberrations in the telescopes, to contrast effects arising from the comparison with the adjacent brighter, more reddish areas, to the effect of seeing (Kuiper, 1955), or to a combination of these.

A distinctive feature of the Martian scene is the seasonal variations of the intensity and polarization of the light reflected by the dark areas. During winter in a particular hemisphere the dark areas in the hemisphere are relatively light. When spring comes the polar cap starts to recede and the dark areas near the cap become darker. As the season progresses the darkening moves to lower latitudes and eventually crosses the equator in late summer or autumn, figure 14, 15. Associated with the change in brightness is a change in polarization, figures 16, 17. It has been argued that these effects are due to a growth of Martian organisms which occurs as the water vapor from the receding polar cap traverses the planet to the other pole. Dollfus has interpreted the change in polarization to be due to a change in particle size, and suggests the new particles may be micro-organisms. However his attempts to simulate the effect by sprinkling organisms on powdered limonite surface produced contrary results.

On the basis that we should first look for abiological explanations I have examined such possibilities and have concluded that at least one seems quite possible (Rea, 1963, 1964). First it should be noted that the temperature regime militates against a biological explanation. In figure 18 I have plotted the temperatures when the height of the darkening wave was attained for several areas. It is noted that the temperatures are rather low, in particular for Depressio Hellespontica where it is only -28° C. This may be low due to experimental error or to an emissivity less than 1. It seems somewhat improbable however that the corrections will raise the temperature above -10° C. While life utilizing water as a solvent may exist under such thermal conditions it must be truly unique to exhibit the growth characteristics of Depressio Hellespontica. In my opinion this renders the biological explanation for the darkening of this area unlikely, and if this is accepted it is only natural to extend this conclusion to the darkening wave for all of the areas.

If this is improbable, can a reasonable abiological hypothesis be presented? I believe this can be done by utilizing a dust idea introduced by Kuiper (Kuiper, 1957). In this interpretation the darkening wave is the result of a seasonal variation in the wind patterns. The wind blows off the smaller dust particles, leaving behind the larger particles which give a darker surface (there is less multiple scattering involving transmitted light) and the characteristic polarization change, figure 19. Another possibility is that the remaining surface is rougher, perhaps consisting of loosely cemented particles, since this would also explain the albedo and polarization effects. Then the normal wind pattern returns, the small dust particles settle again on the ground, and it reverts to its appearance before the onset of the winds. It is also consistent but not necessary to postulate that the composition of the dark and light areas is the same, the only difference being in the particle size. In the dust hypothesis the dark areas would be elevated so that only the larger particles or agglomerated small particles would be able to remain on them, the independent smaller particles generally settling in the lower areas.

This proposal explains nicely the regenerative property of the dark areas. After a dust storm, which can cover a major part of the planet, the dark areas are not obscured for a long period, but rapidly regain their pre-storm appearance. Öpik (Öpik, 1962) has argued that this must be due to a Martian life which would project through a settled dust layer, for otherwise the dust would have created a planet of uniform level. This argument is weakened by the widely held belief (e.g. Dollfus, 1961), which he also subscribes to, that Mars does not have a surface of uniform elevation, figure 20. In the present model this regenerative feature is readily explained by the dust settling predominantly in lower areas, leaving the higher dark areas in essentially their normal state.

An observation which supports this model is the temporary darkening of normally bright areas during a dust storm (Slipher, 1962). Slipher states that along the edges of large yellow clouds there are transitory dark regions which he believes are due to moistening of the soil by precipitated water, figure 21. However the dryness of the atmosphere must ensure that any wetting of the soil will be possible only for brief periods in early morning, and certainly not in the middle of the day. A more probable explanation is that the bright area has had its overlying dust layer temporarily removed by the intense winds which caused the dust storm laying bare the underlying stratum. After the storm has subsided, or has moved to a different location on the planet, the dust settles back and the bright aspect is regained.

Other abiological explanations for the seasonal phenomena have also been advanced. Arrhenius (Arrhenius, 1918) has proposed that the canals are covered with hygroscopic salts which form concentrated brine solutions as water becomes available. The large dark areas in winter are frozen solutions covered with dust; in spring and summer they melt and the dust settles to the bottom. The solutions have a low reflecting power and appear dark. This is not now accepted because of the low humidity of the atmosphere and the failure to observe specular reflection from the canals and dark areas.

Any change, due to hydration or other effects, which increases the absorption coefficient of the surface material will explain both the intensity and polarization shifts. This possibility must be kept in mind even though suitable mechanisms have not yet been proposed.

On the basis of these remarks it seems justified to conclude that abiological hypotheses be given at least equal credence as a Martian biota for explaining the seasonal variations.

In addition to seasonal changes there are secular changes which have affected many different areas. Of the several which are pictured in Slipher's book one of the most impressive is the variation in the Thoth-Nepenthes region, figure 22. Another area which underwent an unusual change is Hellas. It is normally very bright, second only to the polar caps, but in 1954 this 800,000 km^2 region was very dark. At the 1956 opposition it was again bright. Secular changes such as these could be explained by variations in the vegetation coverage of the surface. However they may also arise from volcanic activity (McLaughlin, 1954), faulting due to internal activity, or perhaps from a redistribution of the dust. The time scale for observed phenomena can be very short, e. g. for the Hellas darkening, so that the prospects are poor for a Martian life to expand sufficiently rapidly over such large areas in the rigorous Martian environment.

One of the most direct observations bearing on the existence of life on Mars was made by Sinton (Sinton, 1959, 1961). Using the 200 inch telescope he recorded the 3 - 4μ spectrum of selected areas on the planet. The spectra possess features which he identified as minima occurring at 3. 45, 3. 58 and 3.69μ, and which are more pronounced for the dark than for the bright areas, figure 23. After examining selected spectra of inorganic, organic and biological specimens he concluded that the minima are probably due to absorption by CH bonds, and in particular that the 3. 69μ minimum testifies to the presence of carbohydrates. The concentration of this organic matter is higher on the dark areas and, in conjunction with the other phenomena associated with them, is then strongly indicative of the presence of life. Later Colthup (Colthup, 1961) noted that the relative intensity of the 3.69μ band is too intense for carbohydrates, that it must be due to an aldehyde CH, and in particular that acetaldehyde is its most likely source. However this is a very volatile chemical and under Martian conditions must all be in the vapor phase (Rea, 1962). Then some mechanism must be devised to explain its preferential concentration over the dark areas. This can conceivably be accomplished, but it does make the interpretation somewhat artifical and forced.

It is possible that the 3. 69 and 3. 58 μ bands are due to other aldehydes than acetaldehyde since conjugating the aldehyde group with an olefinic or aromatic system does not shift these bands appreciably (Pinchas, 1955). However it must be remembered that the relative intensities of the 3. 69 and 3. 45 μ bands are such that the mole ratio of CH_2 + CH_3 groups to CHO groups can not be greater than about 2 : 1. On the basis of our terrestrial experience such systems, covering the major part of large areas of a planetary surface, are difficult to conceive. Of course the absorbers may be in the vapor phase, but the criticism raised against acetaldehyde will then apply.

The entire question of the source of the Sinton bands has been examined in detail in our laboratory (Rea, et al, 1963). We have recorded the reflection spectra of a large number of inorganic, organic and biological samples, but have failed to find a satisfactory explanation for the features. It is not difficult to find organic samples with a band near 3.45 μ, e.g. cellulose, figure 24. But the other two, and in particular that at 3.69 μ do not have ready explanations. The situation is no better for the inorganics -- carbonates can be used to explain the 3.45 μ band, e.g. $CaCO_3$, figure 25, but not the others unless one postulates the surface has large concentrations of $BaCO_3$ and/or $PbCO_3$. Since this is improbable due to the low cosmic abundance of these cations we are left in a most unsatisfactory state -- no explanation that we consider acceptable has been found. Considering this I do not prefer to use the Sinton bands as an argument for the existence of Martian life.

Conclusion

It is a fair statement to say that the evidence for life on Mars is very uncertain, and that better data are required. What are the topographical details, and in particular are the canals and dark areas elevated or depressed? Are the blues and greens artifacts, or will spectra obtained with high spatial resolution provide objective confirmation? What is the dependence of the spectral brightness and polarization of powdered samples of limonite, felsitic rhyolite, and other possible materials on the particle size distribution? Will infrared spectra, obtained with higher spatial and spectral resolution, give spectral details that will clarify the assignment of the Sinton bands and spatial information that will decide whether the absorber is in the atmosphere or on the surface? Will infrared spectra in wavelength regions not accessible to ground-based telescopes reveal bands due to olefinic or aromatic CH groups or to the C = O bond and perhaps shed new light on the origin of the Sinton bands?

But, no matter what the answers to these questions are, we will not be able to make positive statements about the existence of life on Mars till biological laboratories are placed on the surface. The remote investigations will provide invaluable information in designing the biological experiments and in choosing a landing site, but they can not answer the initial questions -- is there life on Mars, and if so what is its nature?

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FIGURE CAPTIONS

Figure 1

The appearance of Mars in 1954 (Finsen, 1961).

Figure 2

Average Martian southern hemisphere summer isotherms, (Gifford, 1956).

Figure 3

Theoretical and observed diurnal temperature variation at the equator of Mars (Sinton and Strong, 1960).

Figure 4

Average temperature variation along the Martian noon meridian for the various seasons (Gifford, 1956).

Figure 5

A microphotometer tracing of the R-branch in the $5\nu_3$ CO_2 band of Mars. The measured lines J = 8, 10, 12, and two solar lines are also shown (Kaplan et al, 1964).

Figure 6

Equivalent width of 2 μ band complex vs. CO_2 amount times effective pressure. Abscissa markings below curve for various telluric air-masses η, above curve for Earth plus Mars from Sinton (S) and Kuiper upper and lower limits (K) (Kaplan et al, 1964).

Figure 7

Phase curve of H_2O, calculated from data in the International Critical Tables.

Figure 8

Doppler shifted H_2O Martian lines (Spinrad et al, 1963).

FIGURE CAPTIONS (Continued)

Figure 9

Comparisons of yellow and blue photographs showing the presence of the obscuring blue haze together with partial clearings (Slipher, 1962).

Figure 10

The great dust storm of 1956 (Slipher, 1962).

Figure 11

The curve in the observed polarization of the bright areas, the dots represent laboratory measurements of pulverized limonite (Dollfus, 1961).

Figure 12

A drawing of Mars by Slipher showing many of the canals (Slipher, 1962).

Figure 13

The spectra of the bright and dark areas (Dollfus, 1957).

Figure 14

The darkening wave, as particularly exemplified by Pandorae Fretum (Slipher, 1962).

Figure 15

Brightness variations of the dark areas plotted against the heliocentric longitude. South is at the top, north at the bottom. The data were obtained by Focas (Dollfus, 1961).

Figure 16

The change in the polarization of the dark areas with the season. The filled circles are for equatorial markings at Martian spring, the open circles for markings in the northern hemisphere at Martian spring (Dollfus, 1961).

Figure 17

The seasonal variation of the polarization on Mars. Plotted against the heliocentric longitude, for a phase angle $V = 25^{\circ}$, are the polarization differences between the dark and bright areas (Dollfus, 1961).

Figure 18

The noon surface temperature at the height of the darkening wave for various dark areas.

Figure 19

Polarization curves for a basalt with varying particle size (Wright et al, 1963).

Figure 20

The repeated occurrence of W-shaped clouds over the Tharsis region in 1954 (Slipher, 1962).

Figure 21

Examples of temporary dark areas adjacent to dust clouds, observed in 1956. In the upper left hand photograph the spot is to the left of Solis Lacus, in the upper right one the normally bright Thaumasia is dark. The 1941 pictures indicate the normal appearance (Slipher, 1962).

Figure 22

Pronounced secular changes in the Thoth-Nepenthes region (Slipher, 1962).

Figure 23

The 3 - 4 μ spectrum of Mars observed by W. M. Sinton (Rea et al, 1963).

Figure 24

The reflection spectrum of cellulose (Rea et al, 1963).

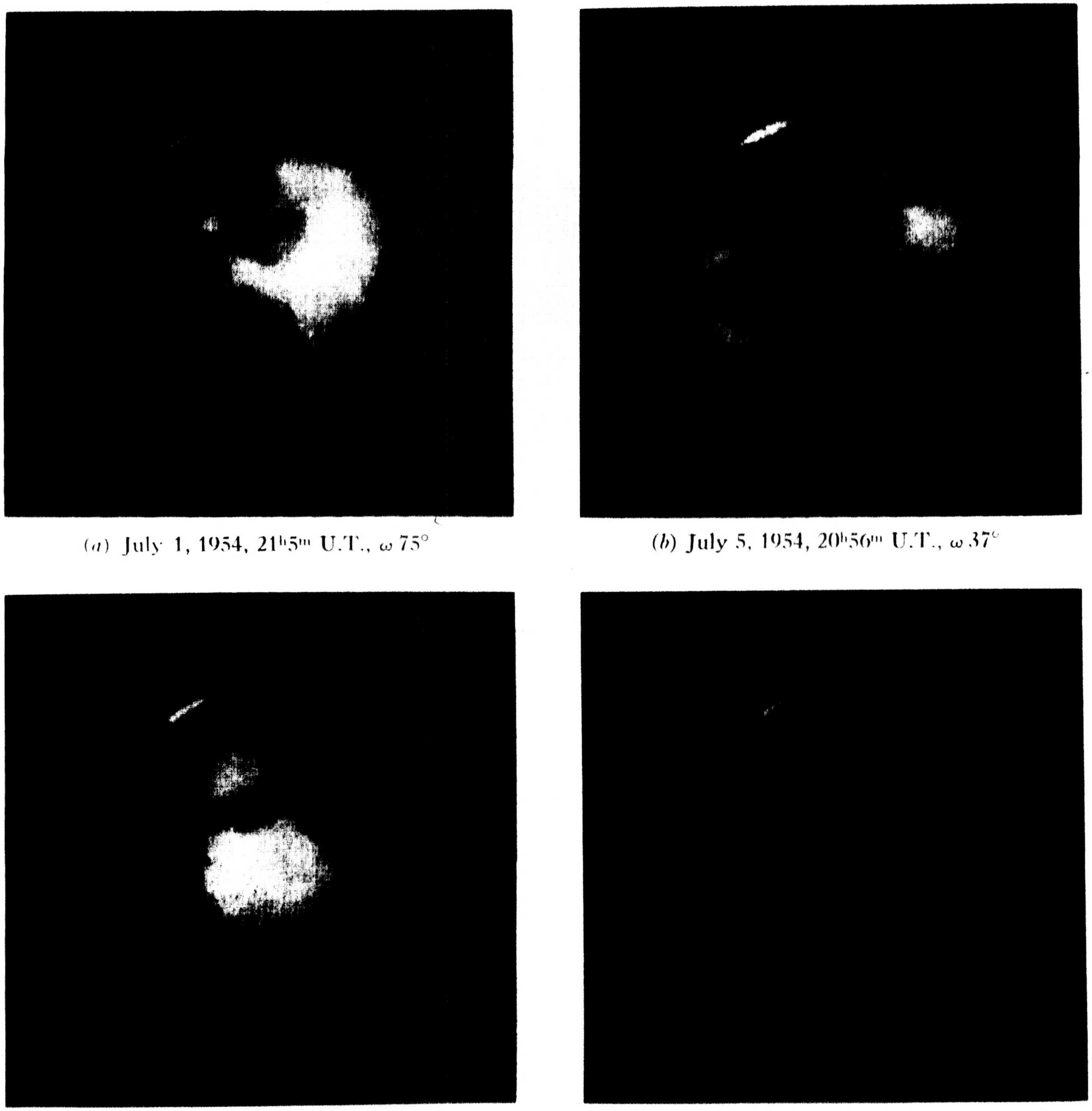
Figure 25

The transmission and reflection spectra of $CaCO_3$ (Rea et al, 1963).

TABLE 1

Some Physical Properties of Mars and Earth

	Mars	Earth
Mass (g)	0.646×10^{27}	5.98×10^{27}
Diameter (km)	6800	12,800
Average density (g cm^{-3})	3.96	5.52
Surface gravitational acceleration (cm sec^{-2})	370	981
Mean distance from Sun (km)	228×10^{6}	150×10^{6}
Angle between rotation axis and orbital plane (deg.)	24.5	23.5
Length of year (days)	687	365
Length of southern spring (days) ...	146	91
Length of southern summer (days)..	160	87
Length of southern fall (days)......	199	93
Length of southern winter (days) ...	182	94
Length of day (hours)	24.6	24



(a) July 1, 1954, 21^h5^m U.T., ω 75°

(b) July 5, 1954, 20^h56^m U.T., ω 37°

(c) July 11, 1954, 20^h16^m U.T., ω 334°

(d) July 14, 1954, 18^h49^m U.T., ω 286°

Figure 1. -- The appearance of Mars in 1954 (Finsen, 1961).

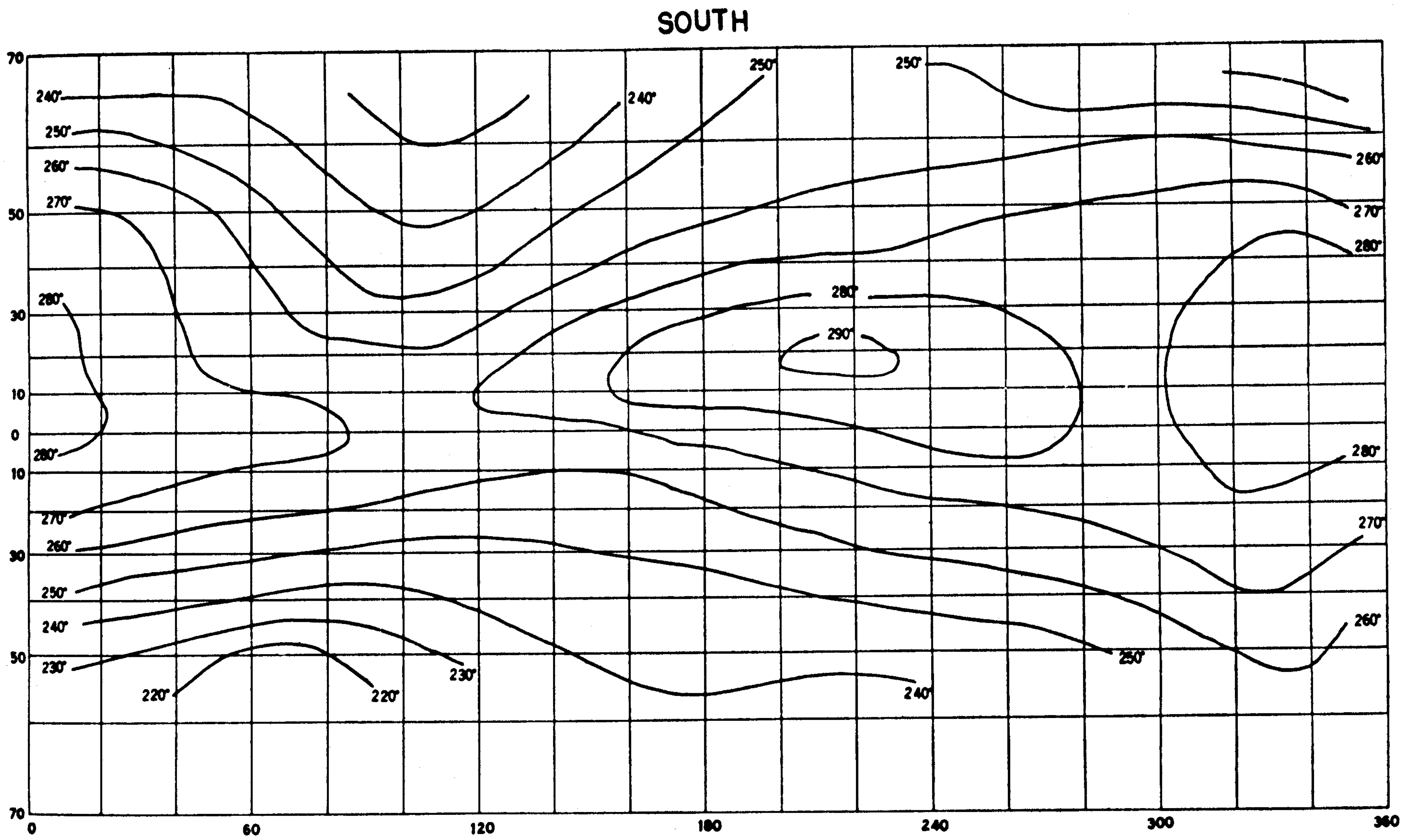


Figure 2. -- Average Martian southern hemisphere summer isotherms, (Gifford, 1956).

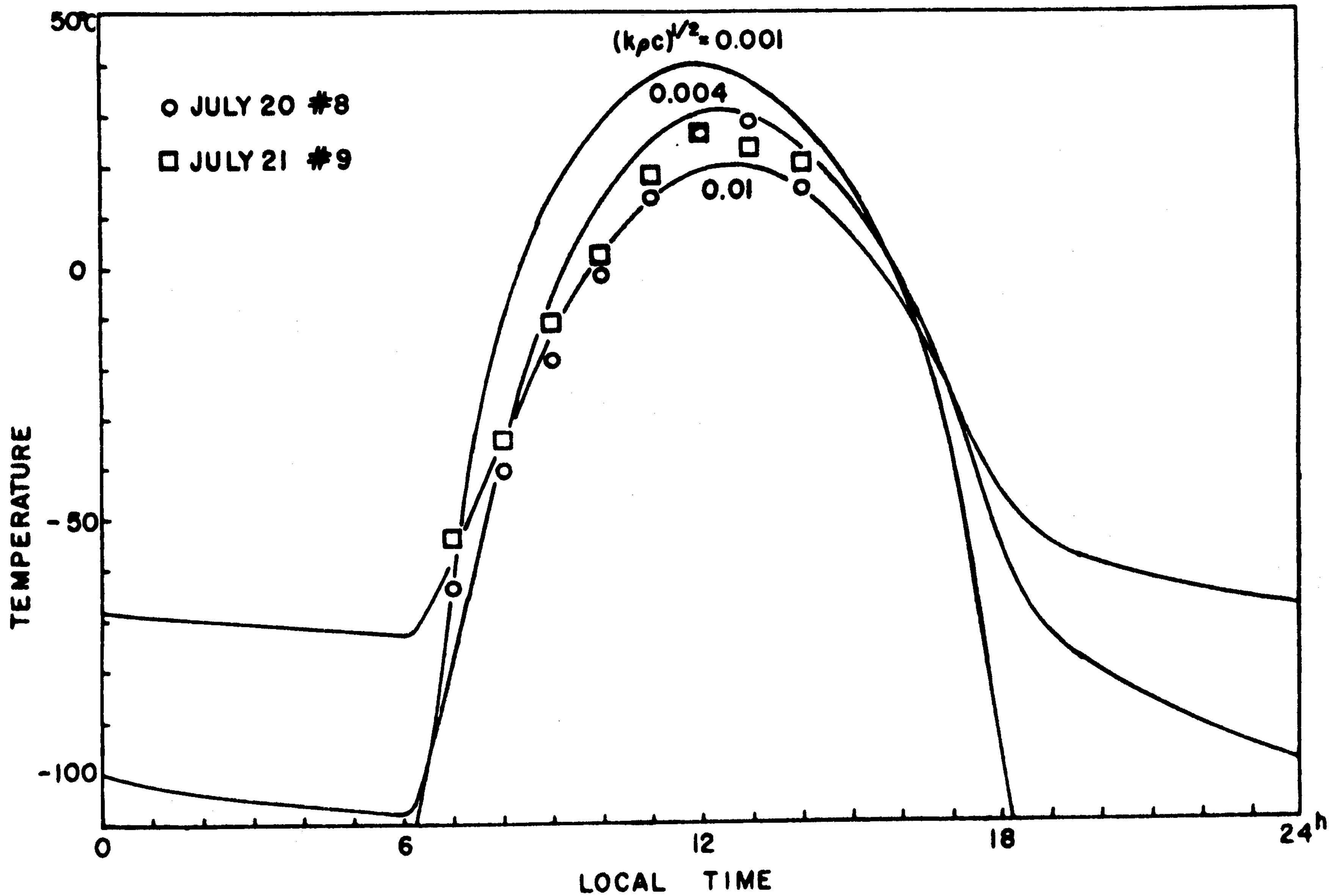


Figure 3. -- Theoretical and observed diurnal temperature variation at the equator of Mars (Sinton and Strong, 1960).

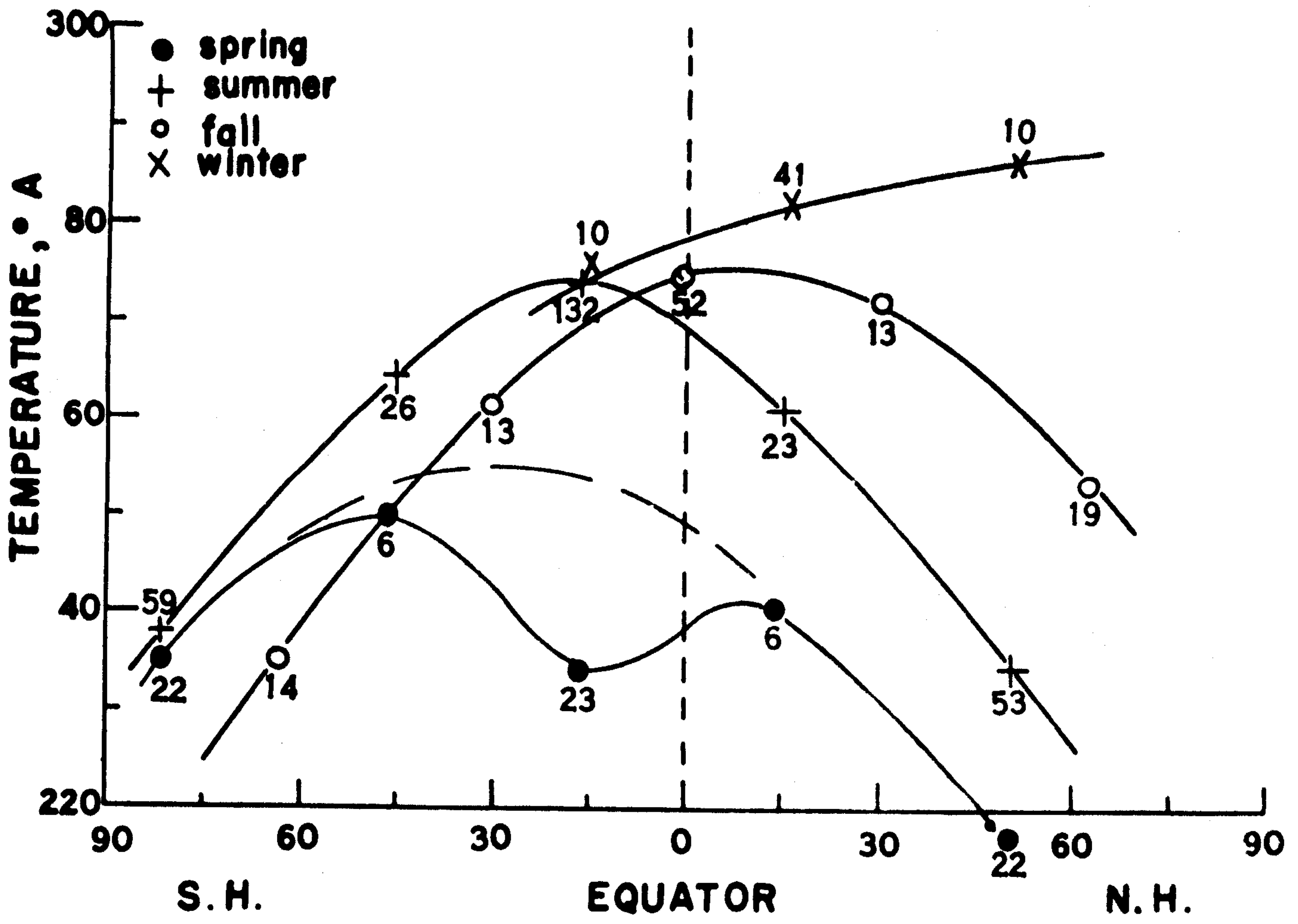


Figure 4. -- Average temperature variation along the Martian noon meridian for the various seasons (Gifford, 1956).

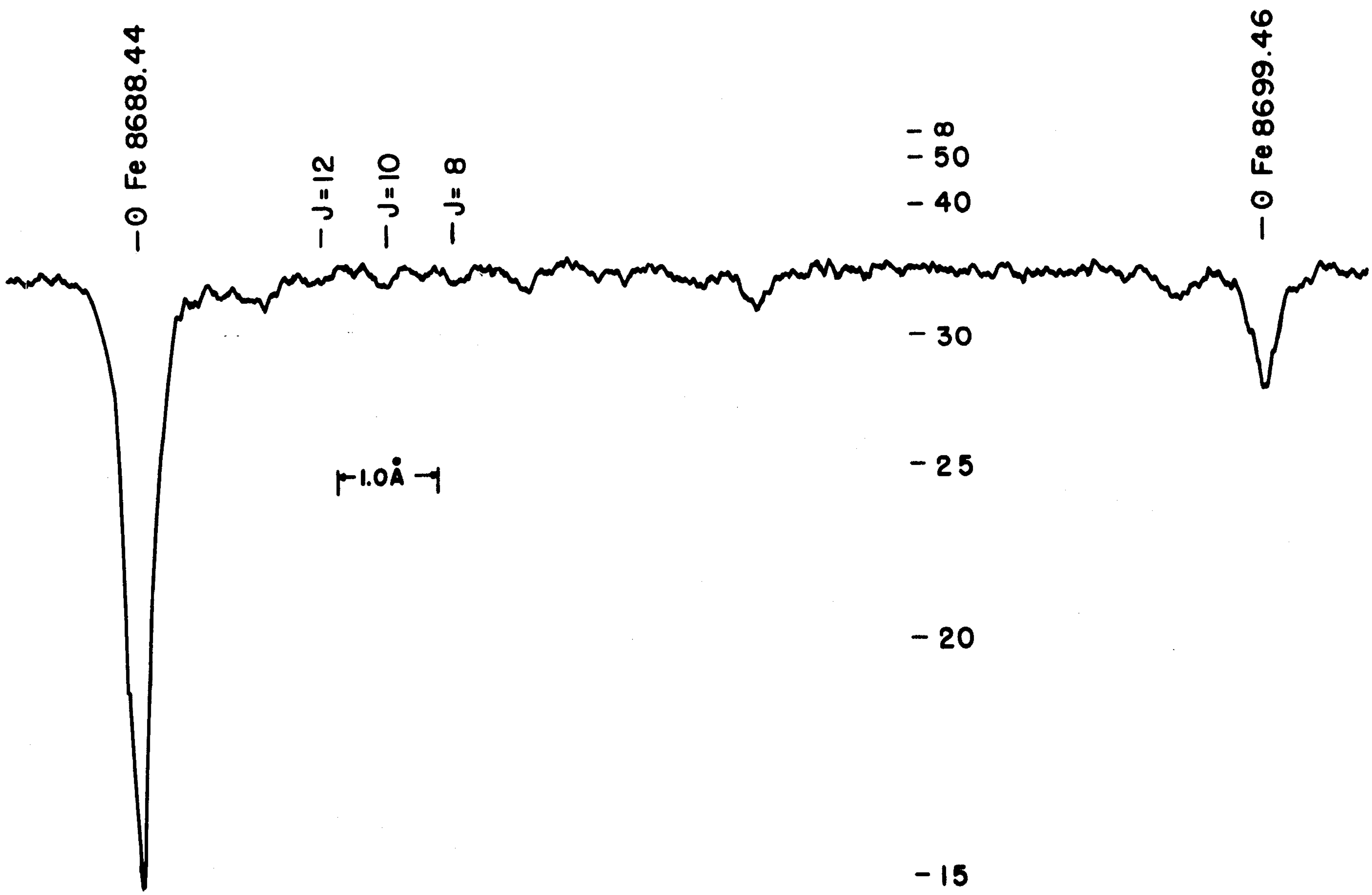


Figure 5. -- A microphotometer tracing of the R-branch in the $5\nu_3$ CO_2 band of Mars. The measured lines J = 8, 10, 12, and two solar lines are also shown (Kaplan et al, 1964).

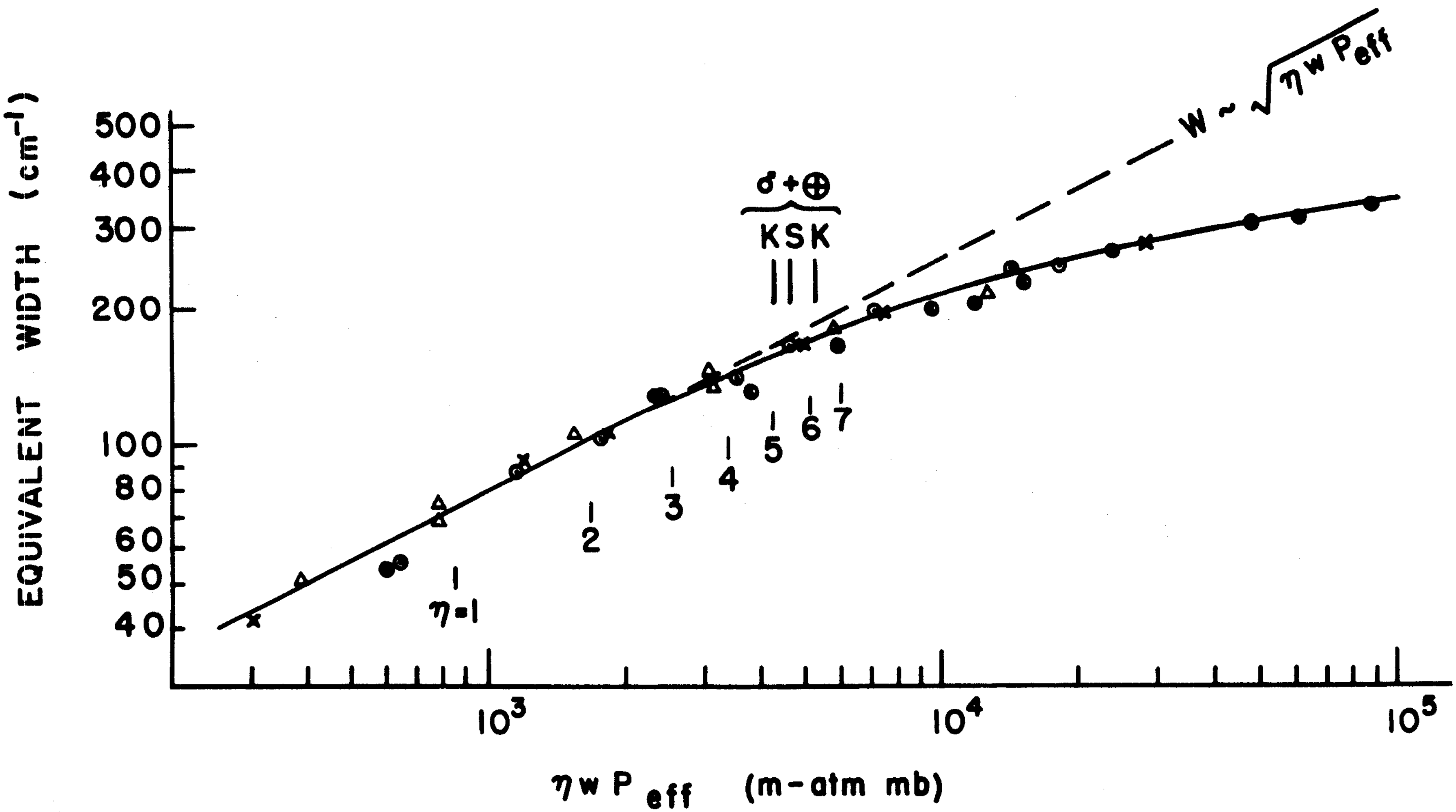


Figure 6. -- Equivalent width of 2 μ band complex vs. CO_2 amount times effective pressure. Abscissa markings below curve for various telluric air-masses η, above curve for Earth plus Mars from Sinton (S) and Kuiper upper and lower limits (K), (Kaplan et al, 1964).

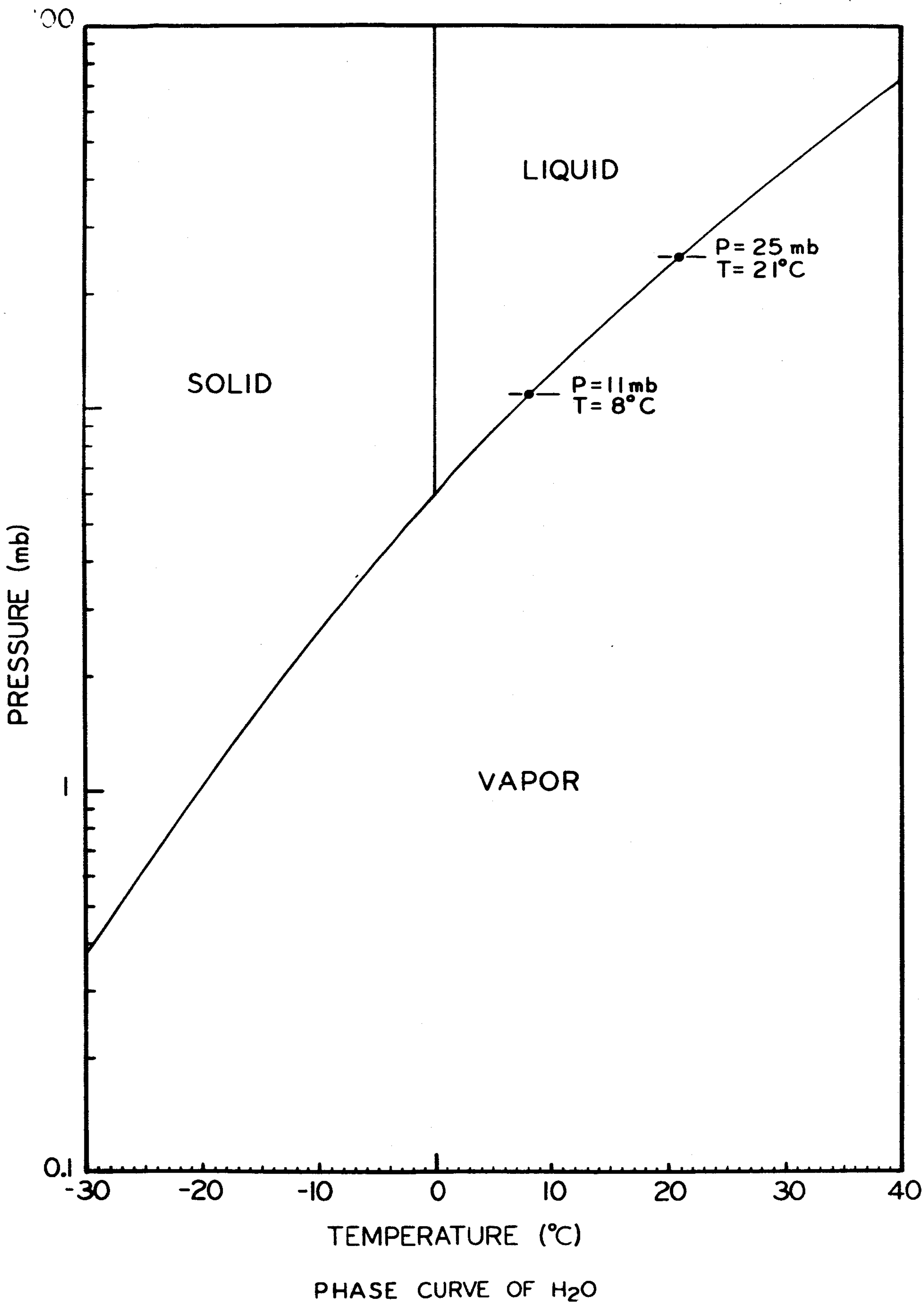


Figure 7. -- Phase curve of H_2O, calculated from data in the International Critical Tables.

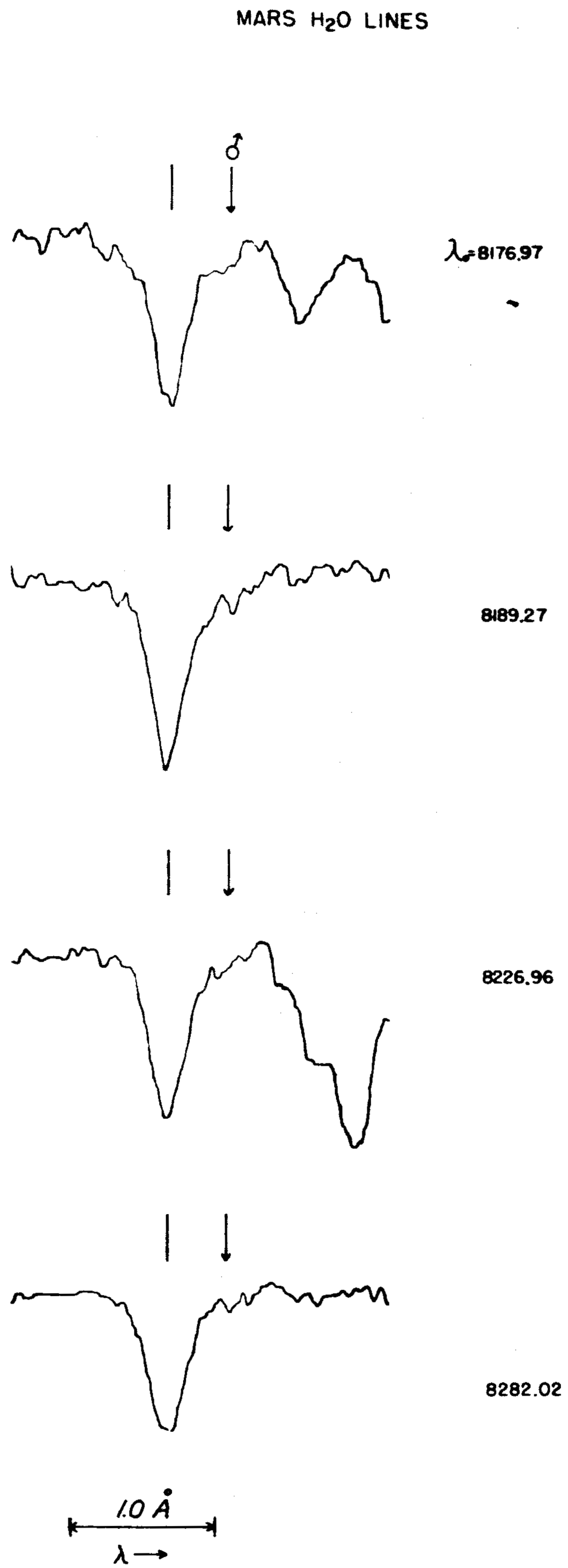
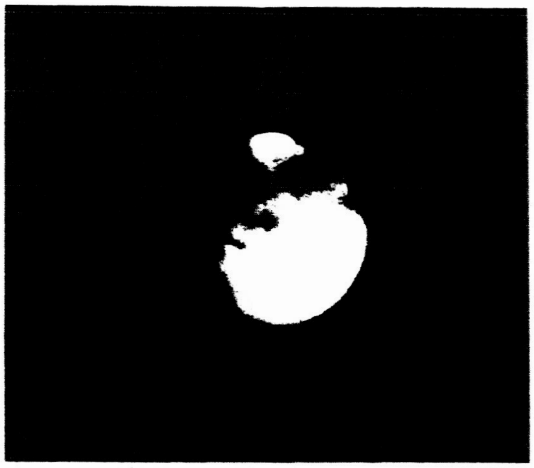


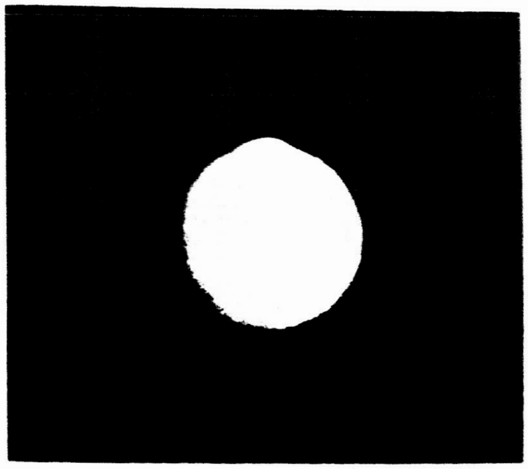
Figure 8. -- Doppler shifted H_2O Martian lines (Spinrad et al, 1963).

PLATE XIV

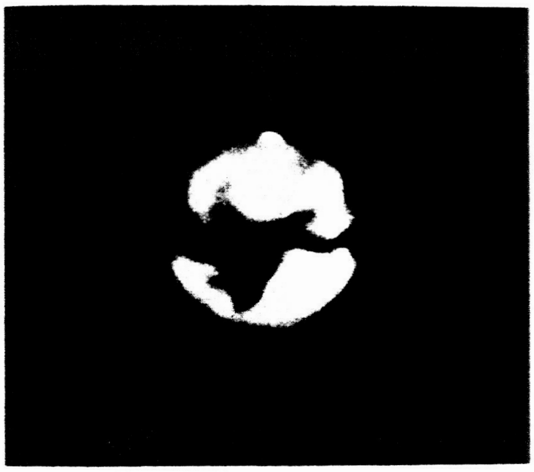
COMPARISONS OF YELLOW AND BLUE PHOTOGRAPHS TO SHOW THAT THE CAP RECORDED IN BLUE LIGHT IS THE SAME IN EVERY DETAIL AS THAT DISPLAYED IN RED AND YELLOW LIGHT.



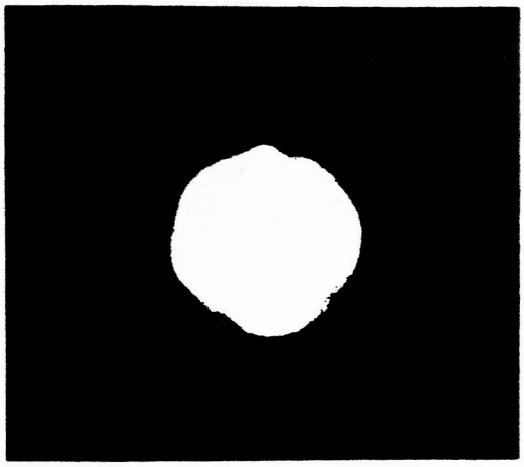
1. 1956 Aug 24 λ84° U.T. 23:49 R May 30 M.D.



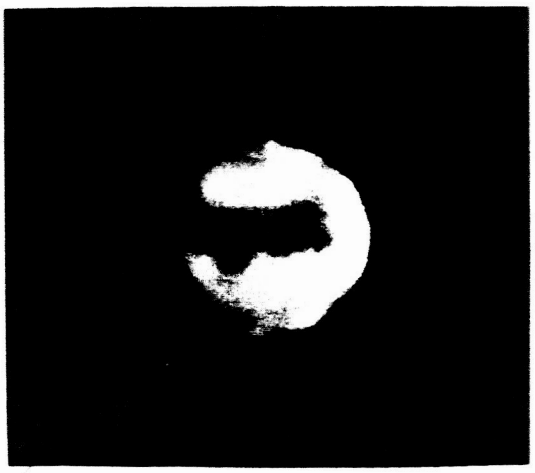
2. 1956 Aug 24 λ79° U.T. 23:27 B May 30 M. D.



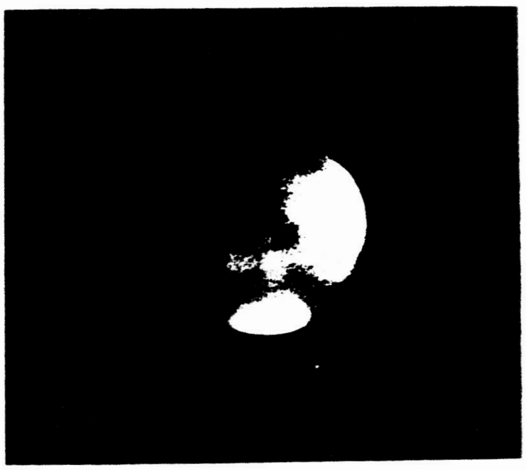
3. 1941 Oct 11 λ305° U.T. 6:00 O July 11 M.D.



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

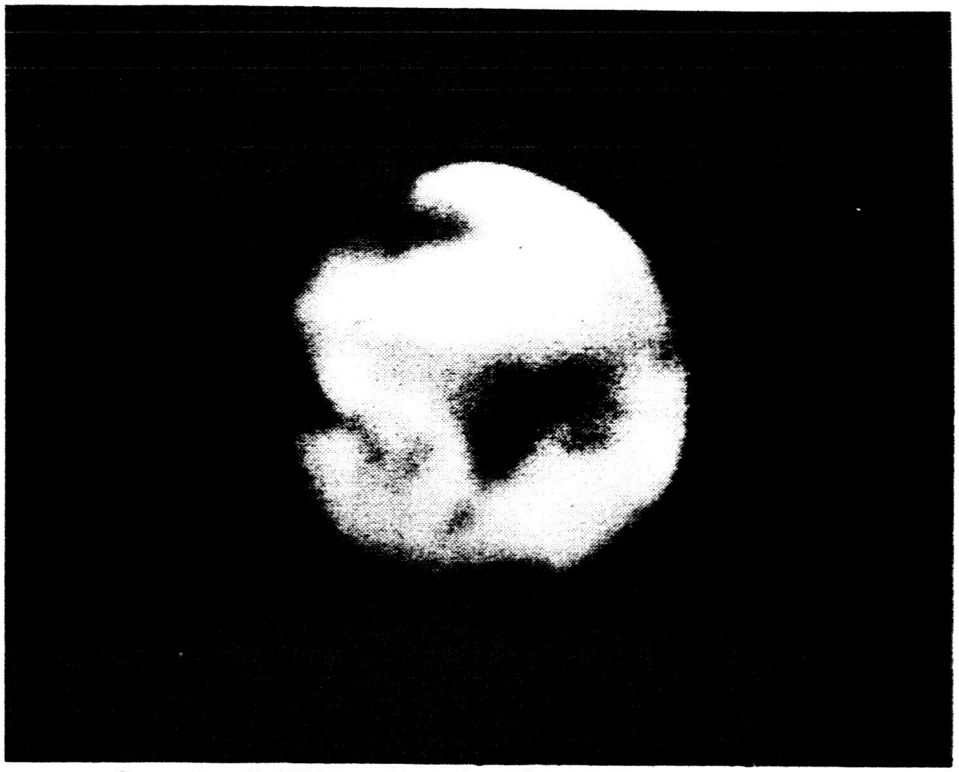


5. 1926 Oct 27 λ10° U.T. 6:48 Y Aug 1 M.D.

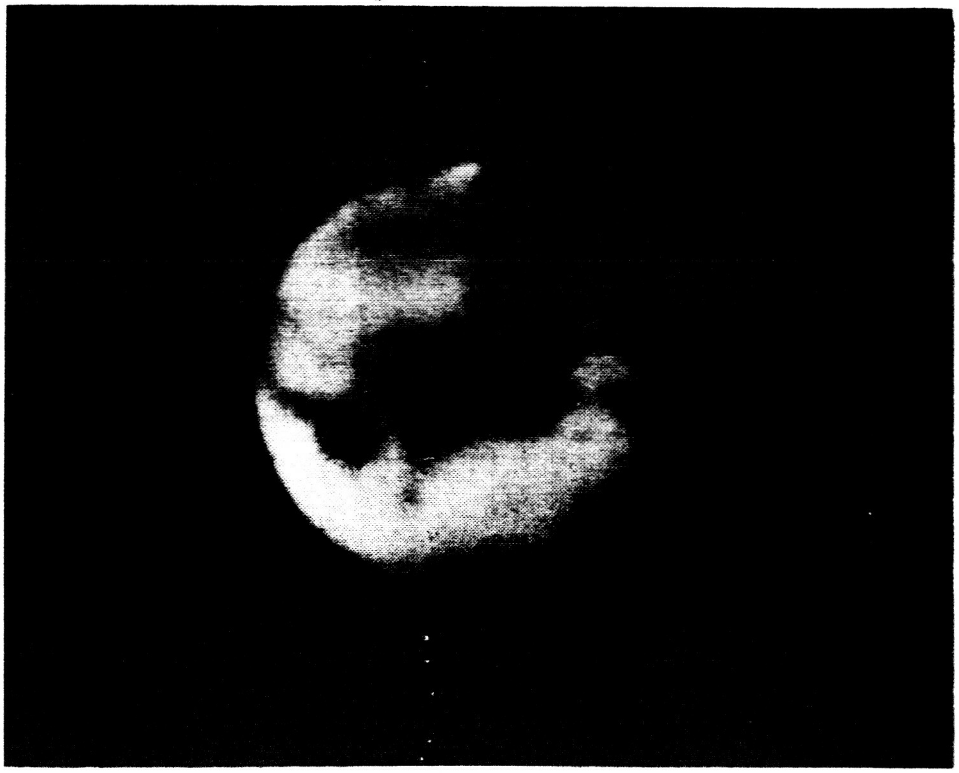


6. 1926 Oct 27 λ22° U.T. 8:06 B Aug 1 M.D.

Figure 9. -- Comparisons of yellow and blue photographs showing the presence of the obscuring blue haze together with partial clearings (Slipher, 1962).



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



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

Figure 10. -- The great dust storm of 1956 (Slipher, 1962).

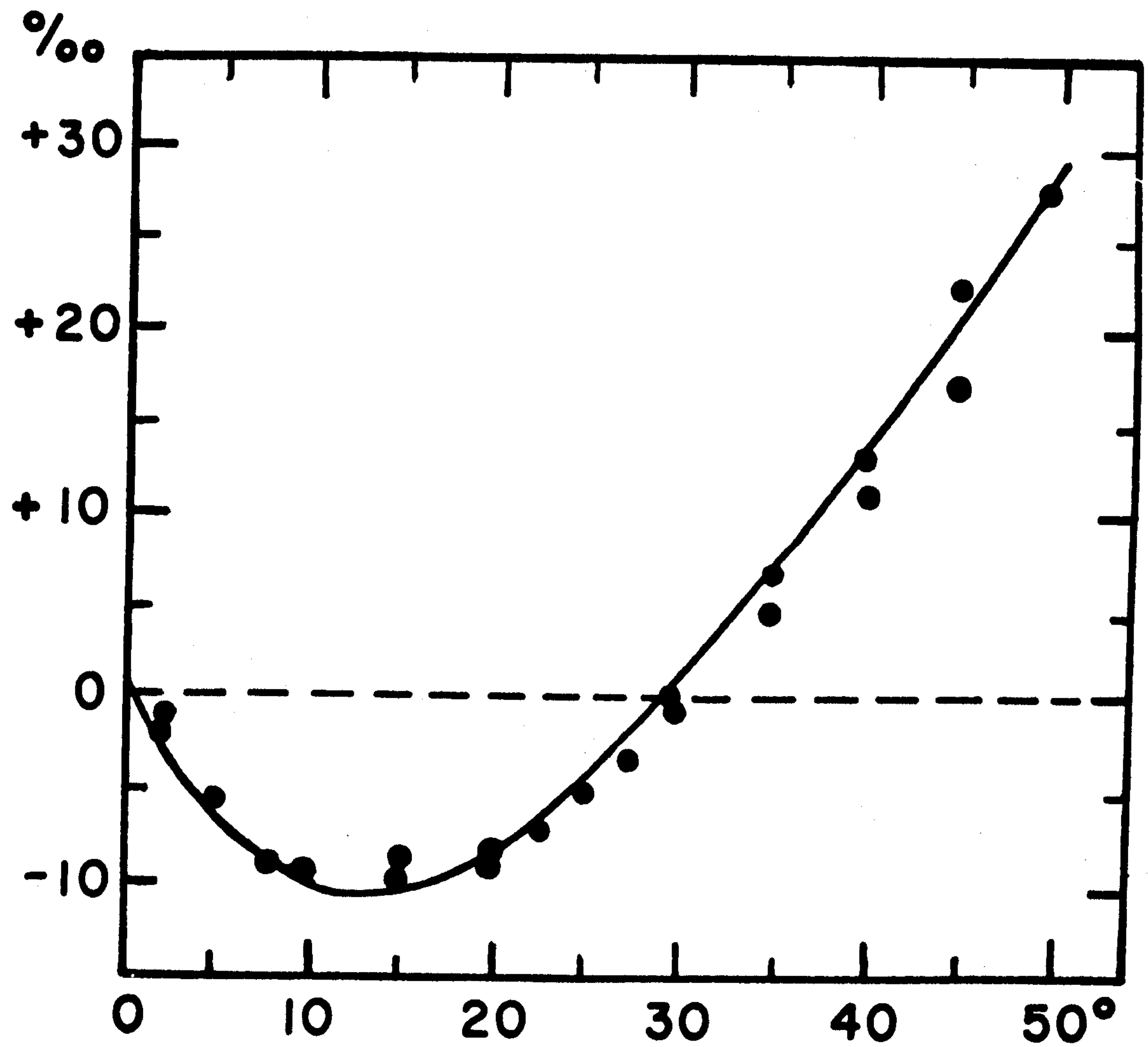


Figure 11. -- The curve in the observed polarization of the bright areas, the dots represent laboratory measurements of pulverized limonite (Dollfus, 1961).

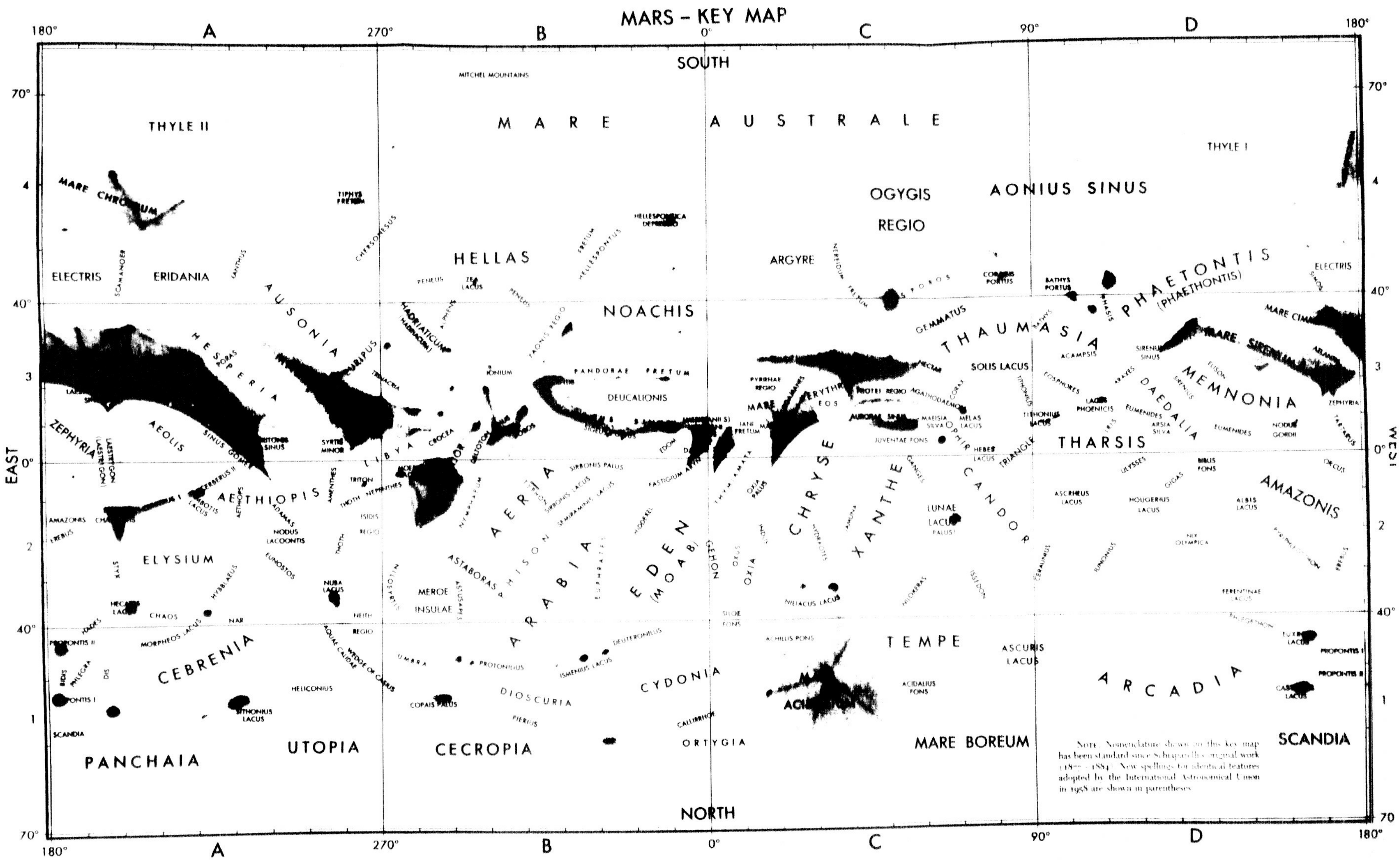
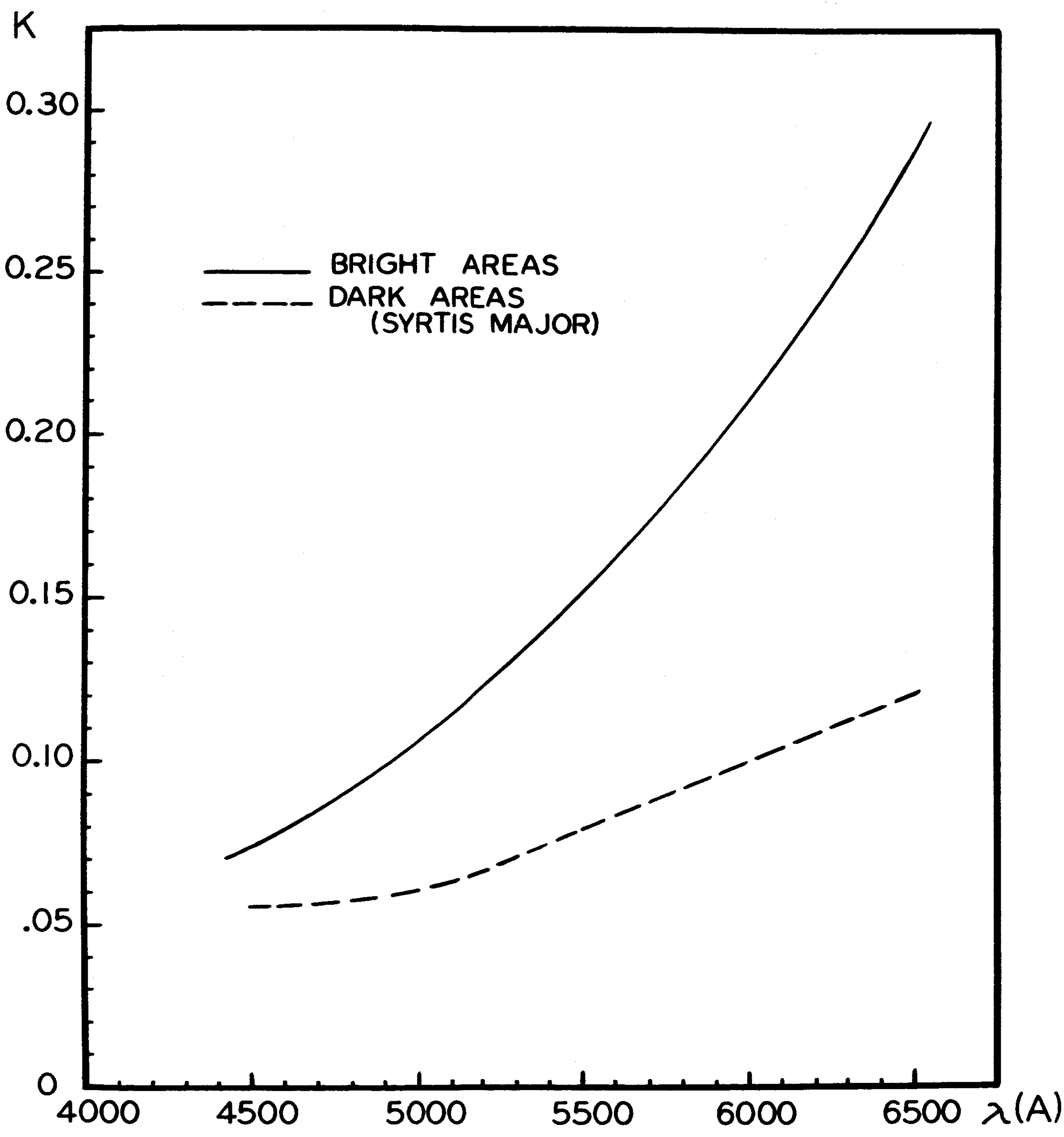


Figure 12. -- A drawing of Mars by Slipher showing many of the canals (Slipher, 1962).



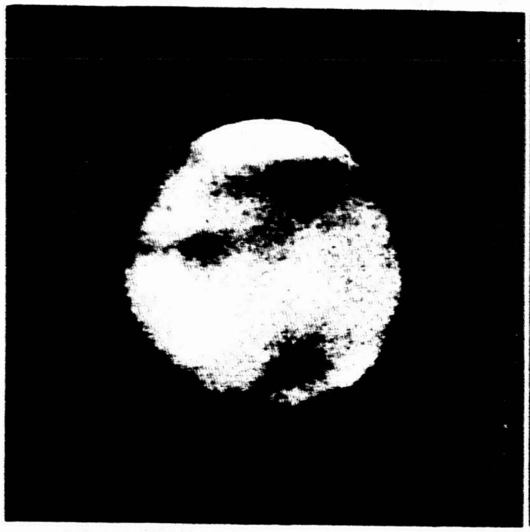
NORMAL ALBEDO FOR BRIGHT AND DARK AREAS

Figure 13. -- The spectra of the bright and dark areas (Dollfus, 1957).

PLATE XI

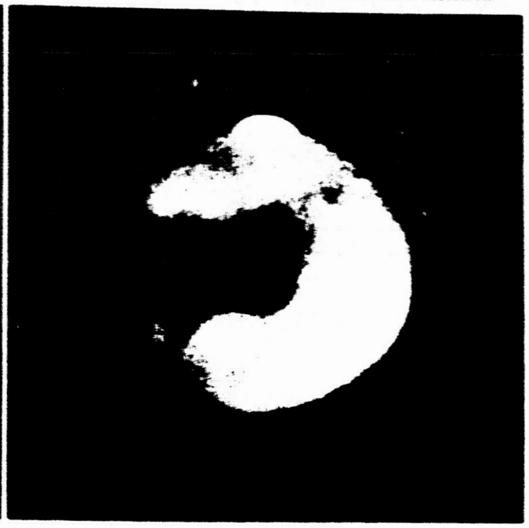
SEASONAL CHANGES IN THE SOUTH CAP AND DARKENING OF THE BLUE-GREEN AREAS

Mar 10
M.D.



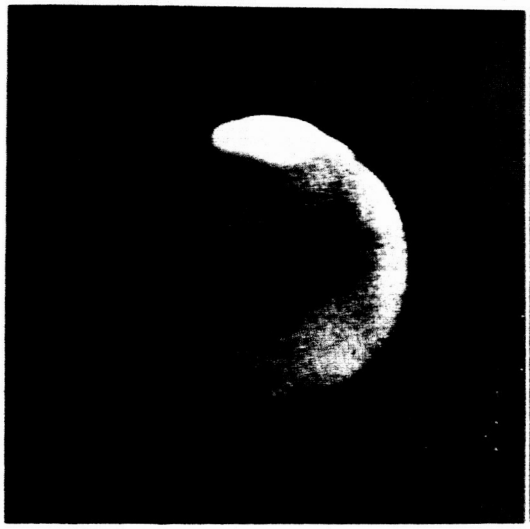
1. 1922 June 7 U.T. 9:05 λ21° Y

June 23
M.D.



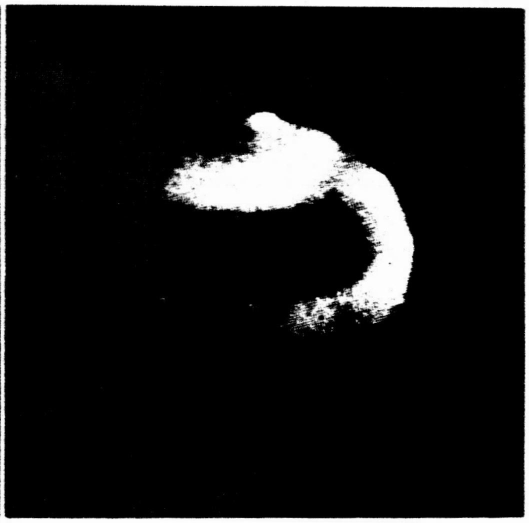
4. 1909 Sept 24 U.T. 9:30 λ55° Y

May 11
M.D.



2. 1924 Aug 3 U.T. 11:40 λ13° Y

Aug 1
M.D.



5. 1926 Oct 27 U.T. 7:42 λ18° Y

May 30
M.D.

3. 1924 Sept 1 U.T. 6:15 λ34° Y

Aug 22
M.D.

6. 1926 Dec 1 U.T. 4:27 λ22° Y

Figure 14 -- The darkening wave, as particularly exemplified by Pandorae Fretum (Slipher, 1962).

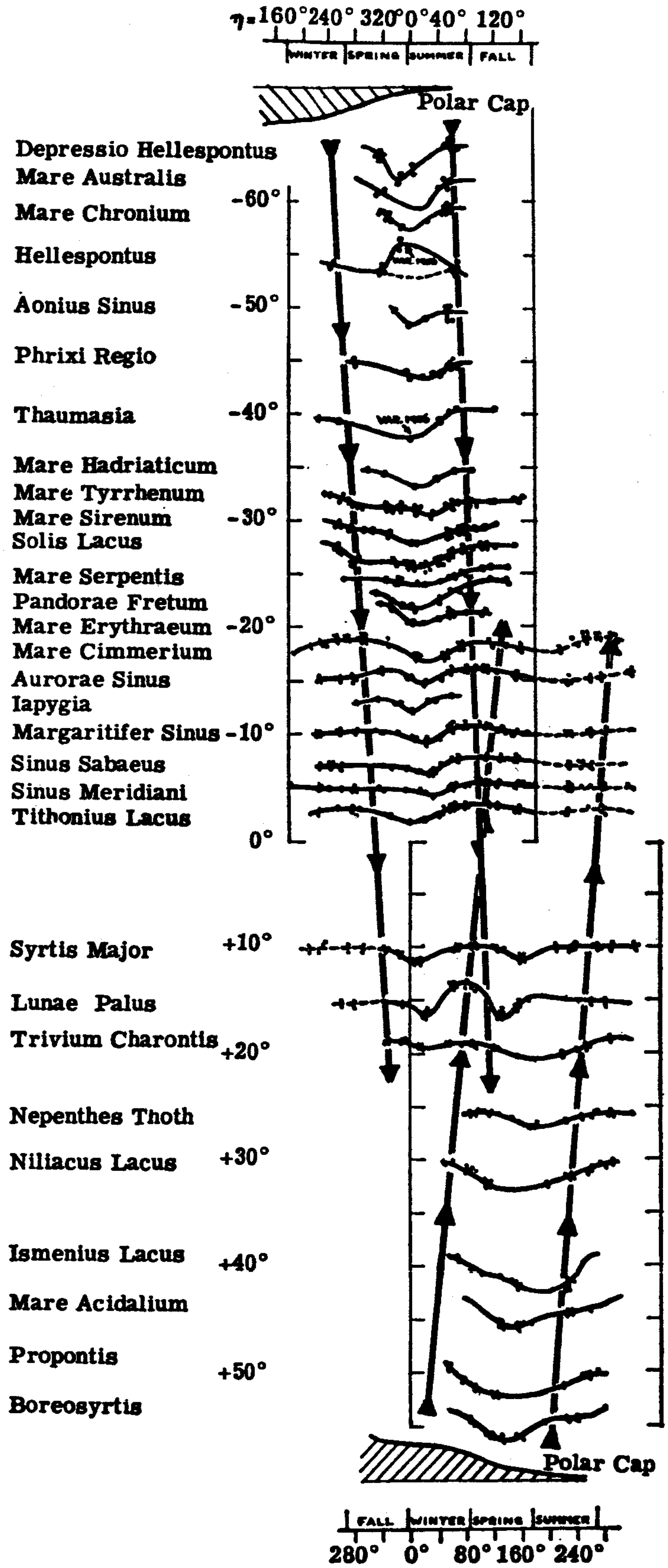


Figure 15. -- Brightness variations of the dark areas plotted against the heliocentric longitude. South is at the top, north at the bottom. The data were obtained by Focas (Dollfus, 1961).

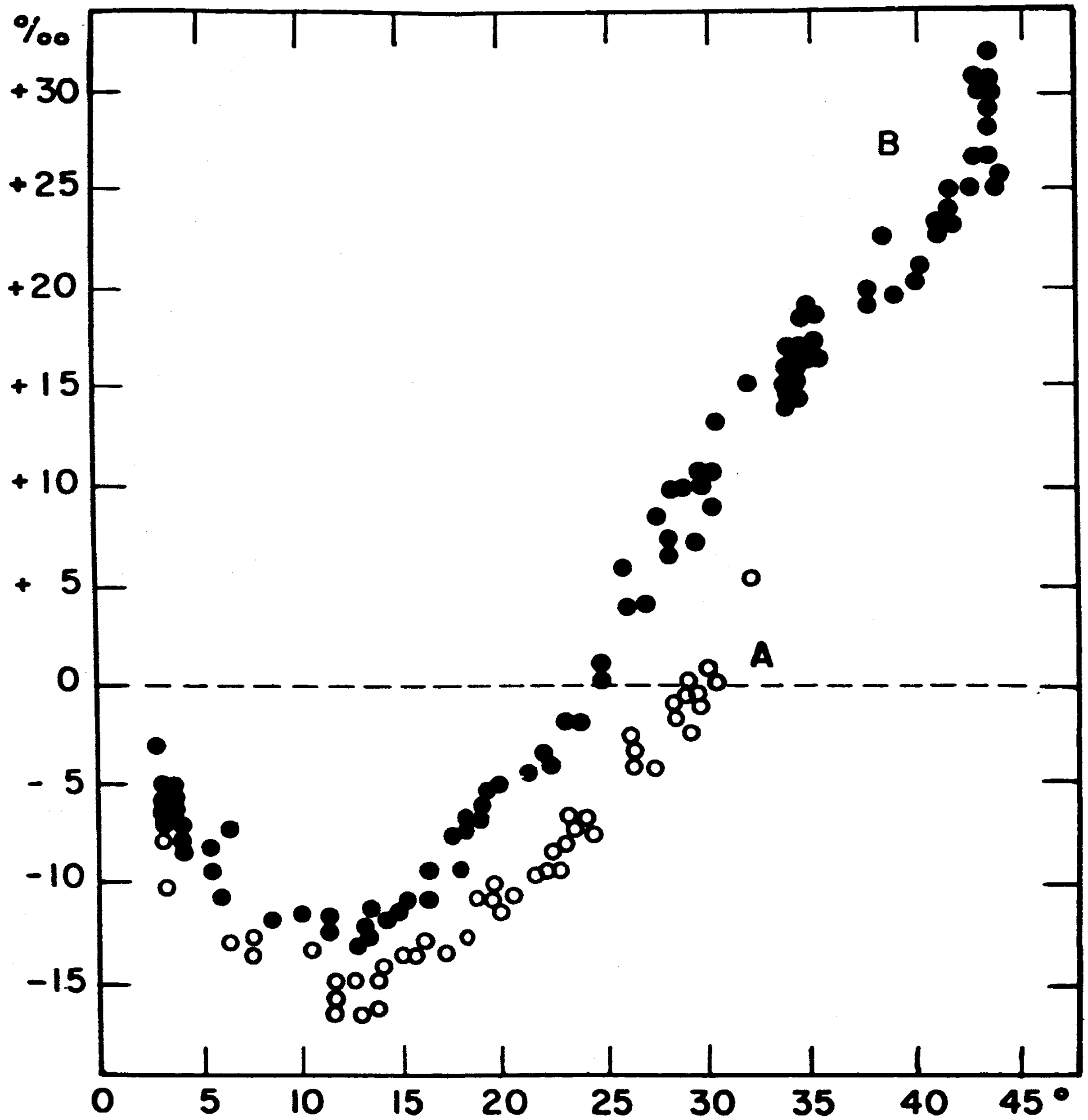


Figure 16. -- The change in the polarization of the dark areas with the season. The filled circles are for equatorial markings at Martian spring, the open circles for markings in the northern hemisphere at Martian spring (Dollfus, 1961).

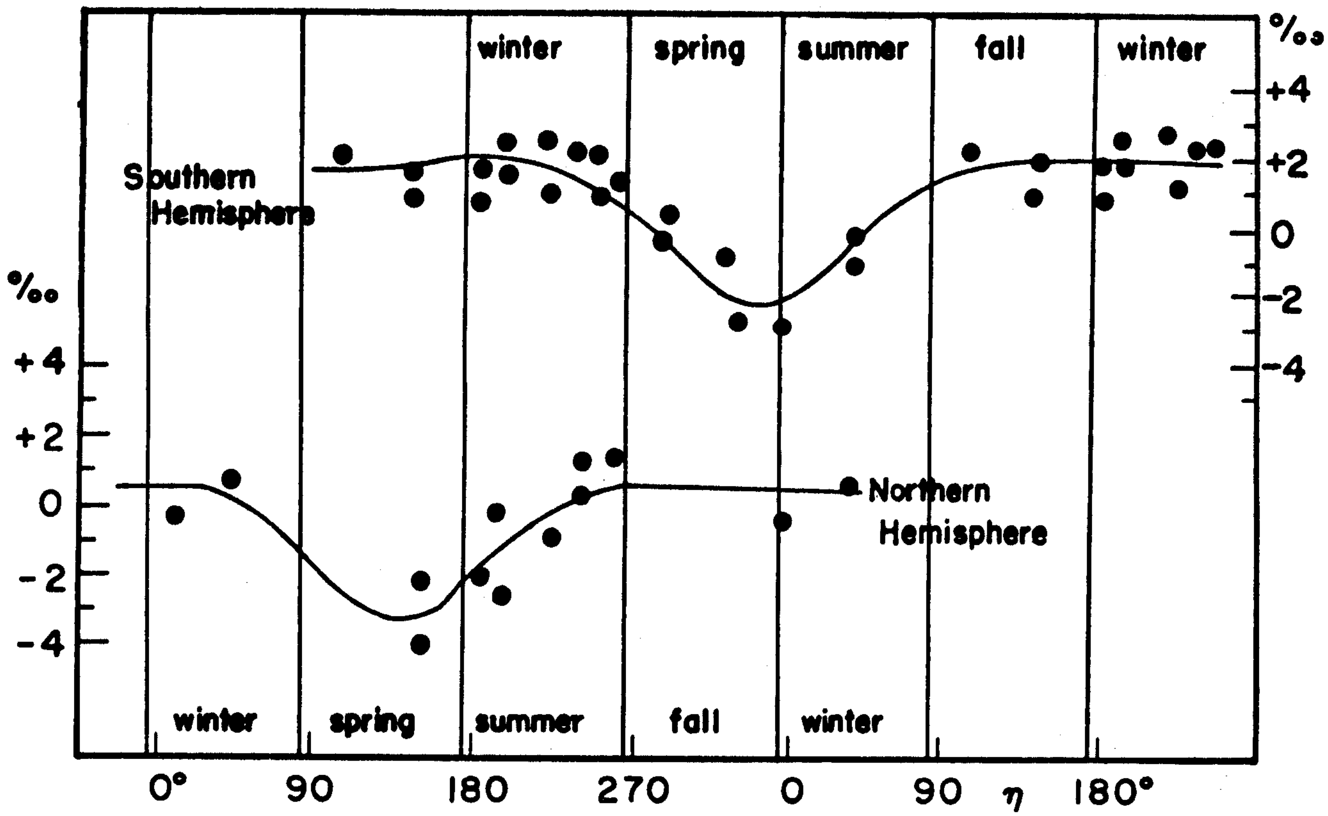


Figure 17. -- The seasonal variation of the polarization on Mars. Plotted against the heliocentric longitude, for a phase angle V = 25°, are the polarization differences between the dark and bright areas (Dollfus, 1961).

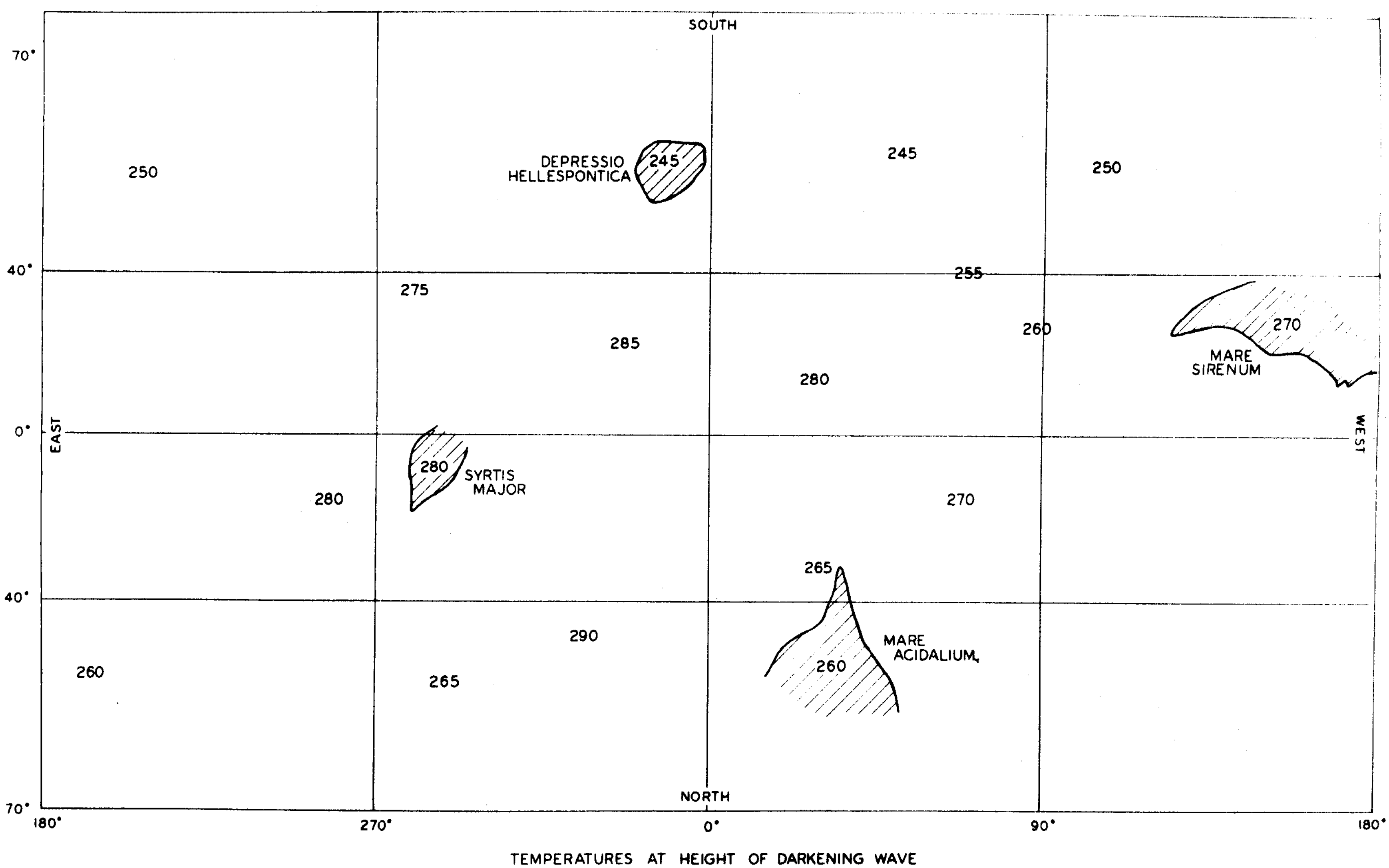


Figure 18. -- The noon surface temperature at the height of the darkening wave for various dark areas.

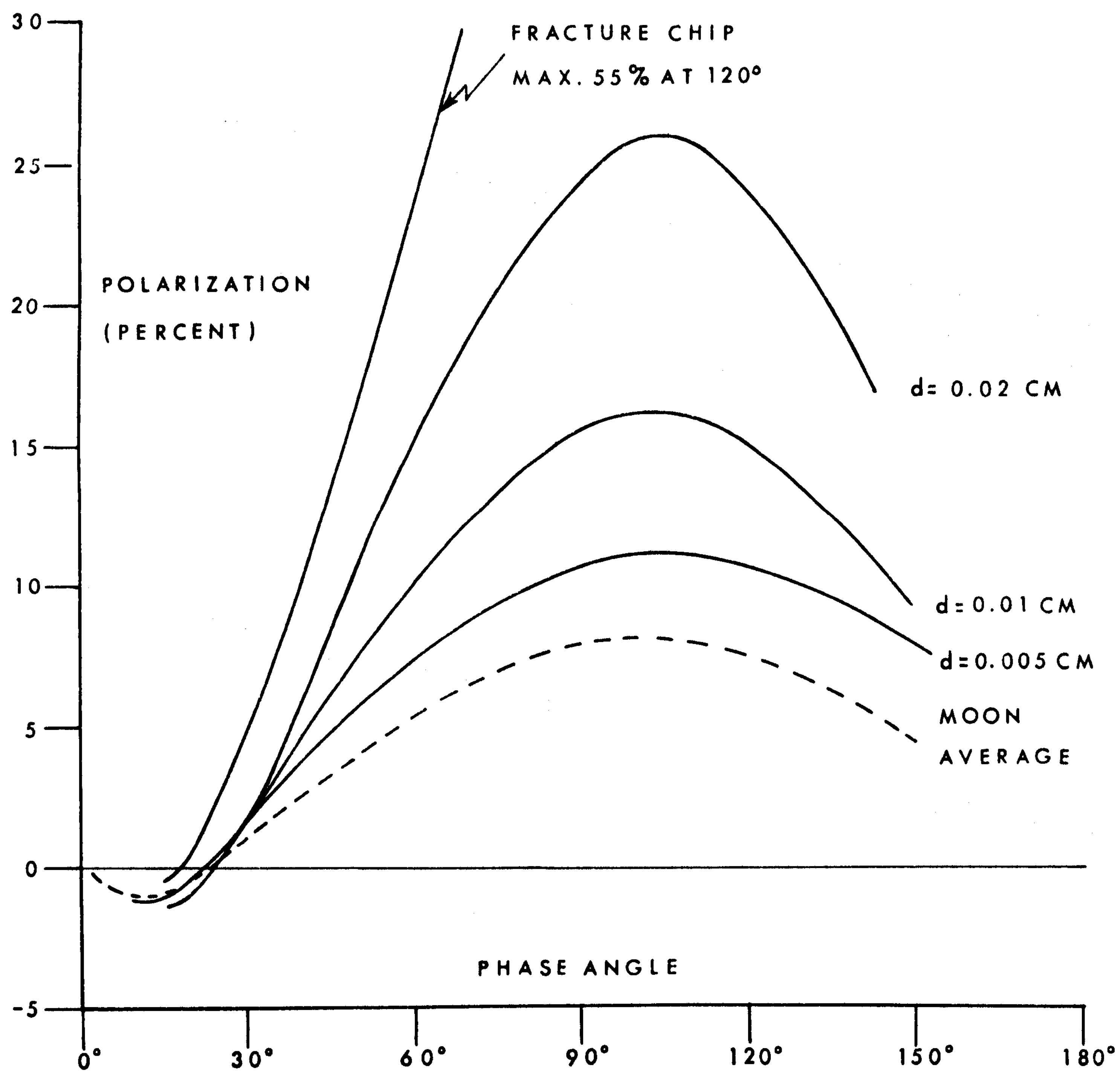
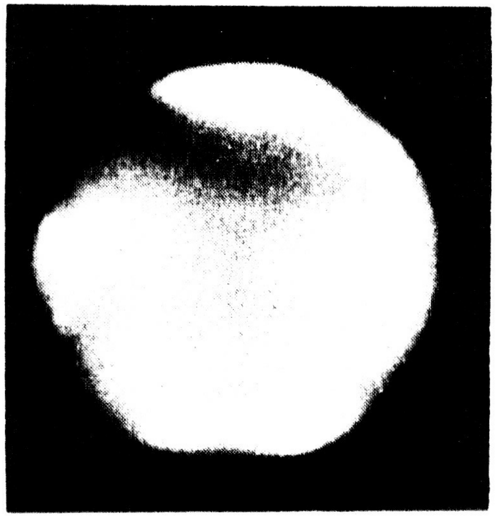
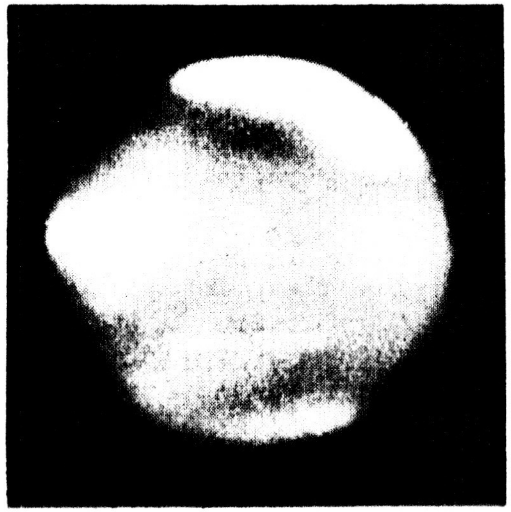


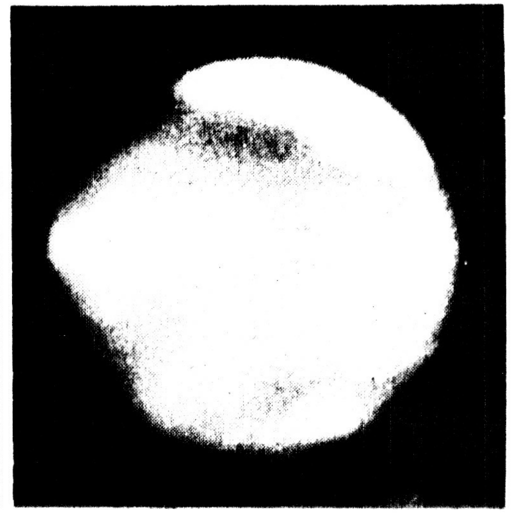
Figure 19. -- Polarization curves for a basalt with varying particle size (Wright et al, 1963).



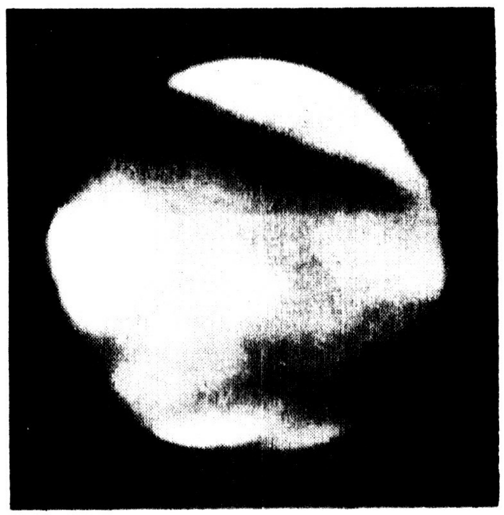
1. June 20 λ161°
U.T. 20:22 B
Mar 23 M.D.



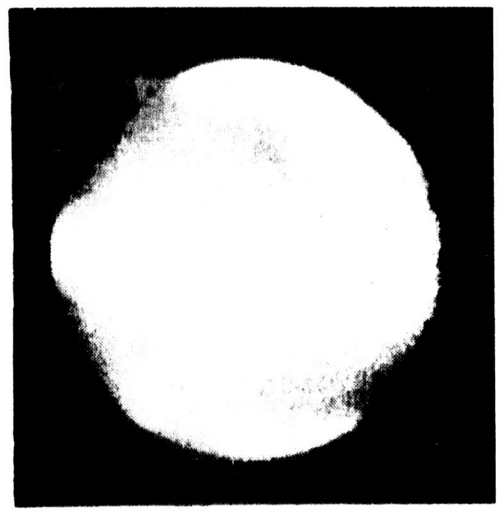
2. June 22 λ147°
U.T. 20:35 B



3. June 26 λ147°
U.T. 23:01 B

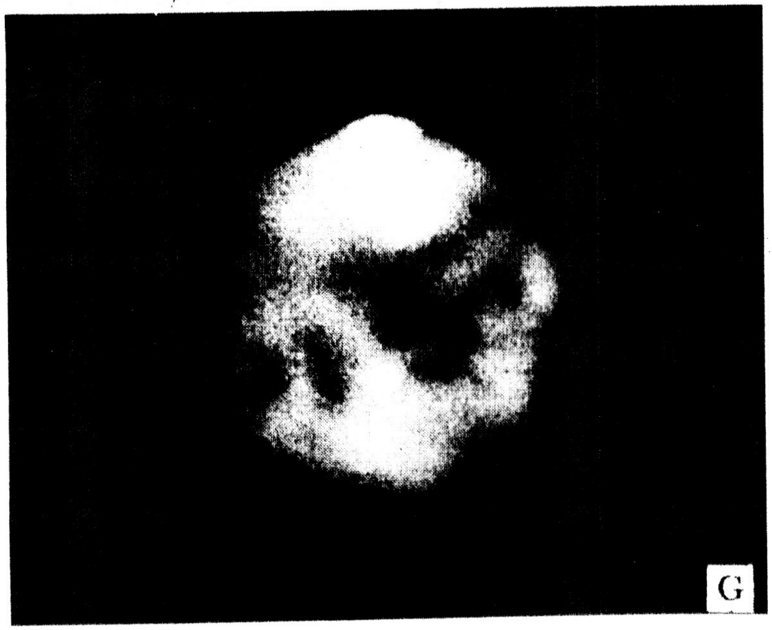


4. June 28 λ157°
U.T. 0:19 B

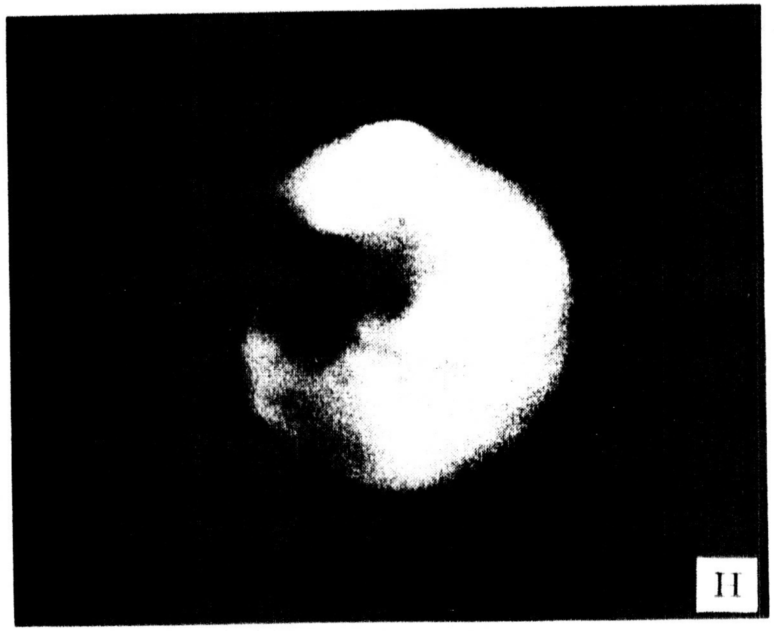


5. June 29 λ146°
U.T. 0:09 B

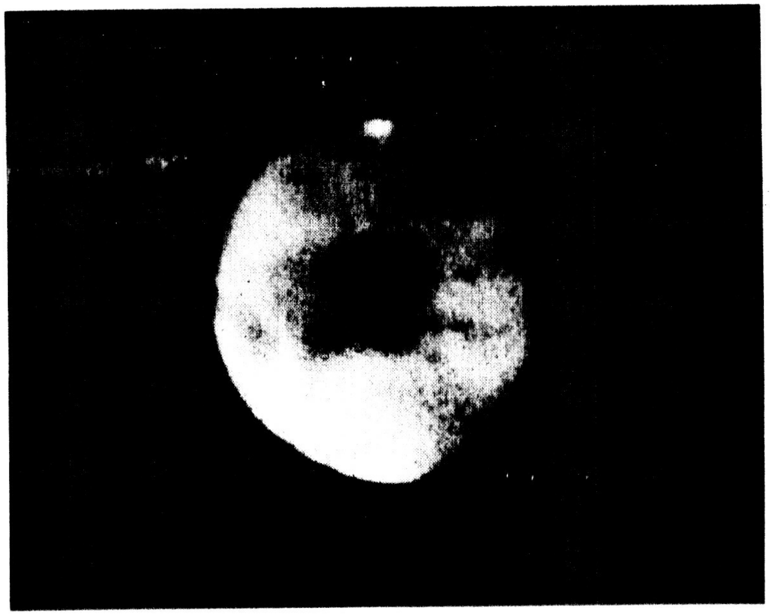
Figure 20. -- The repeated occurrence of W-shaped clouds over the Tharsis region in 1954 (Slipher, 1962).



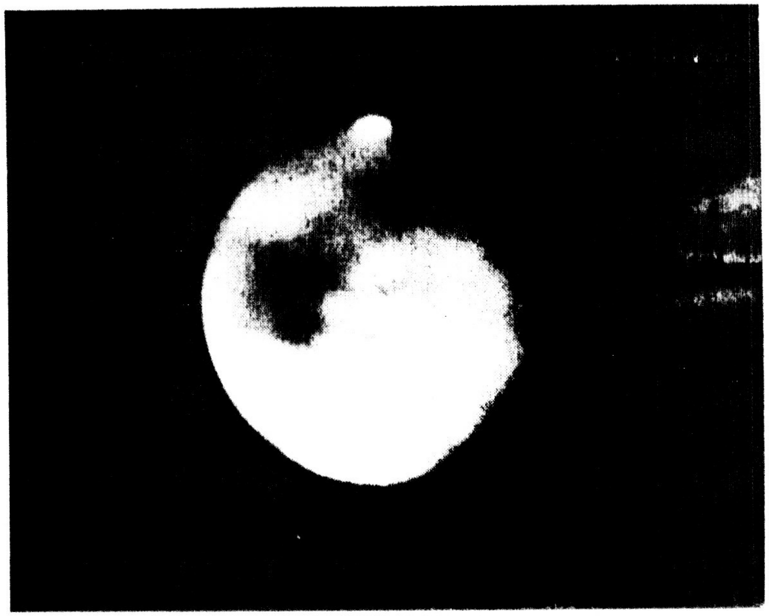
1956 Sept 12 $\lambda 37°$
U.T. 7:25 June 11 M.D. R



1956 Sept 9 $\lambda 73°$
U.T. 8:06 June 9 M.D. Y

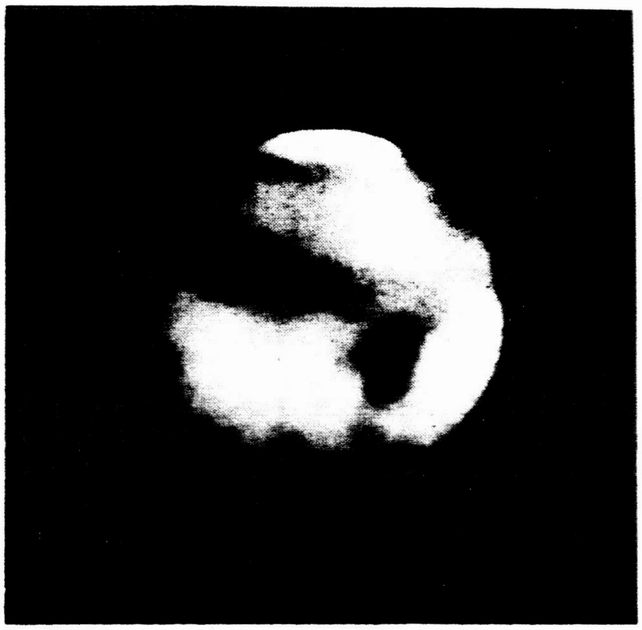


1941 Nov 10 $\lambda 62°$
U.T. 7:07 July 30 M.D. Y

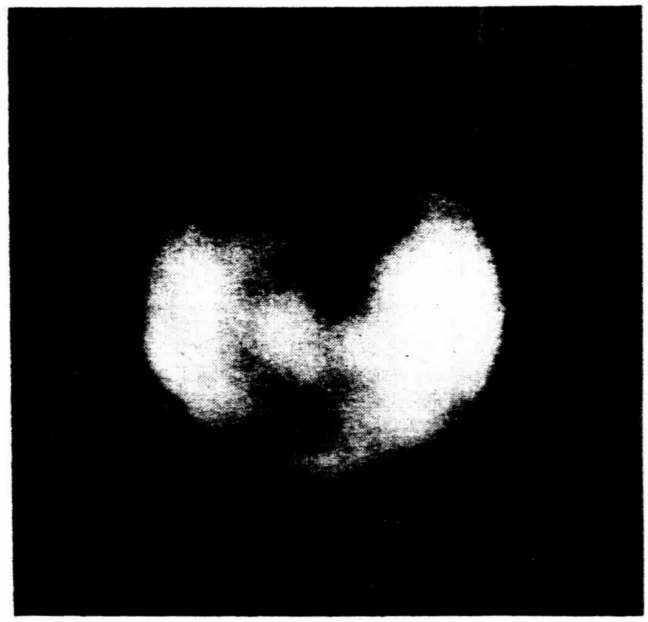


1941 Nov 4 $\lambda 82°$
U.T. 5:22 July 28 M.D. Y

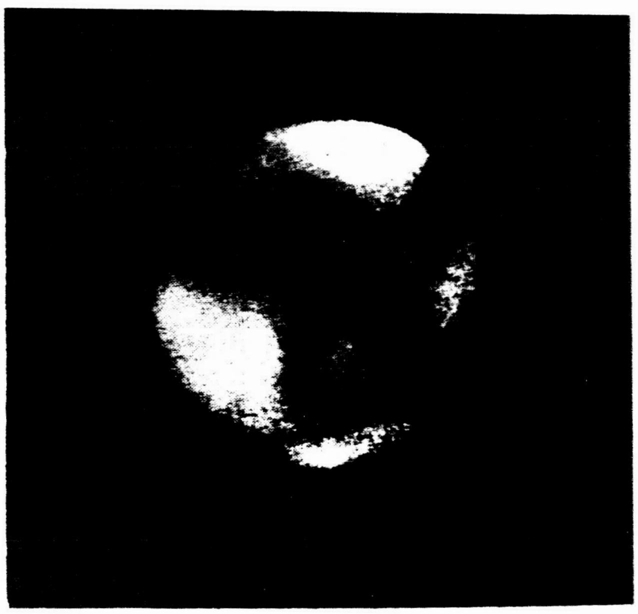
Figure 21. -- Examples of temporary dark areas adjacent to dust clouds, observed in 1956. In the upper left hand photograph the spot is to the left of Solis Lacus, in the upper right one the normally bright Thaumasia is dark. The 1941 pictures indicate the normal appearance (Slipher, 1962).



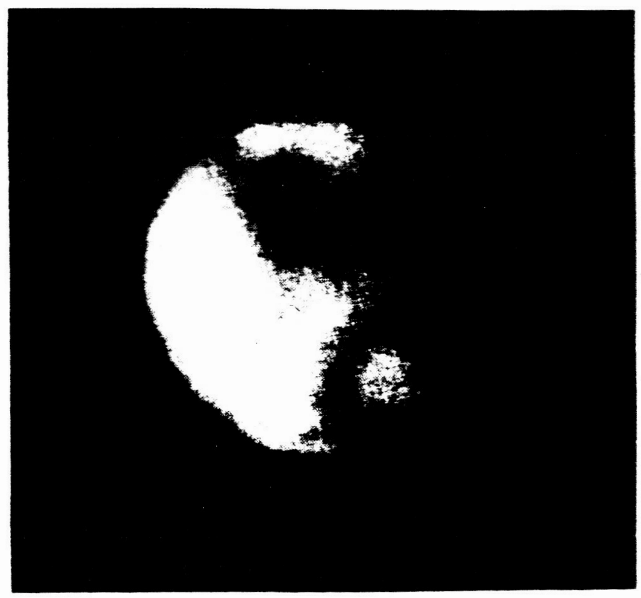
2. 1907 July 3 $\lambda 270°$
U.T. 4:21 Apr 7 M.D. Y



8. 1920 Apr 23 $\lambda 285°$
U.T. 8:47 Jan 25 M.D. Y



9. 1922 June 18 $\lambda 260°$
U.T. 7:25 Mar 16 M.D. Y



12. 1928 Dec 29 $\lambda 245°$
Sept 28 M. D. Y

Figure 22. -- Pronounced secular changes in the Thoth-Nepenthes region (Slipher, 1962).

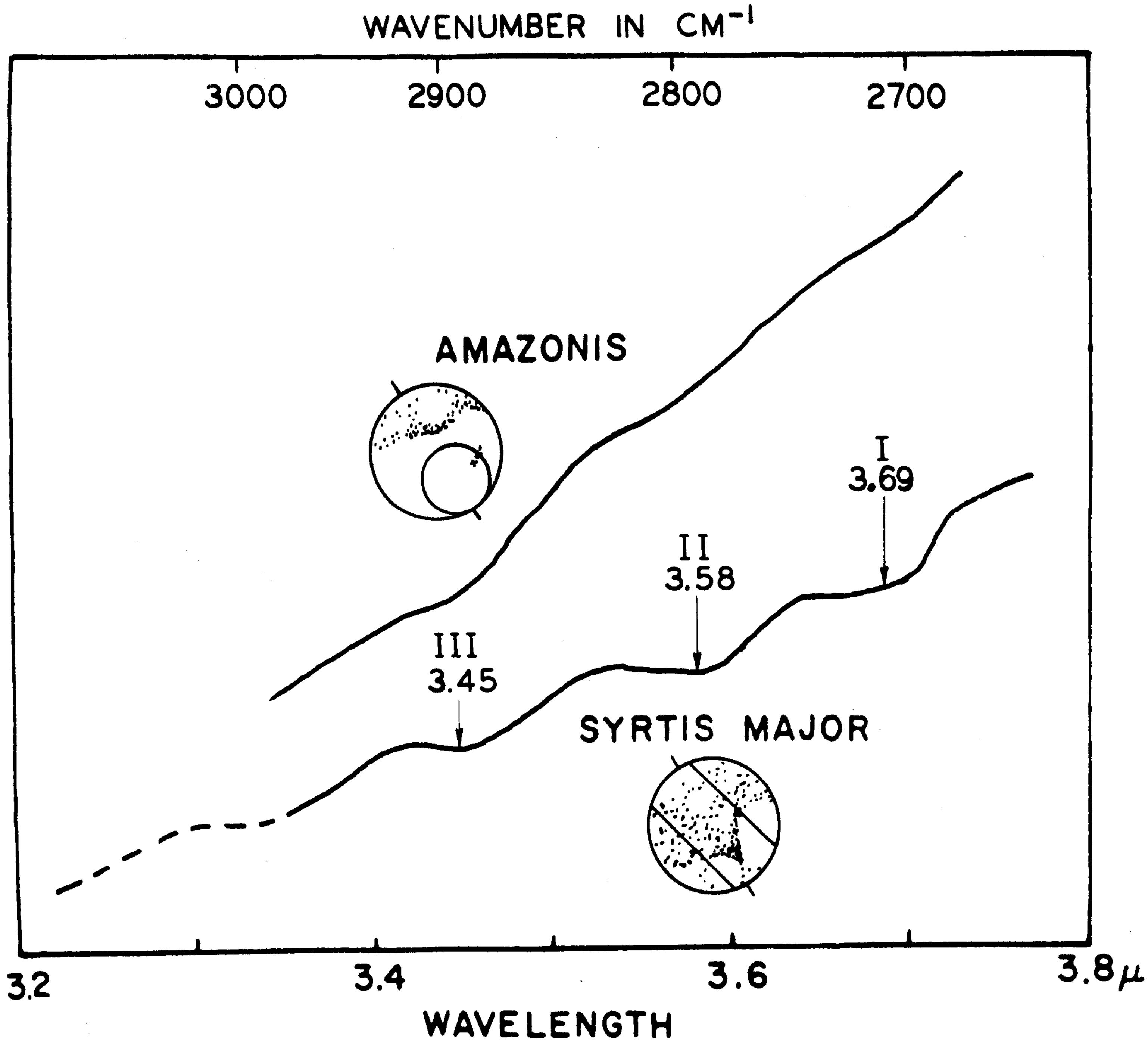
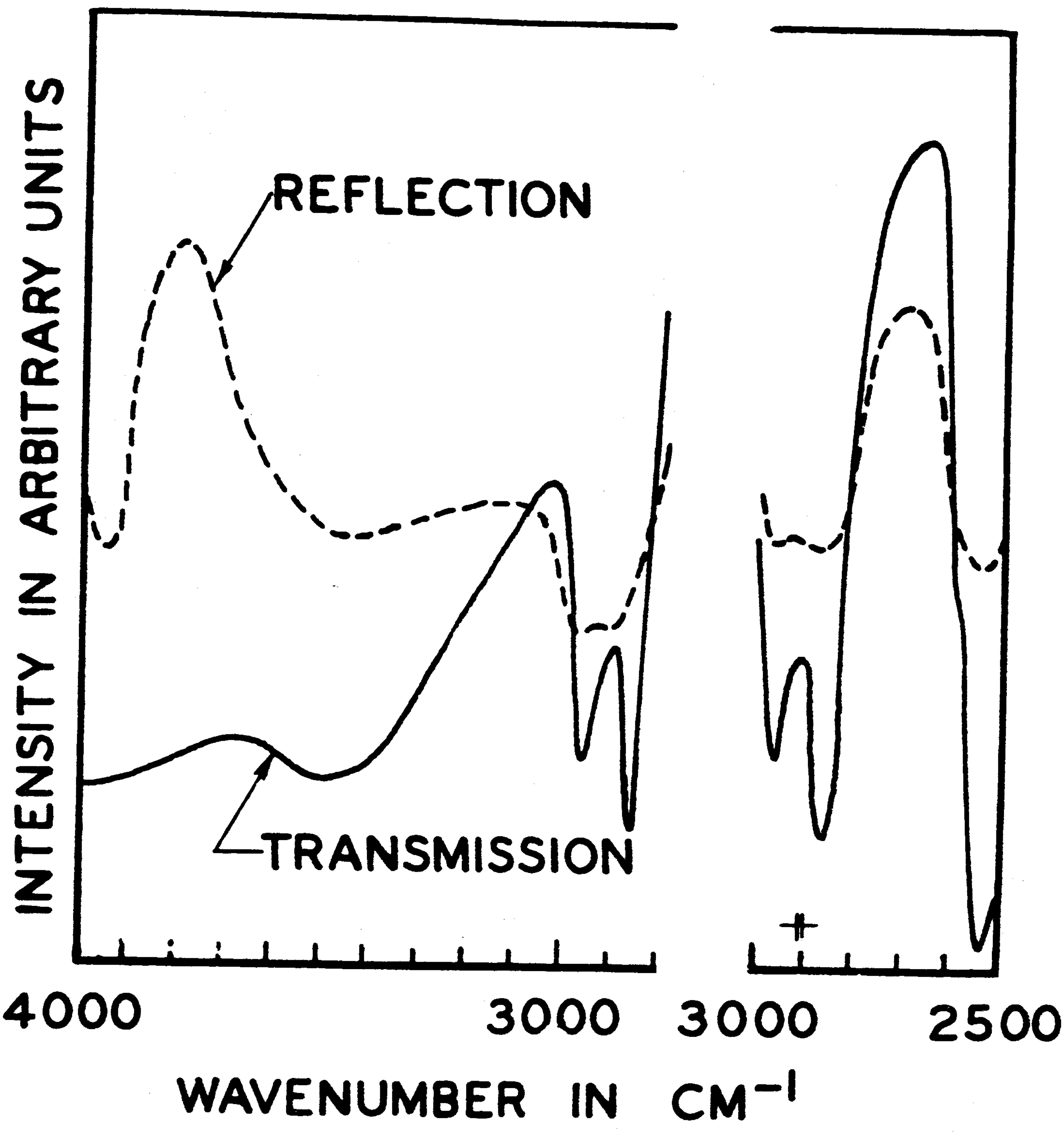


Figure 23. -- The 3 - 4 μ spectrum of Mars observed by W. M. Sinton (Rea et al, 1963).



--e 25. -- The transmission and reflection spectra of $CaCO_3$ (Rea et al, 1963).

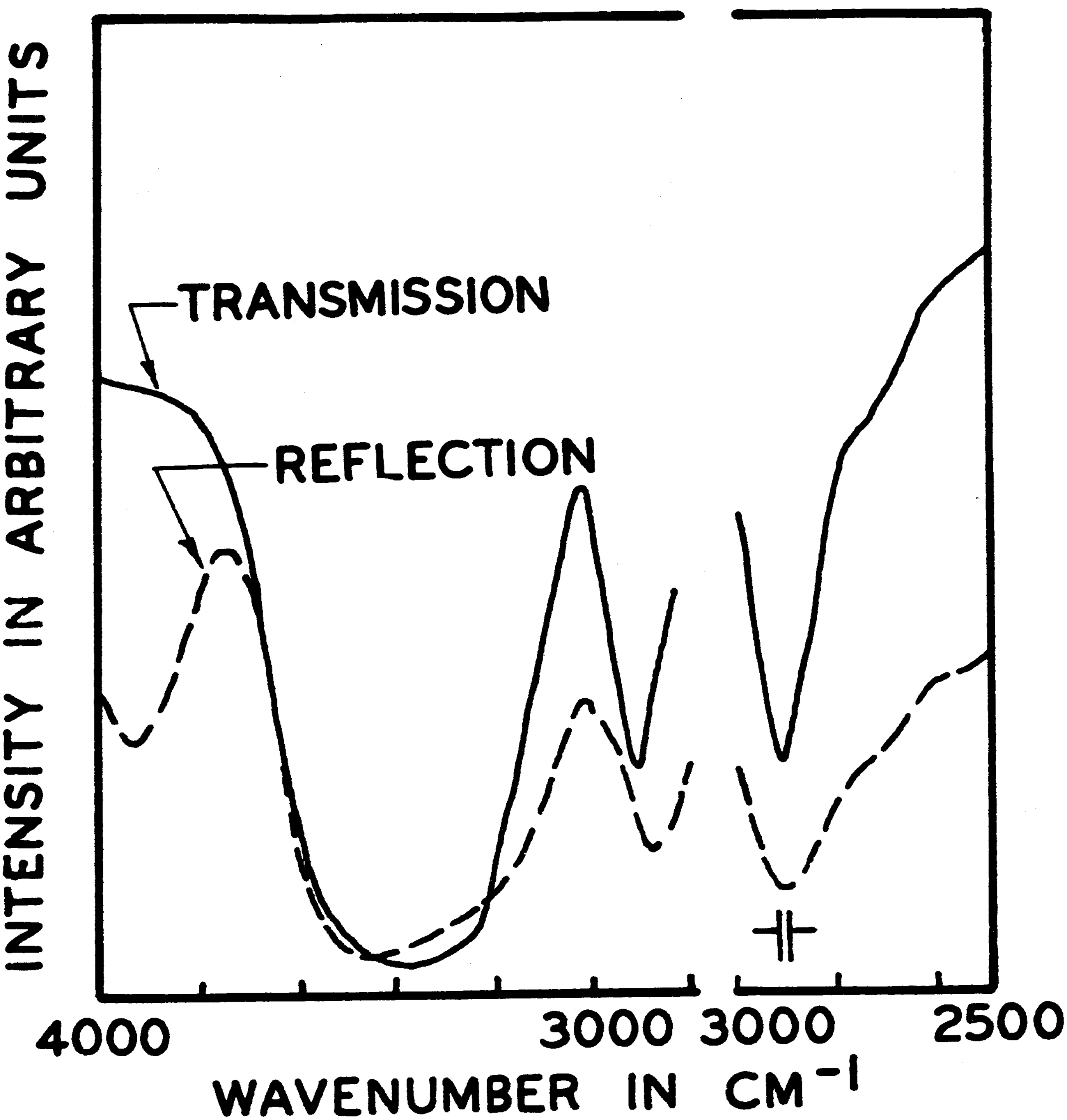


Figure 24. -- The reflection spectrum of cellulose (Rea et al, 1963).