ESTIMATION OF THE DENSITY OF MARTIAN SOIL FROM RADIOPHYSICAL MEASUREMENTS IN THE 3-CENTIMETER RANGE

by

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Estimation of the Density of Martian Soil From Radiophysical Measurements in the 3-Centimeter Range

N. N. Krupenio

Abstract

The density of the Martian soil is evaluated at a depth up to one meter using the results of radar measurement at $\lambda_0 = 3.8$ cm and polarized radio astronomical measurement at $\lambda_0 = 3.4$ cm. conducted onboard the automatic interplanetary stations "Mars-3" and "Mars-5". Significant variations are noted for the values of the soil density. The average value of the soil density according to all measurements is $\bar{\rho} = 1.37 \pm 0.33$ g/cm^3. /2.

The average value of the relative tangent angle of loss in the matter of the Martian soil is the ratio of the tangent angle of loss to the density of the matter which depends on the chemical composition of the matter. $tg\Delta/\rho = (4.3 \pm 1.7)\cdot 10^{-3}$, which corresponds to the silicate rocks of acid or medium composition.

A map of the distribution of the permittivity and soil density is derived, which was drawn up according to radiophysical data in the 3 centimeter range.

Introduction

/3.

Kortikov (1962), and also Campbell and Ulrichs (1969), researched the connection between the density $-\rho$ and the permittivity $-\varepsilon$ in different earth dehydrated rocks with a varying degree of the state of comminution. These studies showed that there exists a close connection between ρ and ε with a 10% accuracy for the large class of rocks from acid to ultrabasic. The results of the research done on the lunar soil, which were brought to earth by the automatic space stations "Luna-16" and "Luna-20" and by the astronauts of the Apollo series of space flights, confirmed these conclusions.

Therefore, it is possible to estimate the density of the Martian soil based on the results of the remote determination of the permittivity of Martian soil.

The local value for the effective permittivity of the soil can be determined from the radar or radiometric (radioastronomic) measurements. During radar measurement ε is determined by the specific effective scattering surface at normal incidence σ_{ON} and the diagram of reverse scattering $B(\theta)$.

Determination of the local values for ε of the lunar soil was conducted by Muhleman (1968) for the landing sites of the automatic space stations in the "Surveyor" series and by Krupenko (1971) for the landing sites of the automatic space stations of the "Luna" series.

The possibility for determining ε of the surface layer matter according to the data from polarized measurements by using radiothermal radiation was shown by Troitskiy (1954) and was first used for the /4.

moon by Soboleva (1967) at λ_0 = 3.2 cm and 6.3 cm.

Because of insufficient angular resolving power on the part of the ground radio telescopes, measurement of the polarization of local sites on Mars was impossible from Earth. Therefore, from ground observation points determination of ε of the Martian soil is only possible by using radar methods.

Radiophysical research of the Martian soil from the space surrounding the planet was conducted only by using radio astronomy polarization methods from onboard artificial satellites "Mars-3" and "Mars-5", although the possibility of long-range radiophysical determination of ε is not limited to only this method. The measurement of ε may also be successfully determined by autonomous and bistatic radar methods conducted from onboard the landing craft or from artificial satellites of the planet.

1. Areas of Research

Ground radar observations of Mars at λ_0 = 3.8 cm were conducted at oppositions in 1967, 1969 and 1971. During these observations the areas near the equatorial regions in latitudes $\varphi = -14 \div +22^0$ were studied.

Radar observations were carried out by uninterrupted irradiation of the transmitter with the help of spectral analysis of the reflected signal (1969, 1971). Resolution along the surface in the direction of the Doppler equator, approximately coinciding with the geometric equator, was determined by the passband width of the central filter of the spectral analyzer and by the integration time of the reflected signal. In the orthogonal direction the resolution was determined /5.

by the width of the diagram of the reverse scattering of the surface. In determining the resolution along the surface in a "north-south" direction, the width of the average curve of the reverse scattering was used on the level of "-3 decibels" for the given opposition. In the 1971 experiments the resolution was increased because of the use of pulse modulation.

In the regions of Mars where radar observations were conducted the obtained resolutions along the surface were 300 x 300 kilometers for the measurements in 1967 and 1969 and 80 x 80 km for the measurements conducted in 1971.

The polarization measurements of the radio emissions of Mars were conducted with the help of 3-cm "RA" radiotelescopes, the general design of which is shown in figure 1. The solar-stellar orientation of the automatic interplanetary stations "Mars-3" and "Mars-5", and also the choice parameters for the orbits of these artificial satellites allowed the study of regions, covering a wide range of latitudes and longitudes. The resolutions on the surface in these experiments were determined by the width of the beam pattern of the antenna equal on the level of "-3 decibels $2\alpha 0.5 \simeq 4^0$, and also by the height of the flight of the automatic interplanetary station and the sighting angles of the antenna. The minimal linear resolution on the surface was approximately 80 km ($\sim 1.3^0$).

Measurements of radiothermal radiation on the automatic interplanetary station "Mars-3" were conducted for the region

$$\varphi = 70^0 - +45^0, \quad \lambda = 185 - 360^0 \text{ and } 0 - 84^0.$$

Measurements on the automatic interplanetary station "Mars-5" were conducted for two regions. The coordinates of the first region (west) are: $\varphi = -23 - 39^0$, $\lambda = 61 - 127^0$, the coordinates of the second region (east) are: $\varphi = -6 - 30^0$, $\lambda = 344 - 360^0$ and $0\text{-}39^0$.

The accuracy of the coordinate reference of the "RA" radiometer's antenna track is on the average better than 1^0 in the experiments on the automatic interplanetary station "Mars-3" and better than 0.5° in the experiments on the automatic interplanetary station "Mars-5".

2. Results of the Evaluation of the Density of the Surface /6.

The density of the surface was evaluated according to Kortikov's formula:

$$\rho = 2(\varepsilon^{\frac{1}{2}} - 1),\ \text{g.cm}^{-3} \qquad (1)$$

Data on the effective ness of the permittivity were taken from the reports of Basharinov et al. (1973, 1975) and (1973).

The values of ρ, obtained from the results of determining ε in the Pettingill . (1973) work were approximated by a polynomial of the third degree, which yielded less error in approximation than a polynomial of the first degree, which was suggested in Pettingill's article (1973). The results of the evaluation of the soil density using radar data in 1971 are presented in figure 2.

The effective permittivity using ground radar measurement data of 1967 and 1969 (Pettingill, 1969; Rogers et al., 1970) was computed in the following manner. The effective area of planet scattering was determined:

$$\sigma_\Sigma = \sigma_c \cdot \frac{\int_{-f_{\partial max}}^{+f_{\partial max}} P(f)\cdot df}{\int_{-f_c}^{+f_c} P(f)\cdot df}, \qquad (2)$$

where: $P(f)$ is the Doppler spectrum of the reflected signal;

f_c is the half width of the frequency response of the central spectroanalyzer filter;

$f\partial_{max}$ is the maximum value of the Doppler frequency of the reflected signal from the planet, which corresponds to the reflection from the limb of the planet at the Doppler equator;

a is the radius of the planet;

σ_c is the effective scattering area of part of the planetary surface, corresponding to the intensity of the reflected signal in the central filter of the spectroanalyzer.

Processing the local Doppler spectra using the method of reverse Abelian transformation yielded the corresponding local curves of reverse scattering $-B(\Theta)$ suggesting symmetry of these curves relative to the preradar point in any direction. Then these curves were approximated by the Hagfors-Bachman Law in the form (Hagfors, 1964): /7.

$$B(\Theta)=\cos^4\Theta + C\sin^2\Theta)^{-3}/_2 \qquad (3)$$

By this we obtained a useful connection between the half-width diagram and the reverse scattering on the "-3db" level of $\Delta B_{0.5}$ and the large-scale root-mean-square slope of the surface $-\sigma_\alpha$ for the values of the parameter C larger than 20, which for Mars at λ_0=3.8 cm. (C_{min}>100).

$$\Delta B_{0.5} \simeq \frac{\sigma\alpha\ (\text{deg})}{1.3}, \text{ deg.} \qquad (4)$$

Using the connection between the specific effectiveness of the scattering area with a normal incidence σ_{ON} with the Fresnel factor of reflection for the case of a normal incidence - R and the relative effective scattering area of the planet, we were able to determine the local values of R:

$$R = \frac{\sigma\Sigma}{\Pi a^2} \cdot \frac{1}{C \cdot \int_0^{\pi/2} B(\Theta) \cdot \sin\Theta d\Theta} \qquad (5)$$

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In addition, using the Fresnel formula we computed the corresponding values of ε.

In determining the effective permittivity in this manner, the reflected signal was not taken into consideration, which is created by the small-scale structure of the surface with a characteristic size of $\ell \lesssim \lambda_0$.

The processing of the Doppler spectra showed that the upper evaluation of the reflected signal intensity from these heterogeneities does not exceed 10% of the total intensity of the reflected signal.

Since this value is less than the error of determination of the total intensity of the reflected signal, we did not take it into consideration when determining the value of ε. Evaluations showed /8. that the aggregate error of the determination of ε with the use of radar in 1967 and 1969 did not exceed 40%, and the aggregate error of ε according to the measurements conducted in 1971 was ≤30% (Pettingill et al. 1973).

The results of determining ρ with the use of radar in 1967 and 1969 are presented in figure 3.

The effective permittivity of the Martian surface from polarized radioastronomic measurements was determined within the framework of a smooth surface model.

However, the real surface in the limits of the area being resolved by the antenna of the radiotelescope is different from the smooth sphere, determinable by the average radius of the planet. The intensity and polarization of the radio emission of the surface depends on the average slopes, and also on the large-scale (in comparison with the wave-length - λ_0) heterogeneities. Therefore, in determining ε and ρ from polarized measurements, it is necessary to include corrections because of the effect of large and small-scale topography. The best way to determine these corrections is a simultaneous measurement of the topographical elements with polarized radioastronomic measurements onboard an artificial satellite at the same bearing angles as the angles for the antenna of the radio telescope. These measurements were not conducted on the automatic interplanetary station "Mars-3" and "Mars-5". Therefore, the topographical elements in the limits of the area of the surface site of the radio telescope's antenna (80-400 km) will be evaluated by us from other measurements.

Information on the average slope angles may be obtained from three sources: from spectrometric measurements near λ_0 = 2 microns, conducted from onboard "Mars-3" and "Mars-5", from measurements of high altitude profiles with the use of ground radar, by displacement of the maximum Doppler spectra relative to the subradar point in ground radar.

Spectrophotometric measurements in the absorption line of CO_2 close to $\lambda_0 = 2$ microns permitted us to determine the altitude profiles along measurement flight paths of the automatic interplanetary stations "Mars-3" and "Mars-5" at an angular instrument resolution of 0.5^0, which is 8 times better angular resolution than the "RA" radiotelescope. By considering the provisional averaging, the resolution of the spectrophotometer on the surface along the measurement flight path was approximately equal to the resolution of the radio telescope's antenna. The different resolution along the surface in the direction orthogonal to the direction of the measurement flight path can lead to a decrease or an increase of the average slopes in comparison with the measurements of the spectrophotometer. The character of the changes will depend on the form of the topography in the direction orthogonal to the direction of the path of measurements. Therefore, the data from the spectrophotometer may be used as solitary data. Figure 4 shows a histogram of the distribution of the average slope angles. This histogram is constructed from the measurements mentioned above. As we see, the maximum value of the average slope angles does not exceed 1.2^0. (In figures 4 and 5, N is the number of measurements of this given value of the parameter). /9.

The evaluation of the average slope angles on the differentiation of the altitude profiles, obtained from radar of Mars and Earth, yields values not exceeding 0.5^0. These evaluations correspond to the bases of 100-300 km. The average slopes within the limits of the surface section with measurements of approximately 300 km were estimated .

according to the deviation of the maximums of the Doppler spectra of the reflected signals relative to the subradar points during radar locations of Mars at λ_0 = 3.8 cm in the work of Rogers et al. (1971). These evaluations yielded average values for the slopes of 0.5° and maximum values of 1.5°.

Thus, our information indicates that it is sufficient to use the values of the average slopes to 1 - 1.5° in evaluating the determination error of ε and ρ.

The determination error of ε from the polarized measurements, as our computations showed, actually depend on the determination error /10.
of the sighting angle of the radio telescope's antenna (Krupenko et al., 1974). In computing the determination errors for ε according to the measurement data on the automatic interplanetary stations "Mars-3" and "Mars-5" we established the orientation errors for the antenna of ±3° (for the automatic interplanetary station "Mars-3") and of ±1.5° (for the automatic interplanetary station "Mars-5"). These values exceeded the orientation error of the automatic interplanetary station and the possible dislocation of the optical axis of the "RA" antenna relative to the structural axes of the automatic interplanetary station because of external loads.

In conjunction with this, the total error of determination also takes into consideration possible average slopes of the surface (±1.0°) in the measurement regions.

Large-scale irregularities lead to a decrease of the radio emission polarization factor, which is equivalent to a decrease of the measurable value of ε and the decrease of ρ. An evaluation of the large-scale irregularities may be conducted by extraterrestrial radar measurements of Mars at $\lambda_0 = 3.8$ cm. According to these data, the average value of the average vale of the average root-mean-square of the slope angles of the large-scale irregularities is $\bar{\sigma}_\alpha \approx 2.6^0$, and the maximum value is $\sigma_{\alpha\ max} = 12^0$. Figure 5 shows a histogram of the distribution of the average root-mean-square slope anles, constructed from radar data of 1967, 1969, 1971 at $\lambda_0 = 3.8$ cm.

The computations show that upon considering the given values for σ_α, the local density of the soil relative to the estimated values for the smooth surface model according to the estimated values for the smooth surface model according to the measurements of the automatic interplanetary stations "Mars-3" and "Mars-5" can increase up to 10%. Corrections in the estimated local values depend slightly on the value of ρ and on the values for the sighting angles of the radio telescope antenna in the areas of measurement.

Data on the small-scale topography of the Martian surface are lacking. Therefore, in analyzing the ground radar and the polarized radioastronomic measurements, they were not considered.

Upon considering the aforementioned evaluations, the accuracy /11.
of determining the local values for the soil density according to the data on the automatic interplanetary stations "Mars-3" and "Mars-5" is equal to +30 - -20%. Figure 6 and figure 7 show examples of estimates of the soil density from the results of two measurement sessions conducted on the automatic interplanetary stations "Mars-3"

and "Mars-5".

3. Comparison of the Results on Evaluation of the Surface Density Using Radar and Radioastronomic Measurement Data

Both radar and radioastronomic measurements showed that there are significant variations of soil density on Mars. According to data compiled from radar measurements, the density of the soil in different areas may vary from 0.4+0.6 to 2.5 + 3.1 g.cm^{-3}. An evaluation of the average values for the soil density according to radar observations in 1967, 1969 and 1971 at λ_0 = 3.8 cm are correspondingly equal to 1.72, 1.2 and 1.28 g.cm^{-3}, which corresponds to the average value of all of these measurements $\bar{\rho}$ = 1.3 g.cm^{-3}.

Radioastronomic measurements on the automatic space interplanetary stations "Mars-3" and "Mars-5" were conducted in different regions, and the measurements from the automatic interplanetary station "Mars-3" permitted measurement of the local characteristics of the ground in a rather large area. Analysis of these measurements showed that for the region, in which the accuracy of determination in the framework of a smooth model ρ < 20% which corresponds to the accuracy of the determination ε < 30%, the average values and variations of ρ respectively equaled: for the automatic interplanetary station "Mars-3" ρ_{min}=1.07; ρ_{max}=3.24; $\bar{\rho}$ = 1.99 g.cm^{-3}; for the station "Mars-5" (western region) ρ_{min}=1.2; ρ_{max}=2.5; $\bar{\rho}$=1.5 g.cm^{-3}; for the station "Mars-5" (eastern region) ρ_{min}=1.2; ρ_{max}=2.2; $\bar{\rho}$=1.66 g.cm^{-3}.

On the average for the measurements of the automatic interplanetary station "Mars-5", the average values of density were equal to /12.

$\bar{\rho}$=1.57 g.cm^{-3}. I.e. on the average, the results of the evaluation of the ground density using the data from the automatic interplanetary station "Mars-3" are higher than those measurements from "Mars-5" and higher than those from the ground radar observations.

As we see from the above data, the region of radioastronomic measurements from station "mars-5" with center coordinates of $\varphi = -3.5^0$, $\lambda = 95^0$, on the average have less ground density than the region $\varphi = -20^0$, $\lambda = 15^0$.

These data coincide with the results of simultaneous infrared measurement temperatures, conducted onboard "Mars-5" (Ksanfomaliti, Moroz, 1975). According to these measurements from February 23, 1974, we determined the thermal inertia parameter of the ground $\gamma = (K.\rho.C)^{-1/2}$, where K is the ground thermal conductivity, C is the thermal capacity of the ground. In the western measurement region the value was $\gamma = 250$, in the eastern region it was $\gamma = 125$. Correspondingly, during this session of measurements we obtained the average value for the gorund density using polarization measurements in the western and eastern regions $\rho = 1.46$ and 1.76 g.cm^{-3}. I.e. the least ground density corresponds to the snallest parameter value for the thermal inertia. Since parameter γ corresponds to the upper layer at a thickness less than 1 mm, then the coincidence of the change in the character of the γ and ρ probably corresponds to the different degree of the state of coominution of the ground in these regions, both close to the surface and as deep as one meter.

The average value for the ground density of Mars according to the data from all of the radiophysical measurements, which were conducted in a 3-x centimeter range, equals $\rho = 1.37$ g.cm^{-3} ± 25%.

The radiophysical measurements, which were conducted at different times and by different methods, in most cases relate to different regions. Therefore, there are probably differences in the determined values for ε and ρ in different experiments. However, there are several general regions, in which both radar and radioastronomic measurements were conducted simultaneously or an entire series of radioastronomic measurements were conducted under different conditions of observation. /13.

The results of all of the radiophysical measurements of Mars in a 3- centimeter range are given on a map of Mars (figure 10). A series of values for the ground density were chosen for the mapping of the ground density values:

ρ :< 0.9; 0.9 ÷ 1.3; 1;3 ÷ 1;7; 1.7 ÷ 2.1; < 2.1 g.cm^{-3} .

By analogy to the lunar ground this series covers the range of density from a very mellow soil to a very dense soil, approximating hard, rocky soil. Density quantization was also chosen considering the accuracy of determining the local value of ρ in the experiments.

The results of the radioastronomic observations for one and the same areas are averaged using all of the measurements where the regions of radar and radioastronomic measurements coincide, the radioastronomic measurements are cited on the map.

An analysis of the set of measurements showed that for the radioastronomic observations of the same regions under different conditions of observation (different angles of antenna orientation and different resolution on the surface), as a rule, the values for ρ

differed not more than one gradation. The differences between the radar and the radiostronomic measurements in several cases exceeds one gradation of density, which may be caused by the topography of the surface and the different resolution on the surface in these experiments.

In this report we have not examined the connections between the substance of the upper cover and the albedo, heights, slopes and other physical parameters. These connections will be examined separately. /14.

4. Electric Conductivity of the Martian Ground

As Troitskiy showed in 1970, the spectrum of radio emission from Mars in the millimeter range yields information on the depth of the electromagnetic waves' penetration. According to the planet's spectrum at the moment of opposition, we determined the parameter $\delta = m.\lambda_0$, which represents the relationship of the depth of penetration of the electromagnetic wave – ℓ_e to the penetration of the daily thermal wave – ℓ_T.

The parameter ℓ_T corresponds to the depth at which the daily variation in the surface temperature, determined by infrared measurements is decreased by e times.

The parameter ℓ_e corresponds to the depth at which the power current of the electromagnetic radiation decreases e amount of times.

The parameters ℓ_e and ℓ_T for the homogenous layer of the surface is determined by:

$$\ell_T = \frac{1}{\rho . C . \gamma} \cdot \sqrt{\frac{T\hat{c}}{\Pi}}, \ \mathrm{cm} \qquad (6)$$

$$\ell_e \approx \frac{\lambda_0}{2\Pi(0.5p+1)\cdot\rho\cdot B} \qquad (7)$$

where T_c = $8.8\cdot10^4$ sec. is the duration of a day on Mars;

C, cal.degree^{-1}.g^{-1} is the thermal capacity of the substance;

$\gamma = (K.\rho.C)^{-1/2}$, cal.cm^2.c$^{1/2}$ – is the thermal inertia parameter;

K, cal.cm^{-1}degree^{-1} – is the substance thermal conductivity;

$B = tg\Delta/\rho$ – is the relative tangential angle of electromagnetic energy loss in the substance.

The parameter m according to the data of Kislyakov et al. (1975), who used the entire set of measurements of the brightness /15. temperatures of Mars in the millimeter range, is equal to m = 4.6±1.

According to the determinations of other authors, choosing part of the brightness temperature measurements in this range, the parameter m varies from 1 to 10.

The value for the depth of penetration of the daily thermal wave was evaluated by Moroz et al. (1974) using the data from infrared radar from the automatic interplanetary station "Mars-3" with a ground density of ρ = 1.2÷0.2 g.cm^{-3}. To determine the values for the thermal inertia (γ = 125 - 250) from these measurements, the value of ℓ_T = 2.7 - 16.5 cm was subtracted. Since the ground, upon judging by the infrared and radiophysical measurements on the station "Mars-3" and "Mars-5", has on the average, an increase of density with the depth then to determine ℓ_T it is necessary to increase the value of the density to $\bar{\rho}$ = 1.3 ± 0.26 g.cm^{-3}. Thereupon the value for the penetration depth of the thermal wave with consideration of the value of the thermal capacity C = 0.19±0.2 cal.degree^{-1}g^{-1} (Troitskiy, 1970) and with the condition of mutual independence of the paramters C, γ and ρ for the regions measured by the station "Mars-3" will equal:

$\ell_T = 2.3 - 6.1$ cm ($\bar{\ell}_T \approx 4$ cm).

According to the measurements of the automatic interplanetary station "Mars-5", in the radio session on February 23, 1974, we obtained the same variations of the γ parameter, which were obtained from measurements on station "Mars-3" (γ = 125 - 250) (Ksanfomaliti, Moroz, 1975). The results of infrared radiometry from onboard the station "Mariner-9" yielded the same average values for the parameter γ that were yielded from "Mars-3", "Mars-5" ($\bar{\gamma}$ = 170) (Kieffer et al., 1973).

Therefore, the value of the average depth of penetration of the daily thermal wave ℓ_T = 2.8 - 6.1 cm will probably equal a wider area of the Martian surface, than the regions studies from onboard the stations "Mars-3" and "Mars-5".

Taking the value m = 4.6 ± 1, and the value ℓ_T = 2.8-6.1 cm, we obtain the average value for the penetration depth of the electro- /16. magnetic waves - ℓ_e (skin-layer): $\bar{\ell}_e$ = 44 - 100 cm (average value $\bar{\ell}_e$ = 65 cm). The value of ℓ_e is determined for the average wave length of the radiophysical measurements λ_0 = 3.6 cm.

Using this value of the average thickness of the skin-layer we can determine the value for the relative tangential angle of electromagnetic radiation loss:

$\bar{B} = (2.6 \div 5.9)\cdot 10^{-3}$ (the average value $\bar{B} = 3.8\cdot 10^{-3}$). According to L.N. Bondar', this value for the parameter corresponds to the silicate soil with 62 - 72% content of SiO_2.

The size of the parameter B for Mars is 1½ to 2 times smaller than that obtained by Troitskiy and Tikhonova (1970) for the moon - $B = (6 \div 9) \cdot 10^{-3}$.

Thus the value obtained for the relative tangential angle of loss for the upper cover of Mars allows us to conclude, in concurrence with the report of Shumlevich and Troitskiy that the chemical composition of the substance of the upper cover of Mars corresponds to acid, or middle silicate rocks. This is in keeping with the results of the infrared spectroscopy of the dust on Mars, conducted from onboard the automatic interplanetary station "Mariner-9" (Hanel et al., 1972).

5. Conclusions

The results of the radiophysical studies of Mars from Earth and the automatic interplanetary stations "Mars-3" and "Mars-5" permit us to make the following conclusions:

1. The average values for the ground density in a layer to 1 meter deep is equal to $\rho = 1.37$ g.cm^{-3} ±25%.

2. The local values for the ground density are large and reach values of $\rho_{min} < 0.5$ g.cm^{-3}, $\rho_{max} = 3$ g.cm^{-3}.

3. The relative tangential angle of loss of substance /17. in the upper layer of ground at a depth up to 1 meter is equal to $B = (2.6 \div 5.9) \cdot 10^{-3}$ cm3. on the average.

In the suggestion about the silicate composition of the upper cover of Mars, this corresponds to acid or middle rocks.

4. The dust cover of Mars has the same nature as the substance of the upper cover in a layer up to 1 meter thick.

Legends for the Figures /18.

Figure 1. General view of the radiotelescope "RA":

1. support horn for receiving signals from space radio emissions;
2. radiator of the parabolic antenna;
3. mirror of the parabolic antenna;
4. instrument container for the radio-telescope.

Figure 2. Density of the Martian ground according to ground radar measurements in 1971. The solid curve corresponds to the approximate results of the measurements with a polynomial of the third degree.

Figure 3. Density of the Martian ground according to data from ground radar observations in 1967 and 1969.

Figure 4. Histogramm of the average slopes for the Martian surface along the path for measurement of the automatic interplanetary station "Mars-3" after the settling of a dust storm.

Figure 5. Histogram of the average RMS of the slope angle of the surface on the bases of $\ell \geq 40$ centimeters according to the data of ground radar.

Figure 6. Density of the ground according to the measurements in one of the sessions with the station "Mars-3".

Figure 7. Density of the ground according to the measurements taken in one of "Mars-5" sessions.

Figure 8. Histogram of the ground density evaluation according to measurement data from the stations "Mars-3" and "Mars-5".

Figure 9. Histogram of the ground density evaluation of Mars according to the data from radar and polarized radioastronomic measurements.

Figure 10. Map of the dielectric penetrability and density of the ground according to the data from radiophysical research in a 3-cm centimeter range.

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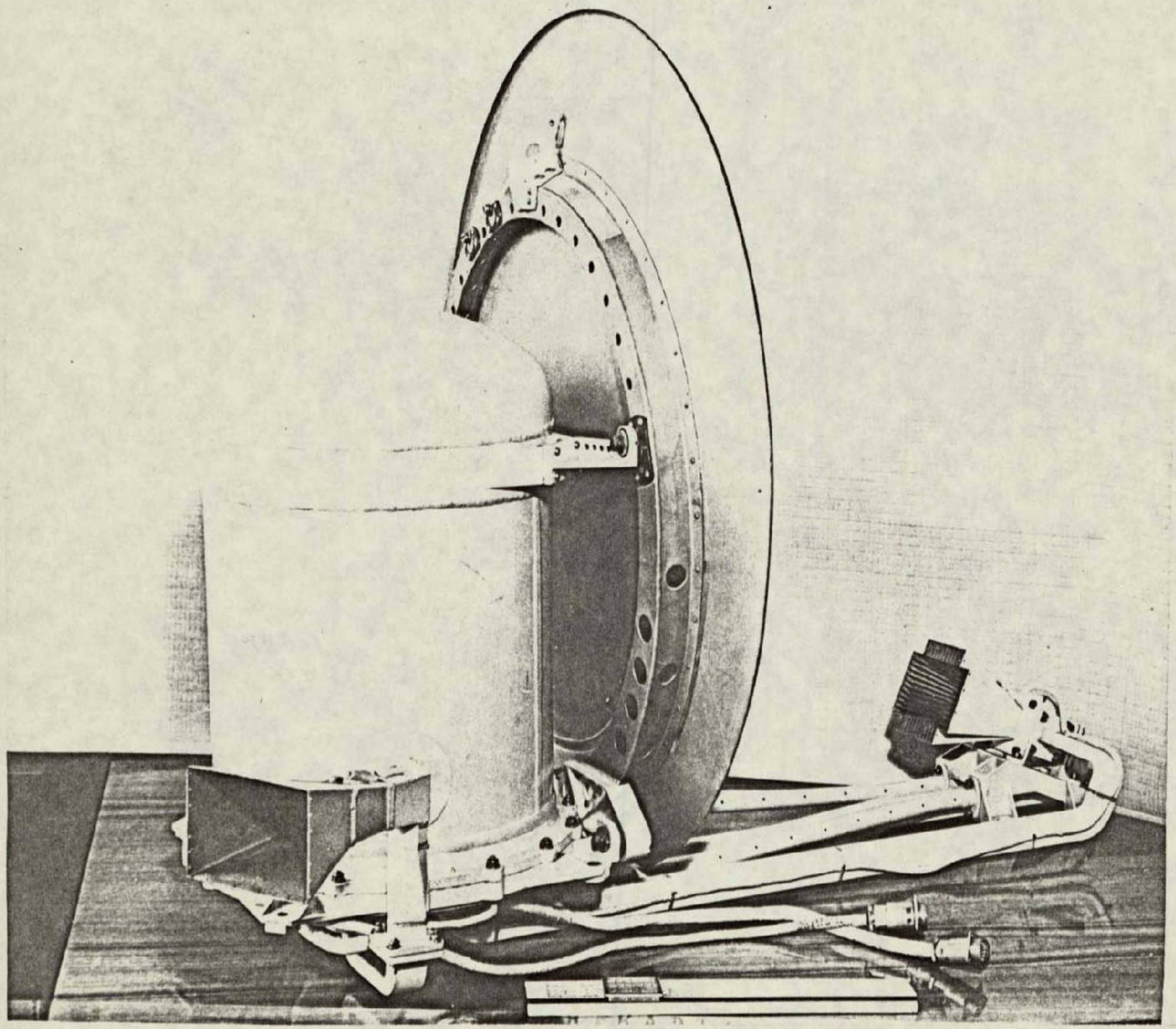


Рис.I

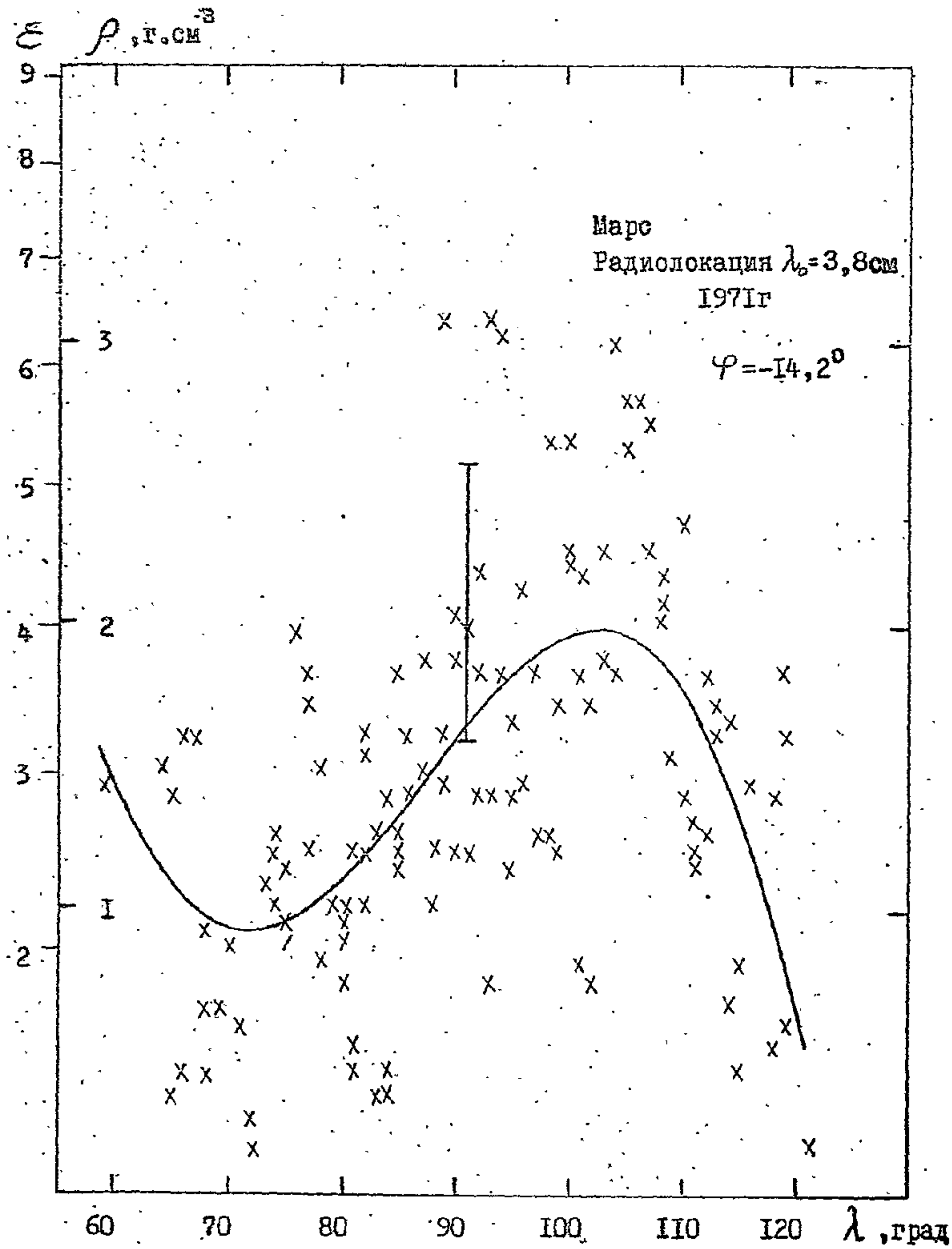

ε ρ, г.см⁻³
9
8
7
6
5
4
3
2
3
2
I
Марс
Радиолокация λ₀=3,8см
I97Iг
φ=-I4,2°
60
70
80
90
100
II0
I20
λ ,град

Рис.2

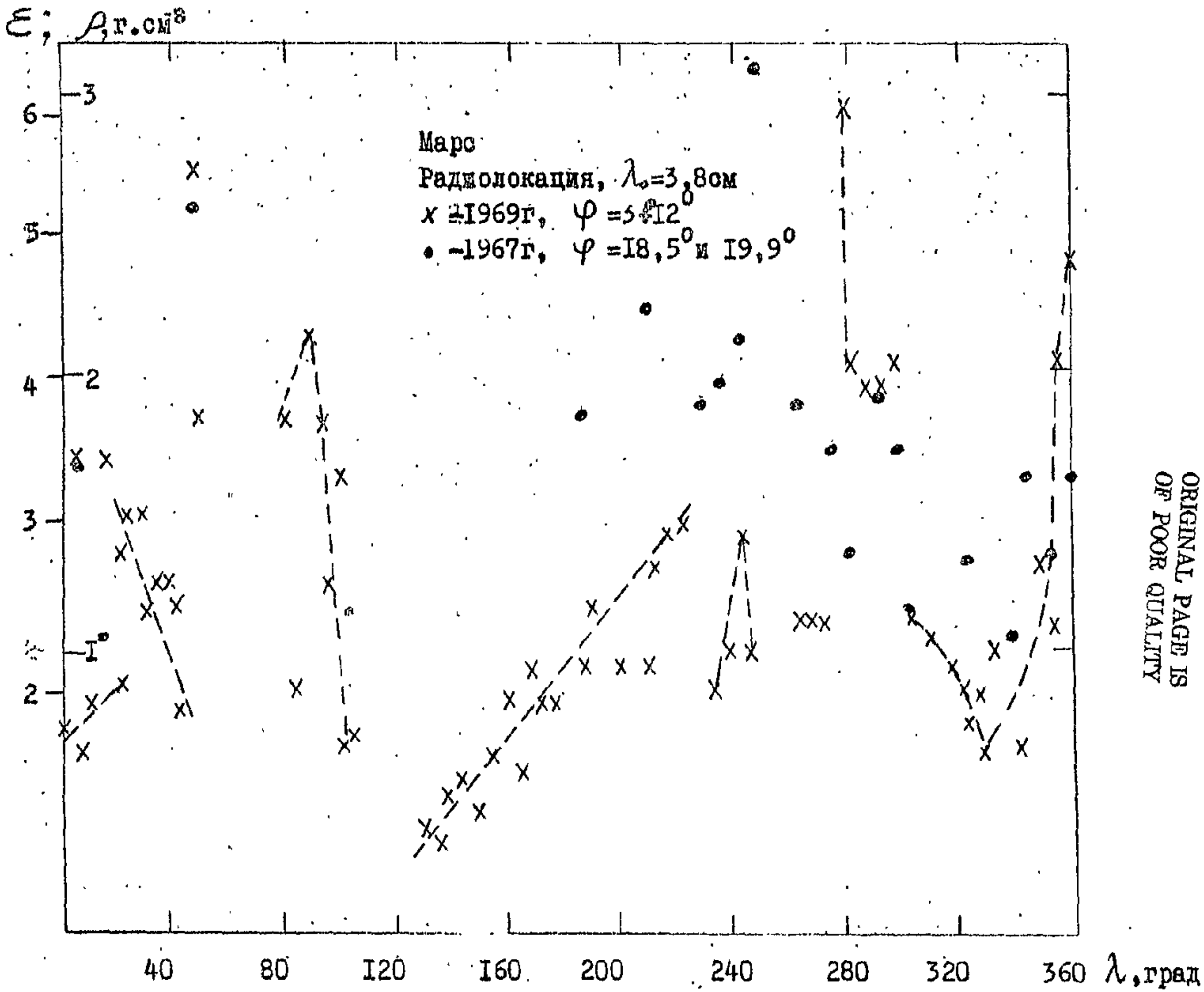
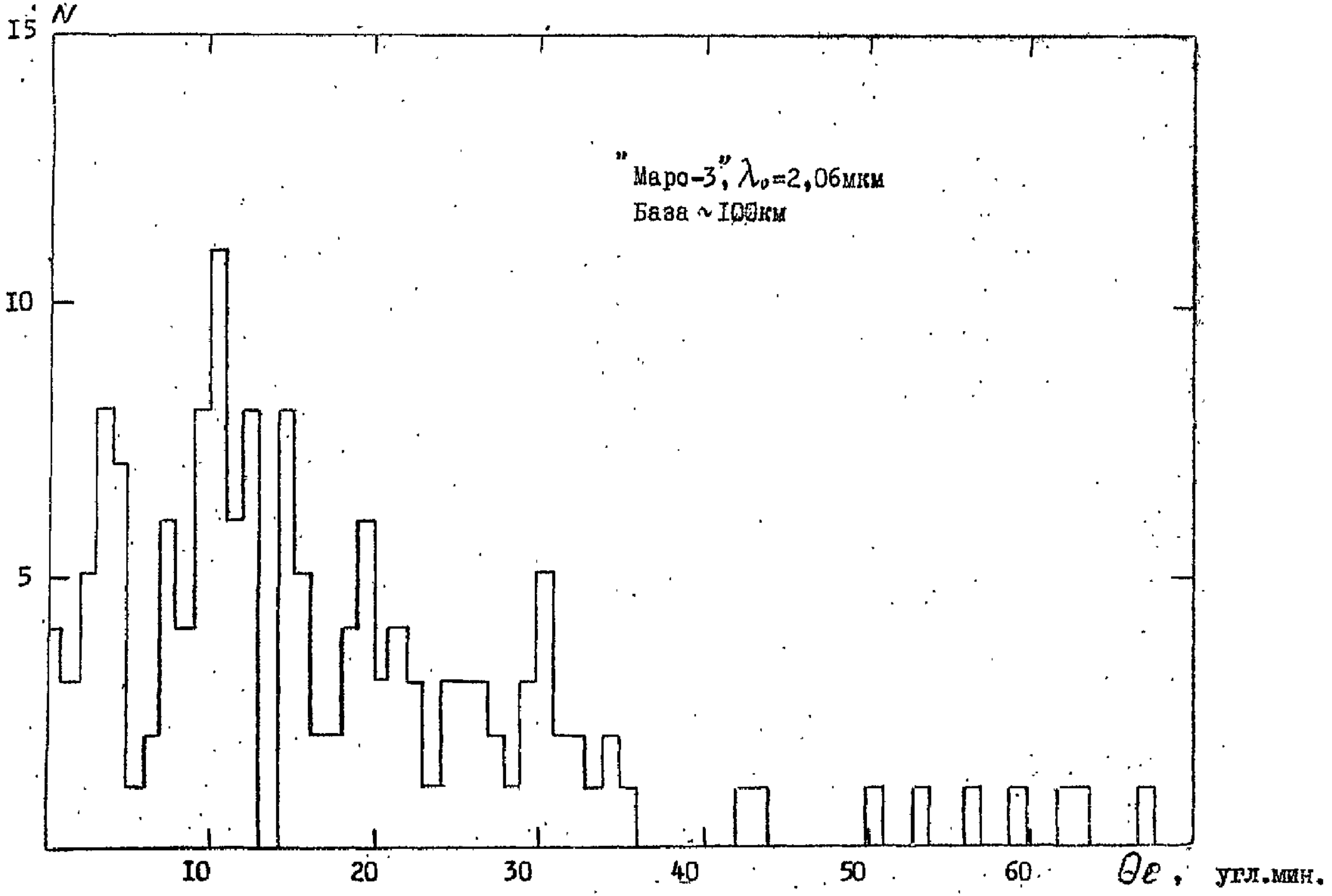

ε; ρ,г.см³
Марс
Радиолокация, λ₀=3,8см
x –1969г,
• –1967г, φ =18,5° и 19,9°
λ,град
40
80
120
160
200
240
280
320
360
2
3
4
5
6
I
2
3

Рис.3



N
15
10
5
"Маро-3", λ_0=2,06мкм
База ~ 100км
10
20
30
40
50
60
θ_e, угл.мин.

Рис.4.

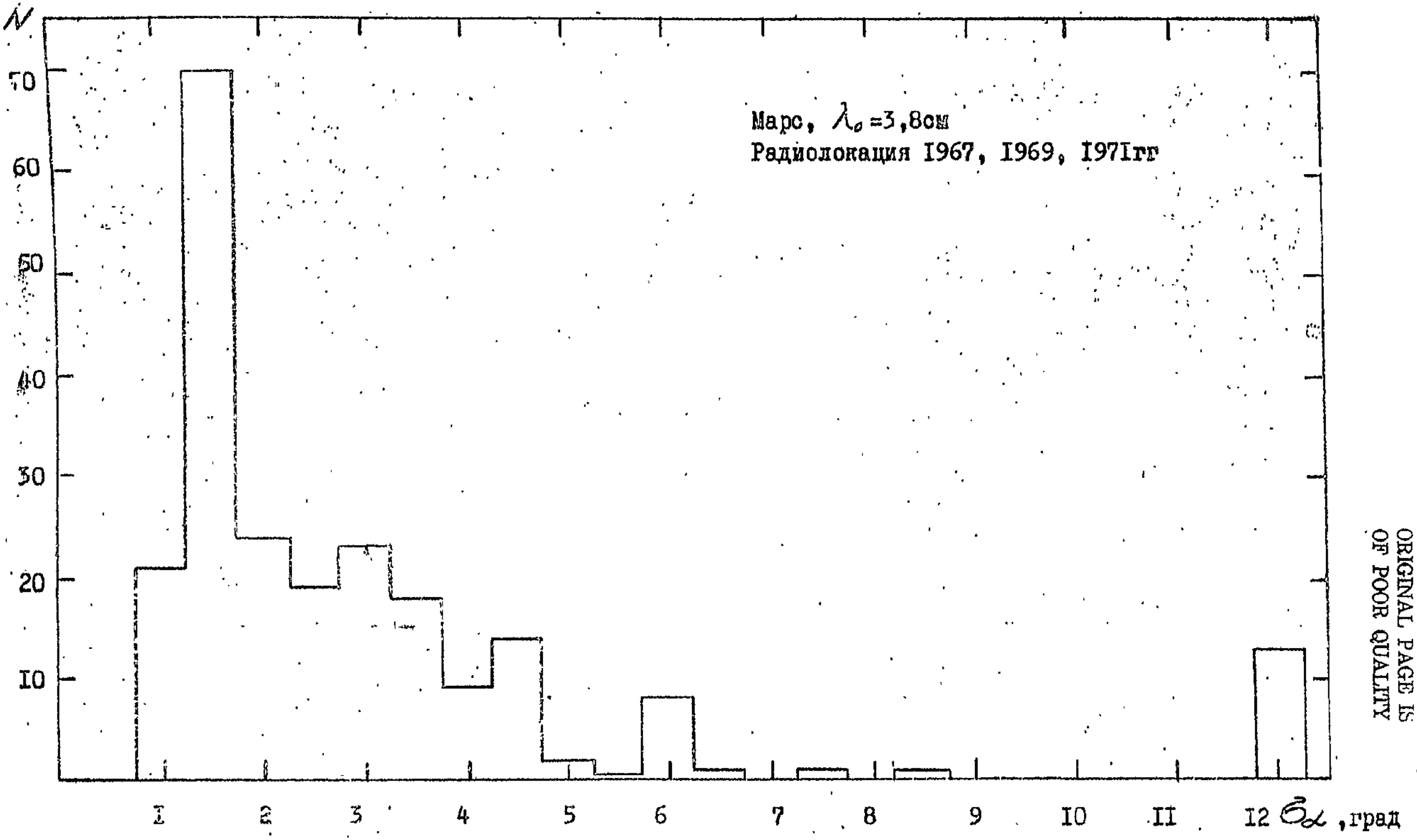
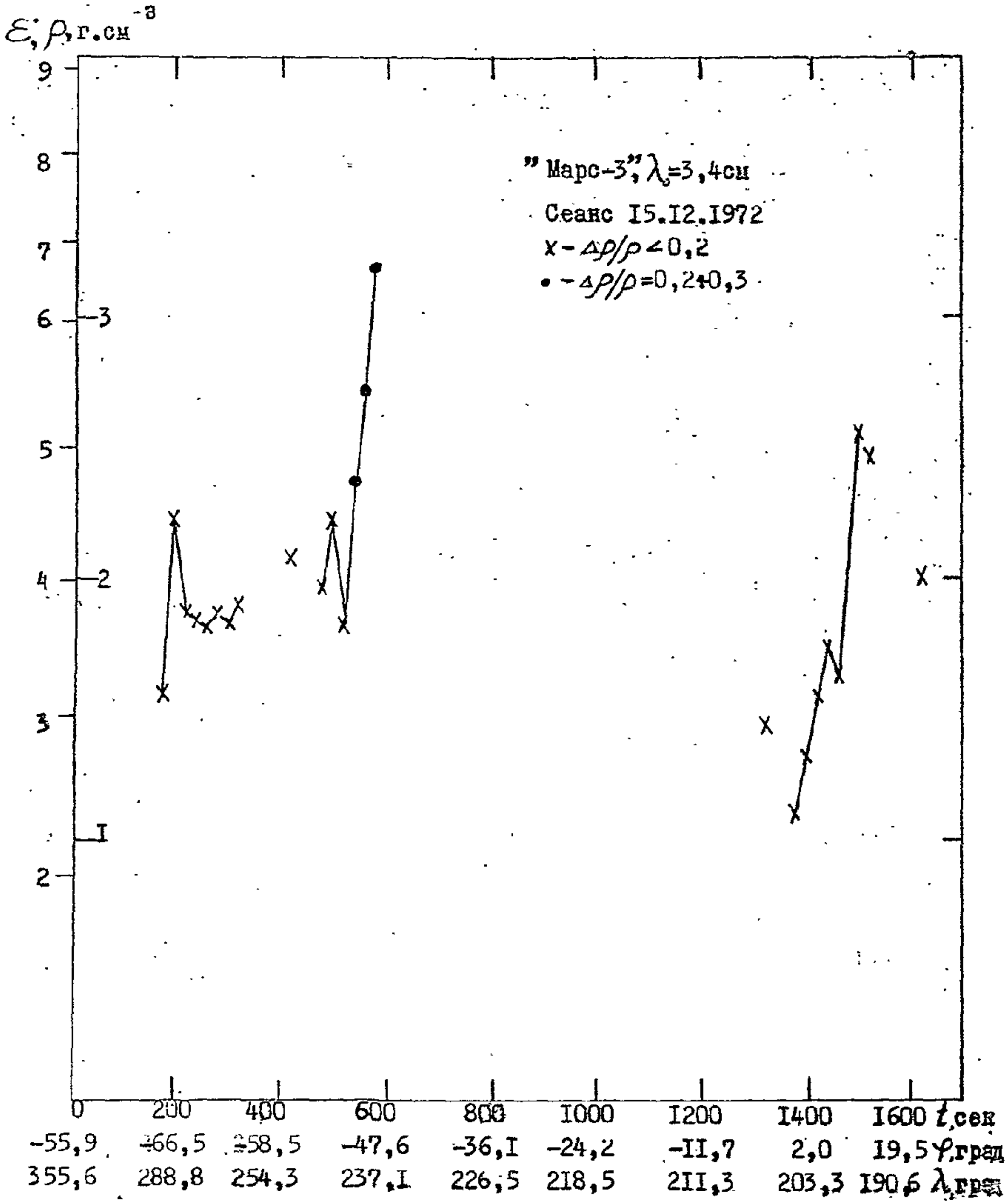

N
70
60
50
40
30
20
10
Марс, λ_o=3,8см
Радиолокация I967, I969, I97Iгг
I
2
3
4
5
6
7
8
9
I0
II
I2
σ_α, град

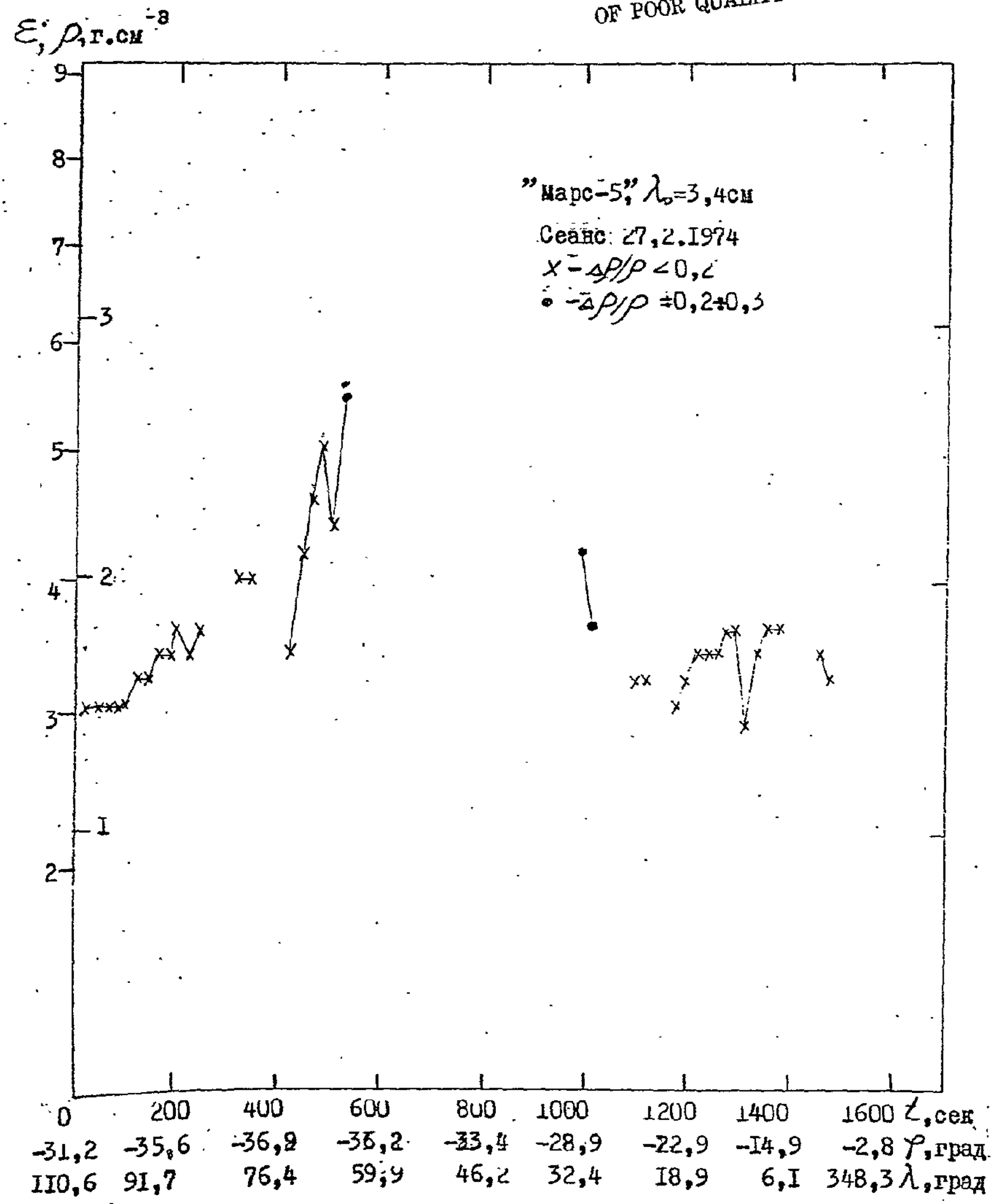
Рис.5

26



ε; ρ, г.см⁻³
"Марс-3", λ=3,4см
Сеанс I5.I2.I972
x - Δρ/ρ < 0,2
• - Δρ/ρ = 0,2÷0,3
9
8
7
6
5
4
3
2
3
2
I
0
200
400
600
800
I000
I200
I400
I600
t, сек
-55,9
-66,5
-58,5
-47,6
-36,I
-24,2
-II,7
2,0
I9,5
φ, град
355,6
288,8
254,3
237,I
226,5
218,5
2II,3
203,3
I90,6
λ, град

Рис.6


ε; ρ, г.см⁻³
"Марс-5", λ₀=3,4см
Сеанс 27.2.1974
x – Δρ/ρ < 0,2
• – Δρ/ρ ÷0,2÷0,3
9
8
7
6
5
4
3
2
3
2
I
0
200
400
600
800
1000
1200
1400
1600
t, сек
-31,2 -35,6 -36,9 -36,2 -33,4 -28,9 -22,9 -14,9 -2,8 φ, град
110,6 91,7 76,4 59,9 46,2 32,4 18,9 6,1 348,3 λ, град

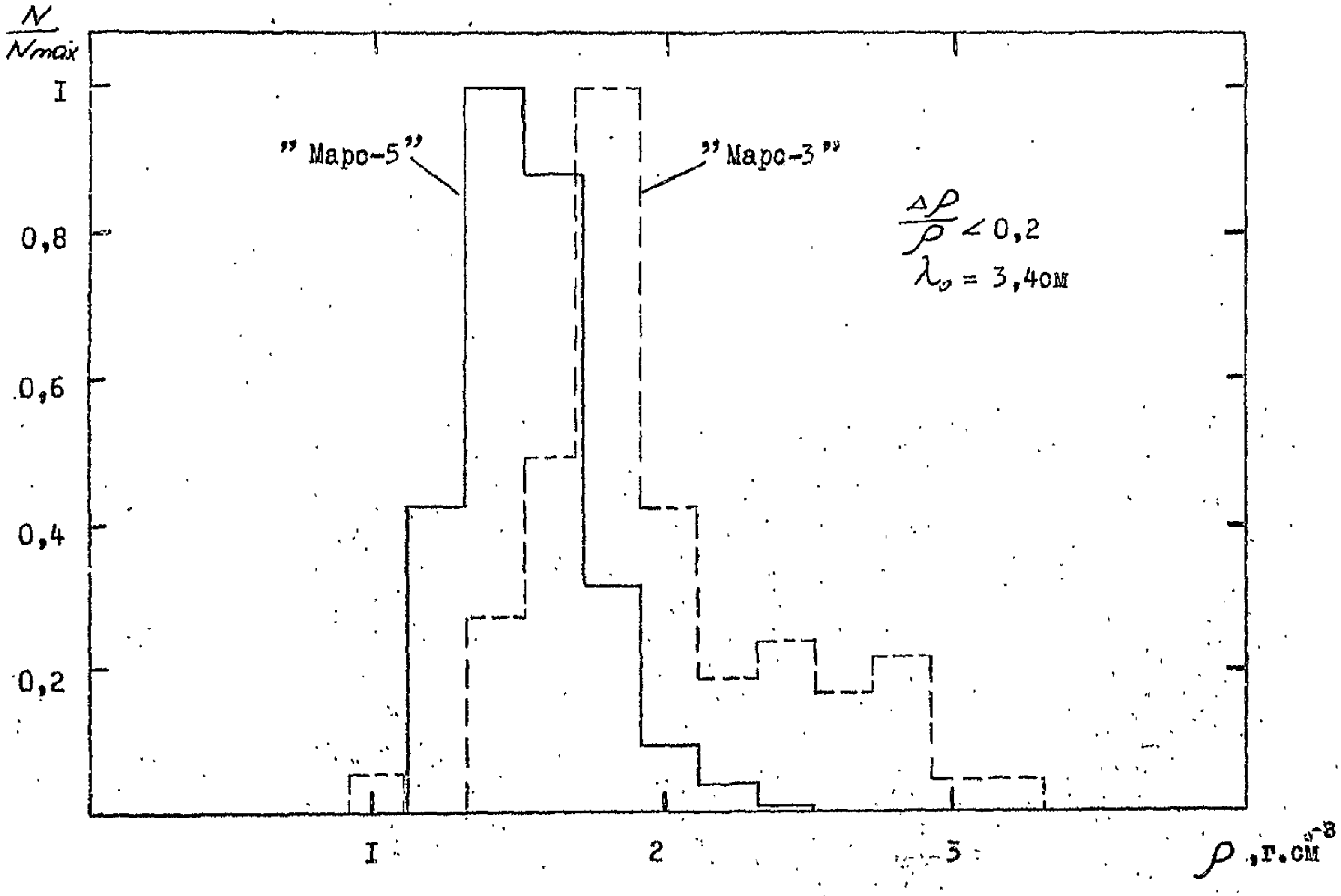


Рис.8

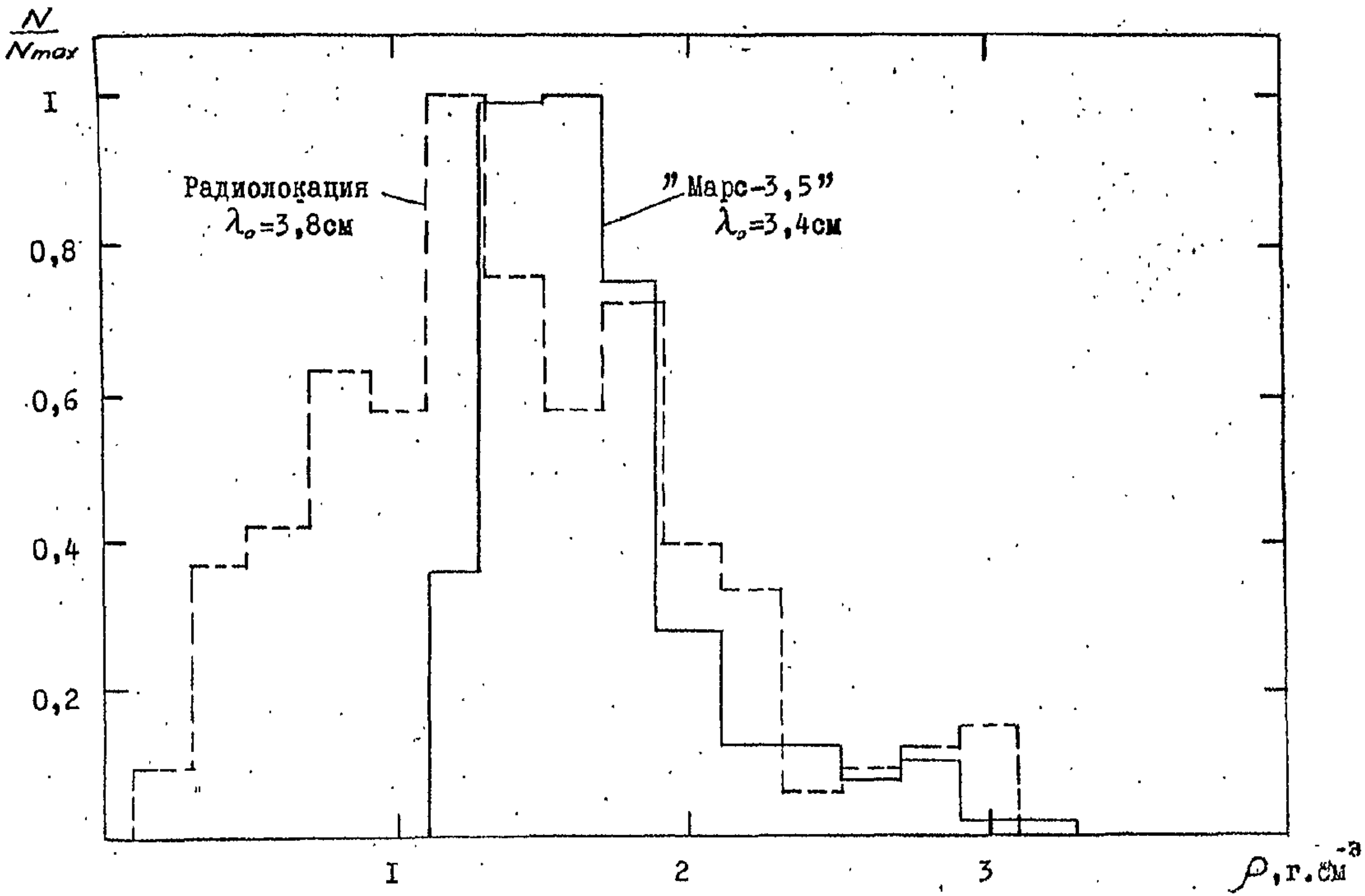
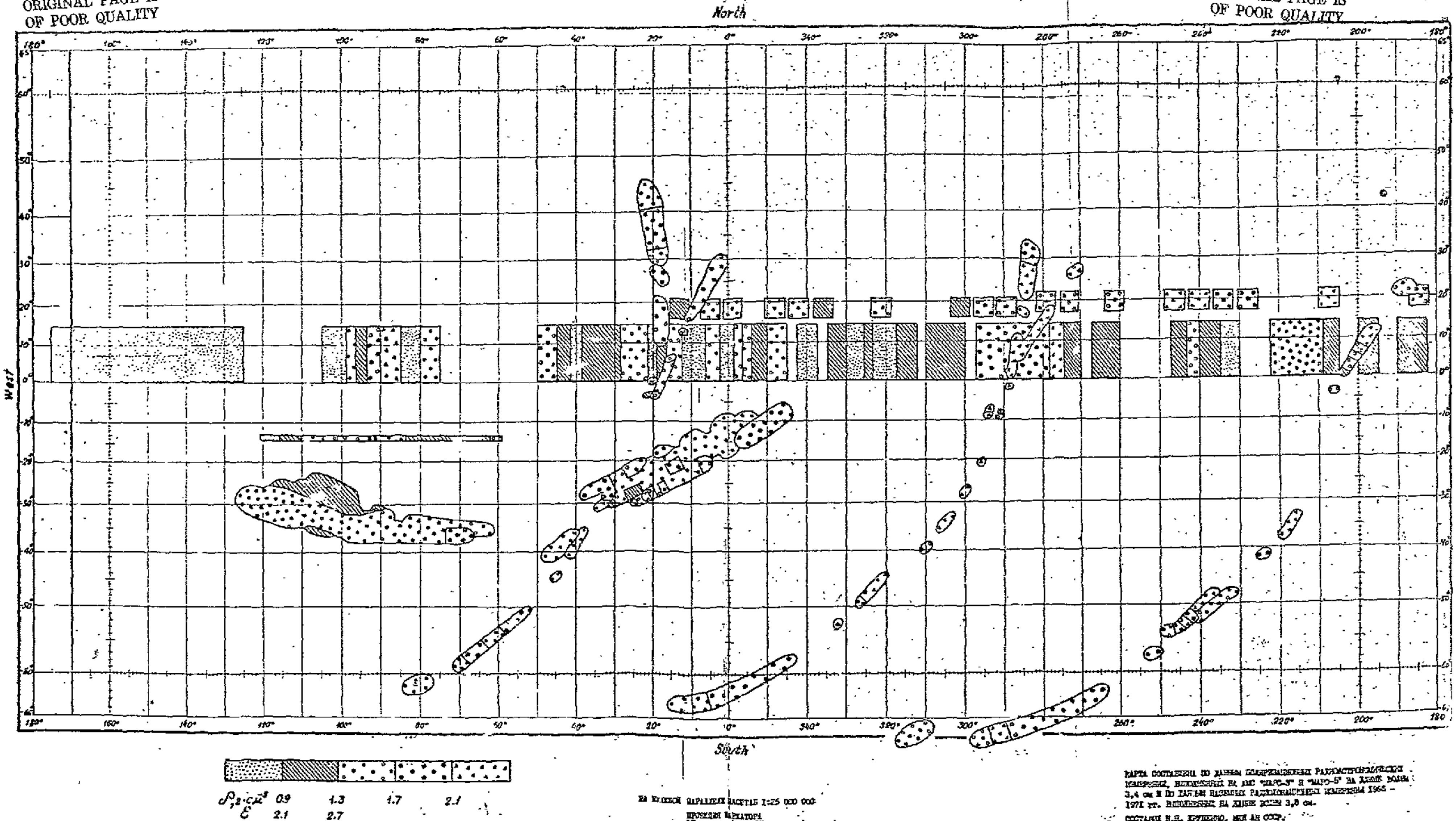

$\frac{N}{N_{max}}$
I
0,8
0,6
0,4
0,2
Радиолокация
λ_o=3,8см
"Марс-3,5"
λ_o=3,4см
I
2
3
ρ, г.см$^{-3}$

Рис.9



…ПАРАЛЛЕЛИ МАСШТАБ 1:25 000 000
ПРОЕКЦИЯ МЕРКАТОРА

Рис.10 КАРТА ДИЭЛЕКТРИЧЕСКОЙ ПРОНИЦАЕМОСТИ И ПЛОТНОСТИ ВЕРХНЕГО ПОКРОВА МАРСА

КАРТА СОСТАВЛЕНА ПО ДАННЫМ ПОЛЯРИЗАЦИОННЫХ РАДИОАСТРОНОМИЧЕСКИХ ИЗМЕРЕНИЙ, ВЫПОЛНЕННЫХ НА АМС "МАРС-3" И "МАРС-5" НА ДЛИНЕ ВОЛНЫ 3,4 см И ПО ДАННЫМ НАЗЕМНЫХ РАДИОЛОКАЦИОННЫХ ИЗМЕРЕНИЙ 1965 – 1971 гг. ВЫПОЛНЕННЫХ НА ДЛИНЕ ВОЛНЫ 3,8 см.

СОСТАВИЛ Н.Н. КРУПЕНИО, ИКИ АН СССР.