FINAL REPORT ON RADAR STUDIES OF THE MARTIAN SURFACE

NASA Grant NSG 7395

(NASA-CR-158002) RADAR STUDIES OF THE MARTIAN SURFACE Final Report (Stanford Univ.) 22 p HC A02/MF A01 CSCL 03B

N79-14979

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January 1979

This document summarizes results of a preliminary analysis of data. It should not be cited without permission of the author.

SUMMARY

This grant was awarded for acquisition, processing, and interpretation of radar data from Mars, especially using the facilities of the Arecibo Observatory. The project is now essentially complete. Results include scattering law studies in the Syrtis Major, Elysium, and Chryse areas of that planet; we have also made reflectivity measurements (of better quality than those obtained in 1975-76). The proposed work at Arecibo was completed earlier than expected; with the remaining time we developed software for general use in the radar program at Arecibo and participated (to a lesser extent) in acquisition and reduction of data from Venus and Mercury. In the final six months of the grant period we are interpreting the results and integrating them with other Mars research programs.

OBJECTIVES

The objectives for this work were the following:

1. Operational Assistance - To provide one observer at the Arecibo Observatory for three to four months to assist in Mars data acquisition and processing.

2. Surface Properties Interpretation - To study surface scattering at selected sites of interest (Tharsis, Elysium, and the Chryse Viking landing site) on the surface of Mars; to provide (minimal) assistance in analysis of Mars topography.

3. Comparison - To compare the new Arecibo results with Viking Bistatic Radar data; to broaden the data base for later use in interpreting Pioneer Venus radar imagery (and much later VOIR imagery).

4. Liaison - To coordinate schedules with the Goldstone Mars radar to minimize redundant experiments and enhance the prospects for dual-frequency observations.

OPERATIONAL ASSISTANCE

The primary objective of this proposal was to provide assistance to the Arecibo radar staff. Though some Mars observations would undoubtedly have been carried out by Dr. D. B. Campbell and his associates, we felt that a more comprehensive Mars program could be executed if we also became involved. It was with this in mind that we proposed sending an additional worker to help specifically with Mars data. In fact, the Mars data were handled rather more quickly than we had expected and we were able to devote time to more general Arecibo radar concerns.

Mars data taking began in late January 1978 and continued into early July. Our committment to the Viking Bistatic Radar Experiment precluded any Stanford involvement, however, until late March. At that point, only ranging data had been taken (see Table I). With Mars moving away from earth, and signals becoming correspondingly weaker, we decided to use time in April to do spectral studies over Syrtis Major. A combination of hardware/software problems also contributed to this decision. Spectra were taken again in late May and in mid-June when the subradar point passed near the Chryse Viking landing site. Signal strengths were always greater when we used the spectral technique, but the surface "resolution" is much coarser than with range-Doppler mapping.

We developed software for analysis of the spectral data and have now completed that work. Some of the results are contained in this report. The spectral analysis software was later modified for more general application to planetary bodies and was used on Mercury data taken in late August.

The ranging data require a much more sophisticated analysis. We had not planned to become heavily involved in this aspect of data reduction, but it was obvious from the start that this was one area where our efforts could be of use. The outline of an analysis program had already been drawn up. We took this and, over the course of several months, perfected and generalized it to the point where it could handle nearly all types of planetary ranging radar data acquired at the Observatory during this decade. Some testing remained, but as of late September (our departure from Arecibo) the program was routinely reducing Mars 1976 and 1978 ranging data and was ready to begin batch processing of 1978 Venus and Mercury data. In a check on the program's operation during a visit (for other purposes) to the Observatory in December we found that only minor problems had developed since September and that essentially all of the Mars, Venus, and Mercury data have now been processed.

MARS SURFACE PROPERTIES INTERPRETATION

Areas on Mars' surface which were probed during the current set of observations are listed in Table I and shown in Fig. 1. The January data, which were the best in terms of signal-to-noise ratio, give topographic information across parts of the north flank of Ascraeus Mons and over the plains to the east of Tharsis. A second traverse along nearly the same track was obtained in late March and early April. These data appear to show a negative topographic anomaly on the west side of Ascraeus Mons; the Arecibo staff is currently examining this result in more detail. We at Stanford may be able to provide some confirmation by considering the skew of the echo in the frequency domain; this task has not yet been performed, however.

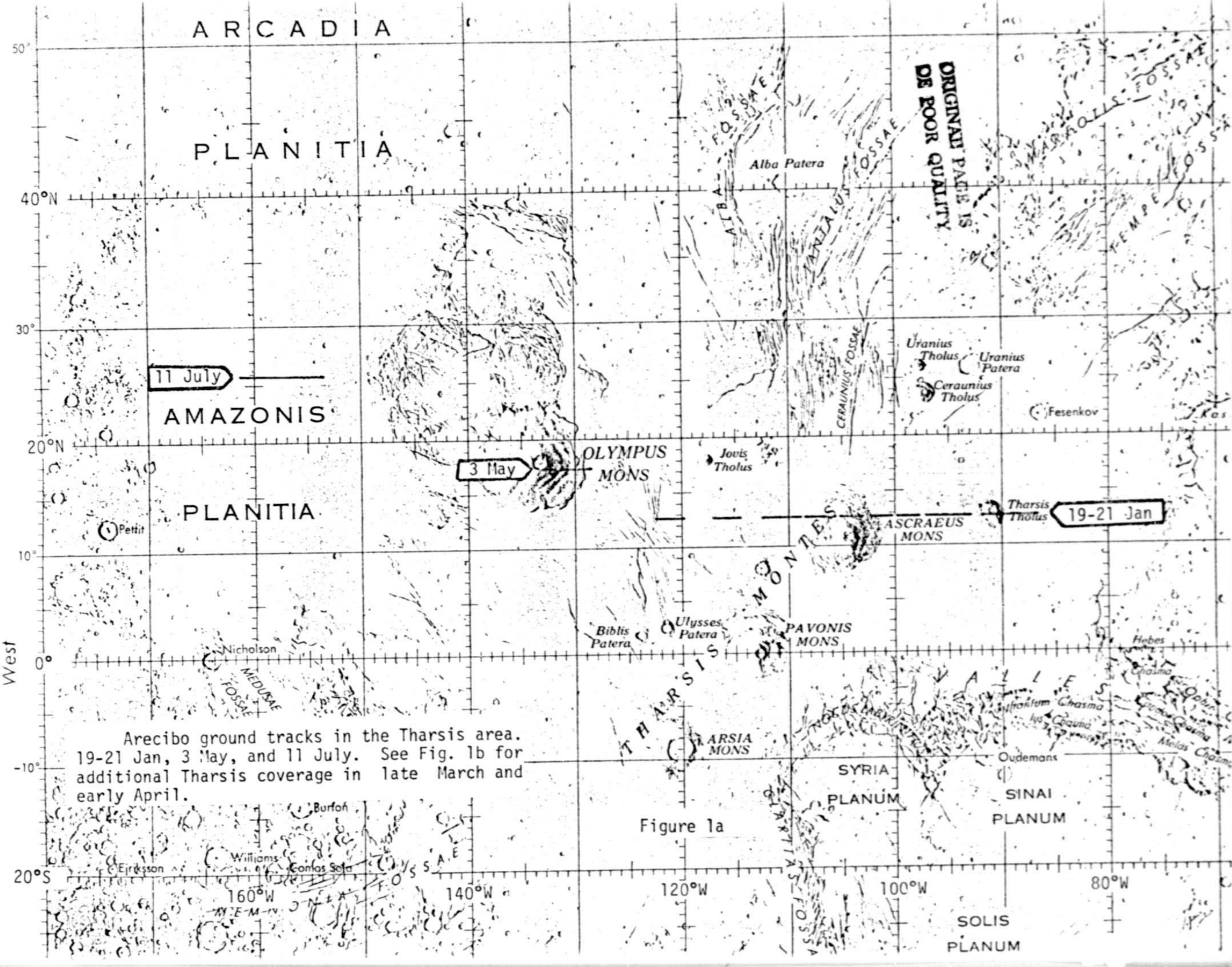
TABLE I

1978 ARECIBO MARS COVERAGE

Dates	Type*	Longitude	Latitude	Comments
19-21 Jan	R	86-122°W	12.6°N	North flank of Ascraeus Mons and plains to either side. Moderately rough to east. Whether altitude of volcano was determined is not yet known.
6 Feb	R	274-307°W	10.4°N	Extremely smooth in western Syrtis Major; Isidis Planitia may be rougher than cratered terrain west of Syrtis, on small scales.
31 Mar-2 Apr	R	71-121°W	12.3°N	Repeat of earlier Ascraeus traverse under less favorable conditions. Surface very smooth over 112-118°W. Also smooth 70-74°W, but rougher beginning about 85°W.
18 Apr	S	276, 288-293°W	14.8°N	Very smooth in spectra.
3 May	R	128-134°W	17.3°N	Potential profile of east side of Olympus Mons; observing conditions poor, however. Data not yet examined.
29-30 May	S	214-252°W	21.4°N	Relatively smooth; fills gaps left from 1976 tracks.
31 May	R	207-227°W	21.6°N	Potential altitude of Elysium Planitia. One run overlaps spectra from preceding day(s).
15-16 Jun	S	42-74°W	23.6°N	Good roughness and reflectivity data for Chryse Viking landing site. Some semblance to lunar maria.
17-18 Jun	R	19-59°W	23.8°N	Ranging both east and west of Viking site.
11 Jul	R	153-161°W	25.7°N	Echo detected; distance to Mars very great.

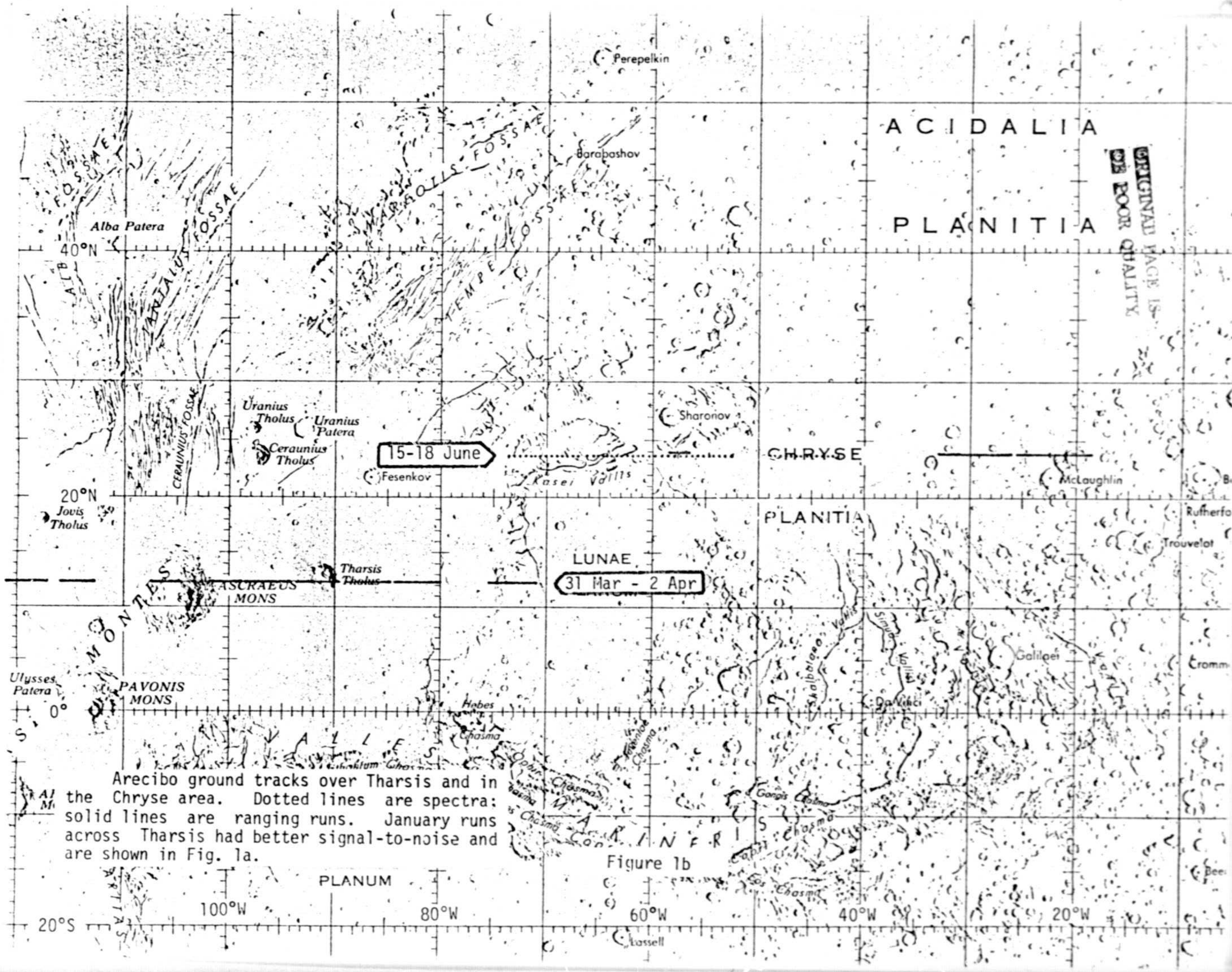
*Data Type: R is ranging (planet elevations; reflectivity and roughness can be obtained in a later processing step).

S is spectra (surface roughness obtained easily, reflectivity likewise; both represent averages over a wide area on the surface).



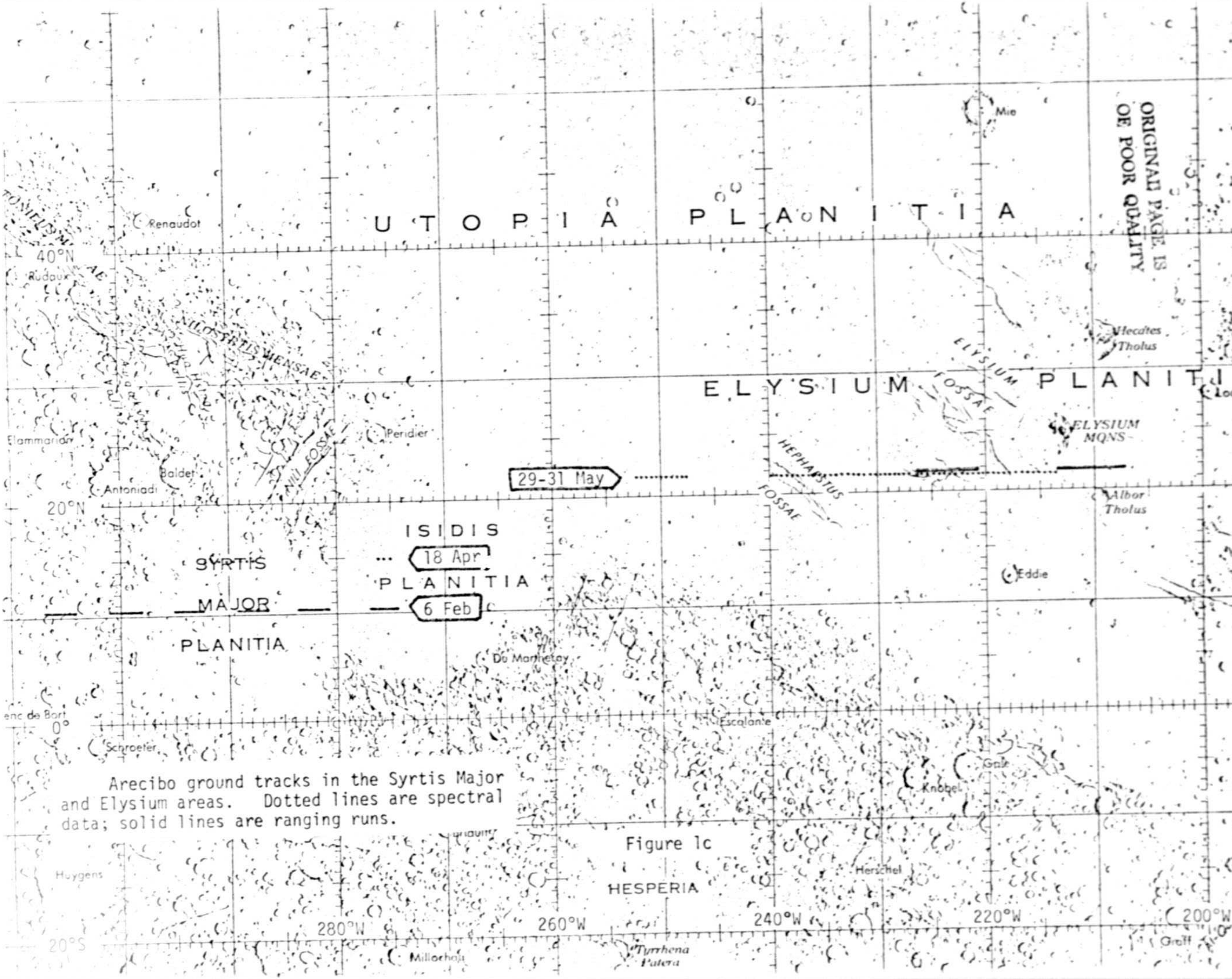
Arecibo ground tracks in the Tharsis area. 19-21 Jan, 3 May, and 11 July. See Fig. 1b for additional Tharsis coverage in late March and early April.

Figure 1a



Arecibo ground tracks over Tharsis and in the Chryse area. Dotted lines are spectra: solid lines are ranging runs. January runs across Tharsis had better signal-to-noise and are shown in Fig. 1a.

Figure 1b

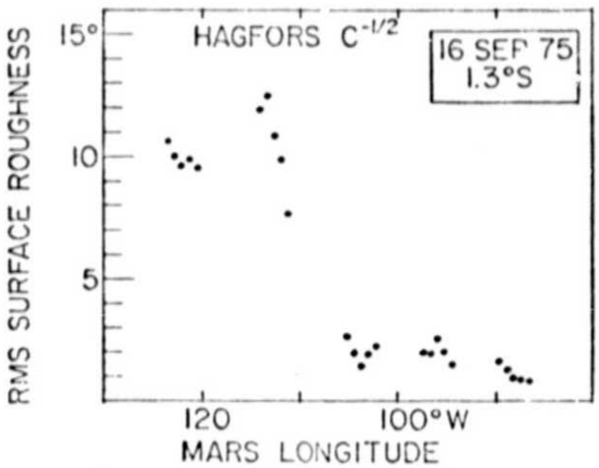


Arecibo ground tracks in the Syrtis Major and Elysium areas. Dotted lines are spectral data; solid lines are ranging runs.

Figure 1c

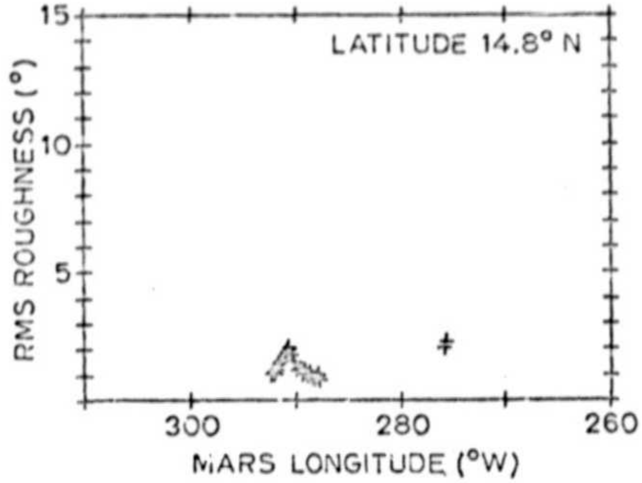
In contrast to results farther south, it appears that the plains east of Ascraeus Mons are rough, or at least relatively so, whereas the plains to the west are extremely smooth. Quantitative results are not yet available but, if this qualitative judgement holds up, this would represent a reversal of the behavior seen in Tharsis traverses at 0-20°S latitude. Radar data taken across the ridge near Pavonis Mons in 1975 and near Arsia Mons in 1971 and 1973 showed very smooth surfaces to the east and extreme roughness to the west (Fig. 2).

Fig. 2 - Surface roughness estimates on a traverse of Tharsis at latitude 1.3°S. The surface immediately east of the ridge is extremely smooth, while that to the west is one of the roughest we have observed on Mars.



The spectra obtained in April from Syrtis Major show an extremely smooth surface (Fig. 3) - one of the smoothest on Mars. Ranging (topography) was also obtained from Syrtis Major, Isidis Planitia, and their environs in February and in April but in both cases over relatively limited areas (Table I, Fig. 1c). The Syrtis Major ranging data from February can be interpreted as showing rms surface roughness as low as 0.1°.

Fig. 3 - Surface roughness estimates in Syrtis Major from 1978 spectra. The apparent increase in roughness near 291°W may be due to scattering by the ridge-like feature Arena Dorsum.



Spectra were obtained along a ground track from 214°W to 252°W at 21.5°N in late May. Many of these new roughness estimates (Fig. 4) fill gaps in the 1976 results (Fig. 5), which were used in evaluating Tritonis Lacus as a possible Viking back-up site. We also scheduled one day of ranging for this area; where the spectra and ranging overlap, it will be interesting to compare inferences of surface roughness using the two types of data.

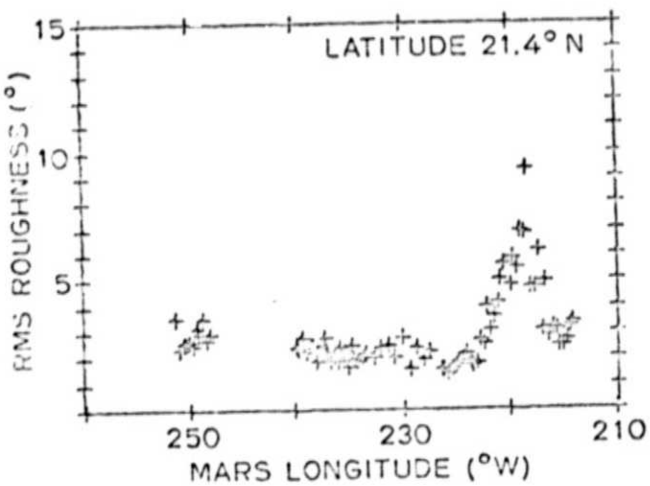


Fig. 4 - Roughness estimates from 1978 spectra. New values fill gaps left from 1976 (Fig. 5). High values near 219°W occur near the lower boundary of Elysium Fossae, but are not associated with any single distinct feature visible in imagery.

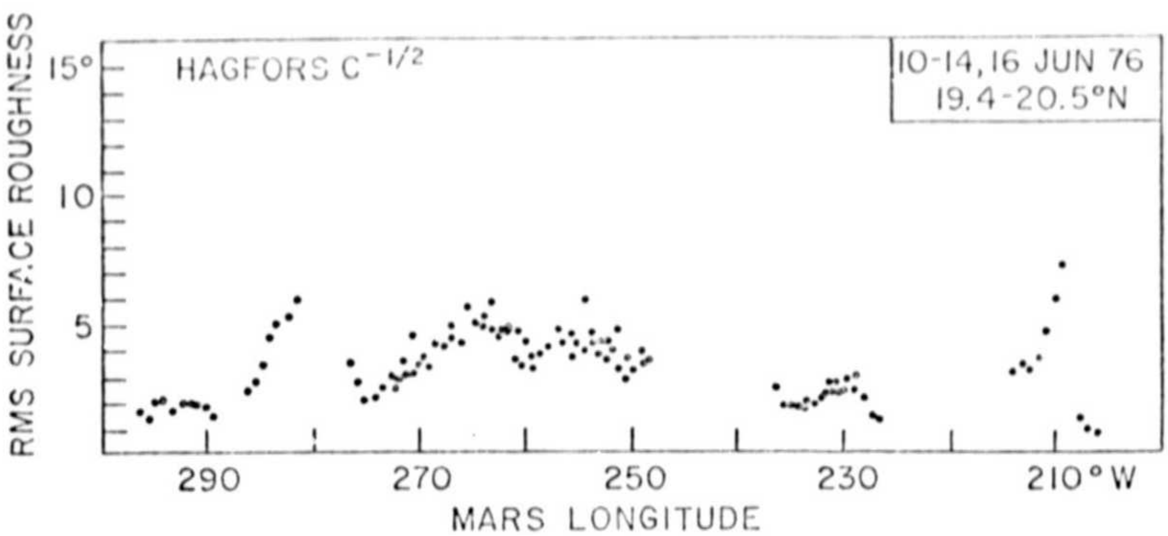


Fig. 5 - Surface roughness estimates from 1976 spectra. Peak near 210°W is due north of Albor Tholus. "A2", the position of the alternate Viking landing site Tritonis Lacus, is at 252°W.

In mid-June we had the opportunity to observe the Viking Chryse landing site at 23.6°N. We obtained two good days of spectra covering 42 to 74°W and then scheduled the following two days for ranging. Local demons (including a fierce electrical storm and power failure) successfully thwarted these observations; we were able to do ranging to both the east and west of Chryse, however (Table I, Fig. 1b).

The 1978 Chryse data confirm conclusions which we drew from 1976 results. Surface roughness appears to decrease as one moves westward from about 45°W. Values at the center of the Basin are typically on the order of 5-6° rms but drop off to about 3° at 53°W (Fig.6). We believe our original estimate of 4-5° rms for surface slopes on 25 meter horizontal scales at the landing site remains accurate (Fig. 7). A much better opportunity (in fact, two opportunities) to observe Chryse will occur during the 1980 opposition. We would anticipate that ranging, scattering law, and polarization measurements could all be undertaken at that time.

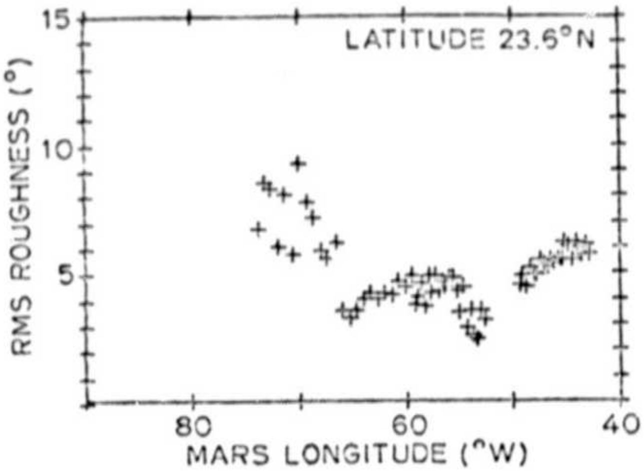


Fig. 6 - Surface roughness estimates in the Chryse region (and west) from 1978 spectra. Linear decrease from 45 to 50°W causes spectral skew (see text and Fig. 12). Low values over 62 to 67°W result from attempted fitting to very noisy spectra across Kasei Vallis. The surface appears to be very inhomogeneous here, explaining the disagreement with Fig.7.

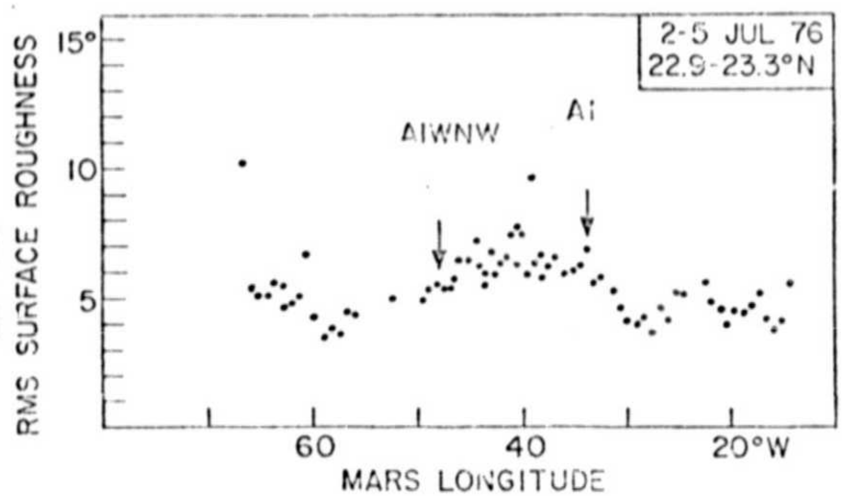


Fig. 7 - Surface roughness estimates over the Chryse region from 1976 spectra. "A1" was the original prime landing site, "A1WNW" was the final site.

In July we had the chance opportunity to take ranging data in Amazonis Planitia (155°W, 26°N). Distance to the planet was quite large at this time and signal strengths were very low. The echo was clearly identified, however. We believe this is the most northerly data point ever obtained by earth-based radar on Mars. The 1980 opposition will present many more such opportunities.

From the 1978 observations we also obtained estimates of surface reflectivity. In 1976 we judged these numbers to be unreliable. System performance seems to have improved since then, but there remains some question as to the accuracy and reproducibility of the numbers which were obtained this time. We find reflectivity estimates of 7-8 percent (Fig. 8) to be characteristic of the Chryse area; such values are typical of lunar maria. We hasten to caution against reading too much into these conclusions, however, because there are large error bars on all reflectivity values. We note, for example,

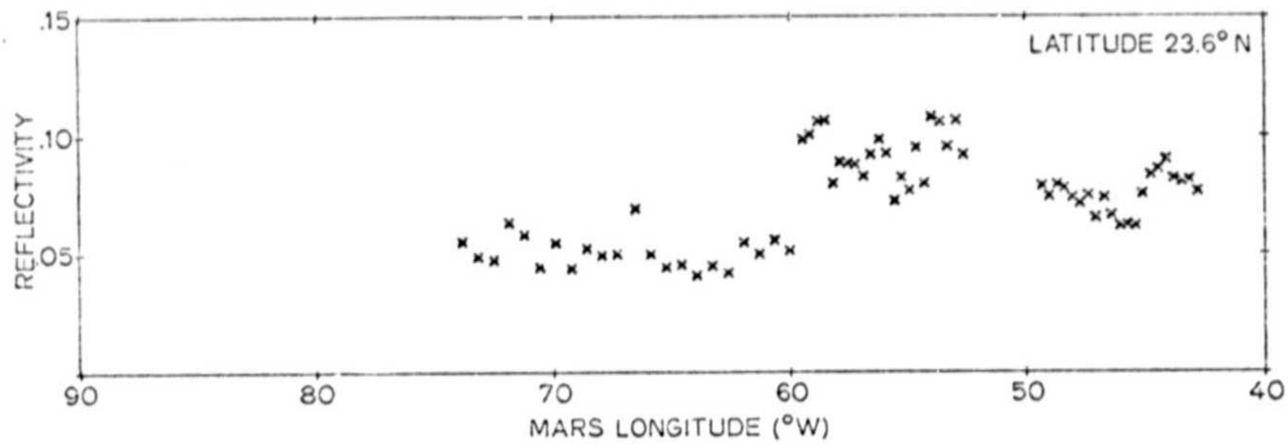


Fig. 8 - Reflectivity estimates from 1978 spectra in the Chryse area. Reflectivities of 0.05, 0.075, and 0.10 correspond to dielectric constants of 2.48, 3.08, and 3.71, respectively. Thus, in a formal sense, the surface at the Viking landing site (near 48°W) could be equated to lunar maria.

that reflectivity derived from Syrtis Major spectra is typically 3-4 percent (Fig. 9); this is not consistent with an interpretation which in many other respects equates Syrtis Major with maria-like basins. Possible system-related causes for reflectivity variations are illustrated in Fig. 10.

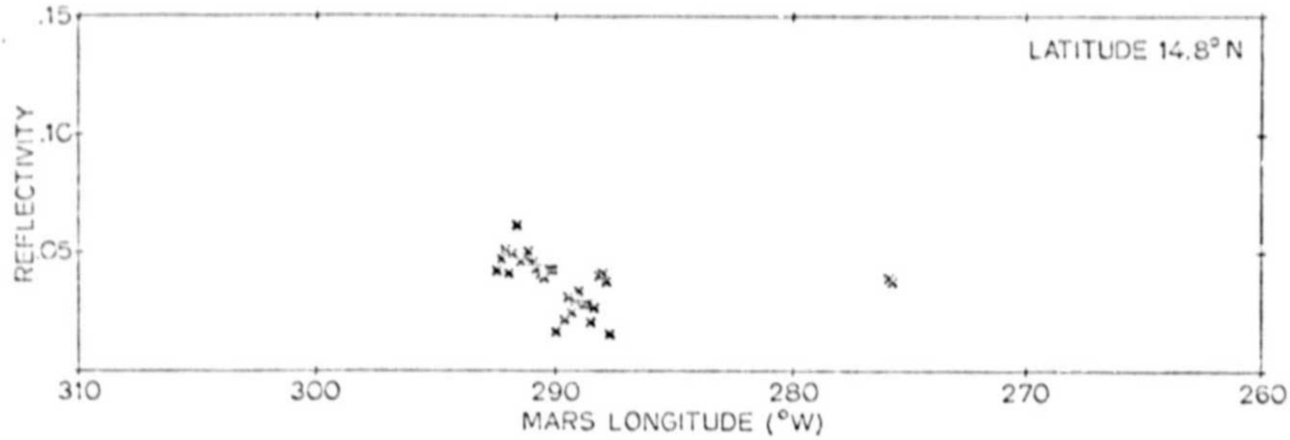


Fig. 9 - Reflectivity estimates in Syrtis Major from 1978 spectra.

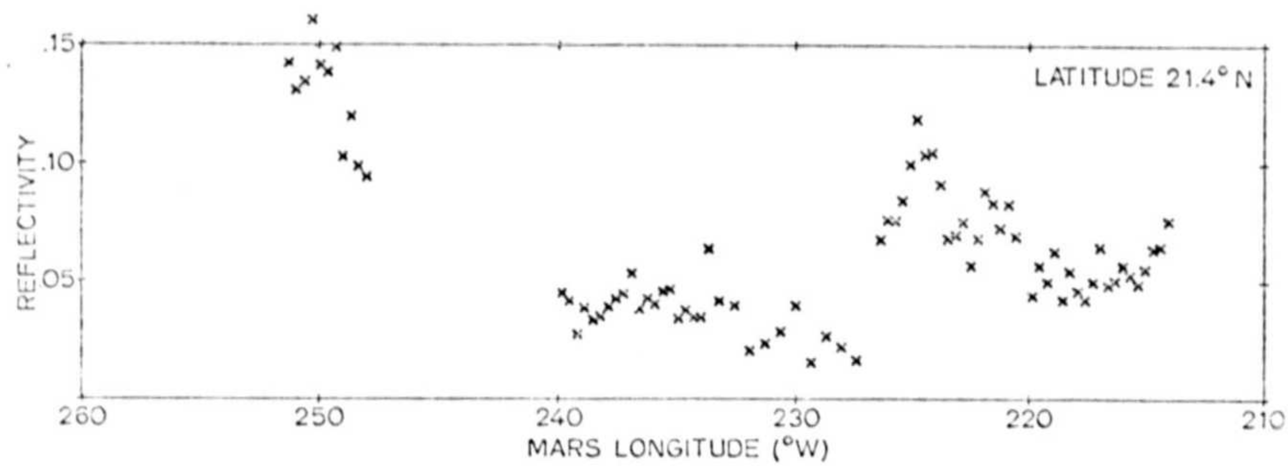


Fig. 10 - Reflectivity estimates from Elysium to Tritonis Lacus. Data were obtained in blocks (214-220, 220-226, 227-234, 234-240, and 248-252°W); the fact that changes in reflectivity occur at (most of) these block boundaries argues for systematic influences on the data. We urge extreme caution in interpretation of the reflectivity estimates.

One remaining aspect of the spectra from Chryse is worthy of note -- the asymmetry about the zero frequency point. One can see this most easily in comparisons of the data with the template curve which has been fitted (Fig. 11).

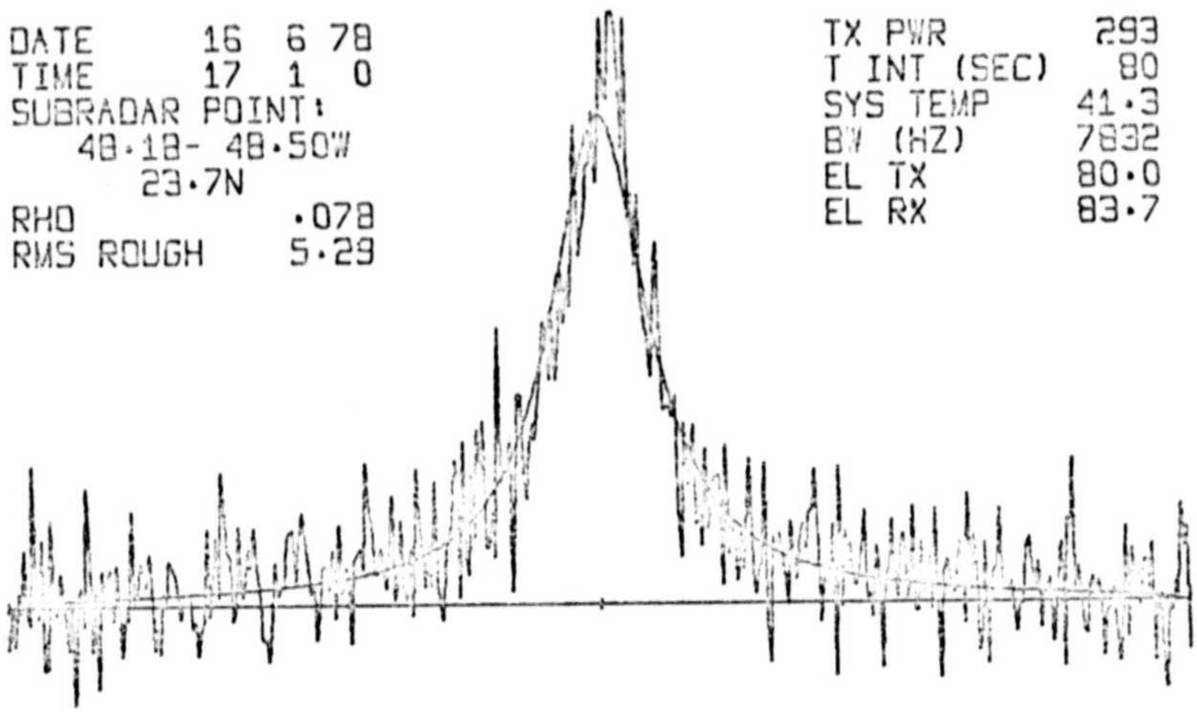


Fig. 11 - Typical spectrum from Chryse area showing skew of data peak toward high frequency (right) side. In the past such skewing has been interpreted as the result of large scale tilts of the planet surface. We find the effect to be double what one would expect, based on published topographic maps of Mars, in this case.

Such skewing could arise from large scale slopes such as one might expect leading to a large basin or continental ridge. In fact, such data have been inverted in the past to give estimates of topography. In this case, however, we find the inferred slope is too large by a factor of about two when compared against published topographic maps from the USGS. A second explanation is that the scattering characteristics of the surface change in such a way that the echo signal appears to be skewed -- that is, the surface cannot be described by a single scattering law. For Chryse we already know that the roughness decreases as the subradar point moves west from 45°W. By simple modeling we have simulated the echo which would result when the roughness decreases as in Fig. 6; Spectra turn out to be skewed by the amount needed to make up the difference between the large scale slopes and the observed value (Fig. 12). We thus conclude

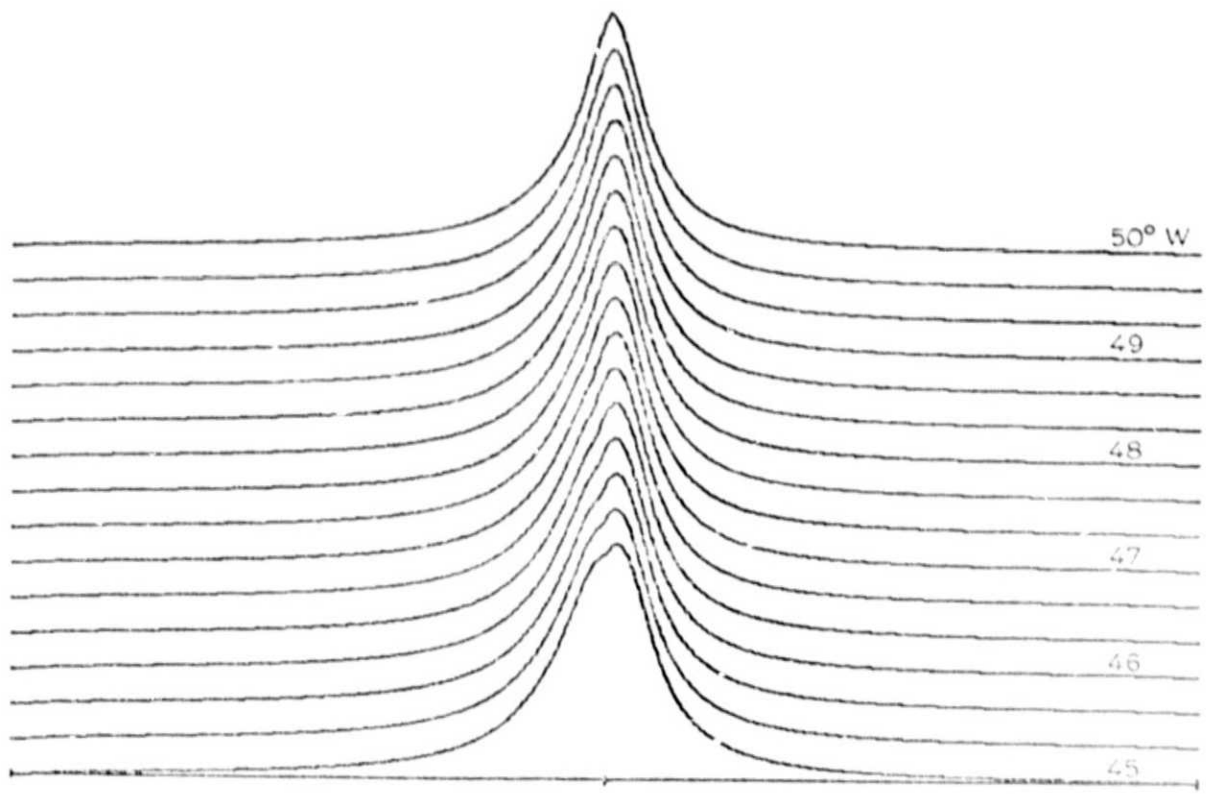


Fig. 12 - Synthesized radar spectra when a linear change in the roughness parameter is postulated over 45 to 50°W. When the magnitude of the change is equal to that shown in Fig. 6 over the same range, the spectral peak is displaced about 50 Hz -- half that observed in the data. The remaining 50 Hz may be attributed to large scale surface tilts.

that equal contributions from large scale slopes and decreasing roughness cause the observed skewing. Following from this, we are forced to conclude that inference of large scale slopes from spectral skew (a common practice in the past) is a questionable procedure.

COMPARISON

Some attempt was made to obtain overlapping coverage between the Arecibo ground tracks and those obtained during the Viking Bistatic Radar Experiment. A bistatic radar pass near the Chryse landing site (Fig. 13) may be compared with Arecibo data from both 1976 and 1978. A second bistatic track near the Tritonis Lacus alternate Viking site intersects Arecibo ground tracks from 1976 and 1978 as well (Fig. 13). In each of the above cases, signal strengths from the bistatic runs were not particularly good, so the extent to which we may be able to compare the two data types remains to be seen. Better opportunities for earth-based probing in these two areas will occur during the 1980 opposition.

A fixed point BSR target in central Syrtis Major may be compared with ranging results from Arecibo (6 Feb) except that the reflection points are separated by over 100 km on the surface. This is another case of very weak bistatic signals because of relatively unfavorable geometry, however.

Most of the good bistatic radar data (in terms of signal-to-noise ratio) are in the North Polar region (Fig. 14); this is entirely inaccessible to earth-based radar observation and so no comparisons will be possible.

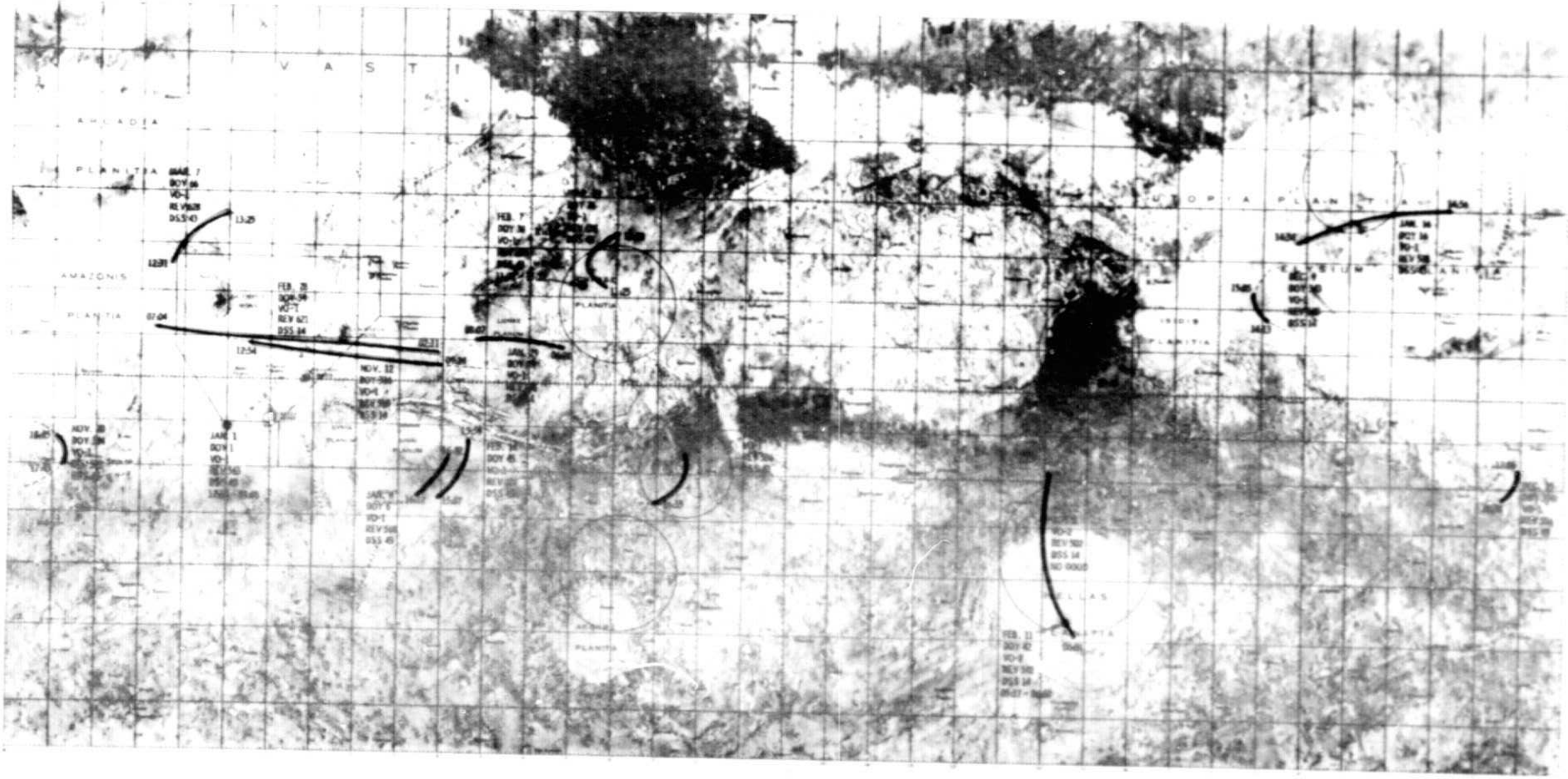
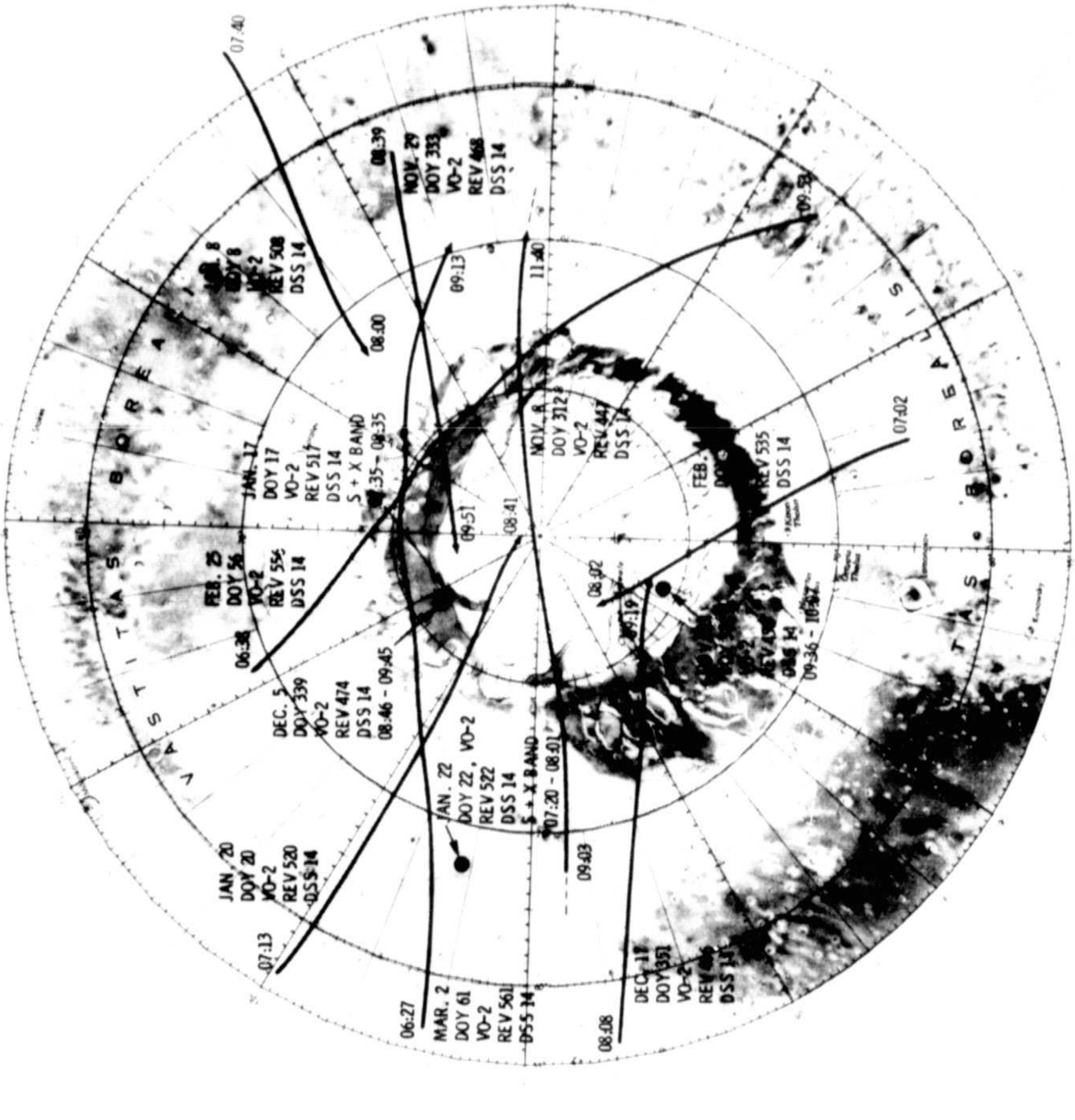


Fig. 13 - Bistatic Radar targets in Mars' equatorial region. Fixed points have been highlighted in yellow, specular point tracks in red.

Bistatic Radar Experiment
Data Acquisition Status
Equatorial Region
8 November 1977 to 17 March 1978


VASTITAS BOREALIS
JAN. 17
DOY 17
VO-2
REV 517
DSS 14
S + X BAND
FEB. 25
DOY 56
VO-2
REV 554
DSS 14
DEC. 5
DOY 339
VO-2
REV 474
DSS 14
08:46 - 09:45
JAN. 22
DOY 22, VO-2
REV 522
DSS 14
S + X BAND
07:20 - 08:01
JAN. 20
DOY 20
VO-2
REV 520
DSS 14
MAR. 2
DOY 61
VO-2
REV 561
DSS 14
NOV. 29
DOY 333
VO-2
REV 468
DSS 14
NOV. 8
DOY 312
VO-2
REV 447
DSS 14
REV 535
DSS 14
07:40
08:00
08:39
09:13
11:40
09:51
08:41
06:38
07:13
06:27
09:03
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09:19

Fig. 14

Comparison with other earth-based radar data sets will be minimal. Except for some very early work (mid- to late 1960's) the northern hemisphere has been little explored by radar. What has been obtained in 1978 will be added to the existing file -- especially through Irwin Shapiro's planetary ephemerides work. The ranging analysis is not yet complete, so we cannot report on Mars topography from 1978. A further processing of these data is planned to obtain surface roughness and reflectivity. No software presently exists to carry out this step, however.

LIAISON

Operation of the Goldstone (JPL) radar facility was very tightly restricted to the actual opposition period. Goldstone obtained echoes in the vicinity of Ascraeus Mons but, as with the Arecibo data, it is not clear that they obtained an echo from the top of the volcano. Otherwise, the two systems operated relatively independently and, to our knowledge, there is no other overlapping data. Arecibo suffered from some serious hardware problems in February and March and by the time those had been solved, Goldstone had ceased operations.

CONCLUSIONS

This twelve-month project has been worthwhile from at least two standpoints. First, needed assistance was provided to the staff at Arecibo Observatory in the area of radar data analysis. Software for reduction of both old and new radar data was developed and is now operational. Though these programs could be more efficient, to our knowledge they contain no errors and represent forward progress compared with the situation of a year ago. Analysis of radar ranging data back to 1976 on Mars is now underway and reprocessing of Venus and Mercury data from the early 1970's is planned. The spectral analysis program has successfully handled all of the accumulated Mars and Mercury data. Second, the desired Mars observations were carried out (subject to the usual equipment limitations). The spectra have been entirely processed and are now available for interpretation; the ranging data are presently being analyzed.

We intend to continue our interpretation of the data and integrate it with other studies during the remainder of the grant period. Though we have no plans for immediate publication of these results, two articles are being discussed. We have already presented the results orally to the Fall 1978 meeting of the Division of Planetary Sciences in Pasadena.

Finally we should note that the opportunity remains for more short-term research work at Arecibo Observatory. Upcoming Venus conjunctions and Jupiter and Saturn oppositions are in hand, but the 1980 Mars opposition remains largely unplanned. This work should be supported since it will provide half a dozen closure points for topographic consistency and will give the best view yet of surface properties in the 20°N to 25°N latitude range. The capabilities of the new Arecibo S-band radar system have by no means been exhausted and we would encourage others to make use of this tool in further studies of planetary astronomy.