RADAR OBSERVATIONS OF MERCURY

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Earth-based radar observations have provided information on the equatorial topography, surface scattering properties, and rotation of Mercury. The recent observational program at Arecibo Observatory has been devoted primarily to the measurement of altimetric profiles using the delay-Doppler technique. These profiles, which were derived from observations made over a 6 yr period, provide fairly extensive coverage over a restricted equatorial band. The data have sufficient resolution and accuracy to permit the identification of radar signatures for features as small as 50-km diameter craters and km high arcuate scarps. More importantly, they have been used to identify large-scale topographic features such as smooth plains subsidence zones and major highlands regions. In this sense the radar data complement spacecraft images, as quantitative altimetry from the latter is limited to shadow measurements of small, high-relief features such as crater rims. Radar data such as that obtained at Arecibo also provide most of what little information is available on the unimaged hemisphere. Measurements of radar cross section, Doppler spectrum shape, and depolarization provide information on the dielectric properties and roughness of the surface. These results can be readily compared with similar measurements for other planets.

Radar probing of Mercury, Venus and Mars began in the early 1960s. The early Mercury observations, like those of her sister planets, were mainly continuous-wave (CW) measurements of radar cross section and Doppler spread. Although these observations provided some information on surface conditions, their most notable contribution was the discovery of Mercury’s nonsynchronous rotation (Pettengill and Dyce 1965).

With the early 1970s came more detailed studies of the planet’s radar
scattering properties (Goldstein 1971) as well as the first attempts to measure Mercurian topography using pulsed or coded transmissions (Smith et al. 1970; Ingalls and Rainville 1972). The latter suggested that Mercury has a somewhat more subdued topographic relief than is the case for the equatorial zones of Venus and Mars. The radar altimetry measurements of Zohar and Goldstein (1974), the last to be published prior to Mariner 10, revealed topographic detail in the form of hills and valleys with 1 to 2 km relief and features resembling large craters.

The Mariner 10 encounters of 1974–75 brought the first great advance in our knowledge of Mercury and, with it, an understandable falloff in interest in Earth-based observations of the planet. The spacecraft results were by no means exhaustive, however. Mariner 10 carried no altimeter and quantitative altimetry was limited to shadow measurements of high-relief features such as crater rims and scarps. Moreover, many of the images were obtained at unfavorable illumination angles and one entire hemisphere was left unimaged. The prospect of doing useful, complementary radar work was greatly enhanced with the installation, in the mid-1970s, of a sensitive S-band radar on the upgraded Arecibo telescope. Starting in 1978, a regular program of radar observations of Mercury was undertaken at Arecibo, primarily for the purpose of obtaining accurate measurements of surface topography. The results of the altimetry measurements obtained over the period between 1978 and 1984 were recently reported by Harmon et al. (1986). This chapter presents several of the more important findings from that paper along with a summary of the current state of our knowledge of the radar scattering properties of the Mercurian surface.

I. ALTIMETRY MEASUREMENT TECHNIQUE

The standard technique for spatially resolving planetary radar echoes is the so-called delay-Doppler method, which combines pulsing or coding of the transmitted wave with Fourier analysis of the coherently detected echo. The technique has been used very successfully on Venus to obtain high-resolution maps of radar reflectivity. Similar attempts to map Mercury have met with much less success due to the weaker echoes for that planet. Thus the emphasis of the Mercury program at Arecibo has been to use the delay-Doppler method to measure altitudes along the Doppler equator rather than to map radar reflectivity.

The altimetry estimation method used at Arecibo is essentially that described in detail by Ingalls and Rainville (1972) and Shapiro (1972). Here one fits numerically computed templates of echo power vs delay to the delay-Doppler data array to estimate the time delay to the leading edge of the planet at each Doppler longitude. From these delays one subtracts the computed delays to a reference sphere of given radius. The residual delays can then be expressed as altitudes relative to an assumed datum (“sea level”). Each al-
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The altitude datum point in the Arecibo profiles corresponds to a spatial resolution cell (radar footprint) measuring 0.15 degrees in longitude by 2.5 degrees in latitude (6 × 100 km). The typical altitude accuracy (for a surface which is flat over this cell) is 100 m.

This estimation method is feasible only for the strong echo from the subradar region. For example, a single day’s observing session at Arecibo yields an altitude profile spanning roughly 14 degrees of longitude along the Doppler equator. Using Mercury’s 5 deg/day rotation, one can construct longer profiles by connecting the individual profiles obtained from observations made on several successive days. Altitude profiles traversing up to 90 degrees of longitude have been obtained at Arecibo by this means. Obviously, to obtain even a modest degree of planetary coverage by this method entails a major observational effort. The data presented by Harmon et al. (1986) were derived from approximately 150 days of observations spread over a 6 yr period.

The primary limitation of Earth-based radar altimetry is that it is restricted to the narrow equatorial zone defined by the possible subradar tracks. Mercury’s 7° orbital inclination to the ecliptic renders a 12° equatorial band accessible to the radar. The most interesting known feature lying outside this zone is the Caloris basin. Fortunately, the accessible band does encompass representative examples of most of the important terrain types found on the planet.

II. EQUATORIAL GLOBAL TOPOGRAPHY

To show the equatorial topography on a global scale, we have plotted all of the Arecibo profiles from 1978 to 1982 on a 0-360° longitude scale in Fig. 1. The data are plotted on an absolute altitude scale where the zero-altitude datum is defined by a 2439.0-km radius reference sphere. In Fig. 2, we show a histogram giving the distribution of altitudes from Fig. 1.

The mean of the altitudes in Fig. 1 is +0.7 km (2439.7 km mean radius). This result is consistent with the mean equatorial radius reported from earlier radar observations (Ash et al. 1971) and radio occultations (Fjeldbo et al. 1976). The zero altitude datum corresponds to the typical elevation of Mercurian lowlands and is close to the most probable altitude (+0.3 km) as given by the peak of the histogram.

The extreme range of measured Mercurian altitudes is 7 km, as measured from the lowest crater floors to the high plateau near the 0°W longitude meridian. For comparison, the Moon has approximately 10 km of peak-to-peak relief about its center of mass (Kaula et al. 1974) or about 7 km of relief (excluding crater floors) about its center of figure (Brown et al. 1974). The typical elevation difference between Mercurian highlands and lowlands is about 3 km, which corresponds to the approximate equivalent width of the altitude distribution in Fig. 2. Like the Moon, Mercury’s altitude distribution is weakly bimodal and skewed toward positive altitudes.
Fig. 1. Combined plot of all Arecibo radar profiles of Mercury from 1978 to 1982, showing absolute altitudes relative to the 2439.0 km radius reference sphere. Latitudes of profiles on this figure range from 12°N to 5°S. All profiles are simply superposed with no latitude averaging (figure from Harmon et al. 1986; copyright Amer. Geophys. Union).

The equatorial zone shows two major topographic highs. The first of these is roughly centered at 10°W longitude and crosses the Mariner 10 eastern terminator. This plateau-like feature has an abrupt drop off on its western side which is associated with an extensive system of faults (see Sec. III.B). The second major high area covers a broad region south of the Caloris basin between 160°W and 240°W. This region contains two local topographic lows at 180°W and 210°W which correspond to smooth plains regions. A third, less extensive highlands area can be seen in the more northerly profiles near 310°W in the unimaged hemisphere.

Mercury’s resonant spin state indicates that the long axis of the planet’s dynamical figure is aligned with the perihelion subsolar points at 0°W and 180°W longitude. The Arecibo results in Fig. 1 show that Mercury’s topographic figure is roughly aligned with its dynamical figure, although the two largest bulges appear to be more closely aligned along a 10°–190°W longitude axis. Goldreich and Peale (1966) have shown that a difference between the equatorial moments of inertia of only about 0.01% (assuming an ellipsoidal figure) would suffice to ensure a high probability of capture into the 3:2 resonance state. This corresponds to variations in the dynamical figure of about 100 m. Hence, it is conceivable that the dynamical figure of Mercury is dominated by a long-wavelength component of uncompensated topography assoc-
Fig. 2. Histogram of the altitudes shown in Fig. 1. The histogram is normalized by the number of altitude data points within each altitude bin, not by area. The lowest and highest altitudes measured (−2.4, +4.6 km) are denoted by arrows (figure from Harmon et al. 1986; copyright Amer. Geophys. Union).

An alternative explanation for the 3:2 spin-orbit resonance is that there is a lunar-like mascon associated with the smooth plains in or around Caloris. Melosh and Dzurisin (1978) have argued that a positive gravity anomaly associated with 400 m of uncompensated material in the circum-Caloris smooth plains would suffice to control the planet's dynamical figure. The Arecibo altitude profiles over the circum-Caloris plains are consistent with a subsidence of these plains under an emplaced load (see Sec. IV.A) which, if partially uncompensated, could strongly influence Mercury's dynamical figure.

III. TOPOGRAPHIC FEATURES: THE IMAGED HEMISPHERE

Mariner 10 imaged the hemisphere of Mercury extending from 10°W to 190°W longitude. Much of the structure in the radar altimetry profiles can be
identified with specific features in the USGS maps of this hemisphere. In this section we present several of the more important results obtained from a comparison of the Arecibo altimetry with the Mariner 10 images and image-derived maps.

A. Crater Depths

Shadow measurements from Mariner 10 images have yielded depth estimates for Mercurian craters with diameters in the range 1 to 170 km (Gault et al. 1975; Malin and Dzurisin 1977, 1978). These studies have revealed a strong similarity between the crater depth/diameter relations for Mercury and the Moon, although large Mercurian craters tend to be shallower than lunar craters of comparable size. Both planets show a flattening or turnover of the depth-vs-diameter curve for diameters > 10 to 20 km.

Radar altimetry offers an alternative crater depth measurement technique, one which is not restricted to structures near the Mariner 10 terminator. However, the large size of the radar footprint limits reliable depth estimates to craters larger than about 40 km in diameter, well beyond the turnover point in

![Diagram showing depth vs diameter for fresh (triangles) and degraded (crosses) Mercurian craters as measured by radar altimetry. The dotted line shows the approximate range of shadow-derived values for fresh and degraded Mercurian craters (Malin and Dzurisin 1977). The straight lines are the fitted power-law depth/diameter relations for fresh craters on (a) the Moon (Pike 1974), and (b) Mercury (Malin and Dzurisin 1977) (figure from Harmon et al. 1986; copyright Amer. Geophys. Union).](image-url)
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the depth/diameter relation. The accuracies of the radar depth estimates for large craters such as Mozart and Handel are comparable to or better than the 15 to 20% accuracy which has been claimed for shadow-derived depths. For smaller craters, the radar depth estimates tend to be less reliable due to the coarse latitude resolution, a point which is discussed in some detail by Harmon et al. (1986).

Figure 3 shows the radar-derived depth estimates vs diameter for 23 craters in the diameter range 40 to 260 km. These data are tabulated crater by crater in Harmon et al. (1986). Only craters in the imaged hemisphere have been included, although the depths shown in Fig. 3 are consistent with the depths of several of the more obvious impact features seen in radar profiles from the unimaged hemisphere. The craters in Fig. 3 are identified as being either fresh (USGS classes C3–C5) or degraded (USGS classes C1–C2). Included in Fig. 3 are the shadow-derived depth data of Malin and Dzurisin (1977); their power-law relation for fresh Mercurian craters is plotted along with an envelope encompassing their range of values for both fresh and degraded craters. Also shown in Fig. 3 is the power-law depth/diameter relation for fresh lunar craters (Pike 1974). The radar-derived depths fall well within the range of the shadow depths, although the radar depths of fresh craters lie, on the average, 17% below the fresh-crater depth/diameter curve of Malin and Dzurisin (1977). Since the radar and shadow depth data sets have no craters in common, it was not possible to determine if there is, in fact, a systematic disagreement between the two techniques. It is clear, however, that the radar depths in Fig. 3 lend strong support to the assertion that large, fresh craters on Mercury are shallower than those on the Moon.

B. A Major Fault System

Figure 4 shows the Arecibo altitude profiles obtained over the USGS H-6 quadrangle along with a map showing the location of the radar ground tracks. The most distinctive large-scale topographic feature in this region is the marked drop in mean elevation which can be seen between 30°W and 40°W longitude. The most impressive part of this drop occurs just west of Handel crater, where the elevation changes by 3 km within 1.5 degrees of longitude (70 km). To the north, a shallower slope occurs across and to the west of Yeats crater. To the south, the high eastern rim and asymmetric profile of Homer basin suggest that this basin also straddles the slope. Inspection of Mariner 10 images and of the geologic map of DeHon et al. (1981) shows that this regional slope occurs in an area with several west-facing intracrater fault scarpers. These scarps, and some associated intercrater lineaments, are shown on the schematic map in Fig. 5. The intercrater features are identified as ridges by DeHon et al. (1981), although they have a highlighted appearance in the Mariner 10 images which would seem to be more suggestive of west-facing scarps. In any event, it is clear that the 3 km drop seen in the radar altimetry is associated with an extensive system of faults which trends north-south over
the northern half of the H-6 quadrangle. It is interesting to note that while this fault system and the arcuate scarps (see next section) have entirely different altimetric signatures, they both give rise to intracrater scarps which are similar in morphology.

C. Arcuate Scarps

The most distinctive tectonic features identified in the spacecraft images are the arcuate scarps, which are generally believed to be thrust faults driven by planetary contraction. Shadow measurements of these features give typical
Fig. 5. Schematic map of the central portion of the H-6 quadrangle covering the region where radar altimetry shows a large west-facing downslope. Approximate topographic contours based on the radar data are shown. The indicated ridges and intracrater scarps are from the geologic map of DeHon et al. (1981). The names of several craters are abbreviated: Ru, Rudaki; Ch, Chaikovskij; Ti, Titian (figure from Harmon et al. 1986; copyright Amer. Geophys. Union).

heights in the range 500 to 1000 m, although a height of 3 km has been estimated for a portion of Discovery Rupes (Dzurisin 1978; Strom et al. 1975).

Three of the arcuate scarps shown on the tectonic maps of Dzurisin (1976, 1978) and Strom et al. (1975) have been identified in radar profiles. All three are located in the same region of the H-6 quadrangle (Fig. 4); we display them on an expanded scale in Fig. 6. These scarps are delineated by shadow and, as they are near the Mariner 10 eastern terminator (illumination from the west), they were mapped as east-facing dips. The radar signatures of the three scarps are similar in that each appears to be a ridge-like feature with a height of 700 m and an across-strike width of roughly 70 km. In each case, the eastern slope of the radar feature agrees well with the location of the image shadow. The two scarps in the lower profile of Fig. 6 have slightly asymmetric profiles which could be consistent with overthrusting from the west. The scarp
Fig. 6. Altitude profiles selected from the H-6 quadrangle (see Fig. 4) showing topography across the three mapped arcuate scarps discussed in the text. Arrows (S) denote the locations of the downthrown (shadow) sides of the scarps as determined from USGS maps and Mariner 10 images. Vertical bars indicate the ±1 standard deviation altitude errors. The subradar tracks for the two profiles are shown on the Mariner 10 image at the top (figure from Harmon et al. 1986; copyright Amer. Geophys. Union).
east of Asvaghosa crater, on the other hand, has a more symmetric and rounded profile. All three scarps have significant downslopes on their western sides and hence are more ridge-like than one would infer from images obtained at a single illumination aspect.

D. A Large Basin (H-7 Quadrangle)

Most of the Arecibo radar coverage on the USGS H-7 map is concentrated in the western half of the quadrangle in an area which is dominated by a large, degraded impact basin. In their survey of large Mercurian basins, Schaber et al. (1977) listed this basin as an 839-km diameter, single-rim structure centered at 130°W, 1°N. It is the second largest Mercurian basin in their survey after Caloris. More recently, Spudis and Strobel (1984) claim to have identified a multiple ring structure for this basin.

In Fig. 7 we show four of the altitude profiles across this basin, along with markers indicating the approximate basin edges as given by the USGS shaded-relief map and Schaber et al. (1977). The profiles show that the topography across this basin is complex and strongly latitude dependent. Some portions of the basin floor appear to have been significantly altered by post-basin impacts. Other portions of the basin appear topographically smooth, possibly indicating a smooth plains fill. The southernmost profile at 47°S is the simplest of the four profiles in Fig. 7. It shows 1.2 km of rather smooth, down-bowed relief, an upraised rim in the east, and a western rim which coincides with a scarp visible in Mariner 10 images. The most northerly profile in Fig. 7 shows a very prominent basin rim in the northwest along with two smooth, down-bowed sections of basin floor in the northwest and northeast. The two northern profiles in Fig. 7 show very little topographic expression across the northeast rim of the basin, whereas the next profile to the south may show some basin rim structure on the eastern side. The radar data show that, overall, the interior of the basin is not significantly lower than the level of the adjacent terrain. This suggests that the basin has been severely modified by post-impact processes such as isostatic relaxation, impact cratering or volcanic infilling. In addition, the interior of the basin may have experienced some local subsidence of smooth plains fill.

E. Smooth Plains

Not surprisingly, regions on Mercury which have been mapped as smooth plains tend to have relatively smooth altitude profiles. The largest mapped expanses of smooth plains lie within the H-8 quadrangle (Schaber and McCauley 1980), and our profiles in this quadrangle (Fig. 8) have a generally smoother appearance than do profiles in, for example, the H-6 quadrangle (Fig. 6). Although smooth, the profiles in Fig. 8 do show some very distinctive large-scale undulations. The Tir Planitia smooth plains appear to be strongly down-bowed. The lowest parts of these plains lie 1 to 1.5 km below the terrain to the east (which includes a mix of Caloris ejecta, smooth plains
Fig. 7. Altitude profiles selected from the H-7 quadrangle showing topography across the large basin centered at 130°W, 15°N. Brackets denote the approximate locations of the basin rim as given by the USGS shaded-relief map and Schaber et al. (1977). Vertical bars indicate ±1 standard deviation altitude errors. The subradar tracks for these profiles are shown on the USGS shaded-relief map at the top (figure from Harmon et al. 1986; copyright Amer. Geophys. Union).
Fig. 8. Top: USGS shaded-relief map of the H-8 quadrangle, with subradar tracks indicated. Note that the Mariner 10 terminator is at 190°W, with terrain to the west unimaged. Bottom: The altitude profiles for H-8. The display format follows that of Fig. 4: Mo, Mozart; TP, Tir Planitia; Tj, Tsuujaruja; Zc, Zonati (figure from Harmon et al. 1986; copyright Amer. Geophys. Union).

and intercrater plains) and the Mozart ejecta blanket to the west. The extension of these plains into the unimaged hemisphere is discussed in the next section.

**IV. TOPOGRAPHIC FEATURES: UNIMAGED HEMISPHERE**

Mercury showed the same face to the Sun at each of the three Mariner 10 encounters, leaving half of the planet unimaged. The unimaged hemisphere extends from 190°W to 10°W longitude. Radar has provided most of what little information is available for this side of the planet.
A. The Circum-Caloris Smooth Plains

The Mariner 10 western terminator runs through the large crater Mozart. As can be seen from Fig. 8, the profiles in the unimaged terrain west of Mozart have the same smooth, down-bowed appearance as the profiles over the imaged plains of Tir Planitia to the east of Mozart. This indicates that the circum-Caloris smooth plains extend well into the unimaged hemisphere, at least to the western edge of the H-8 quadrangle.

Harmon et al. (1986) suggested subsidence under an emplaced load as the most likely explanation for the down-bowing of the smooth plains in Fig. 8. The distinctive topography and the existence of mare-like ridges in Tir Planitia suggest that the circum-Caloris region has been subjected to a lithospheric loading and flexure process similar to that for the lunar maria. In this sense, the radar topography offers indirect support for a volcanic origin for the Mercurian smooth plains. However, certain objections to the volcanic hypothesis remain unanswered, and the question of the origin of the smooth plains must still be considered open.

B. Other Features

In Fig. 9, we show the Arecibo profiles in the region 250–360°W longitude, which includes the western half of the H-9 and the entirety of the H-10 quadrangle.

![Graph of altitude profiles](image)

Fig. 9. Altitude profiles for the longitude range 250 to 360°W. These longitudes include the H-10 quadrangle and the western half of H-9. This entire region lies in the unimaged hemisphere. The display format follows that of Figs. 4 and 8.
quadrangles. Here we note a variety of terrain features. The most striking large-scale topographic feature is the highlands region between 295–315°W. The 2 to 3 km height of these highlands above the adjacent plains is comparable with the height of the large plateau dominating the eastern half of the H-6 quadrangle. The eastern slope of the H-6 plateau can in fact be seen near 350°W at the western edge of the H-10 quadrangle (Fig. 9). Relatively smooth terrain, possibly intercrater plains, can be seen extending over 280-295°W and in a northerly profile between 330 and 355°W. A number of features can be seen in Fig. 9 which are suggestive of large impact craters. The largest of these is a 2.5 km deep crater at 279°W, 8°N. The size and structure of this crater suggests that it may be a ring basin of the same class as Renoir and Rodin. Two other large craters can be seen atop the highlands at 300°W and 306°W, and a third crater can be seen at 350°W, 11°N.

The topography of the small portion of the unimaged hemisphere which we have studied does not appear to be markedly different from that of the imaged hemisphere. Also, no evidence has been found for the existence of another Caloris-scale impact structure in the equatorial zone of this hemisphere.

V. RADAR SCATTERING PROPERTIES

Most of the recent radar studies at Arecibo have concentrated on surface topography. However, work has been done, both at Arecibo and other facilities, which bears on the radar scattering properties of the Mercurian surface. These studies can be used to place some constraints on the roughness and dielectric properties of the upper surface layers of the planet.

A. Radar Cross Section and Quasi-Specular Roughness

Some useful information can be derived from simple CW observations of the planet. If the echo is predominantly quasi-specular, then the total radar cross section (normalized by the projected area of the planet) provides a first-order estimate of the Fresnel reflection coefficient of the surface. Recent (unpublished) CW observations at Arecibo and earlier observations at Goldstone (Goldstein 1971) have estimated the average radar cross section of Mercury at 0.06 at 13-cm wavelength. For comparison, solid rock surfaces have reflection coefficients in the range 0.15 to 0.25, while rock powders have reflectivities of 0.03 to 0.06 (Campbell and Ulrichs 1969; Evans 1969). One can conclude, therefore, that the upper meter or so of the Mercurian surface is dominated by relatively porous soils or regolith rather than by consolidated rock. The same conclusion holds for the Moon, which has a comparable radar cross section (0.06) at 23-cm wavelength (Hagfors 1967; Evans 1969). Venus, by contrast, has an average reflectivity of 0.11 at 13-cm wavelength (Carpenter 1966), which suggests that this planet has more exposed bedrock than does Mercury. The total radar cross section of Mercury varies over the range 0.04 to 0.08,
depending on the location of the subradar point on the planet. This is much smaller than the range of cross sections (0.04–0.15) measured for Mars.

The central portion of the radar Doppler spectrum of a terrestrial planet is typically dominated by a narrow peak associated with quasi-specular scatter from smooth surface undulations with horizontal scales greater than the observing wavelength. The width of this peak can be used to estimate the rms slope of these undulations. This type of analysis has been done most extensively for Mars, where rms slopes have been found to vary between 0.25 and 10°. On the average, Mercury spectra are broader and the inferred rms slopes are larger than those obtained for Venus and Mars (Pettengill 1978). At Arecibo, we have used the delay-Doppler data to estimate specific cross section as a function of incidence angle along the Doppler equator. Such a technique is more sensitive to spatial inhomogeneities in scattering than is an analysis based on CW-derived Doppler spectra. We find the smoothest and most homogeneous surfaces on Mercury to be in the smooth plains, for which we measure rms slopes of about 4°. However, the smooth plains are considerably rougher than many of the plains regions on Mars, where rms slopes can be 1° or less. Presumably this reflects the fact that Mercury has not been subject to the same erosional/depositional processes which have altered the Martian surface. Outside the smooth plains, the Mercurian Doppler spectra tend to be broader and to be extremely irregular in a way which is indicative of highly inhomogeneous scattering. In many cases, these scattering variations can be identified with known features such as large craters.

B. Diffuse Scattering and Radar Polarization

Studies of the wings of the Doppler spectrum and of the degree of depolarization of the echo can provide information on the relative importance of diffuse scattering by wavelength-scale surface structure. We have estimated that diffuse scatter accounts for approximately 27% of the total radar cross section of Mercury, a percentage which is comparable to that estimated for the Moon and Venus (Harmon and Ostro 1985). Volcanic plains regions on Mars have been found to show much higher percentages of diffuse scatter as well as near-complete depolarization of the diffuse echo, conditions which are indicative of extremely chaotic small-scale surface texture. Goldstein (1971) noted two depolarization enhancements arising from rough regions in the unimaged hemisphere of Mercury. Recent dual-polarization CW observations at Arecibo have revealed some bumps and asymmetries in the Mercury spectra, including Goldstein's feature near 230°W longitude. These features are very subdued compared to the Martian features, however, and in no case have we found depolarization to exceed 40% for any portion of the diffuse echo of the planet. If Mercury does possess volcanic plains, they must have a smoother small-scale texture than those on Mars.
VI. CONCLUSION

Earth-based radar has proven to be an important tool for the remote sensing of Mercury and may be one of the few sources of new observational data on the planet for the foreseeable future. Data coverage over the accessible subradar zone remains incomplete, and additional observations are planned at Arecibo to fill in some of the gaps. Some upgrades to the Arecibo telescope and radar system are being considered which would improve the quality of the altimetry data, especially for observations made at larger geocentric distances, and which would justify a more serious effort at reflectivity mapping of the planet.

It is obvious that the next great advance in Mercury studies must await another spacecraft, preferably an orbiter. The Arecibo altimetry data provide a good sample of the sort of topographic features one would expect to measure with an orbiting altimeter. Among the most interesting results of the radar observations are the discoveries of large-scale topographic signatures for such features as the circum-Caloris smooth plains and the H-6 fault zone. While some preliminary speculation on the tectonics of such regions based on the radar results may be in order, a fuller understanding of Mercurian tectonics will only come from a comparison of altimetry with gravimetric data and higher-quality imagery.

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