intensities at each value of delay and frequency as derived from Muhleman's law.

A new determination of the Venus rotation period and spin axis direction has recently been made by Jurgens (*6*) on the basis of feature positions measured between 1964 and 1969. These values, which we employed in this reduction, are 243.0 days for the rotation period, 272.7° for the right ascension of the northern axis, and + 65.3° for its declination. The longitude reference was defined such that the 320° meridian contained the sub-Earth point at 0^h UT on 20 June 1964. Because our definitions of the rotation period and spin axis direction differ slightly from those of Rogers and Ingalls (*2, 3*), there is a difference of about 3° in the origin of longitude between the two systems (0° on their map corresponds approximately to 3° on ours).

The 11 maps were appropriately weighted and added together. The resultant composite map is shown as Fig. 1. Contours outline the major areas of differing contrast in Fig. 2. The areas above 40° latitude and below −50° latitude are tentative, as the signal-to-noise ratio was relatively poor in these regions. A number of regions whose reflectivity is significantly higher than that of their surroundings are apparent. Two of these, the region variously called α, F, or Faraday at −30° latitude, 0° longitude, and the β complex at 30° latitude, 280° longitude (seen under a different aspect angle this region separates into two features, which we have called Gauss and Hertz), have been observed with monostatic systems since 1964. Of major interest are the low-reflectivity features that are not normally apparent with monostatic systems because of the ambiguity problem.

These features seem to separate into two types: (i) large, irregularly shaped areas such as those centered on 27° latitude, 330° longitude to at least 30° longitude, and those centered on −20° latitude, 293° longitude; and (ii) circular features. The two circular features centered on 30° latitude, 320° longitude, and on −30° latitude, 337° longitude, seem to have a central feature reminiscent of some lunar craters, although they are approximately 1000 km in diameter. As was mentioned by Rogers and Ingalls (*2*), there is a temptation to equate the low-reflectivity features with lunar maria, which are smoother and have a lower reflectivity than the surrounding highlands. Such an interpretation, however, will have to await observations in the depolarized receiving mode, where the predominant echo power arises from diffuse scattering.

Although agreement between the maps at the two wavelengths is good in respect to general boundaries between regions of differing reflectivity, the relative contrasts seem to differ markedly in some instances. For small features this difference may be partly due to the different resolutions used, since the 3.8-cm map had an area resolution approximately four times better than ours. The feature α or Faraday at −30° latitude, 0° longitude, which is resolved at both wavelengths, seems to have a considerably higher relative contrast at 3.8 cm than at 70 cm. This is the result either of greater roughness at a scale of 3.8 cm as compared with 70 cm or of increased elevation that would make atmospheric absorption at 3.8 cm considerably less than for the surrounding area of lower elevation.

Despite the considerable advance that the radar interferometer represents over other methods in mapping the surface scattering of Venus at radio wavelengths, we still know very little about the actual nature of the surface. Differences in the backscattered power may be due to changes in the small-scale roughness, mean slope, dielectric constant, or, in the case of wavelengths of less than 10 cm, in the surface height (with the resultant change in atmospheric absorption). Observations in the depolarized mode would help greatly to resolve this problem, but, so far, little has been done in this direction because of the greater sensitivity required. Jurgens and Dyce (*4*) have reported observing a depolarized return from the β complex at 30° latitude, 280° longitude, and possibly from Faraday at −30° latitude, 0° longitude, which indicates that at least part of the enhancement of these regions is due to an increase in the roughness on the scale of 70 cm.

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7. We thank I. Shapiro of the Massachusetts Institute of Technology and his staff for supplying the needed ephemerides, and the engineering staff of the Arecibo Observatory for their help in setting up the interferometer. The Arecibo Observatory is operated by Cornell University under contract to the National Science Foundation, with partial support from the Advanced Research Projects Agency.

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Lunar Surface: Changes in 31 Months and Micrometeoroid Flux

Abstract. *Comparison of pictures of the lunar surface taken 31 months apart by Surveyor 3 and Apollo 12 show only one change in the areas disturbed by Surveyor: a 2-millimeter particle, in a footpad imprint, that may have fallen in from the rim or been kicked in by an approaching astronaut. Vertical walls 6 centimeters high did not collapse and dark ejecta remained dark. No meteorite craters as large as 1.5 millimeters in diameter were seen on a smooth soil surface 20 centimeters in diameter; this indicates a micrometeoroid flux lower than 4×10^{-7} micrometeoroids per square meter-second at an energy equivalent to about 3×10^{-8} gram at 20 kilometers per second. This flux is near the lower limit of previous determinations.*

During the period from 20 April to 3 May 1967, the spacecraft Surveyor 3 sent to Earth thousands of television pictures of the lunar surface near its landing site in Oceanus Procellarum at 23.34°W longitude, 2.99°S latitude (ACIC coordinate system). On 20 November 1969, the site was visited by Apollo 12 astronauts Alan Bean and Charles Conrad, who took a number of pictures of the surface with a hand camera on 70-mm film. This provides an opportunity to compare pictures of the same small areas of the lunar surface taken 31 months apart.

I have made a preliminary comparison, examining areas that had been disturbed by the Surveyor spacecraft. These disturbances produced markings in the lunar soil which were easily identifiable and simpler in shape than the irregularities, on a scale of centimeters and smaller, characteristic of the undisturbed lunar surface. Accordingly,

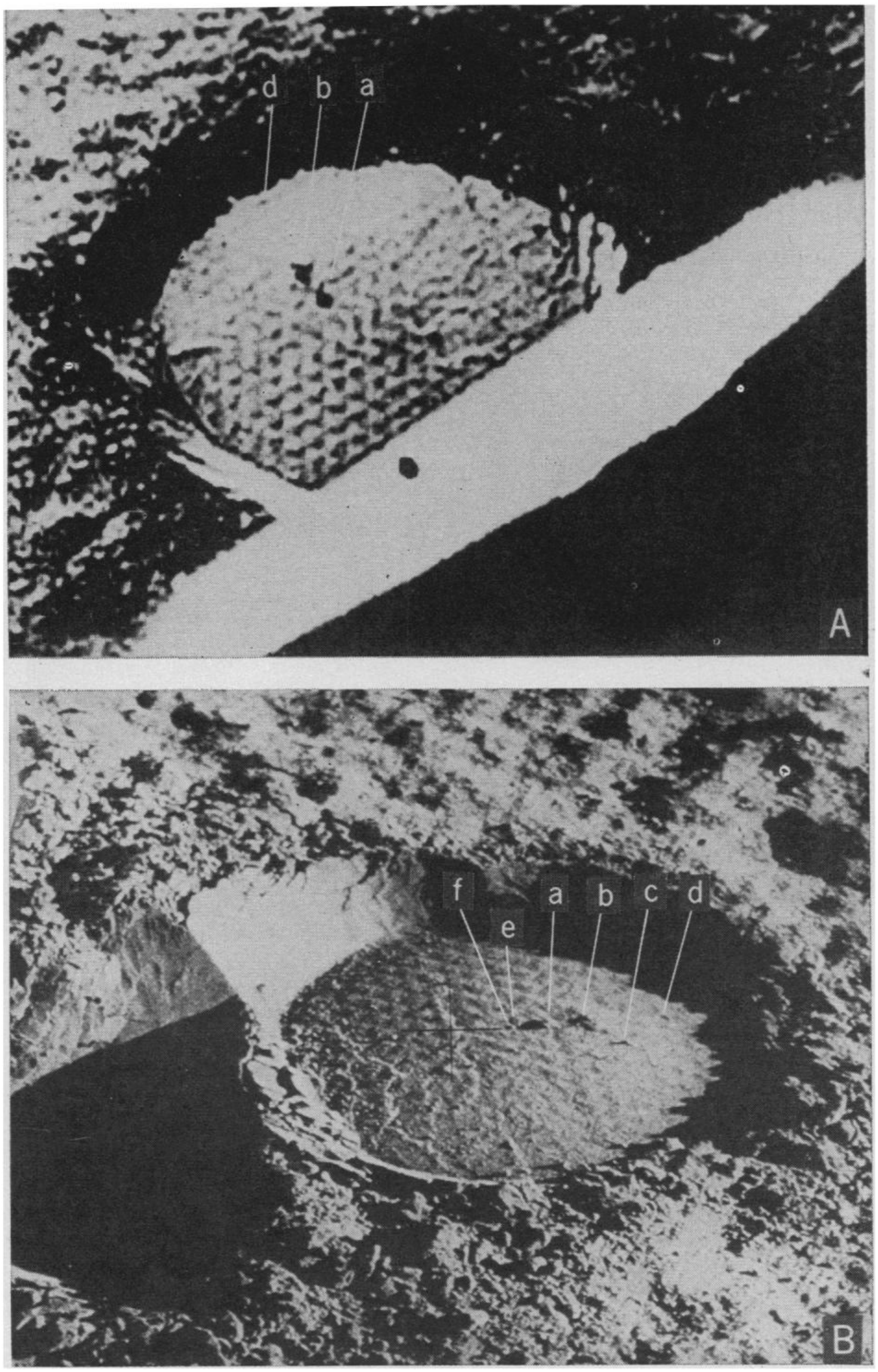

Fig. 1. Imprint in lunar soil made by footpad 2 of Surveyor 3. (A) Part of Surveyor 3 television picture taken 21 April 1967, at 08:24:20 UT. Sun in east, 27° above horizontal. View from north of west. Picture was processed by digital computer. (B) Part of photograph from Apollo 12 hand camera taken 20 November 1969, about 05:22 UT. Sun in east, 23° above horizontal. View from south. From photograph AS 12-48-7110. Waffle pattern in imprint is a replica of that on bottom of Surveyor footpad. (*a* and *b*) Two particles clearly visible on floor of imprint in each picture. (*c*) A particle visible only in Apollo picture. (*d*) Pit visible in both pictures. (*e*) Pit visible in Apollo picture, tentatively identified in Surveyor picture. (*f*) Small particle next to pit *e*.

changes in the disturbed areas should be easier to detect. The surface disturbances studied included groups of imprints produced by two of the footpads of Surveyor during its final (third) landing event (*1*), as well as markings made in operations by the Surveyor soil mechanics surface sampler after landing (*2*)—four trenches, seven bearing tests, impact tests, and other surface contacts.

About 60 Surveyor and 20 Apollo pictures were examined in detail; the Apollo pictures included several stereo pairs. The material consisted of prints made from copy negatives, in turn prepared from a master positive, on film, of the original 70-mm negative. In addition, for Surveyor, prints were made from negatives prepared by digital computer processing of the television signals recorded on magnetic tapes, and from negatives of photoprint mosaics. Enlargements were up to two-thirds of lunar scale. The view angles and, in general, the sun angles, in the Apollo photographs were different from those in the Surveyor pictures.

I have found only one definite change in the surface, other than those obviously produced by the astronauts—on the bottom of an imprint made by Surveyor footpad 2, all of the pertinent Apollo pictures show a particle, about 2 mm in diameter, that does not appear in any of the Surveyor pictures (Fig. 1, particle *c*). A variety of digital computer image-processing techniques were tried to enhance the Surveyor pictures to reveal the object, or its shadow,

Fig. 2. Part of Apollo 12 photograph, taken 20 November 1969, showing trenches made by Surveyor 3 surface sampler. Far corner of nearer trench preserves vertical wall, about 6 cm deep, dug 22 April 1967. From photograph AS 12-48-7108.

Fig. 3. Apollo 12 photograph taken 20 November 1969. Note dark throw-out from impact of Surveyor footpad on 20 April 1967. Apollo photograph AS 12-48-7110.

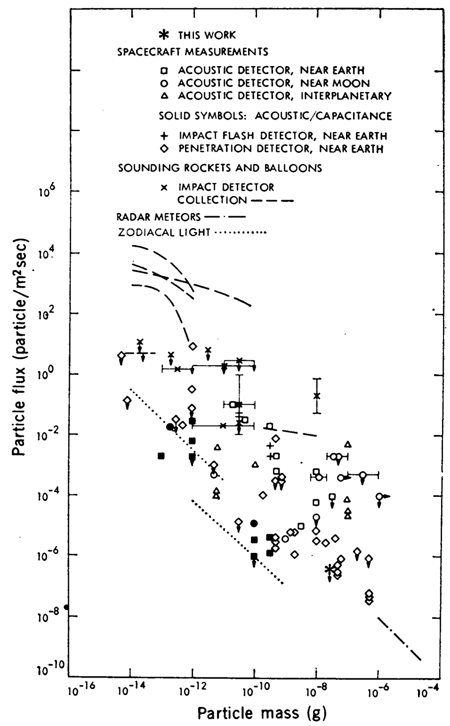

Fig. 4. Micrometeoroid flux versus mass. Based on McDonnell (*6*); result of this work added.

without success. If the particle had been present when the Surveyor pictures were taken, its shadow, at least, should have been easily detected. (The camera line resolution was 1 mm at the imprint, and the sun was 27° above the horizon at the time Fig. 1A was televised.) I conclude that the particle was emplaced subsequent to the Surveyor picture-taking. It may have fallen from the rim of the footpad imprint or may, perhaps, have been kicked in by an astronaut as he approached.

The Apollo pictures show that the sides of several steep walls made by Surveyor footpads and surface samples were still in place. These include the vertical wall of a trench 6 cm deep (Fig. 2). The cohesion and internal friction previously reported for lunar soil (*3*) are sufficient, according to standard soil mechanics analysis (*4*), to hold such a wall against lunar gravity for an extended time.

Surface areas darkened by ejected fines during the Surveyor landing still appeared dark compared to the undisturbed surface (Fig. 3).

On the floor of the footpad imprint shown in Fig. 1, any crater as large as 1.5 mm in diameter should have been visible in the Apollo pictures. (The line resolution is 0.4 mm or better.) I noted only two pits. One of these, pit *d*, is visible in Surveyor as well as Apollo pictures. The other pit, *e*, appears in the Apollo pictures and may also appear in Surveyor pictures; it is immediately adjacent to a small particle, 1 to 2 mm in diameter, and most likely was produced when the adjacent particle fell in during the final landing event of Surveyor. Thus, no meteorite craters as large as 1.5 mm in diameter appeared on the bottom of the imprint, 20 cm in diameter, during 31 months. Thus, the rate of impact was less than 1.0 particle/m^2-mo or 4×10^{-7} particle/m^2-sec for particles producing craters 1.5 mm in diameter. This is for a solid angle of almost 2π.

Braslau (*5*) found that a projectile impacting dry sand at 6.4 km/sec produced an ejecta mass, plus compression, equivalent to 4700 times the projectile mass. On this basis, a crater 1.5 mm in diameter would be produced by a 3×10^{-7}-g micrometeoroid impacting at 6.4 km/sec. At 20 km/sec, a velocity more typical of primary meteorites, the impacting mass, for the same energy, would be 3×10^{-8} g. A flux of 4×10^{-7} particle/m^2-sec of this mass is near the lower limit of meteoroid flux derived from spacecraft measurements and many orders of magnitude lower than some previous estimates (Fig. 4). It is consistent with zodiacal light and radar meteor data and with some of the more recent spacecraft data obtained with acoustic-capacitance and penetration sensors. The absence of detectable craters in the imprint of the Surveyor 3 footpad implies, then, a very low micrometeoroid flux on the lunar surface.

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