of the structure. But whatever the cause of this difference in reflection, colorimetric methods would appear to be of help in structural studies, particularly in areas of poor outcrop.

Conclusion

Color aerial photographs almost always contain geologic information that is not recorded on conventional black-and-white aerial photography. Recent investigations, reported in part herein, have convinced the author that, while subjective photo interpretation procedures may well provide significant geologic information from color aerial photographs, a quantitative approach to photo interpretation studies may ultimately be the most rewarding.

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*Surface Roughness of the Moon**

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IN RECENT years considerable interest has been aroused in the radar determination of the order of surface roughness of planetary bodies. In particular, quite a few attempts (Evans 1960, Hayre 1961, Hughes 1960, Leadabrand 1960, Pettengill 1960) have been made recently using the results of monostatic and bistatic radar reception of lunar echoes, to determine the roughness of the visible lunar surface. Senior and Siegel (1960) suggest a quasi-smooth moon at radar frequencies while Leadabrand et al. (1960) state that the central portion of the visible lunar surface up to approximately 600 μ sec-radar depth is quasi-smooth, while the outer areas up to the limbs are rough. Evans (1960 a) shows that approximately 50% of return power is returned from first 50 micro-second depth (0.1 radius of the moon), and therefore the central part of the moon must be smooth while the outer areas are said to obey Lambert's scattering law. In this article, Davies-Moore-Hayre (1961) Model is used to estimate the lunar surface roughness.

A study of some recent moon echo results (Evans 1960 and 1961. Pettengill 1960) seems to suggest that it may be necessary to analyze the variation of radar scattering cross-section with the angle of incidence (θ) in three different ranges. This is necessitated because small changes in θ correspond to very large changes in distance from the center of the moon surface. The angle of incidence varies from zero to ninety degrees as the the angle subtended at the earth based receiver by an annular area on the moon varies from zero to seventeen minutes, and the corresponding radius from the center of the visible surface to the illuminated area changes from zero to the radius of the moon. This would then imply that one would associate different roughness characteristics with each range of angles as discussed later in this article.

Various models have so far been used to predict the roughness of the target terrain from the radar return data. The Davies-Moore-Hayre Model (Hayre and Moore 1961) uses the experimental autocovariance of the elevations and their probability density function, in applying the Kirchhoff-Huygens' principle. Certain assumptions about perfect conductivity, isotropic scatterers, near-vertical incidence and no part of the terrain being shadowed by any other part, etc. were employed. Contour maps were used to calculate the autocovariance functions. This resulted in the following expression for the radar scattering cross-section.

$$\sigma_0 = (4\sqrt{2}\,\pi B^2/\lambda^2)(\theta \cos^2\theta/\sin\theta)\exp(-4k^2\sigma^2\cos^2\theta) \cdot \sum_{n=1}^{\alpha} (4k^2\sigma^2\cos^2\theta)^n \cdot [(n-1)!(2B^2k^2\sin^2\theta + n^2)^{3/2}]^{-1} \qquad (1)$$

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where

σ = standard deviation of elevation of points on the surface above the mean level
λ = wave-length
$k = 2\pi/\lambda$, wave number
θ = angle of incidence measured from the surface normal
B = constant in height-distance exponential autocovariance function.

Equation (1) may be approximated by the following expressions applicable in two ranges of incidence angles, namely zero to three degrees, and three to fifteen degrees:

$$\sigma_0 \propto (B/\lambda)^2 \exp(-4k^2\sigma^2) \sum_{n=1}^{\infty} (4k^2\sigma^2)^n \cdot [(n-1)!(2B^2k^2\theta^2 + n^2)^{3/2}]^{-1} \quad \text{for } 0 \leq \theta \leq 3^0 \quad (2)$$

$$\sigma_0 \propto \exp(-10\theta) \quad \text{or} \quad \exp(-10.1 \sin \theta) \quad \text{for } 3^0 \leq \theta \leq 14^0 \quad (3)$$

Equation (3) is an heuristic fit to the lunar echo data at 10 centimeter wave-length by Hughes (1960), and Pettengill (1960) respectively. One possible set of values of B/λ and σ/λ which gives a reasonable fit of (1) to (3) is approximately 1.0 and 0.1 respectively (Hayre 1961) although a larger value of B/λ and a smaller value of σ/λ would seem appropriate for Pettengill's data, taken at 0.682 meter wave-length. Comparable values of B/σ may fit Pettengill's data and result in a more reasonable estimate of the standard deviation of the central lunar surface. The transitional value in going from a quasi-smooth to a rough surface is shown* to be $\sigma/\lambda = 0.08$–0.125. This seems to indicate that the lunar surface is rough indeed. Moreover, the central portion of the moon may have a ratio of autocovariance constant to the standard deviation of 10. One may increase the estimated values of B/λ and σ/λ in order to be conservative.

Nothing may be inferred about the presence or absence of dust layers, if any, from the above analysis. The above estimate of the standard deviation of the central lunar surface, included in about one-tenth radius of the moon, does seem to give an indication that crevices deeper than two times the standard deviation may only exist in small number. The probability of existence of such crevices would be less than approximately 4.55%, if the distribution of surface perturbations above and below the average lunar surface is assumed to be normal. Further work on the acoustic simulation of moon echoes and an estimate of the order of roughness of the moon's surface is in progress at the University of New Mexico.

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