A knowledge of the scattering characteristics of geologic surfaces is important when attempting to interpret satellite images of planets. In a previous paper (1) we discussed the scattering properties of the Lunar Lake playa as observed by the Portable Apparatus for Rapid Acquisition of Bidirectional Observations of Land and Atmosphere or PARABOLA (2) at a wavelength of 0.66 μm. The playa is an extremely flat and compacted surface composed primarily (>90%) of clay minerals with particle sizes ~1-20 μm (3). It was found that, to a first approximation, the playa behaves as a Lambertian scatterer, i.e. the observed brightness of the playa is independent of the observer's position (1,4)(see Figure 1). However, there were systematic discrepancies noted between the Lambertian model and the observed data. Especially noteworthy was the rapid increase in observed radiance at high phase angles in the solar principal plane and the observation that the radiance continued to increase beyond the emission angle at which a specular peak was expected. At azimuths greater than 30° out of the solar principal plane, the observed radiance drops to an almost constant value. Because no volume scattering model could adequately account for the observed scattering behavior of the playa, it was hypothesized that the sharp increases in radiance were due to Fresnel scattering (or surface scattering) from surface facets with some slope distribution and that both volume and surface scattering components were necessary to completely describe the data (1).

To test the Fresnel hypothesis, a model was derived to predict the radiance due to Fresnel scattering given an index of refraction (i.e. composition) and a statistical distribution of facets. Inversely, the Fresnel model can be used to extract a statistical distribution of facet orientations given the radiance due to Fresnel scattering and the index of refraction. The model assumes that a surface is composed of many small facets that are oriented in some statistically defined way, and makes use of the fact that the Fresnel reflection coefficient increases with increasing local incidence angle. The equation describing the radiance is given by:

\[ I = \frac{FRP}{4\cos(e)} \]

where \( I \) is the radiance (W/m^2/sr), \( F \) is the solar irradiance (W/m^2), \( R \) is the Fresnel reflection coefficient (which is a function of the index of refraction), \( P \) is the probability function describing the orientation of facets, and \( e \) is the emission angle of the instrument. We assumed for simplicity that the volume scattering component of the observed radiance could be modeled with a Lommel-Seeliger equation with multiple scattering included. This is equivalent to the Hapke function (5) assuming that the roughness and opposition terms are set to zero, and that the phase function is isotropic. These assumptions are reasonable since the brightness of the playa indicates that multiple scattering dominates. A single scattering albedo of 0.94 was estimated from the observed PARABOLA data by requiring the simplified Hapke model to just underestimate the minimum observed radiance. The simplified Hapke model was then subtracted from the observed radiance and the residual was assumed to be due to Fresnel scattering. The probability function was determined by fitting the Fresnel model to residual data from three different incidence angles and assuming an index of refraction of 1.52, an average of typical clays. The best fit probability function was exponential. The Fresnel model and observed residual data for an incidence angle of 63° are shown in Figure 2. The exponential probability function nicely explains the observation that the radiance peak is confined to a narrow azimuth zone around the solar principal plane. Given
a constant incidence and emission angle, variations in relative azimuth from the solar principal plane by even 15 degrees significantly increase the slope required for Fresnel reflection, and so the Fresnel contribution to the overall radiance is minor.

Electron micrographs show that the playa surface is composed of spheroidal particles, with only a few platy minerals observed. This observation is not inconsistent with the Fresnel model since spheroidal particles can be modeled as aggregates of facets and the relative abundance of facets with different slopes can be varied by changing the ellipticity of the particle. Additionally, the scale of the probability function is not certain and may be much larger than individual particles. Future work will involve reconciling the physical form of the playa surface and the model derived facet distribution.

We would like to thank Dan Kremser for helping us obtain the electron micrographs.

References

Fig. 1. Plot showing all data points (−180) gathered during a one day period by PARABOLA at Lunar Lake Playa, Nevada. Curve is Lambertian function generated by assuming it contained the midpoint of the data collected at a solar incidence angle of 28°. After (1).

Fig. 2. Plot showing the predicted radiance factor of the Fresnel model (curve) assuming an exponential probability function for slope orientations and a surface index of refraction of 1.52 -- an average value for many clays. Data points are the residual radiance factor after the simplified Hapke model (single scattering albedo = 0.94) is subtracted from the observed data. Error bars are one standard deviation. Note the lack of a Fresnel peak at e=63°.